Bifunctional Aminosulfonamide-Catalyzed Asymmetric Conjugate Addition to Alkenyl Alkynyl Ketimines as Enone Surrogates

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1. General Information

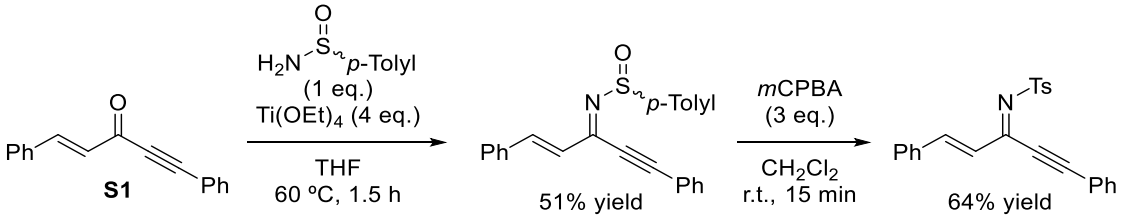
^{1}H NMR spectra were measured on a JEOL JNM-FX400 (400 MHz) spectrometer and a JEOL JNM-ECA500 (500 MHz) spectrometer. Chemical shifts were reported in ppm from tetramethylsilane as an internal standard. Data were reported as follow: chemical shift, multiplicity (s = singlet, d = doublet, t = triplet, q = quartet, dd = doublet of doublet, td = triplet of doublet, m = multiplet, br = broad, and app = apparent), coupling constants (Hz), and integration. ^{13}C NMR spectra were measured on a JEOL JNM-FX400 (100 MHz) and a JEOL JNM-FX500 (125 MHz) spectrometer with complete proton decoupling. Chemical shifts were reported in ppm from the residual solvent as an internal standard. High performance liquid chromatography (HPLC) was performed on Shimadzu 20A instruments using Daicel CHIRALPAK AD-3, IA-3, IA, IC-3, IC, ID and IG 4.6 mm × 25 cm columns. High-resolution mass spectra (HRMS) were performed on Thermo SCIENTIFIC Exactive Plus. Optical rotations were measured on a JASCO DIP-1000 digital polarimeter. For thin layer chromatography (TLC) analysis throughout this work, Merck precoated TLC plates (silica gel 60 GF254, 0.25 mm) were used. The products were purified by flash column chromatography on silica gel 60N (Kanto Chemical Co. Inc., 40-50 μm). Solvents were removed under reduced pressure using Büchi Rotavapor apparatus.

In experiments requiring dry solvents, tetrahydrofuran (THF) was purchased from Kanto Chemical Co. Inc. as “Dehydrated”. All other solvents were purchased from FUJIFILM Wako Pure Chemical Corporation, Ltd. Chloroform ($CHCl_3$) and tetrahydrofuran (THF) were stored over 4Å molecular sieves. Acetonitrile (MeCN) was stored over 3Å molecular sieves. Ethyl acetate (EtOAc), hexane, diethyl ether (Et_2O), dioxane, methanol (MeOH), ethanol (EtOH), 2-propanol (*i*PrOH), dichloromethane (CH_2Cl_2) and dichloroethane (DCE) were used without further purification. Reagents were purchased from Aldrich, Tokyo Chemical Industry Co., Ltd. (TCI), Nacalai Tesque, Inc., FUJIFILM Wako Pure Chemical Corporation, Ltd. or Peptide Institute, Inc. and used without purification except for aldehydes. The commercially available aldehydes were distilled and stored under a nitrogen atmosphere at 5 °C.

tert-Butyl ((1*E*,3*Z*)-1,5-diphenylpent-1-en-4-yn-3-ylidene)carbamate (**1a**),[1] 4-(benzyloxy)butanal[2], 2,2,2-trifluoro-*N*-(4-oxobutyl)acetamide[3] were synthesized according to the literature procedures.

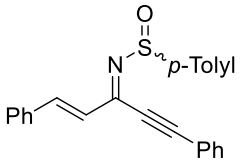
2. Synthesis of *Z*-Ketimines

◆ Synthesis of *N*-sulfinyl- or *N*-Ts-protected ketimine



Ketone **S1** was synthesized according to the literature procedure.[4]

***N*-((1*E*,3*Z*)-1,5-Diphenylpent-1-en-4-yn-3-ylidene)-4-methylbenzenesulfinamide**



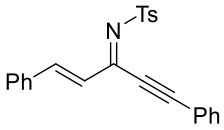
To a solution of **S1** (697 mg, 3 mmol, 1 eq.) and 4-methylbenzenesulfinamide (466 mg, 3.0 mmol, 1 eq.) in THF (6 mL) was added tetraethyl orthotitanate ($Ti(OEt)_4$) (1.9 mL, 9 mmol, 3 eq.) at room temperature. After stirring for 1.5 h at 60 °C, the reaction mixture was cooled to room temperature and quenched by adding brine. After stirring for 1 h at the same temperature, insoluble materials were filtered off through celite and washed with EtOAc thoroughly. The filtrate was concentrated and then purified by column chromatography on silica gel (hexane/EtOAc = 3/1 as eluent) to afford *N*-((1*E*,3*Z*)-1,5-diphenylpent-1-en-4-yn-3-ylidene)-4-methylbenzenesulfinamide (471 mg, 1.53 mmol, 51% yield) as a brown oil.

^{1}H-NMR (500 MHz, $CDCl_3$): δ 7.77 (d, J = 8.0 Hz, 2H), 7.70-7.68 (m, 2H), 7.66 (d, J = 16.0 Hz, 1H), 7.55-7.51 (m, 3H), 7.49-7.46 (m, 2H), 7.42-7.39 (m, 3H), 7.31 (d, J = 9.0 Hz, 2H), 7.03 (d, J = 16.5 Hz, 1H), 2.40 (s, 3H)

^{13}C-NMR (125 MHz, $CDCl_3$): δ 156.4, 144.7, 143.6, 142.2, 134.5, 132.4, 130.8, 130.4, 129.8, 128.9, 128.8, 128.1, 127.7, 124.7, 120.1, 103.8, 81.1, 21.4

HRMS (ESI): calcd. for $C_{24}H_{19}ONNaS^+$ ($[M+Na]^+$): 392.1080, found: 392.1084 ($[M+Na]^+$)

***N*-((1*E*,3*Z*)-1,5-Diphenylpent-1-en-4-yn-3-ylidene)-4-methylbenzenesulfonamide**



To a solution of *N*-((1*E*,3*Z*)-1,5-diphenylpent-1-en-4-yn-3-ylidene)-4-methylbenzenesulfinamide (184 mg, 0.5 mmol, 1 eq.) in CH_2Cl_2 (2.5 mL) was added *m*-chloroperoxybenzoic acid (*m*CPBA) (431 mg, 1.5 mmol, 3 eq.) at room temperature and the solution was stirred for 15 min at the same temperature. The mixture was then quenched with saturated $Na_2S_2O_3$ aq. and extracted with CH_2Cl_2. The combined organic layers were dried over Na_2SO_4 and concentrated *in vacuo*. The residue was purified by column chromatography on silica gel

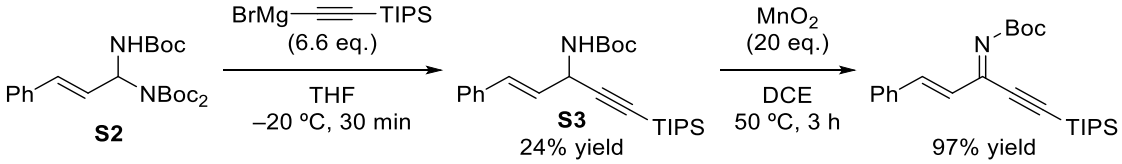
(hexane/EtOAc = 3/1 as eluent) to afford the *N*-((1*E*,3*Z*)-1,5-diphenylpent-1-en-4-yn-3-ylidene)-4-methylbenzenesulfonamide (123 mg, 0.32 mmol, 64% yield) as a white solid.

^{1}H-NMR (500 MHz, $CDCl_3$): δ 7.94 (d, *J* = 8.5 Hz, 2H), 7.87 (d, *J* = 16.0 Hz, 1H), 7.75 (d, *J* = 7.0 Hz, 2H), 7.58-7.57 (m, 2H), 7.54-7.51 (m, 1H), 7.46 (app t, *J* = 7.8 Hz, 2H), 7.43-7.41 (m, 3H), 7.32 (d, *J* = 8.0 Hz, 2H), 6.99 (d, *J* = 16.0 Hz, 1H), 2.42 (s, 3H)

^{13}C-NMR (125 MHz, $CDCl_3$): δ 158.3, 148.1, 143.8, 137.6, 134.3, 133.0, 131.22, 131.19, 129.5, 129.1, 128.7, 128.6, 128.3, 127.7, 120.3, 107.5, 82.2, 21.6

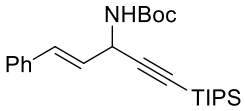
HRMS (ESI): calcd. for $C_{24}H_{19}O_2NNaSi^+$ ([M+Na]$^+$): 408.1029, found: 408.1033 ([M+Na]$^+$)

◆ Synthesis of *tert*-butyl ((1*E*,3*Z*)-1-phenyl-5-(triisopropylsilyl)pent-1-en-4-yn-3-ylidene) carbamate



Boc-protected aminal **S2** was synthesized according to the literature procedure.[5]

***tert*-Butyl (*E*)-(1-phenyl-5-(triisopropylsilyl)pent-1-en-4-yn-3-yl)carbamate (S3)**



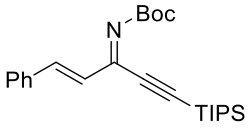
To a stirred suspension of magnesium (163 mg, 6.6 mmol, 6.6 eq.) in THF (10 mL) was added ethyl bromide (493 µL, 6.6 mmol, 6.6 eq.) at room temperature dropwise under a nitrogen atmosphere. To the reaction mixture was added (triisopropylsilyl)acetylene (1.5 mL, 6.6 mmol, 6.6 eq.) dropwise at room temperature, and the solution was stirred for 1 h at 50 °C to give a solution of ((triisopropylsilyl)ethynyl)magnesium bromide. To the solution was added **S2** (449 mg, 1.0 mmol, 1.0 eq.) in THF (3 mL) at −20 ºC. After stirring for 30 min at the same temperature, the mixture was then quenched with saturated NH_4Cl aq. and extracted with EtOAc. The combined organic layers were dried over Na_2SO_4, and concentrated. The residue was purified by flash column chromatography on silica gel (eluent with hexane/EtOAc = 20/1, 2nd run with hexane/Et_2O = 15/1) to afford **S3** as a white solid (98.2 mg, 0.24 mmol, 24% yield).

^{1}H-NMR (500 MHz, $CDCl_3$): δ 7.37 (d, *J* = 7.5 Hz, 2H), 7.32 (t, *J* = 7.8 Hz, 2H), 7.25 (t, *J* = 6.8 Hz, 1H), 6.89 (d, *J* = 15.5 Hz, 1H), 6.19 (dd, *J* = 16.0, 5.0 Hz, 1H), 5.24 (br s, 1H), 4.80 (br s, 1H), 1.47 (s, 9H), 1.10 (s, 21H)

^{13}C-NMR (125 MHz, $CDCl_3$): δ 154.6, 136.2, 131.8, 128.6, 127.9, 126.6, 126.5, 104.4, 86.1, 80.0, 45.1, 28.3, 18.6, 11.1

HRMS (ESI): calcd. for $C_{25}H_{39}O_2NNaSi^+$ ([M+Na]$^+$): 436.2642, found: 436.2646 ([M+Na]$^+$)

***tert*-Butyl ((1*E*,3*Z*)-1-phenyl-5-(triisopropylsilyl)pent-1-en-4-yn-3-ylidene)carbamate**



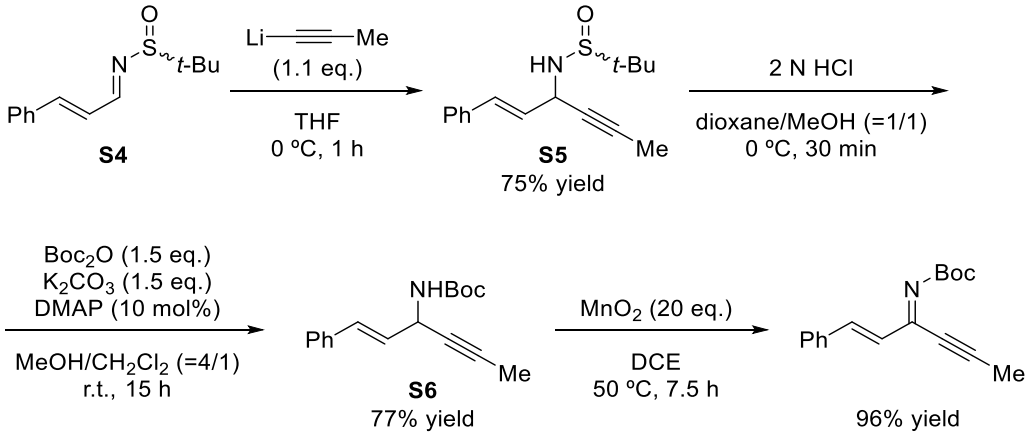
To a stirred solution of **S3** (98.2 mg, 0.24 mmol, 1.0 eq.) in DCE (1 mL) was added activated manganese dioxide (MnO_2) (412 mg, 4.7 mmol, 20 eq.) at room temperature. After stirring vigorously for 3 h at 50 ºC, insoluble materials were filtered off. The filtrate was concentrated to give the corresponding ketimine (94.8 mg, 0.23 mmol, 97% yield) as a white solid.

^{1}H-NMR (500 MHz, $CDCl_3$): δ 7.67 (d, J = 16.0 Hz, 1H), 7.49 (app br d, J = 6.0 Hz, 2H), 7.42-7.38 (m, 3H), 6.87 (d, J = 16.5 Hz, 1H), 1.56 (s, 9H), 1.20-1.12 (m, 3H), 1.16 (s, 18H)

^{13}C-NMR (125 MHz, $CDCl_3$): δ 161.1, 152.0, 144.8, 134.9, 130.1, 128.9, 128.2, 127.9, 102.9, 96.6, 82.3, 28.1, 18.6, 11.1

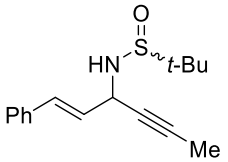
HRMS (ESI): calcd. for $C_{25}H_{37}O_2NNaSi^+$ ($[M+Na]^+$): 434.2486, found: 434.2489 ($[M+Na]^+$)

◆ Synthesis of *tert*-butyl ((1*E*,3*Z*)-1-phenylhex-1-en-4-yn-3-ylidene)carbamate



Imine **S4** was synthesized according to the literature procedure.[6]

(*E*)-2-Methyl-*N*-(1-phenylhex-1-en-4-yn-3-yl)propane-2-sulfinamide (S5)



To a stirred solution of propyne (1.0 M in hexane, 5 mL, 5 mmol, 5 eq.) in THF (5 mL) was added butyl lithium (BuLi) (1.56 M in hexane, 2.1 mL, 3.3 mmol, 1.1 eq.) at 0 ºC dropwise under a nitrogen atmosphere. To the reaction mixture was added **S4** (706 mg, 3 mmol, 1 eq.) dropwise at 0 ºC and the solution was stirred for 1 h at room temperature. The mixture was then quenched with saturated NH_4Cl aq. and extracted with EtOAc. The combined organic layers were dried over Na_2SO_4 and concentrated. The residue was purified by flash column chromatography on silica gel (hexane/EtOAc = 3/1~1/1 as eluent) to afford **S5** (622 mg, 2.2 mmol, 75% yield, dr = >20/1) as a brown oil.

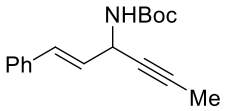
(major diastereomers)

^{1}H-NMR (500 MHz, $CDCl_3$): δ 7.41 (d, J = 7.5 Hz, 2H), 7.33 (t, J = 7.8 Hz, 2H), 7.26 (t, J = 7.3 Hz, 1H), 6.75 (d, J = 15.0 Hz, 1H), 6.14 (dd, J = 15.8, 6.8 Hz, 1H), 4.77 (br s, 1H), 3.43 (br d, J = 5.0 Hz, 1H), 1.90 (d, J = 1.5 Hz, 3H), 1.24 (s, 9H)

^{13}C-NMR (125 MHz, $CDCl_3$): δ 135.8, 132.1, 128.3, 127.7, 127.2, 126.5, 82.5, 76.8, 55.7, 49.0, 22.3, 3.5

HRMS (ESI): calcd. for $C_{16}H_{21}ONNaS^+$ ([M+Na]$^+$): 298.1236, found: 298.1235 ([M+Na]$^+$)

***tert*-Butyl (*E*)-(1-phenylhex-1-en-4-yn-3-yl)carbamate (S6)**



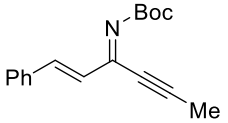
To a solution of **S5** (622 mg, 2.2 mmol, 1.0 eq.) in MeOH/dioxane (2.2/2.2 mL) was added 2 M HCl (in dioxane, 2.4 mL, 4.8 mmol, 2.2 eq.) at room temperature. After stirring for 30 min at 0 ºC, the mixture was concentrated *in vacuo*. The residue was dissolved in MeOH/CH_2Cl_2 (2/0.5 mL) and di-*tert*-butyl dicarbonate (Boc_2O) (758 µL, 3.3 mmol, 1.5 eq.), K_2CO_3 (456 mg, 3.3 mmol, 1.5 eq.) and *N*,*N*-dimethyl-4-aminopyridine (DMAP) (27 mg, 0.22 mmol, 10 mol%) were added to the solution. After stirring for 15 h at room temperature, the mixture was then quenched with H_2O and extracted with CH_2Cl_2. The combined organic layers were dried with Na_2SO_4 and concentrated *in vacuo*. The residue was washed with hexane to give **S6** as a white solid (461 mg, 1.70 mmol, 77% yield).

^{1}H-NMR (500 MHz, $CDCl_3$): δ 7.39 (d, J = 7.5 Hz, 2H), 7.31 (t, J = 7.8 Hz, 2H), 7.24 (t, J = 8.0 Hz, 1H), 6.75 (br d, J = 16.0 Hz, 1H), 6.16 (dd, J = 16.0, 5.5 Hz, 1H), 5.16 (br s, 1H), 4.79 (br s, 1H), 1.89 (d, J = 2.5 Hz, 3H), 1.47 (s, 9H)

^{13}C-NMR (125 MHz, $CDCl_3$): δ 154.6, 136.2, 131.0, 128.4, 127.7, 127.2, 126.6, 80.8, 79.8, 76.5, 44.3, 28.3, 3.5

HRMS (ESI): calcd. for $C_{17}H_{21}O_2NNa^+$ ([M+Na]$^+$): 294.1465, found: 294.1469 ([M+Na]$^+$)

***tert*-Butyl ((1*E*,3*Z*)-1-phenylhex-1-en-4-yn-3-ylidene)carbamate**



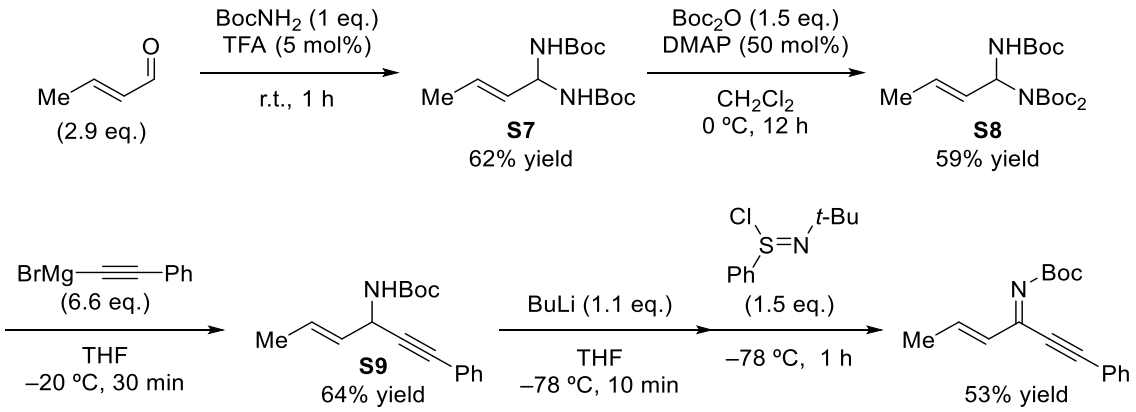
To a stirred solution of **S6** (136 mg, 0.5 mmol, 1 eq.) in DCE (2.5 mL) was added activated MnO_2 (869 mg, 10 mmol, 20 eq.) at room temperature. After stirring vigorously for 7.5 h at 50 ºC, insoluble materials were filtered off. The filtrate was concentrated to give the corresponding ketimine (130 mg, 0.48 mmol, 96% yield) as a white solid.

^{1}H-NMR (500 MHz, $CDCl_3$): δ 7.54 (d, J = 16.5 Hz, 1H), 7.54-7.53 (m, 2H), 7.43-7.35 (m, 3H), 6.83 (d, J = 16.5 Hz, 1H), 2.14 (s, 3H), 1.57 (s, 9H)

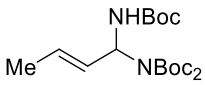
^{13}C-NMR (125 MHz, $CDCl_3$): δ 161.8, 152.8, 144.2, 135.0, 130.0, 128.9, 128.1, 127.9, 96.9, 82.2, 72.3, 28.1, 4.4

HRMS (ESI): calcd. for $C_{17}H_{19}O_2NNa^+$ ([M+Na]$^+$): 292.1308, found: 292.1311 ([M+Na]$^+$)

◆ **Synthesis of *tert*-butyl ((3*Z*,4*E*)-1-phenylhex-4-en-1-yn-3-ylidene)carbamate**



***tert*-Butyl (*E*)-(*tert*-butoxycarbonyl)(1-((*tert*-butoxycarbonyl)amino)but-2-en-1-yl)carbamate (S8)**



To a suspension of *tert*-butyl carbamate ($BocNH_2$) (1.2 g, 10 mmol, 1.0 eq.) in crotonaldehyde (1.2 mL, 14.6 mmol, 2.9 eq.) was added trifluoroacetic acid (TFA) (21 μL, 0.028 mmol) at room temperature. The mixture was stirred for 1 h and the product was solidified in the solvent aldehyde. The solid was filtered *in vacuo* and washed with hexane to give **S7** (908 mg, 3.1 mmol, 62% yield).

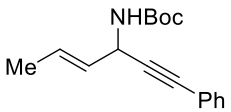
To a stirred solution of obtained **S7** (908 mg, ca. 3.1 mmol, 1 eq.) and DMAP (189 mg, 1.6 mmol, 50 mol%) in CH_2Cl_2 (31 mL) was added Boc_2O (1.1 mL, 4.7 mmol, 1.5 eq.) at 0 ºC. After stirring for 12 h, the reaction mixture was quenched with saturated NH_4Cl aq. and extracted with EtOAc. The combined organic layers were washed with brine, dried over Na_2SO_4 and then concentrated. The residue was purified by flash column chromatography on silica gel (hexane/EtOAc = 15/1~3/1 as eluent) to give **S8** (711 mg, 1.84 mmol, 59% yield) as a white solid.

^{1}H-NMR (500 MHz, $CDCl_3$): δ 6.49 (dd, J = 14.8, 1.2 Hz, 1H), 5.38 (dd, J = 14.5, 6.0 Hz, 1H), 4.44 (br s, 1H), 4.27 (br s, 1H), 1.51 (s, 18H), 1.44 (s, 9H), 1.25 (d, J = 6.5 Hz, 3H)

^{13}C-NMR (125 MHz, $CDCl_3$): δ 154.9, 151.4, 124.9, 119.8, 83.2, 79.3, 46.3, 28.4, 27.9, 21.2

HRMS (ESI): calcd. for $C_{19}H_{33}O_6N_2^-$ ($[M-H]^+$): 385.2344, found: 385.2348 ($[M-H]^+$)

***tert*-Butyl (*E*)-(1-phenylhex-4-en-1-yn-3-yl)carbamate (S9)**



To a stirred suspension of magnesium (374 mg, 15.4 mmol, 6.6 eq.) in THF (15 mL) was added ethyl bromide (1.1 mL, 15.4 mmol, 6.6 eq.) at room temperature dropwise under a nitrogen atmosphere. To the

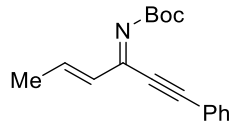
reaction mixture was added phenylacetylene (1.7 mL, 15.4 mmol, 6.6 eq.) dropwise at room temperature to give a solution of (phenylethynyl)magnesium bromide. To the solution was added **S8** (901 mg, 3 mmol, 1.0 eq.) in THF (9 mL) at −20 ºC. After stirring for 30 min at the same temperature, the mixture was then quenched with saturated NH_4Cl aq. and extracted with EtOAc. The combined organic layers were dried over Na_2SO_4 and concentrated. The residue was purified by flash column chromatography on silica gel (eluent with hexane/EtOAc = 7/1) to afford **S9** as a white solid (397 mg, 1.46 mmol, 64% yield).

^{1}H-NMR (500 MHz, $CDCl_3$): δ 7.44-7.42 (m, 2H), 7.31-7.30 (m, 3H), 6.00-5.93 (m, 1H), 5.55 (dd, *J* = 15.3, 5.3 Hz, 1H), 5.19 (br s, 1H), 4.82 (br s, 1H), 1.74 (dd, *J* = 6.8, 1.3 Hz, 3H), 1.47 (s, 9H)

^{13}C-NMR (125 MHz, $CDCl_3$): δ 154.7, 131.7, 128.31, 128.25, 128.23, 128.0, 122.7, 87.2, 84.2, 80.0, 44.6, 28.4, 17.4

HRMS (ESI): calcd. for $C_{17}H_{21}O_2NNa^+$ ([M+Na]$^+$): 294.1465, found: 294.1468 ([M+Na]$^+$)

***tert*-Butyl ((3*Z*,4*E*)-1-phenylhex-4-en-1-yn-3-ylidene)carbamate**



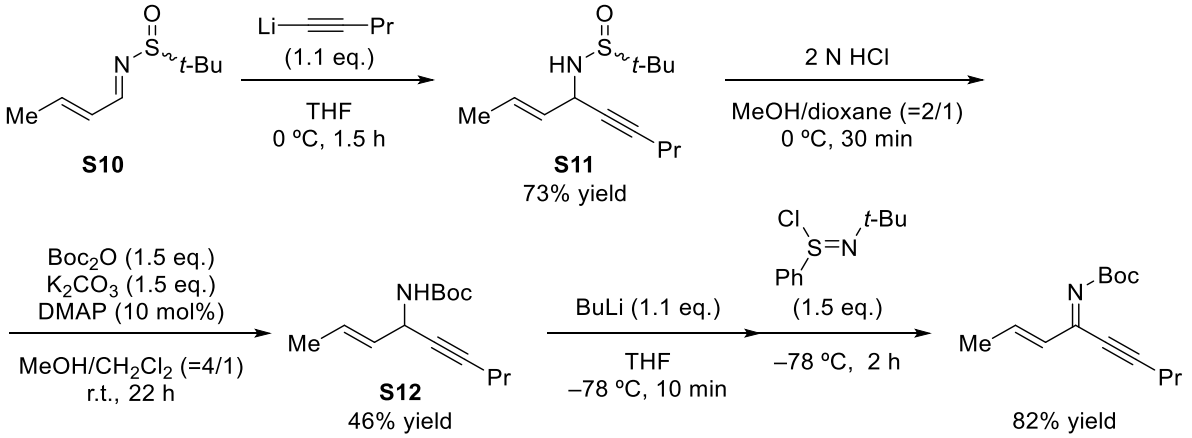
To a stirred solution of **S9** (397 mg, 1.5 mmol) in THF (5.8 mL) was added BuLi (1.56 M in hexane, 1 mL, 1.6 mmol, 1.1 eq.) at –78 °C dropwise under a nitrogen atmosphere. The reaction mixture was stirred at –78 °C for 10 min. To the reaction mixture was added *N*-*tert*-butylbenzenesulfinimidoyl chloride[7] (472 mg, 2.2 mmol, 1.5 eq.) dropwise at –78 °C, and the solution was stirred for 1 h at –78 °C. The mixture was then quenched with saturated NH_4Cl aq. and extracted with EtOAc. The combined organic layers were dried over Na_2SO_4 and concentrated. The residue was purified by flash column chromatography on silica gel with dry ice jacket (hexane/EtOAc = 40/1 as eluent) to afford the corresponding ketimine as a pale yellow oil (208 mg, 0.77 mmol, 53% yield).

^{1}H-NMR (500 MHz, $CDCl_3$): δ 7.52 (d, *J* = 7.5 Hz, 2H), 7.43 (tt, *J* = 7.5, 1.7 Hz, 1H), 7.37 (tt, *J* = 7.3, 1.6 Hz, 2H), 7.00-6.92 (m, 1H), 6.28 (d, *J* = 15.5 Hz, 1H), 1.99 (dd, *J* = 6.8, 1.8 Hz, 3H), 1.56 (s, 9H)

^{13}C-NMR (125 MHz, $CDCl_3$): δ 161.6, 152.2, 144.3, 132.3, 131.8, 130.1, 128.5, 120.6, 97.6, 82.2, 80.5, 28.1, 18.5

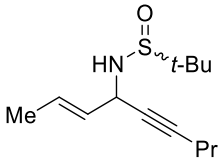
HRMS (ESI): calcd. for $C_{17}H_{19}O_2NNa^+$ ([M+Na]$^+$): 292.1308, found: 292.1312 ([M+Na]$^+$)

◆ Synthesis of *tert*-butyl ((3*Z*,4*E*)-1-phenylhex-4-en-1-yn-3-ylidene)carbamate



Imine **S10** was synthesized according to the literature procedure.[8]

(*E*)-2-Methyl-*N*-(non-2-en-5-yn-4-yl)propane-2-sulfinamide (S11)



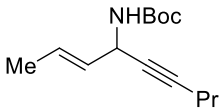
To a stirred solution of pent-1-yne (325 µL, 3.4 mmol, 1.1 eq.) in THF (2.1 mL) was added BuLi (2.1 mL, 3.3 mmol, 1.1 eq.) at 0 ºC dropwise under a nitrogen atmosphere. To the reaction mixture was added **S10** (520 mg, 3 mmol, 1 eq.) dropwise at 0 ºC and the solution was stirred for 1.5 h at room temperature. The mixture was then quenched with saturated NH_4Cl aq. and extracted with EtOAc. The combined organic layers were dried over Na_2SO_4 and concentrated. The residue was purified by flash column chromatography on silica gel (hexane/EtOAc = 3/1~1/1 as eluent) to afford **S11** as a brown oil (522 mg, 2.2 mmol, 73% yield, dr = >20/1). (major diastereomer)

^{1}H-NMR (500 MHz, $CDCl_3$): δ 5.90-5.83 (m, 1H), 5.48-5.43 (m, 1H), 4.57 (br t, J = 5.3 Hz, 1H), 3.30 (br d, J = 4.5 Hz, 1H), 2.20 (td, J = 7.3, 2.0 Hz, 2H), 1.73 (d, J = 6.5 Hz, 3H), 1.57-1.49 (m, 2H), 1.22 (s, 9H), 0.98 (t, J = 7.5 Hz, 3H)

^{13}C-NMR (125 MHz, $CDCl_3$): δ 129.0, 128.2, 85.8, 78.0, 55.2, 48.5, 22.1, 21.5, 20.3, 17.0, 13.0

HRMS (ESI): calcd. for $C_{13}H_{24}ONS^+$ ($[M+H]^+$): 242.1573, found: 242.1572 ($[M+H]^+$)

***tert*-Butyl (*E*)-non-2-en-5-yn-4-ylcarbamate (S12)**



To a solution of the **S11** (522 mg, 2.2 mmol, 1.0 eq.) in MeOH/dioxane (2.2/1.1 mL) was added 2 M HCl (in dioxane, 2.4 mL, 4.8 mmol, 2.2 eq.) at room temperature. After stirring for 30 min at 0 ºC, the mixture was concentrated *in vacuo*. The residue was dissolved in MeOH/CH_2Cl_2 (2/0.5 mL) and Boc_2O (751 µL, 3.3 mmol, 1.5 eq.), K_2CO_3 (452 mg, 3.3 mmol, 1.5 eq.) and DMAP (27 mg, 0.22 mmol, 10 mol%) were added to the solution. After stirring for 22 h at room temperature, the mixture was then quenched with H_2O and extracted with CH_2Cl_2. The combined organic layers were dried with Na_2SO_4 and concentrated *in vacuo*. The residue was

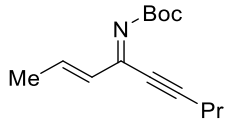
purified by flash column chromatography on silica gel (hexane/EtOAc = 7/1 as eluent) to afford **S12** as a colorless oil (239 mg, 1.0 mmol, 46% yield).

^{1}H-NMR (500 MHz, $CDCl_3$): δ 5.90-5.83 (m, 1H), 5.46 (dd, J = 15.0, 4.0 Hz, 1H), 4.92 (br s, 1H), 4.68 (br s, 1H), 2.18 (td, J = 7.3, 2.0 Hz, 2H), 1.70 (d, J = 6.5 Hz, 3H), 1.57-1.49 (m 2H), 1.45 (s, 9H), 0.98 (t, J = 7.5 Hz, 3H)

^{13}C-NMR (125 MHz, $CDCl_3$): δ 154.4, 128.8, 126.7, 84.1, 79.2, 77.9, 43.9, 28.1, 21.8, 20.4, 17.0, 13.1

HRMS (ESI): calcd. for $C_{14}H_{23}O_2NNa^+$ ($[M+Na]^+$): 260.1621, found: 260.1620 ($[M+Na]^+$)

***tert*-Butyl ((2*E*,4*Z*)-non-2-en-5-yn-4-ylidene)carbamate**



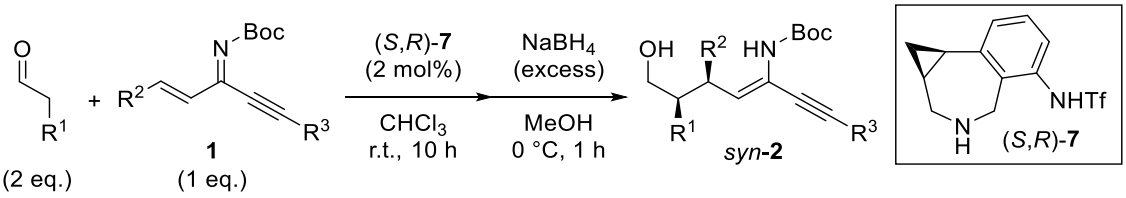
To a stirred solution of **S12** (239 mg, 1 mmol) in THF (4 mL) was added BuLi (1.56 M in hexane, 705 µL, 1.1 mmol, 1.1 eq.) at –78 °C dropwise under a nitrogen atmosphere. The reaction mixture was stirred at –78 °C for 10 min. To the reaction mixture was added *N*-*tert*-butylbenzenesulfinimidoyl chloride[7] (324 mg, 1.5 mmol, 1.5 eq.) dropwise at –78 °C, and the solution was stirred for 2 h at –78 °C. The mixture was then quenched with saturated NH_4Cl aq. and extracted with EtOAc. The combined organic layers were dried over Na_2SO_4, and concentrated. The residue was purified by flash column chromatography on silica gel with dry ice jacket (hexane/EtOAc = 40/1 as eluent) to afford the corresponding ketimine (193 mg, 0.82 mmol, 82% yield) as a pale yellow oil.

^{1}H-NMR (500 MHz, $CDCl_3$): δ 6.87-6.80 (m, 1H), 6.18 (d, J = 15.5 Hz, 1H), 2.39 (t, J = 7.0 Hz, 2H), 1.93 (dd, J = 7.0, 1.5 Hz, 3H), 1.66-1.60 (m, 2H), 1.54 (s, 9H), 1.03 (t, J = 7.5 Hz, 3H)

^{13}C-NMR (125 MHz, $CDCl_3$): δ 161.6, 152.5, 143.7, 132.0, 100.4, 81.7, 72.9, 27.9, 21.4, 21.1, 18.3, 13.4

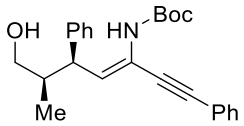
HRMS (ESI): calcd. for $C_{14}H_{22}O_2N^+$ ($[M+H]^+$): 236.1645, found: 236.1646 ($[M+H]^+$)

3. General Procedure for Conjugate Addition to *Z*-Ketimines



To a mixture of (*S*,*R*)-**7**[9] (0.6 mg, 0.002 mmol, 2 mol%) and ketimine **1** (0.1 mmol, 1 eq.) in $CHCl_3$ (200 μL) was added an aldehyde (0.2 mmol, 2.0 eq.) at room temperature. After stirring for 10 h, the mixture was diluted with MeOH (ca. 2 mL) and cooled to 0 ºC. $NaBH_4$ (excess) was then added to the mixture. After stirring for 1 h, the reaction mixture was quenched with H_2O and extracted with EtOAc. The organic layers were washed with brine, dried with Na_2SO_4 and concentrated *in vacuo*. The residue was purified by silica gel chromatography (hexane/EtOAc = 7/1 ~ 1/1 as eluent) to give the *syn*-**2**.

***tert*-Butyl ((5*S*,6*R*,*Z*)-7-hydroxy-6-methyl-1,5-diphenylhept-3-en-1-yn-3-yl)carbamate (*syn*-2a)**



Was obtained as a white solid (36.9 mg, 0.094 mmol, 94%, dr = >20/1, 94% ee), following the general procedure with propanal (14 μL, 0.2 mmol) and the corresponding ketimine (33 mg, 0.1 mmol).

$[\alpha]_D^{30}$: −193.6 (*c* 1.0, $CHCl_3$)

^{1}H-NMR (500 MHz, $CDCl_3$): *δ* 7.50-7.48 (m, 2H), 7.39-7.36 (m, 3H), 7.33-7.26 (m, 4H), 7.21 (tt, *J* = 7.3, 1.7 Hz, 1H), 6.55 (br d, *J* = 10.5 Hz, 1H), 5.78 (br s, 1H), 3.76-3.72 (m, 1H), 3.70-3.66 (m, 1H), 3.68 (app t, *J* = 10.5 Hz, 1H), 2.50 (br s, 1H), 2.18-2.10 (m, 1H), 1.47 (s, 9H), 0.83 (d, *J* = 6.5 Hz, 3H)

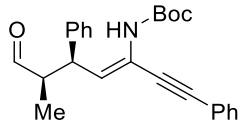
^{13}C-NMR (125 MHz, $CDCl_3$): *δ* 153.3, 143.0, 131.6, 129.9, 128.9, 128.6, 128.5, 128.0, 126.4, 122.1, 116.9, 92.4, 84.0, 80.8, 67.0, 51.2, 42.0, 28.3, 15.9

HRMS (ESI): calcd. for $C_{25}H_{29}O_3NNa^+$ ([M+Na]$^+$): 414.2040, found: 414.2045 ([M+Na]$^+$)

HPLC analysis: Daicel Chiralpak IA-3, hexane/*i*PrOH = 40/1, flow rate = 1.0 mL/min, retention time; 29.7 min and 32.1 min (major)

Before reduction

***tert*-Butyl ((5*S*,6*R*,*Z*)-6-methyl-7-oxo-1,5-diphenylhept-3-en-1-yn-3-yl)carbamate**



$[\alpha]_D^{23}$: −131.0 (*c* 1.0, $CHCl_3$)

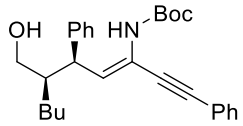
^{1}H-NMR (500 MHz, $CDCl_3$): *δ* 9.81 (d, *J* = 2.5 Hz, 1H), 7.48-7.46 (m, 2H), 7.39-7.36 (m, 3H), 7.34-7.32 (m, 2H), 7.27-7.26 (m, 2H), 7.23 (tt, *J* = 7.3, 1.4 Hz, 1H), 6.69 (s, 1H), 5.88 (s, 1H), 4.05 (app t, *J* = 10.0 Hz, 1H),

2.86-2.80 (m, 1H), 1.46 (s, 9H), 0.97 (d, *J* = 7.0 Hz, 3H)

^{13}C-NMR (125 MHz, CDCl$_3$): *δ* 204.6, 152.3, 141.3, 131.6, 129.0, 128.8, 128.5, 128.0, 126.8, 122.9, 121.9, 119.0, 93.1, 83.4, 80.6, 51.7, 48.2, 28.3, 12.4

HRMS (ESI): calcd. for $C_{25}H_{28}O_3N^+$ ([M+H]$^+$): 390.2064, found: 390.2061 ([M+H]$^+$)

***tert*-Butyl ((5*S*,6*R*,*Z*)-6-(hydroxymethyl)-1,5-diphenyldec-3-en-1-yn-3-yl)carbamate (*syn*-2b)**



Was obtained as a colorless oil (43.3 mg, 0.1 mmol, >99%, dr = >20/1, 93% ee), following the general procedure with hexanal (25 μL, 0.2 mmol) and the corresponding ketimine (33 mg, 0.1 mmol).

$[\alpha]_D^{27}$: −176.6 (*c* 1.0, CHCl$_3$)

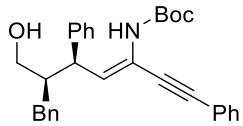
^{1}H-NMR (500 MHz, CDCl$_3$): *δ* 7.50-7.48 (m, 2H), 7.38-7.36 (m, 3H), 7.33-7.26 (m, 4H), 7.21 (t, *J* = 7.5 Hz, 1H), 6.50 (br d, *J* = 10.5 Hz, 1H), 5.77 (br s, 1H), 3.83-3.72 (m, 3H), 2.70 (br s, 1H), 1.99 (br s, 1H), 1.46 (s, 9H), 1.37-1.29 (m, 1H), 1.26-1.11 (m, 5H), 0.77 (t, *J* = 7.3 Hz, 3H)

^{13}C-NMR (125 MHz, CDCl$_3$): *δ* 153.4, 143.1, 131.5, 130.5, 128.9, 128.6, 128.5, 128.0, 126.4, 122.1, 116.6, 92.4, 84.0, 80.8, 63.8, 49.8, 46.8, 29.1, 28.9, 28.3, 22.8, 13.9

HRMS (ESI): calcd. for $C_{28}H_{35}O_3NNa^+$ ([M+Na]$^+$): 456.2509, found: 456.2508 ([M+Na]$^+$)

HPLC analysis: Daicel Chiralpak IC, hexane/*i*PrOH = 20/1, flow rate = 1.0 mL/min, retention time; 11.1 min (major) and 14.4 min

***tert*-Butyl ((5*S*,6*R*,*Z*)-6-benzyl-7-hydroxy-1,5-diphenylhept-3-en-1-yn-3-yl)carbamate (*syn*-2c)**



Was obtained as a colorless oil (46.7 mg, 0.1 mmol, >99%, dr = >20/1, 90% ee), following the general procedure with 3-phenylpropanal (26 μL, 0.2 mmol) and the corresponding ketimine (33 mg, 0.1 mmol).

$[\alpha]_D^{26}$: −101.3 (*c* 1.0, CHCl$_3$)

^{1}H-NMR (500 MHz, CDCl$_3$): *δ* 7.47-7.45 (m, 2H), 7.39-7.35 (m, 6H), 7.26-7.20 (m, 4H), 7.15-7.09 (m, 3H), 6.55 (br d, *J* = 10.5 Hz, 1H), 5.80 (br s, 1H), 3.91 (app t, *J* = 10.8 Hz, 1H), 3.80-3.76 (m, 1H), 3.62-3.58 (m, 1H), 2.59 (dd, *J* = 14.0, 4.0 Hz, 1H), 2.48 (dd, *J* = 14.0, 10.0 Hz, 1H), 2.41 (br s, 1H), 2.33-2.27 (m, 1H), 1.46 (s, 9H)

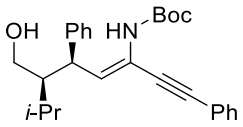
^{13}C-NMR (125 MHz, CDCl$_3$): *δ* 153.2, 143.0, 140.6, 131.6, 129.2, 129.1, 129.0, 128.9, 128.5, 128.2, 128.1, 126.6, 125.8, 122.0, 117.2, 92.7, 83.9, 80.8, 62.5, 49.3, 48.6, 35.4, 28.3

HRMS (ESI): calcd. for $C_{31}H_{33}O_3NNa^+$ ([M+Na]$^+$): 490.2353, found: 490.2359 ([M+Na]$^+$)

HPLC analysis: Daicel Chiralpak IC, hexane/*i*PrOH = 20/1, flow rate = 1.0 mL/min, retention time; 19.8 min

(major) and 37.9 min

***tert*-Butyl ((5*S*,6*R*,*Z*)-6-(hydroxymethyl)-7-methyl-1,5-diphenyloct-3-en-1-yn-3-yl)carbamate (*syn*-2d)**



Was obtained as a colorless oil (42.0 mg, 0.1 mmol, >99%, dr = >20/1, 93% ee), following the general procedure with isovaleraldehyde (22 μL, 0.2 mmol) and the corresponding ketimine (33 mg, 0.1 mmol).

$[\alpha]_D^{26}$: −205.5 (*c* 1.0, $CHCl_3$)

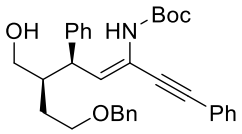
^{1}H-NMR (500 MHz, $CDCl_3$): *δ* 7.51-7.48 (m, 2H), 7.38-7.37 (m, 3H), 7.34-7.28 (m, 4H), 7.23-7.20 (m, 1H), 6.45 (br d, *J* = 11.5 Hz, 1H), 5.74 (br s, 1H), 3.99 (app t, *J* = 11.0 Hz, 1H), 3.79-3.71 (m, 2H), 3.60 (br s, 1H), 2.02-1.99 (m, 1H), 1.60-1.54 (m, 1H), 1.46 (s, 9H), 0.97 (d, *J* = 7.0 Hz, 3H), 0.82 (d, *J* = 7.5 Hz, 3H)

^{13}C-NMR (125 MHz, $CDCl_3$): *δ* 154.1, 143.1, 133.7, 131.5, 128.9, 128.8, 128.5, 127.9, 126.5, 122.2, 115.9, 92.5, 84.2, 81.1, 61.7, 53.3, 49.4, 28.2, 27.4, 21.7, 16.4

HRMS (ESI): calcd. for $C_{27}H_{33}O_3NNa^+$ ([M+Na]$^+$): 442.2353, found: 442.2357 ([M+Na]$^+$)

HPLC analysis: Daicel Chiralpak IA, hexane/*i*PrOH = 40/1, flow rate = 1.0 mL/min, retention time; 17.0 min and 20.4 min (major)

***tert*-Butyl ((5*S*,6*R*,*Z*)-8-(benzyloxy)-6-(hydroxymethyl)-1,5-diphenyloct-3-en-1-yn-3-yl)carbamate (*syn*-2e)**



Was obtained as a colorless oil (44.8 mg, 0.088 mmol, 88%, dr = >20/1, 98% ee), following the general procedure with 4-(benzyloxy)butanal (36 mg, 0.2 mmol) and the corresponding ketimine (33 mg, 0.1 mmol).

$[\alpha]_D^{26}$: −136.1 (*c* 1.0, $CHCl_3$)

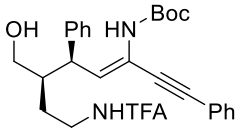
^{1}H-NMR (500 MHz, $CDCl_3$): *δ* 7.48-7.46 (m, 2H), 7.37-7.35 (m, 3H), 7.31-7.25 (m, 12H), 7.19 (t, *J* = 7.0 Hz, 1H), 6.53 (br d, *J* = 9.0 Hz, 1H), 5.81 (br s, 1H), 4.42 (s, 2H), 3.82 (app t, *J* = 10.5 Hz, 1H), 3.82-3.73 (m, 2H), 3.52-3.48 (m, 1H), 3.45-3.40 (m, 1H), 3.07 (br s, 1H), 2.17-2.14 (m, 1H), 1.66-1.53 (m, 2H), 1.46 (s, 9H)

^{13}C-NMR (125 MHz, $CDCl_3$): *δ* 153.1, 143.1, 138.2, 131.7, 129.0, 128.8, 128.6, 128.5, 128.3, 128.2, 127.8, 127.7, 126.6, 122.3, 117.6, 92.6, 84.1, 80.8, 73.1, 68.9, 64.1, 49.4, 44.7, 30.1, 28.4

HRMS (ESI): calcd. for $C_{33}H_{37}O_4NNa^+$ ([M+Na]$^+$): 534.2615, found: 534.2620 ([M+Na]$^+$)

HPLC analysis: Daicel Chiralpak IG, hexane/*i*PrOH = 10/1, flow rate = 1.0 mL/min, retention time; 19.1 min and 21.1 min (major)

***tert*-Butyl ((5*S*,6*R*,*Z*)-6-(hydroxymethyl)-1,5-diphenyl-8-(2,2,2-trifluoroacetamido)oct-3-en-1-yn-3-yl)carbamate (*syn*-2f)**



Was obtained as an oil (31.3 mg, 0.061 mmol, 61%, dr = >20/1, 94% ee), following the general procedure with 2,2,2-trifluoro-*N*-(4-oxobutyl)acetamide (37 mg, 0.2 mmol) and the corresponding ketimine (33 mg, 0.1 mmol).

$[\alpha]_D^{30}$: −99.9 (*c* 1.0, $CHCl_3$)

^{1}H-NMR (500 MHz, $CDCl_3$): δ 7.49-7.47 (m, 2H), 7.39-7.37 (m, 3H), 7.33 (t, *J* = 7.8 Hz, 2H), 7.26-7.22 (m, 3H), 6.51 (br d, *J* = 10.0 Hz, 1H), 5.83 (br s, 1H), 3.88-3.80 (m, 3H), 3.39-3.25 (m, 2H), 2.43 (br s, 1H), 2.09-2.05 (br m, 1H), 1.62-1.58 (m, 2H), 1.47 (s, 9H)

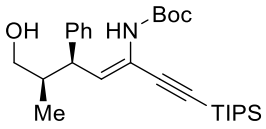
^{13}C-NMR (125 MHz, $CDCl_3$): δ 157.2 (q, *J* = 36.7 Hz), 153.1, 142.2, 131.6, 129.2, 129.0, 128.6, 127.9, 127.4, 126.9, 121.8, 117.8, 116.0 (q, *J* = 288.9 Hz), 92.9, 83.6, 80.9, 63.8, 48.7, 44.3, 38.1, 29.1, 28.3

^{19}F-NMR (466 MHz, $CDCl_3$): δ –75.9

HRMS (ESI): calcd. for $C_{28}H_{31}O_4N_2F_3Na^+$ ($[M+Na]^+$): 539.2128, found: 539.2130 ($[M+Na]^+$)

HPLC analysis: Daicel Chiralpak ID, hexane/*i*PrOH = 20/1, flow rate = 1.0 mL/min, retention time; 11.5 min and 12.4 min (major)

***tert*-Butyl ((5*S*,6*R*,*Z*)-7-hydroxy-6-methyl-5-phenyl-1-(triisopropylsilyl)hept-3-en-1-yn-3-yl)carbamate (*syn*-2g)**



Was obtained as a white solid (37.0 mg, 0.078 mmol, 78%, dr = >20/1, 99% ee), following the general procedure with propanal (14 μL, 0.2 mmol) and the corresponding ketimine (41 mg, 0.1 mmol).

$[\alpha]_D^{29}$: −105.1 (*c* 1.0, $CHCl_3$)

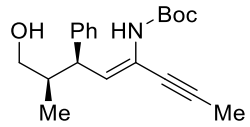
^{1}H-NMR (500 MHz, $CDCl_3$): δ 7.33-7.28 (m, 2H), 7.23-7.18 (m, 3H), 6.55 (br d, *J* = 10.0 Hz, 1H), 5.64 (br s, 1H), 3.72-3.62 (m, 2H), 3.68 (app t, *J* = 11.0 Hz, 1H), 2.49 (br s, 1H), 2.13-2.05 (m, 1H), 1.45 (s, 9H), 1.14 (br s, 21H), 0.80 (d, *J* = 7.0 Hz, 3H)

^{13}C-NMR (125 MHz, $CDCl_3$): δ 153.2, 143.1, 130.3, 128.7, 127.9, 126.4, 116.9, 101.2, 94.8, 80.8, 67.1, 51.4, 42.1, 28.3, 18.7, 15.9, 11.3

HRMS (ESI): calcd. for $C_{28}H_{45}O_3NNaSi^+$ ($[M+Na]^+$): 494.3061, found: 494.3063 ($[M+Na]^+$)

HPLC analysis: Daicel Chiralpak IA-3, hexane/*i*PrOH = 40/1, flow rate = 0.7 mL/min, retention time; 12.8 min (major) and 15.5 min

***tert*-Butyl ((6*S*,7*R*,*Z*)-8-hydroxy-7-methyl-6-phenyloct-4-en-2-yn-4-yl)carbamate (*syn*-2h)**



Was obtained as a colorless oil (30.1 mg, 0.091 mmol, 91%, dr = >20/1, 86% ee), following the general procedure with propanal (14 μL, 0.2 mmol) and the corresponding ketimine (27 mg, 0.1 mmol).

$[\alpha]_D^{22}$: −80.8 (*c* 1.0, $CHCl_3$)

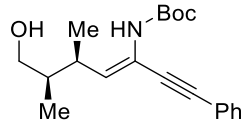
^{1}H-NMR (500 MHz, $CDCl_3$): *δ* 7.29 (t, *J* = 7.8 Hz, 2H), 7.23-7.18 (m, 3H), 6.38 (br d, *J* = 10.5 Hz, 1H), 5.66 (br s, 1H), 3.66 (br s, 2H), 3.54 (app t, *J* = 10.8 Hz, 1H), 2.44 (br s, 1H), 2.11-2.04 (m, 1H), 2.03 (s, 3H), 1.44 (s, 9H), 0.81 (d, *J* = 7.5 Hz, 3H)

^{13}C-NMR (125 MHz, $CDCl_3$): *δ* 153.2, 143.3, 128.5, 127.9, 127.7, 126.3, 117.1, 89.4, 80.5, 74.8, 66.9, 50.6, 41.7, 28.3, 15.9, 4.2

HRMS (ESI): calcd. for $C_{20}H_{27}O_3NNa^+$ ($[M+Na]^+$): 352.1883, found: 352.1889 ($[M+Na]^+$)

HPLC analysis: Daicel Chiralpak IA, hexane/*i*PrOH = 20/1, flow rate = 1.0 mL/min, retention time; 13.4 min (major) and 25.1 min

***tert*-Butyl ((5*S*,6*R*,*Z*)-7-hydroxy-5,6-dimethyl-1-phenylhept-3-en-1-yn-3-yl)carbamate (*syn*-2i)**



Was obtained as a colorless oil (19.2 mg, 0.058 mmol, 58%, dr = >20/1, 96% ee), following the general procedure with propanal (14 μL, 0.2 mmol) and the corresponding ketimine (27 mg, 0.1 mmol).

$[\alpha]_D^{30}$: −23.8 (*c* 1.0, $CHCl_3$)

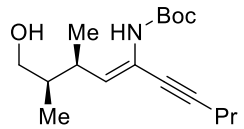
^{1}H-NMR (500 MHz, $CDCl_3$): *δ* 7.46-7.43 (m, 2H), 7.34-7.33 (m, 3H), 6.19 (br d, *J* = 10.0 Hz, 1H), 5.79 (br s, 1H), 3.63 (dd, *J* = 11.0, 5.5 Hz, 1H), 3.53 (dd, *J* = 11.3, 4.8 Hz, 1H), 2.67-2.59 (m, 1H), 2.12 (br s, 1H), 1.64-1.58 (m, 1H), 1.48 (s, 9H), 1.09 (d, *J* = 7.0 Hz, 3H), 1.00 (d, *J* = 7.0 Hz, 3H)

^{13}C-NMR (125 MHz, $CDCl_3$): *δ* 153.3, 132.4, 131.5, 128.8, 128.4, 122.2, 116.4, 91.9, 84.1, 80.6, 67.0, 42.2, 37.9, 28.3, 18.2, 15.1

HRMS (ESI): calcd. for $C_{20}H_{27}O_3NNa^+$ ($[M+Na]^+$): 352.1883, found: 352.1888 ($[M+Na]^+$)

HPLC analysis: Daicel Chiralpak AD-3, hexane/*i*PrOH = 20/1, flow rate = 0.5 mL/min, retention time; 30.8 min (major) and 32.7 min

***tert*-Butyl ((2*R*,3*S*,*Z*)-1-hydroxy-2,3-dimethyldec-4-en-6-yn-5-yl)carbamate (*syn*-2j)**



Was obtained as a colorless oil (26.6 mg, 0.086 mmol, 86%, dr = >20/1, 89% ee), following the general

procedure with propanal (14 μL, 0.2 mmol) and the corresponding ketimine (24 mg, 0.1 mmol).

$[\alpha]_D^{30}$: −37.3 (*c* 1.0, $CHCl_3$)

^{1}H-NMR (500 MHz, $CDCl_3$): δ 6.05 (br d, *J* = 10.0 Hz, 1H), 5.65 (br s, 1H), 3.59-3.47 (m, 2H), 2.53-2.45 (m, 1H), 2.31 (t, *J* = 7.3 Hz, 2H), 2.09 (br s, 1H), 1.61-1.55 (m, 3H), 1.46 (s, 9H), 1.04 (d, *J* = 7.0 Hz, 3H), 1.00 (t, *J* = 7.3 Hz, 3H), 0.98 (d, *J* = 7.0 Hz, 3H)

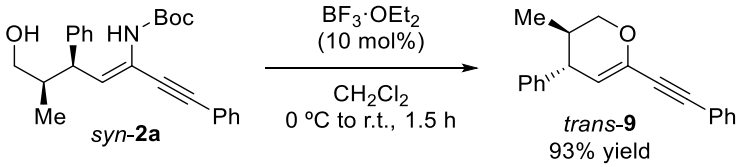
^{13}C-NMR (125 MHz, $CDCl_3$): δ 153.3, 130.1, 116.5, 93.2, 80.4, 75.8, 67.1, 42.1, 37.7, 28.3, 22.0, 21.2, 18.4, 15.2, 13.5

HRMS (ESI): calcd. for $C_{17}H_{29}O_3NNa^+$ ($[M+Na]^+$): 318.2040, found: 318.2048 ($[M+Na]^+$)

HPLC analysis: Daicel Chiralpak IC, hexane/*i*PrOH = 20/1, flow rate = 1.0 mL/min, retention time; 10.4 min (major) and 13.5 min

4. Transformations of the the Conjugate Adduct

◆ Cyclization of the conjugate adduct *syn*-2a



To a solution of *syn*-**2a** (61 mg, 0.16 mmol, 1 eq.) in CH_2Cl_2 (1.6 mL) was added boron trifluoride diethyl ether complex ($BF_3{\cdot}OEt_2$) (2.0 μL, 0.016 mmol, 10 mol%) at 0 ºC and the solution was stirred for 1.5 h at room temperature. The mixture was then quenched with H_2O and extracted with CH_2Cl_2. The combined organic layers were dried over Na_2SO_4 and concentrated *in vacuo*. The residue was then purified by column chromatography on silica gel (hexane/EtOAc = 7/1 as eluent) to afford *trans*-**9** (39.8 mg, 0.16 mmol, 93%) as a white solid.

trans-9

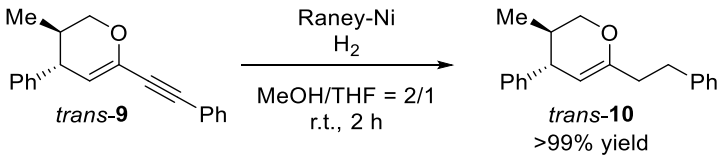
$[\alpha]_D^{25}$: 4.3 (*c* 1.0, $CHCl_3$)

^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.49-7.47 (m, 2H), 7.35-7.31 (m, 5H), 7.25-7.23 (m, 3H), 5.31 (d, *J* = 2.8 Hz, 1H), 4.12 (dd, *J* = 11.0, 3.4 Hz, 1H), 3.77 (app t, *J* = 10.2 Hz, 1H), 3.11 (dd, *J* = 8.4, 3.2 Hz, 1H), 2.00-1.94 (m, 1H), 0.94 (d, *J* = 6.8 Hz, 3H)

^{13}C-NMR (125 MHz, $CDCl_3$): δ 143.7, 137.4, 131.7, 128.6, 128.4, 128.3, 128.2, 126.7, 122.3, 112.0, 87.8, 84.4, 71.0, 46.5, 35.0, 15.6

HRMS (ESI): calcd. for $C_{20}H_{19}O^+$ ([M+H]$^+$): 275.1430, found: 275.1432 ([M+H]$^+$)

◆ Selective hydrogenation of *trans*-9



After Raney-Ni (37.0 mg) was washed with 1 M NaOH aq. (6 mL×2), it was rinsed with water until the pH value was nearly 7 (3 mL×3). Afterwards it was washed with MeOH (6 mL×3) and was added to MeOH (3.4 mL). To the stirred suspension was added *trans*-**9** (33 mg, 0.12 mmol, 1 eq.) in THF (1.7 mL) at room temperature. The mixture was then hydrogenated under H_2 (balloon) at room temperature for 2 h and filtered through a Celite pad. The filtrate was evaporated under reduced pressure. The crude mixture was purified by preparative thin layer chromatography (hexane/EtOAc = 7/1) to afford *trans*-**10** as a colorless oil (33.6 mg, 0.12 mmol, >99% yield).

trans-10

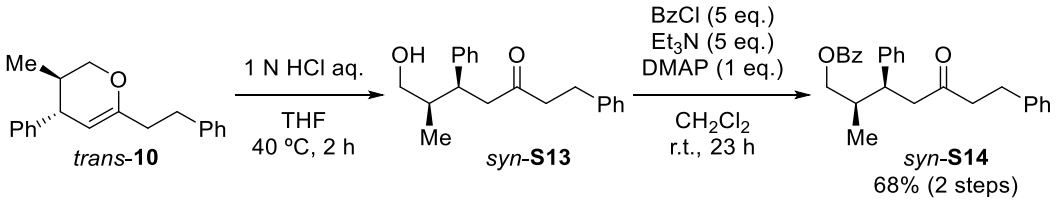
$[\alpha]_D^{26}$: 25.3 (*c* 1.0, $CHCl_3$)

^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.32-7.28 (m, 3H), 7.23-7.16 (m, 5H), 7.02-7.00 (m, 2H), 4.40 (br d, *J* = 1.6 Hz, 1H), 4.00 (dd, *J* = 10.6, 3.4 Hz, 1H), 3.64 (app t, *J* = 10.0 Hz, 1H), 2.91 (br d, *J* = 7.6 Hz, 1H), 2.86 (d, *J* = 10.4 Hz, 1H), 2.85 (t, *J* = 7.2 Hz, 1H), 2.47-2.35 (m, 2H), 1.80-1.74 (m, 1H), 0.87 (d, *J* = 6.8 Hz, 3H)

^{13}C-NMR (125 MHz, $CDCl_3$): δ 153.3, 145.3, 141.7, 128.6, 128.3, 128.14, 128.12, 126.2, 125.8, 100.1, 70.5, 45.9, 35.9, 35.5, 33.3, 15.6

HRMS (ESI): calcd. for $C_{20}H_{23}O_3^+$ ($[M+H]^+$): 279.1743, found: 279.1744 ($[M+H]^+$)

◆ Hydrolysis of *trans*-10



To a solution of *trans*-**10** (8.0 mg, 0.029 mmol, 1 eq.) in THF (287 µL) was added 1 N HCl aq. (287 µL) at room temperature and the solution was stirred for 2 h at 40 ºC. The mixture was then quenched with brine and extracted with CH_2Cl_2. The combined organic layers were dried over Na_2SO_4 and concentrated *in vacuo*. The residue was used for the next reaction without purification because dehydrative condensation of *syn*-**S13** occurs during the purification process.

The residue was dissolved in CH_2Cl_2 (287 µL) and benzoyl chloride (BzCl) (16.7 µL, 0.14 mmol, 5 eq.), Et_3N (20.1 µL, 0.14 mmol, 5 eq.) and *N*,*N*-dimethyl-4-aminopyridine (DMAP) (27 mg, 0.22 mmol, 1 eq.) were added to the solution. After stirring for 23 h at room temperature, the mixture was then quenched with brine and extracted with CH_2Cl_2. The combined organic layers were dried over Na_2SO_4 and concentrated *in vacuo*. The crude mixture was purified by preparative thin layer chromatography (hexane/EtOAc = 10/1) to afford *syn*-**S14** (7.9 mg, 0.02 mmol, 68%) as a white solid.

syn-S13

The δ-hydroxyketone *syn*-**S13** was not observed by ^{13}C-NMR and HRMS analysis due to the rapid dehydrative condensation to *trans*-**10**.

^{1}H-NMR (400 MHz, $CDCl_3$): δ 7.37-7.26 (m, 4H), 7.24-7.17 (m, 6H), 3.75-3.68 (m, 2H), 2.78-2.74 (m, 3H), 1.97-1.93 (m, 5H), 1.73 (t, *J* = 13.2 Hz, 1H), 0.65 (d, *J* = 6.8 Hz, 3H)

syn-S14

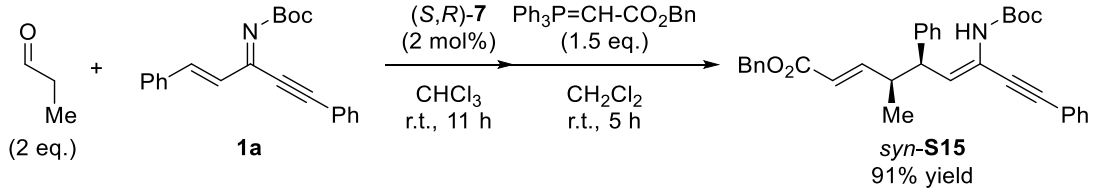
$[\alpha]_D^{23}$: 5.1 (*c* 1.0, $CHCl_3$)

^{1}H-NMR (400 MHz, $CDCl_3$): δ 8.06 (d, *J* = 7.2 Hz, 2H), 7.58 (t, *J* = 7.4 Hz, 1H), 7.46 (t, *J* = 7.8 Hz, 2H), 7.28 (t, *J* = 7.2 Hz, 2H), 7.23-7.21 (m, 3H), 7.16 (d, *J* = 6.8 Hz, 3H), 7.04 (d, *J* = 7.2 Hz, 2H), 4.16-4.11 (m, 2H), 3.43-3.39 (m, 1H), 2.92-2.85 (m, 2H), 2.77-2.62 (m, 3H), 2.56-2.51 (m, 1H), 2.24-2.18 (m, 1H), 0.86 (d, *J* = 7.2 Hz, 3H)

^{13}C-NMR (125 MHz, $CDCl_3$): δ 208.5, 166.5, 141.2, 140.9, 133.0, 130.2, 129.6, 128.5, 128.45, 128.43, 128.41, 128.2, 126.7, 126.0, 67.8, 46.7, 45.0, 42.7, 37.2, 29.5, 14.2

HRMS (ESI): calcd. for $C_{27}H_{28}O_3Na^+$ ([M+Na]$^+$): 423.1931, found: 423.1938 ([M+Na]$^+$)

◆ Wittig reaction of the conjugate adduct



To a mixture of (*S*,*R*)-**7** (0.6 mg, 0.002 mmol, 2 mol%) and **1a** (33 mg, 0.1 mmol, 1 eq.) in $CHCl_3$ (200 µL) was added propanal (14 µL, 0.2 mmol, 2.0 eq.) at room temperature. After stirring for 11 h, the residue was passed through a short silica gel/Na_2SO_4 plug, eluting with a solution of EtOAc and concentrated *in vacuo*. The residue was dissolved in CH_2Cl_2 (1 mL) and benzyl (triphenylphosphoranylidene)acetate (61.5 mg, 0.15 mmol, 1.5 eq.) was added to the solution. After stirring for 5 h, the mixture was evaporated under reduced pressure. The residue was purified by silica gel chromatography (hexane/EtOAc = 7/1 ~ 1/1 as eluent) to give the *syn*-**S15** (47.6 mg, 0.091 mmol, 91%).

syn-S15

$[\alpha]_D^{27}$: −37.3 (*c* 1.0, $CHCl_3$)

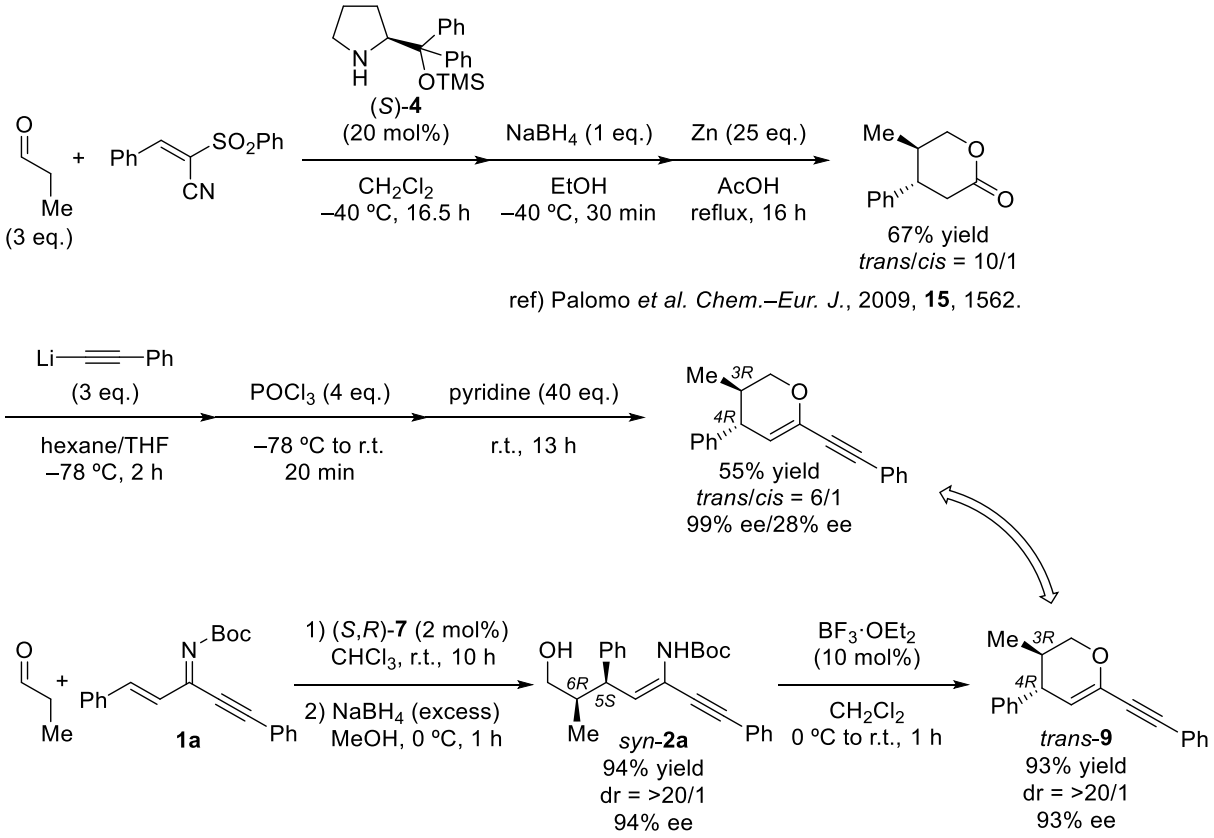
^{1}H-NMR (500 MHz, $CDCl_3$): δ 7.45-7.43 (m, 2H), 7.37-7.29 (m, 10H), 7.25-7.23 (m, 2H), 7.22-7.19 (m 1H), 7.08 (dd, *J* = 16.0, 8.0 Hz, 1H), 6.58 (br s, 1H), 5.90 (dd, *J* = 16.0, 1.0 Hz, 1H), 5.82 (br s, 1H), 5.16 (s, 2H), 3.75 (dd, *J* = 10.5, 9.0 Hz, 1H), 2.81-2.75 (m, 1H), 1.45 (s, 9H), 0.97 (d, *J* = 7.0 Hz, 3H)

^{13}C-NMR (125 MHz, $CDCl_3$): δ 166.4, 152.8, 152.3, 142.5, 136.2, 131.5, 128.8, 128.5 (2 peaks overlap), 128.45, 128.41, 128.04, 127.98, 127.96, 126.5, 122.2, 120.7, 118.8, 92.5, 83.8, 80.4, 65.9, 51.9, 42.6, 28.3, 17.8

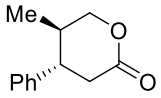
HRMS (ESI): calcd. for $C_{34}H_{35}O_4NNa^+$ ([M+Na]$^+$): 544.2458, found: 544.2457 ([M+Na]$^+$)

5. Determination of Absolute Configuration of the Conjugate Adduct

The absolute configuration of conjugate adduct *syn*-**2a** was determined to be (5*S*,6*R*) by conversion to *trans*-**9** as shown below.[10]



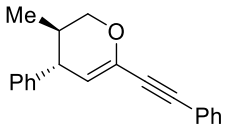
(4*S*,5*R*)-5-Methyl-4-phenyltetrahydro-2H-pyran-2-one



To a mixture of (*S*)-**4** (65.1 mg, 0.2 mmol, 20 mol%) and (*E*)-3-phenyl-2-(phenylsulfonyl)acrylonitrile (269 mg, 1 mmol, 1 eq.) in CH_2Cl_2 (0.5 mL) at −40 ºC was added propanal (216 μL, 3 mmol, 3 eq.) and the mixture was stirred at −40 ºC for 16.5 h. The reaction mixture was then diluted with EtOH (2 mL). To the resulting mixture was added a suspension of $NaBH_4$ (38 mg, 1 mmol, 1 eq.) in EtOH (4 mL). The reaction was stirred at –40 ºC for 30 min and quenched with H_2O. The aqueous phase was extracted with CH_2Cl_2. The combined organic layers were dried over Na_2SO_4, filtered, and concentrated. To a solution of the crude in acetic acid (AcOH) (4mL) under N_2 atmosphere was added Zn (powder, 1.6 g, 25 mmol, 25 eq.) and the resulting mixture was refluxed for 16 h. The reaction mixture was then diluted with CH_2Cl_2 (2 mL) and filtered through celite and washed with CH_2Cl_2 thoroughly. After concentration, the residue was diluted with CH_2Cl_2 (2 mL), washed with 1M NaOH aq. and extracted with CH_2Cl_2. The solvent was evaporated and the residue was purified by flash column chromatography on silica gel (hexane/EtOAc = 7/1~3/1 as eluent) to afford (4*S*,5*R*)-5-methyl-4-phenyltetrahydro-2H-pyran-2-one (127.2 mg, 0.67 mmol, 67% yield, dr = 10/1) as a yellow oil.

Spectroscopic data were in agreement with the ones previously reported in the literature.[10]

(3*R*,4*R*)-3-Methyl-4-phenyl-6-(phenylethynyl)-3,4-dihydro-2H-pyran



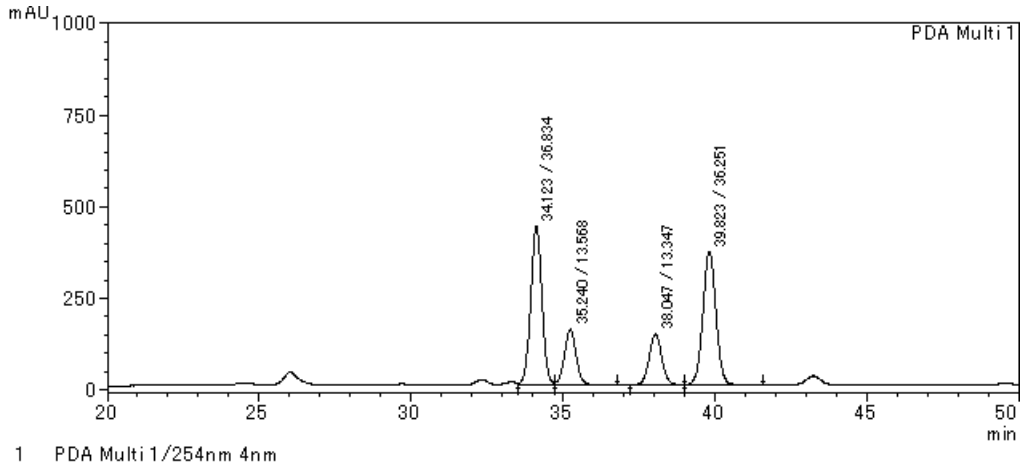
To a stirred solution of BuLi (1.56 M in hexane, 391 mL, 0.61 mmol, 3.05 eq.) was added phenylacetylene (66 μL, 0.6 mmol, 3.0 eq.) at −78 ºC dropwise under a nitrogen atmosphere. To the reaction mixture was added (4*S*,5*R*)-5-methyl-4-phenyltetrahydro-2H-pyran-2-one (38 mg, 0.2 mmol, 1 eq.) dropwise at −78 ºC, and the solution was stirred for 2 h at the same temperature. To the reaction mixture was added phosphoryl chloride ($POCl_3$) (75 mg, 0.8 mmol, 4 eq.) dropwise at –78 °C. The reaction mixture was warmed to room temperature and stirred for 20 min. To the reaction mixture was added pyridine (643 μL, 8 mmol, 40 eq.) dropwise at room temperature. After stirring for 13 h at the same temperature, the mixture was then quenched with H_2O and extracted with EtOAc. The combined organic layers were dried over Na_2SO_4 and concentrated. The residue was purified by flash column chromatography on silica gel (hexane/EtOAc = 7/1~1/1 as eluent) to afford (3*R*,4*R*)-3-methyl-4-phenyl-6-(phenylethynyl)-3,4-dihydro-2H-pyran (30.4 mg, 0.11 mmol, 55% yield, trans/cis = 6/1, 99% ee/93% ee) as a yellow solid.

Spectroscopic data of *trans*-(3*R*,4*R*)-3-Methyl-4-phenyl-6-(phenylethynyl)-3,4-dihydro-2H-pyran were in agreement with *trans*-**9** synthesized from **1a**.

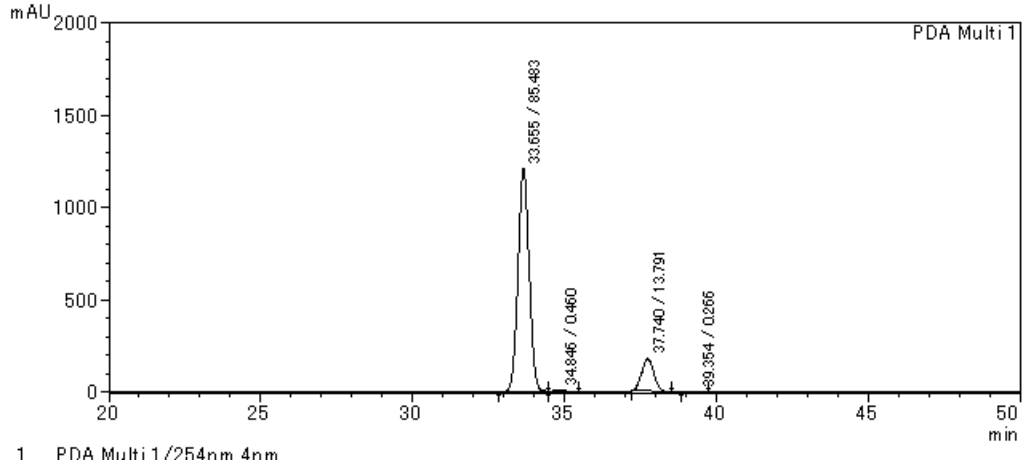
The absolute configuration of *trans*-**9** synthesized from **1a** was determined to be (3*R*,4*R*) by comparison of the HPLC retention time with that of *trans*-**9** synthesized from (*E*)-3-phenyl-2-(phenylsulfonyl)acrylonitrile.

Comparison of the HPLC retention time

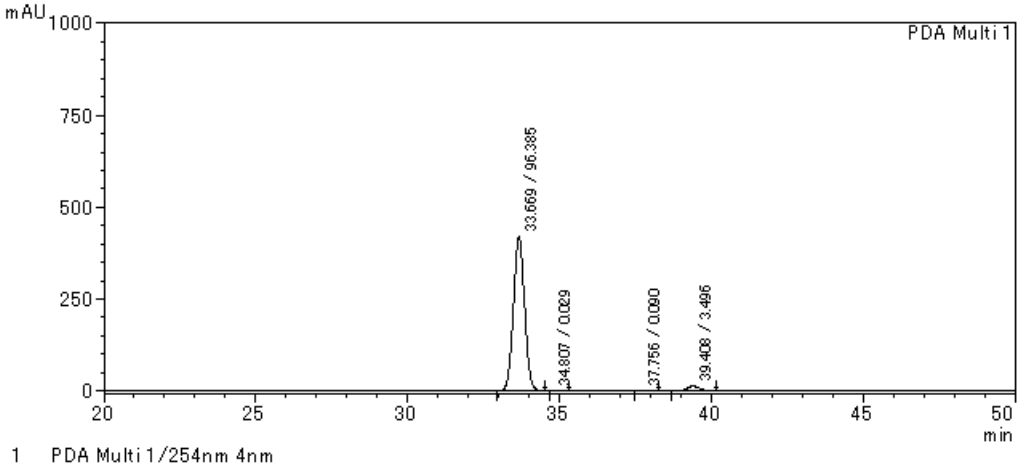
rac-**9**



trans-**9** synthesized from (*E*)-3-phenyl-2-(phenylsulfonyl)acrylonitrile

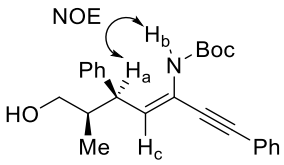


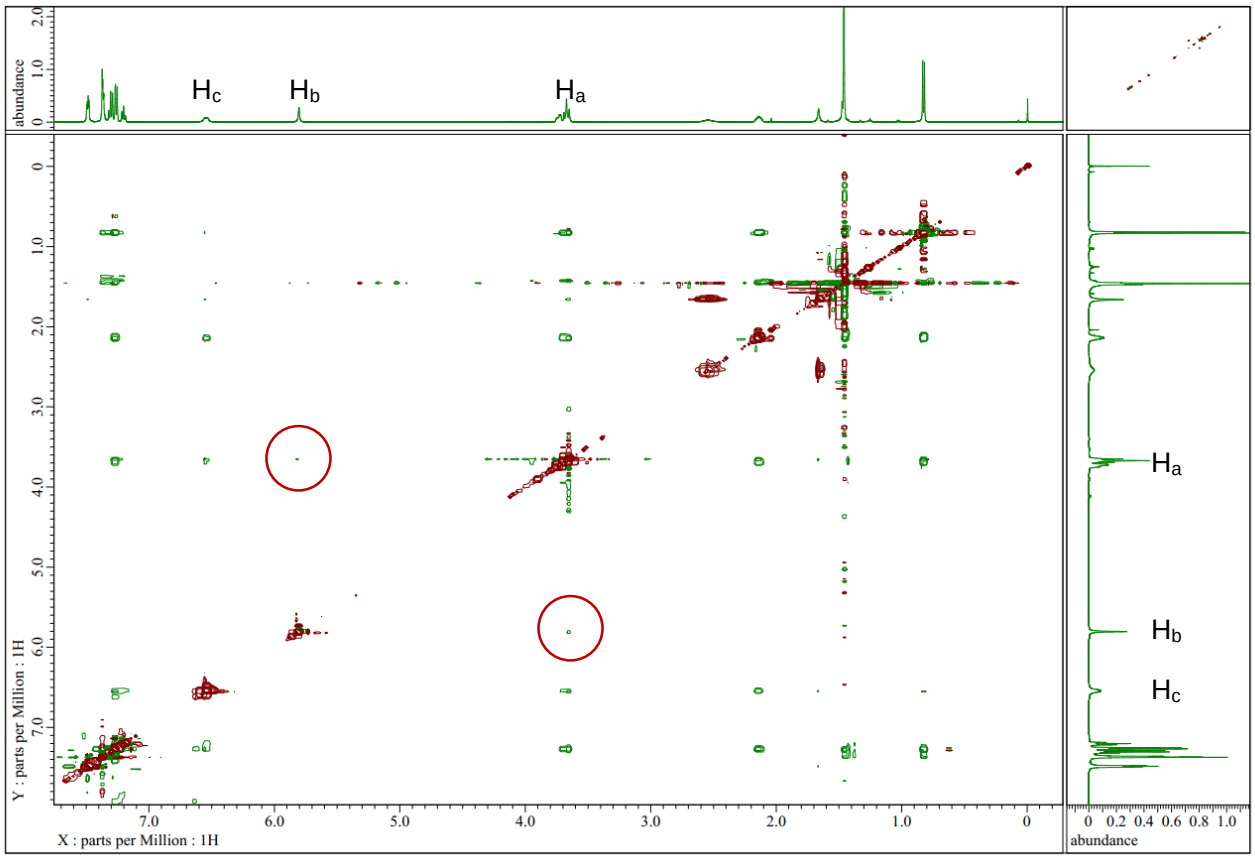
trans-**9** synthesized from **1a**



6. NOE Analysis

NOE spectra for **2a**





7. References

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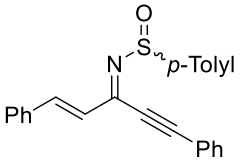
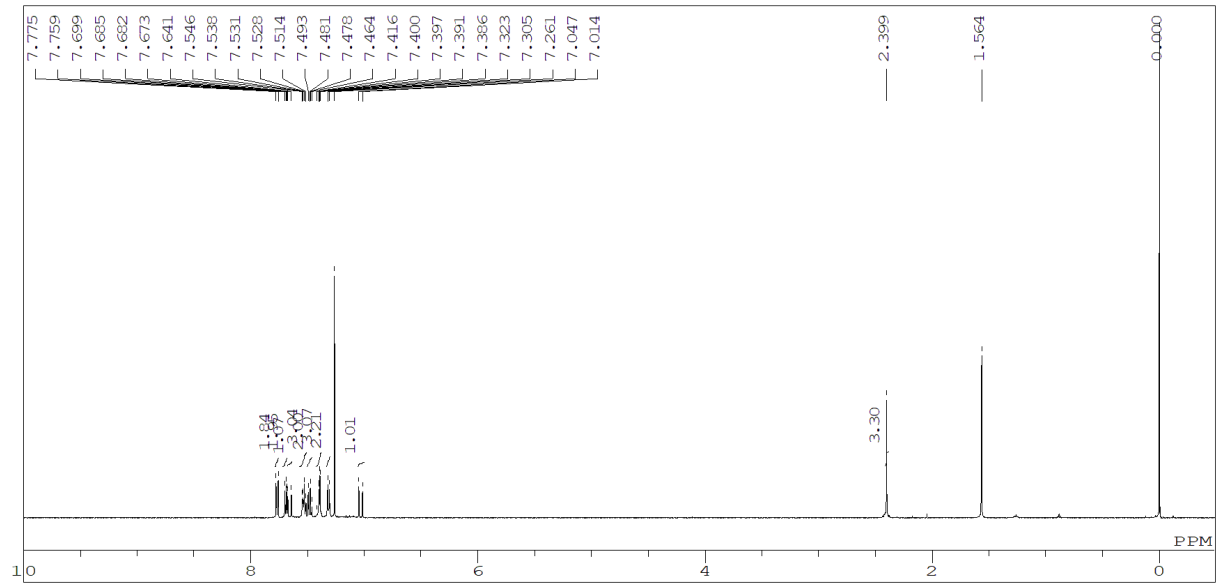
8. ^{1}H and ^{13}C NMR Spectra

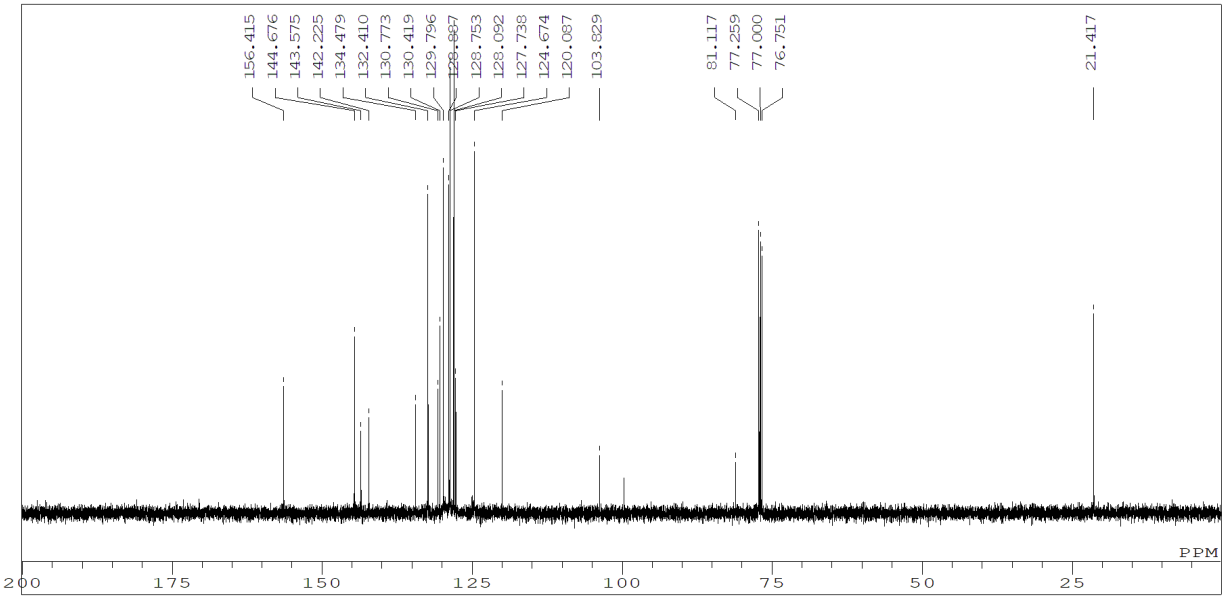
***N*-((1*E*,3*Z*)-1,5-diphenylpent-1-en-4-yn-3-ylidene)-4-methylbenzenesulfinamide**



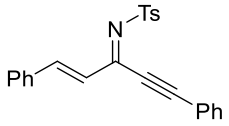
^{1}H-NMR (500 MHz, $CDCl_3$)



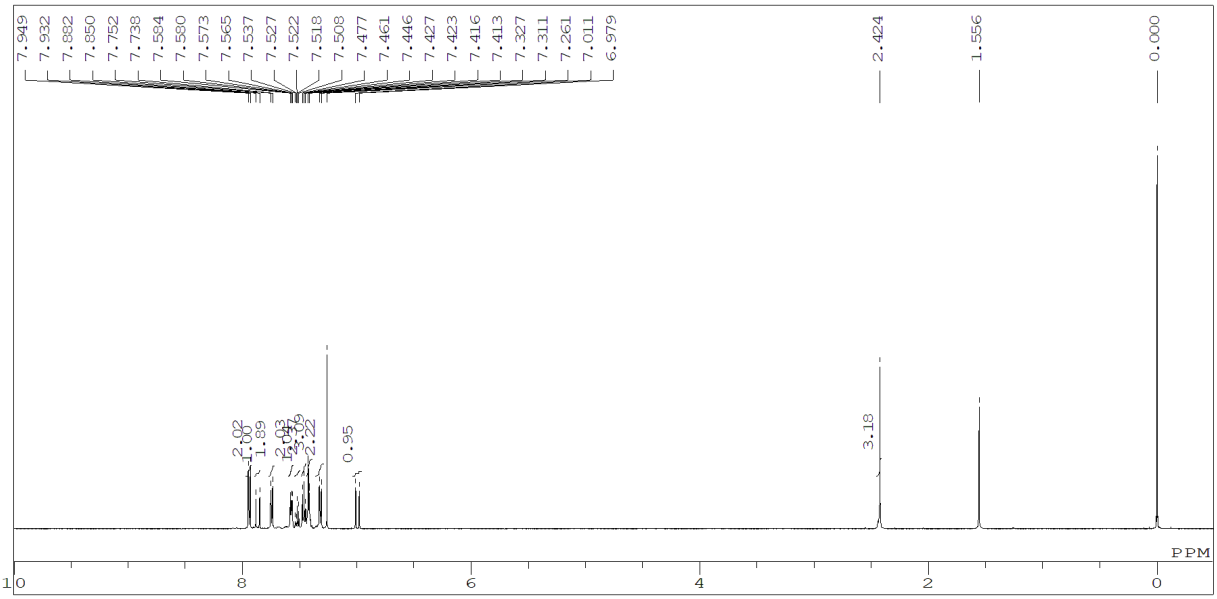
^{13}C-NMR (125 MHz, $CDCl_3$)



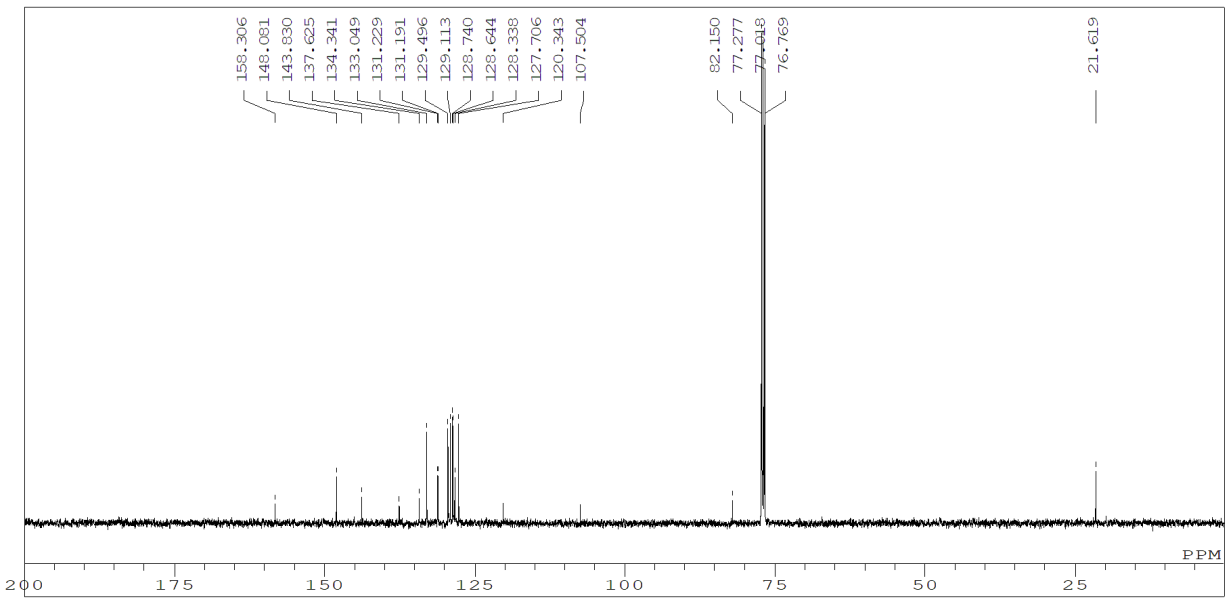
***N*-((1*E*,3*Z*)-1,5-diphenylpent-1-en-4-yn-3-ylidene)-4-methylbenzenesulfonamide**



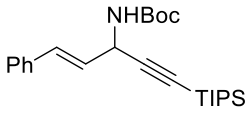
^{1}H-NMR (500 MHz, $CDCl_3$)



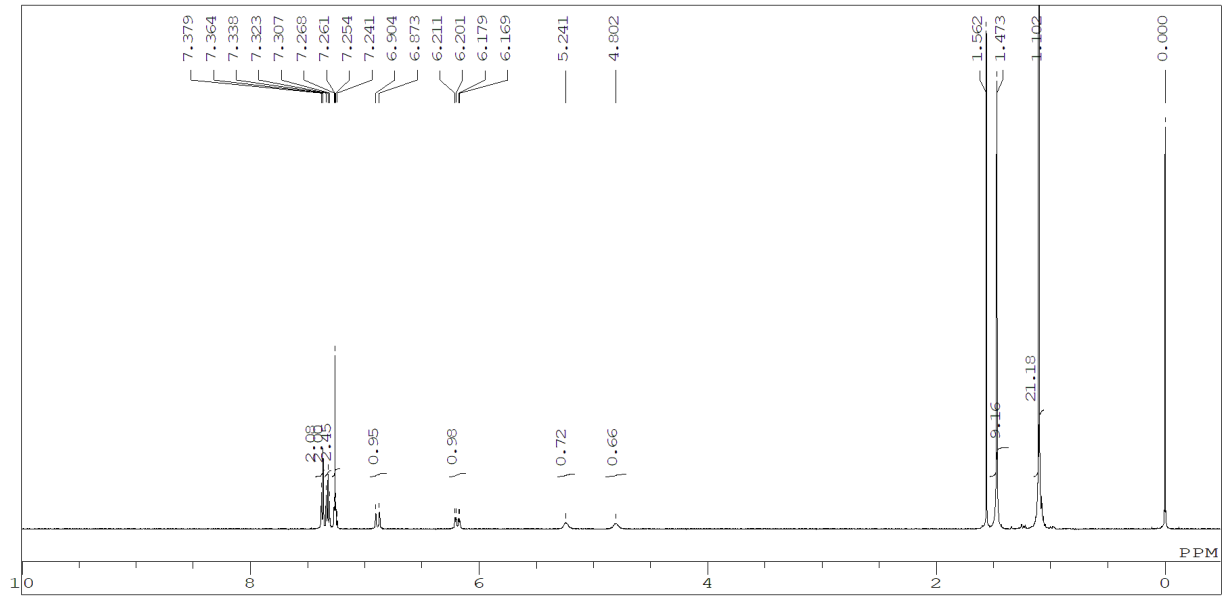
^{13}C-NMR (125 MHz, $CDCl_3$)



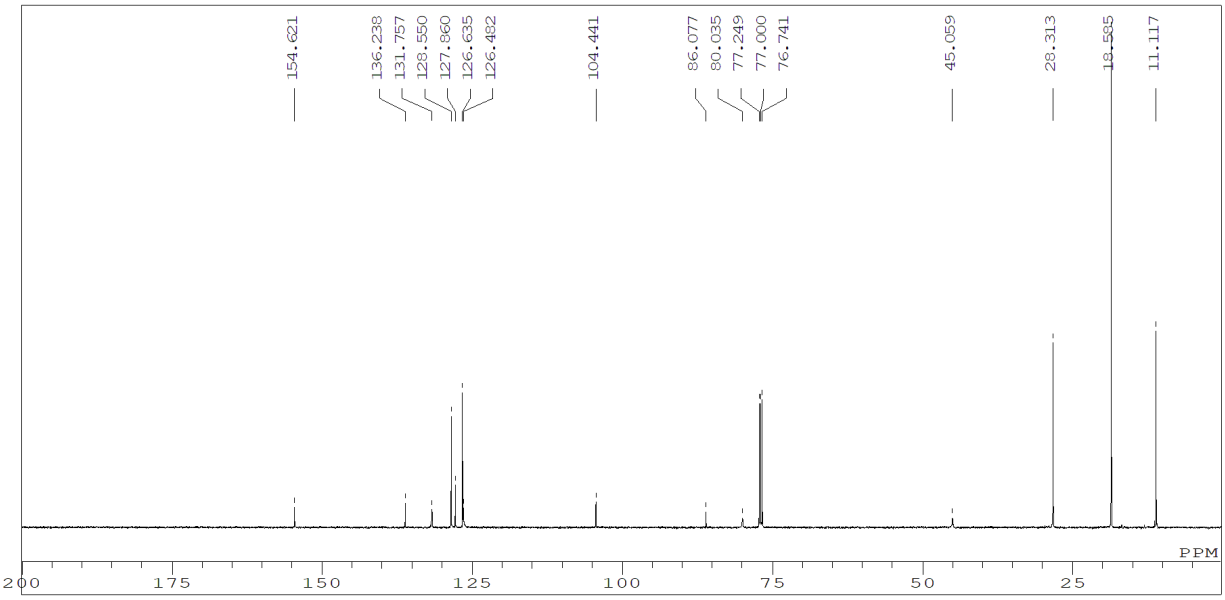
***tert*-Butyl (*E*)-(1-phenyl-5-(triisopropylsilyl)pent-1-en-4-yn-3-yl)carbamate (S3)**



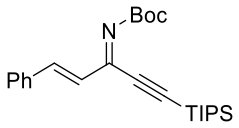
^{1}H-NMR (500 MHz, $CDCl_3$)



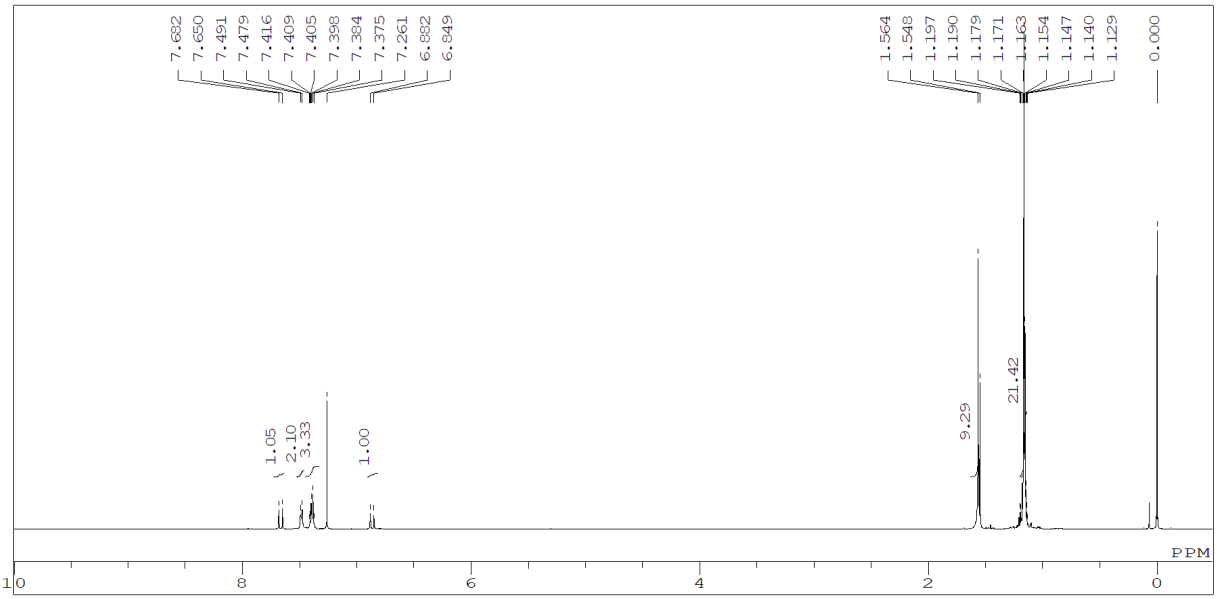
^{13}C-NMR (125 MHz, $CDCl_3$)



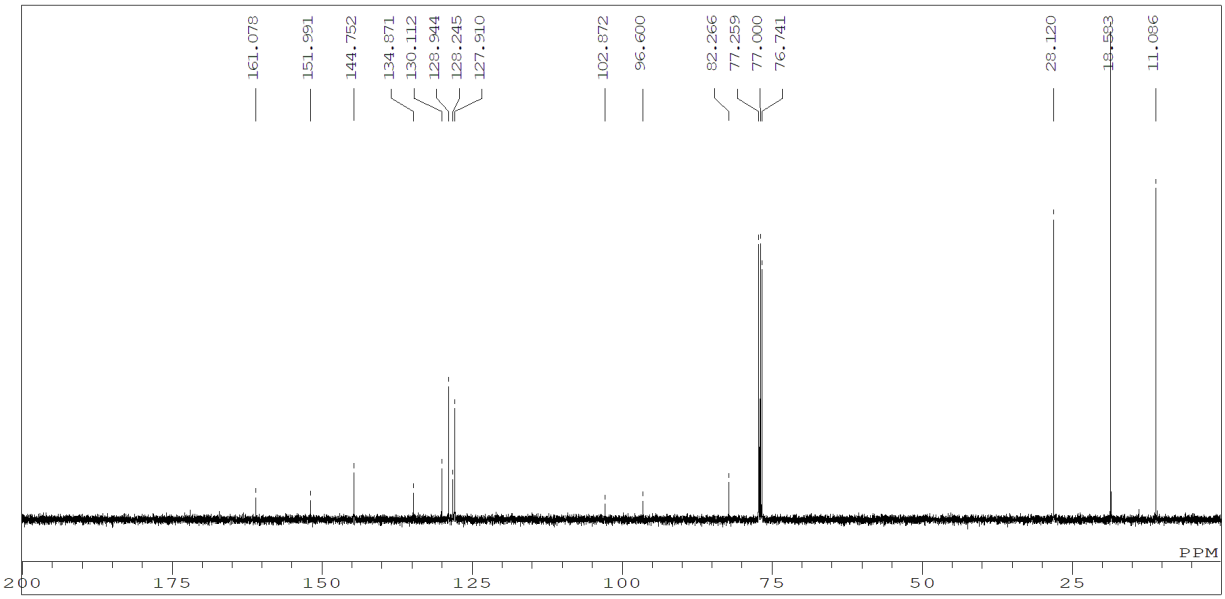
***tert*-Butyl ((1*E*,3*Z*)-1-phenyl-5-(triisopropylsilyl)pent-1-en-4-yn-3-ylidene)carbamate**



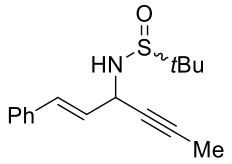
^{1}H-NMR (500 MHz, $CDCl_3$)



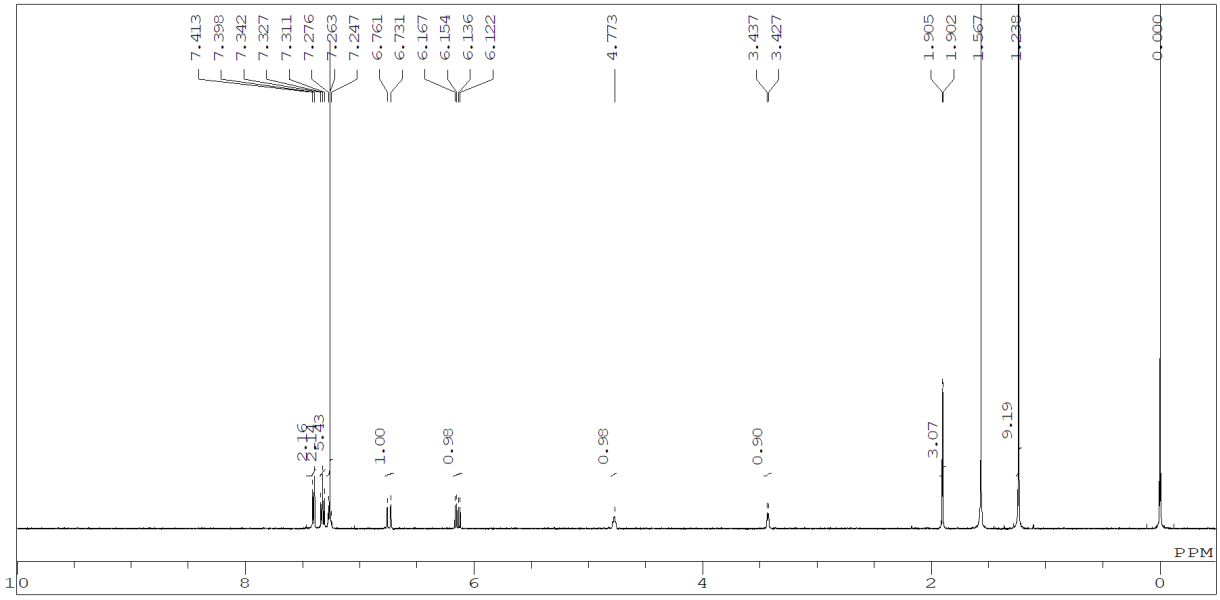
^{13}C-NMR (125 MHz, $CDCl_3$)



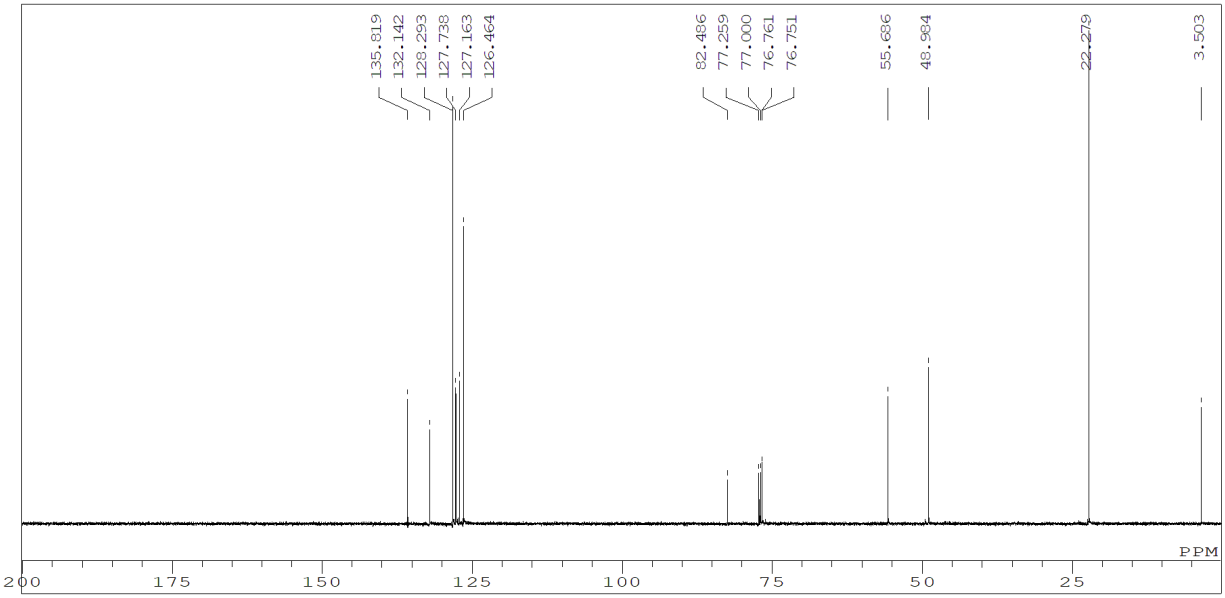
(*E*)-2-methyl-*N*-(1-phenylhex-1-en-4-yn-3-yl)propane-2-sulfinamide (S5)



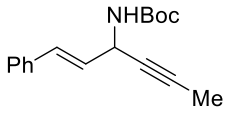
^{1}H-NMR (500 MHz, $CDCl_3$)



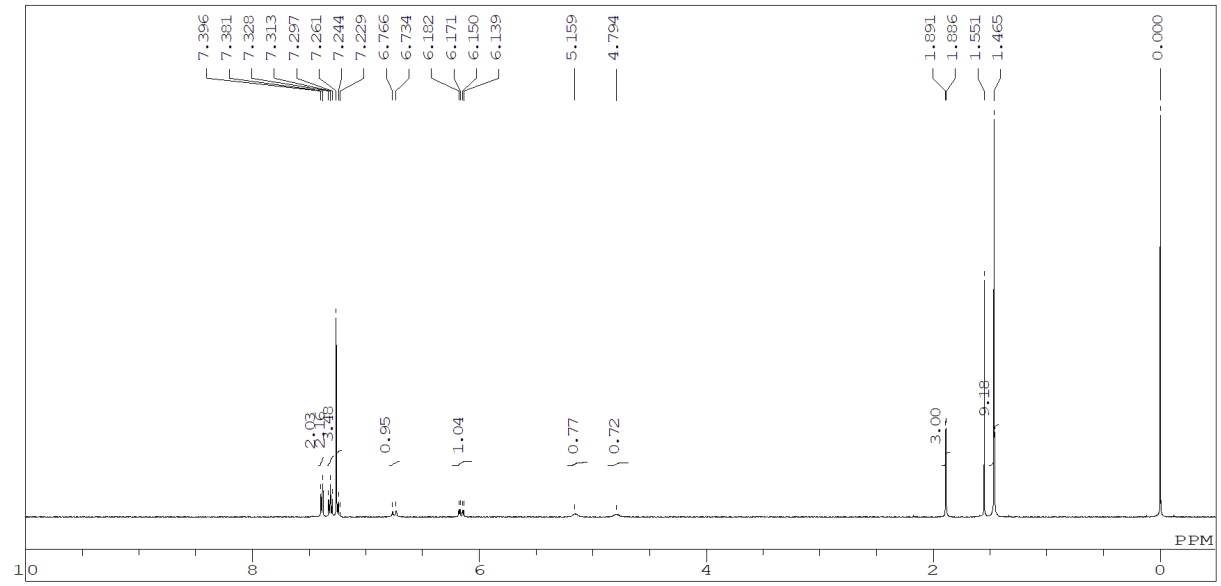
^{13}C-NMR (125 MHz, $CDCl_3$)



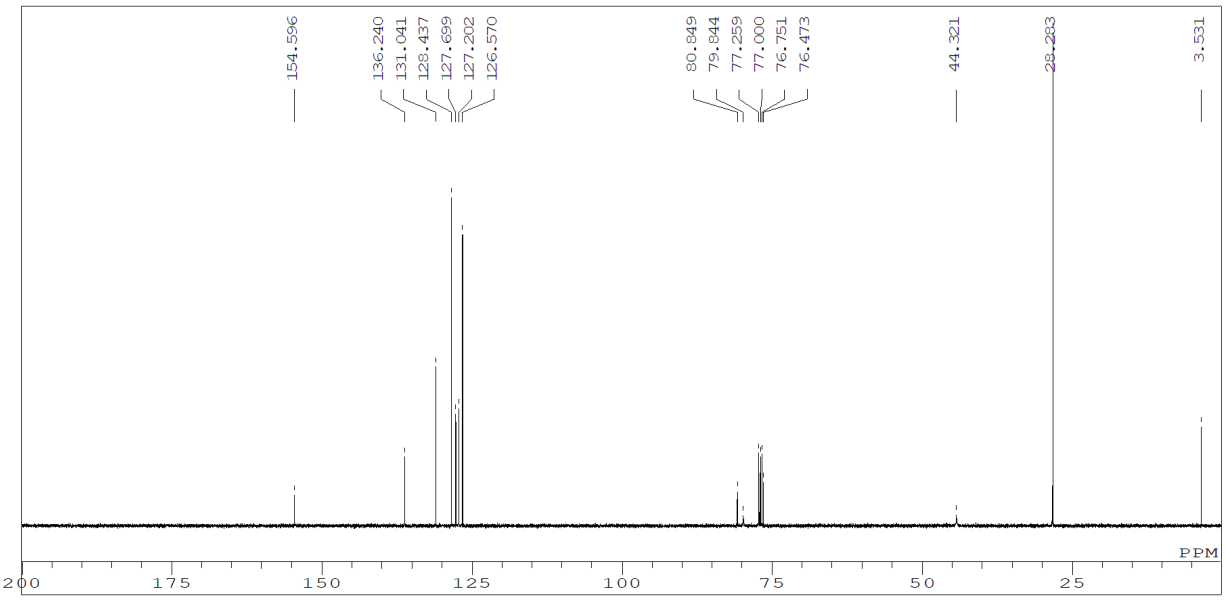
***tert*-Butyl (*E*)-(1-phenylhex-1-en-4-yn-3-yl)carbamate (S6)**



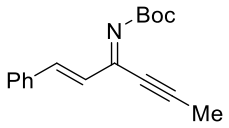
^{1}H-NMR (500 MHz, $CDCl_3$)



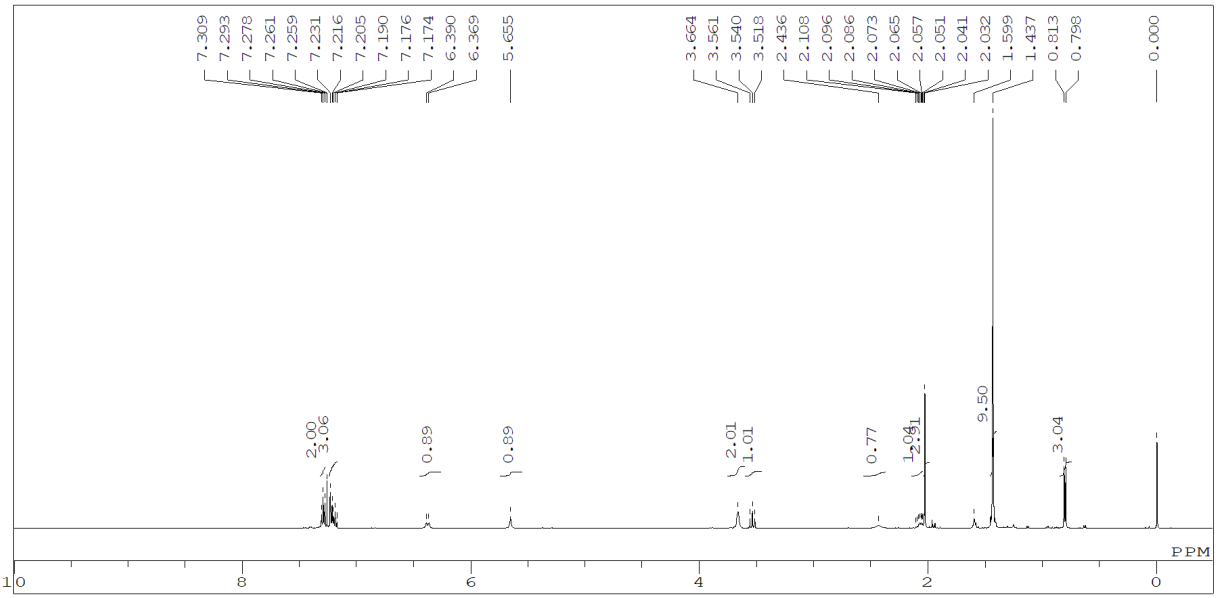
^{13}C-NMR (125 MHz, $CDCl_3$)



***tert*-Butyl ((1E,3Z)-1-phenylhex-1-en-4-yn-3-ylidene)carbamate**



^{1}H-NMR (500 MHz, $CDCl_3$)



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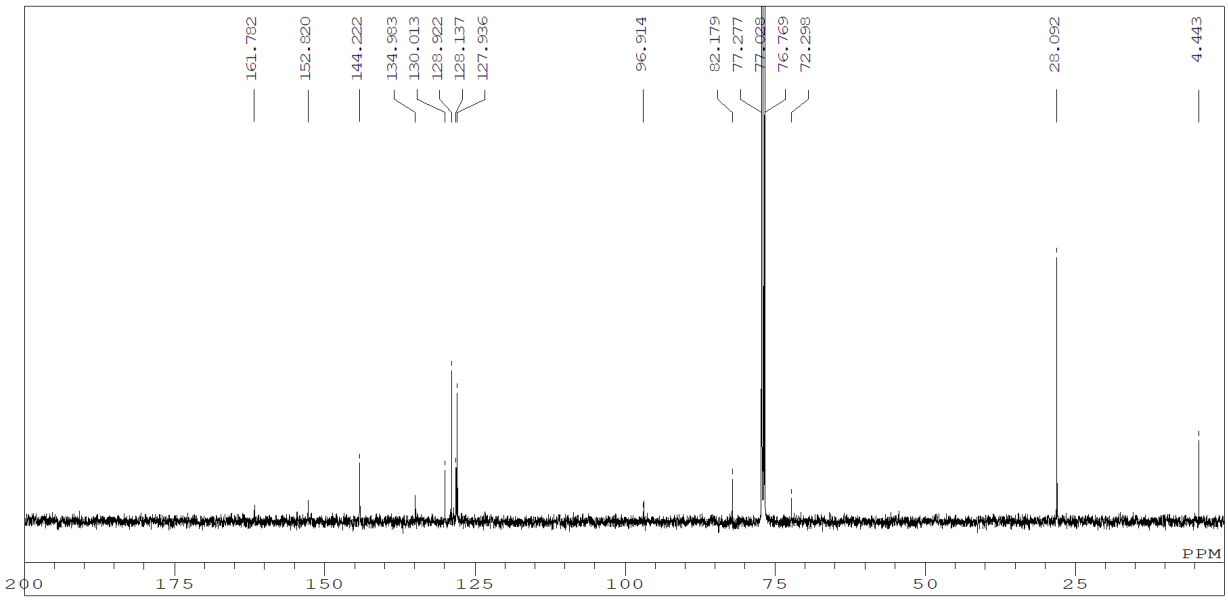
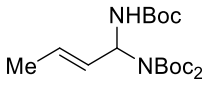
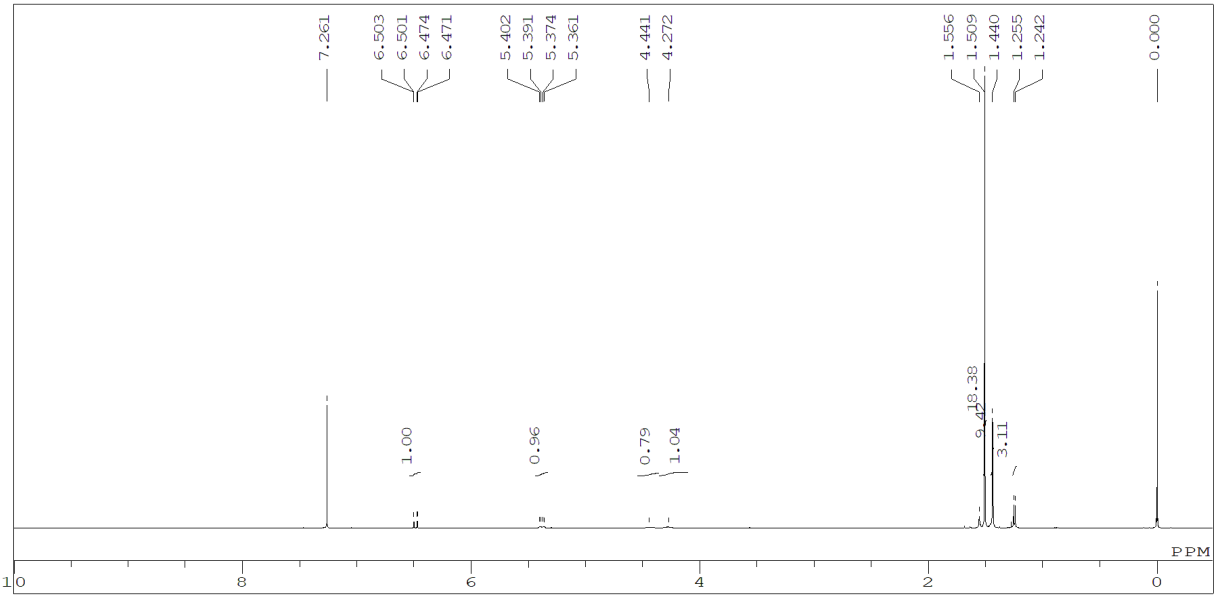


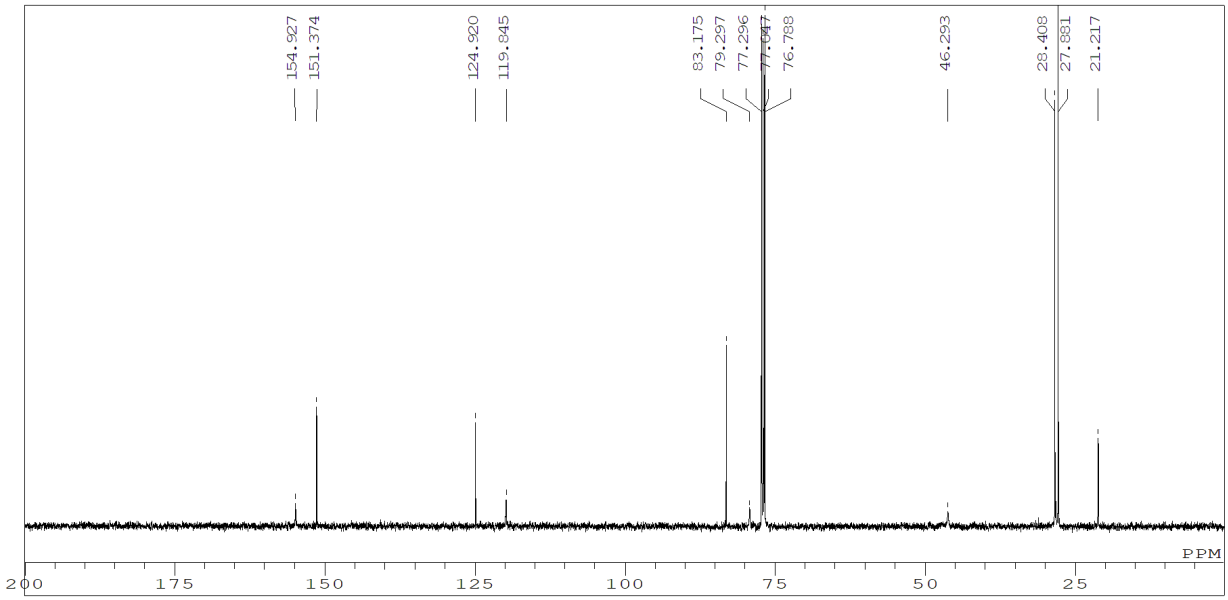
***tert*-Butyl (*E*)-(*tert*-butoxycarbonyl)(1-((*tert*-butoxycarbonyl)amino)but-2-en-1-yl)carbamate (S8)**



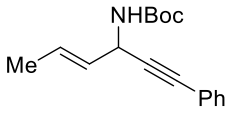
^{1}H-NMR (500 MHz, $CDCl_3$)



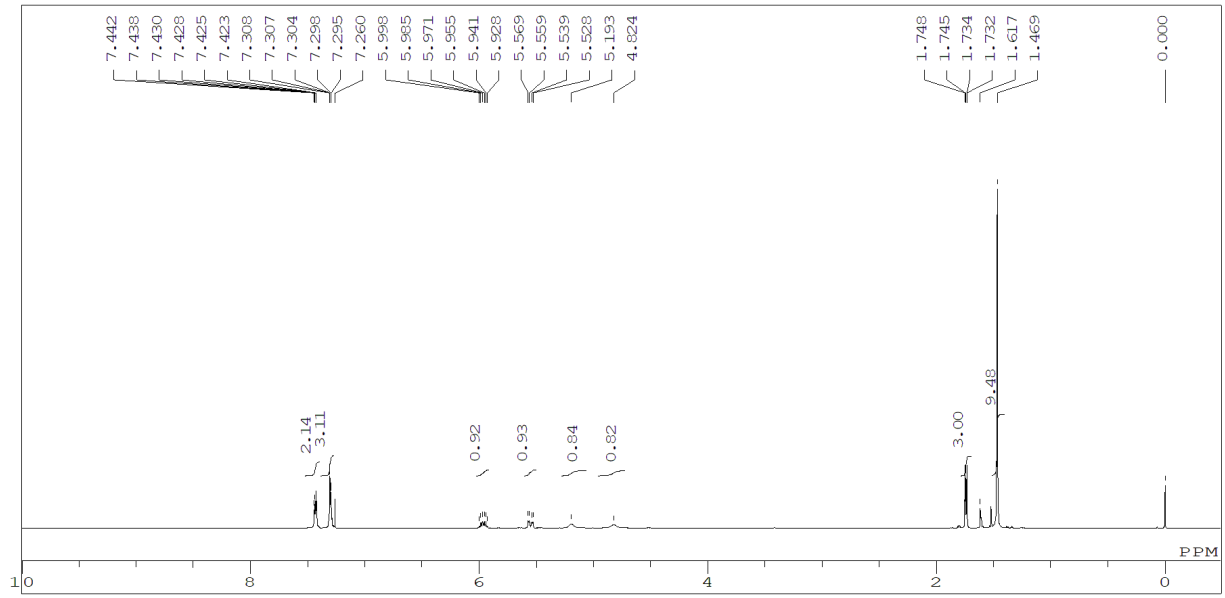
^{13}C-NMR (125 MHz, $CDCl_3$)



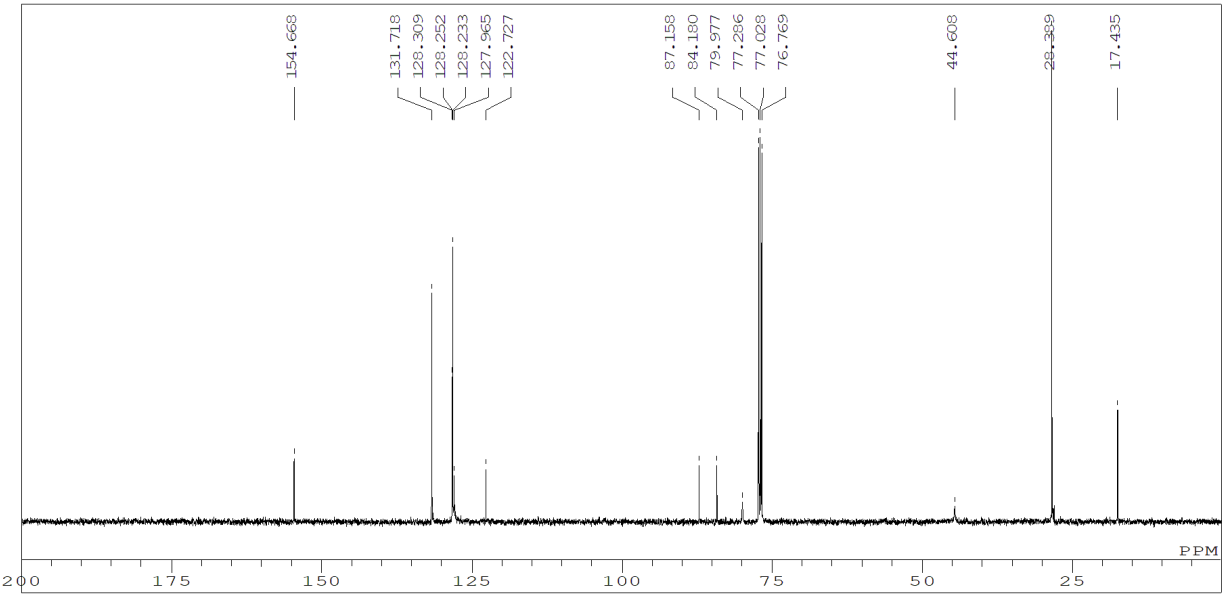
***tert*-Butyl (*E*)-(1-phenylhex-4-en-1-yn-3-yl)carbamate (S9)**



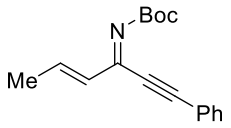
^{1}H-NMR (500 MHz, $CDCl_3$)



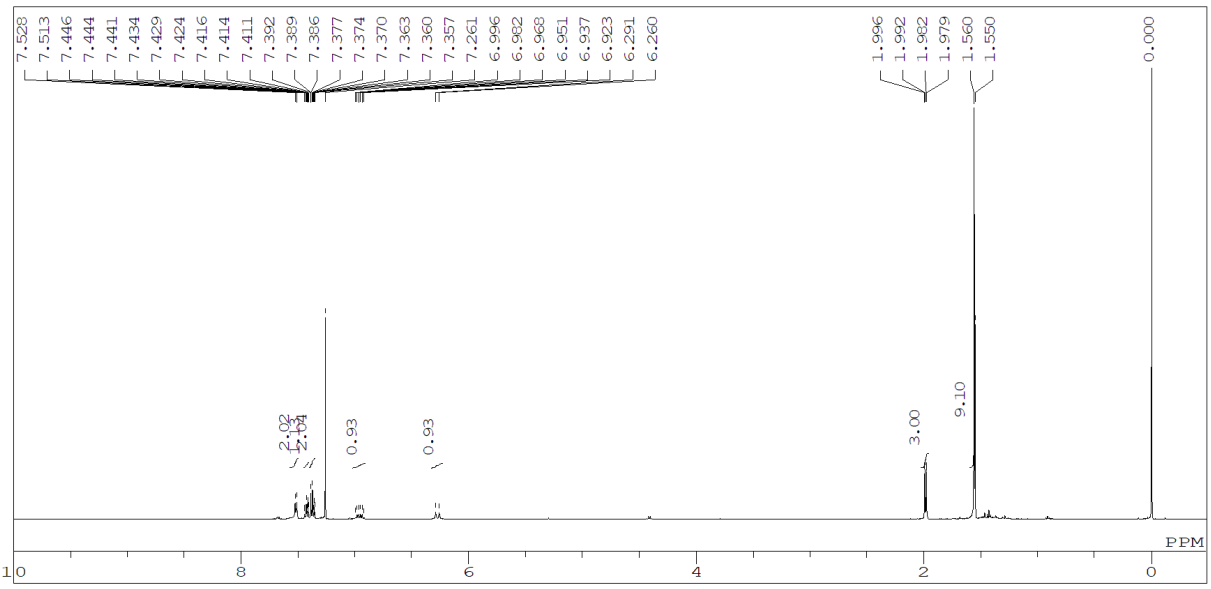
^{13}C-NMR (125 MHz, $CDCl_3$)



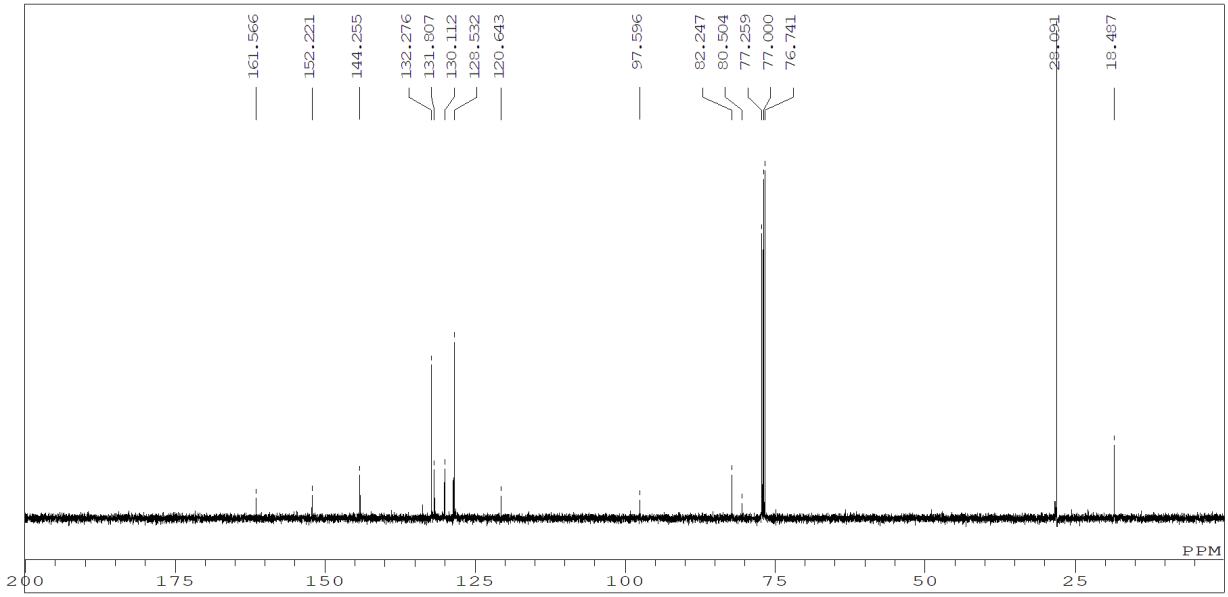
***tert*-Butyl ((3*Z*,4*E*)-1-phenylhex-4-en-1-yn-3-ylidene)carbamate**



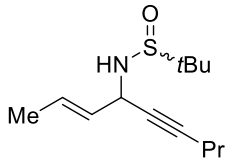
^{1}H-NMR (500 MHz, $CDCl_3$)



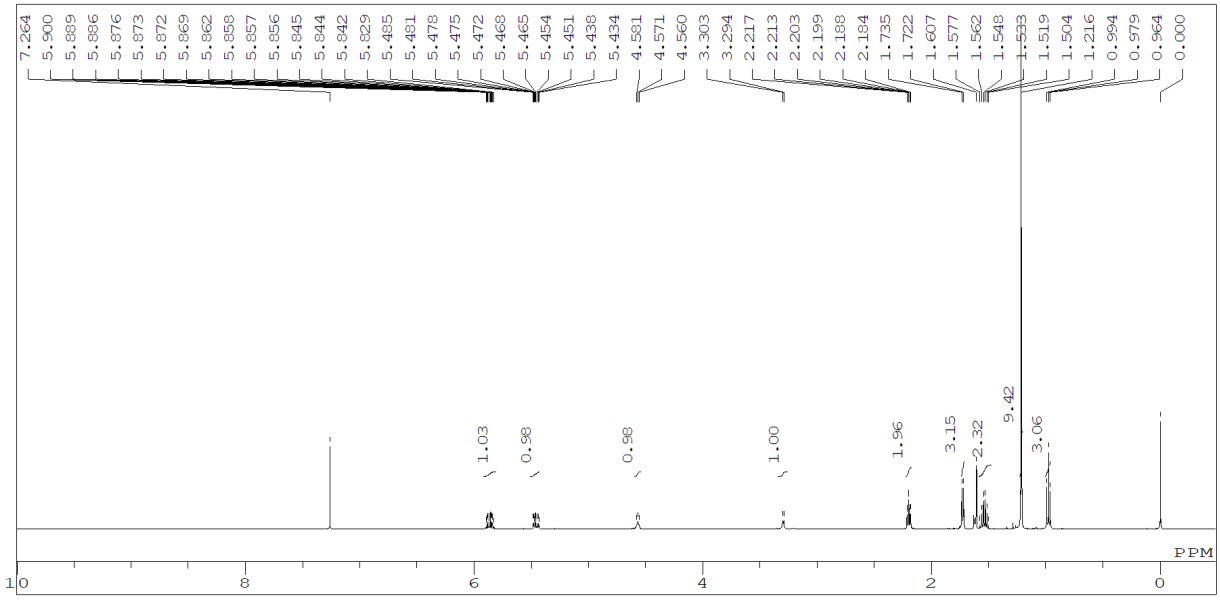
^{13}C-NMR (125 MHz, $CDCl_3$)



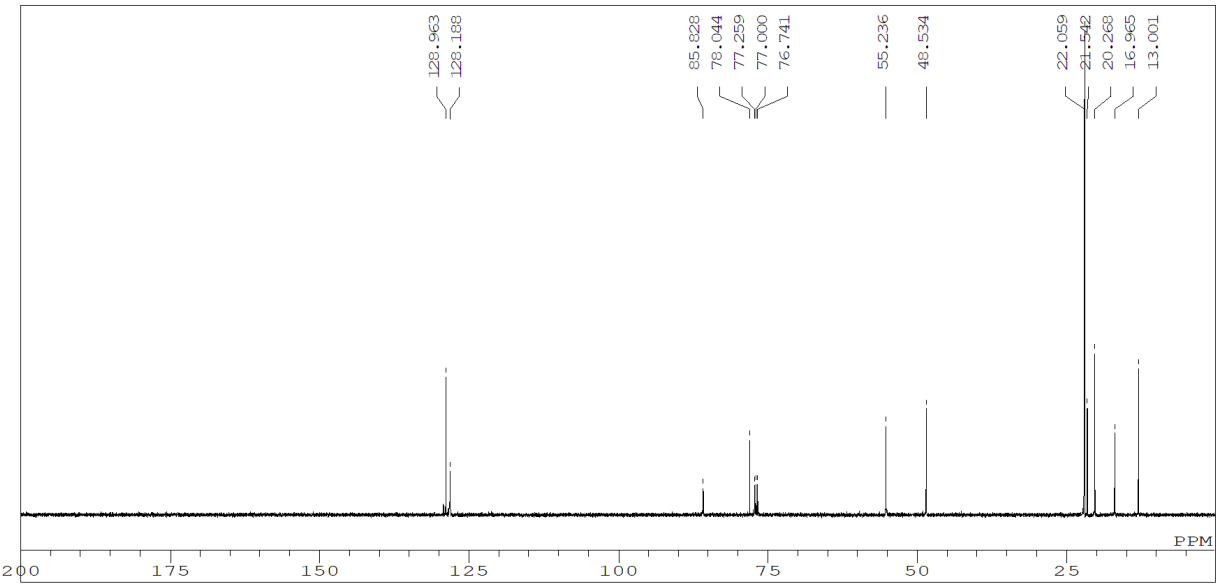
(*E*)-2-methyl-*N*-(non-2-en-5-yn-4-yl)propane-2-sulfinamide (S11)



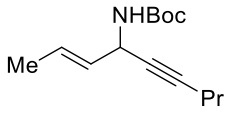
^{1}H-NMR (500 MHz, $CDCl_3$)



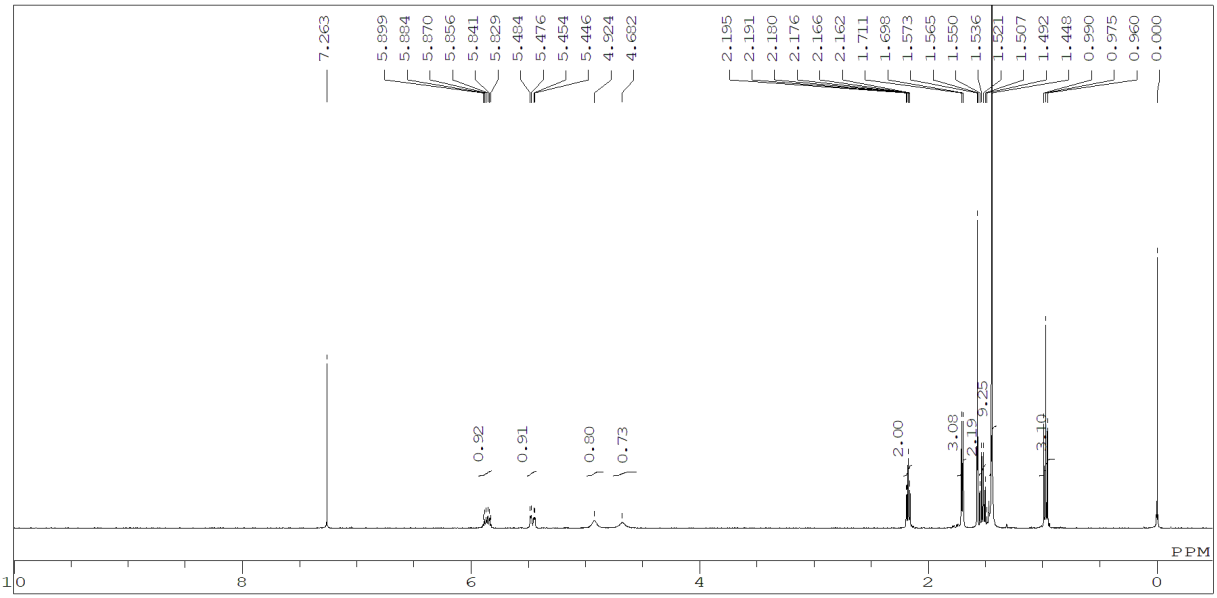
^{13}C-NMR (125 MHz, $CDCl_3$)



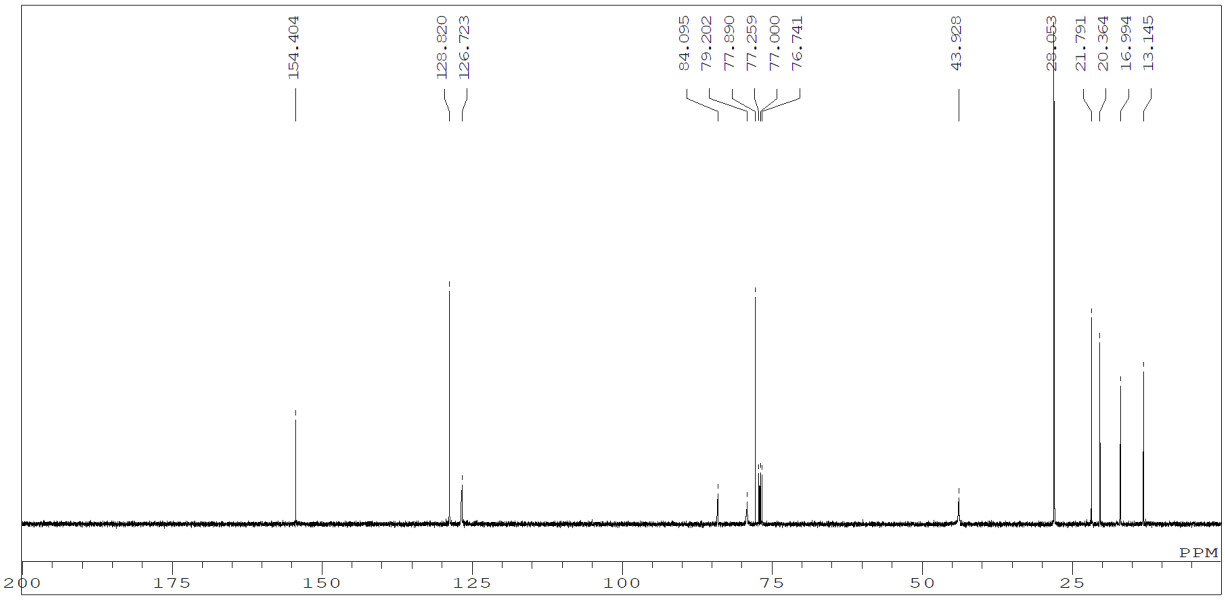
***tert*-Butyl (*E*)-non-2-en-5-yn-4-ylcarbamate (S12)**



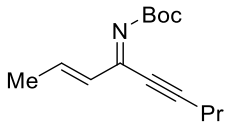
^{1}H-NMR (500 MHz, $CDCl_3$)



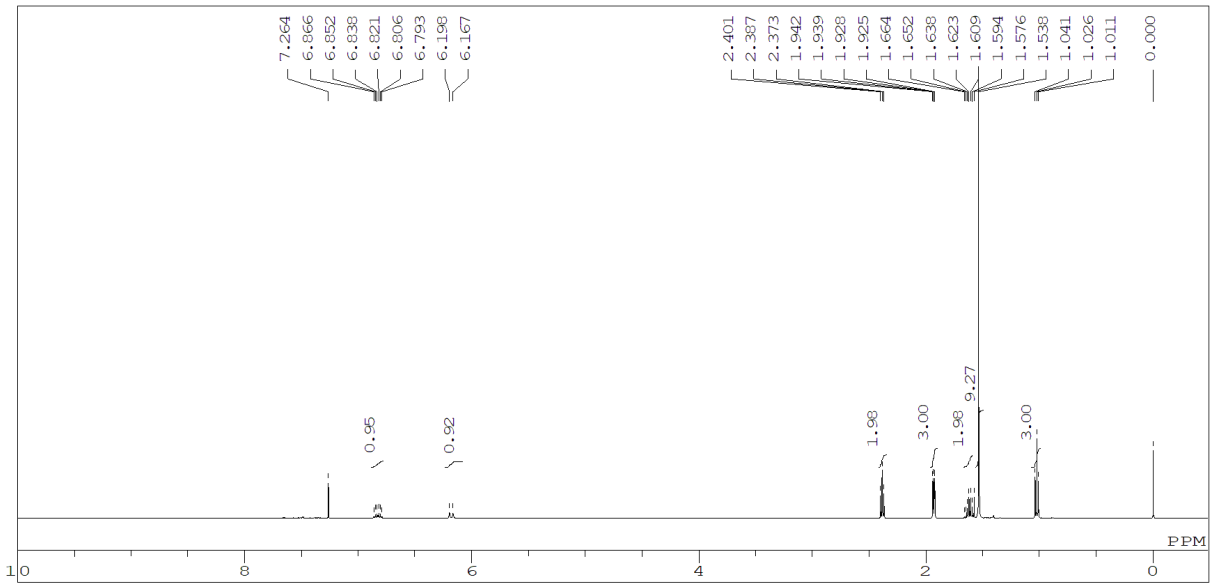
^{13}C-NMR (125 MHz, $CDCl_3$)



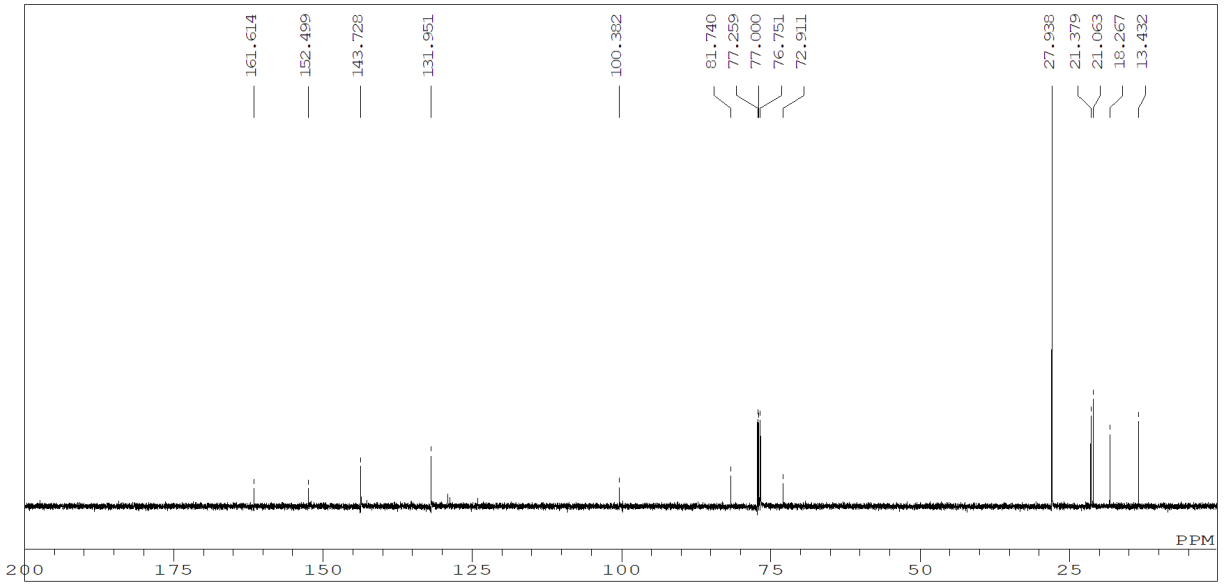
***tert*-Butyl ((2*E*,4*Z*)-non-2-en-5-yn-4-ylidene)carbamate**



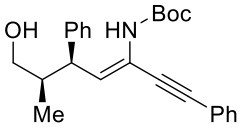
^{1}H-NMR (500 MHz, $CDCl_3$)



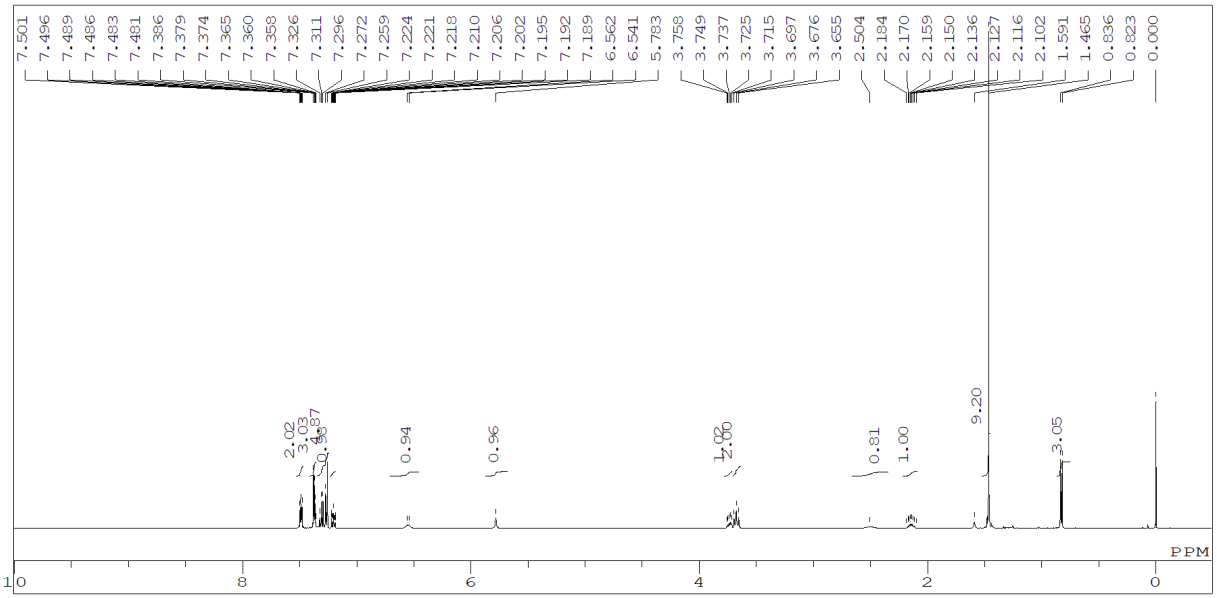
^{13}C-NMR (125 MHz, $CDCl_3$)



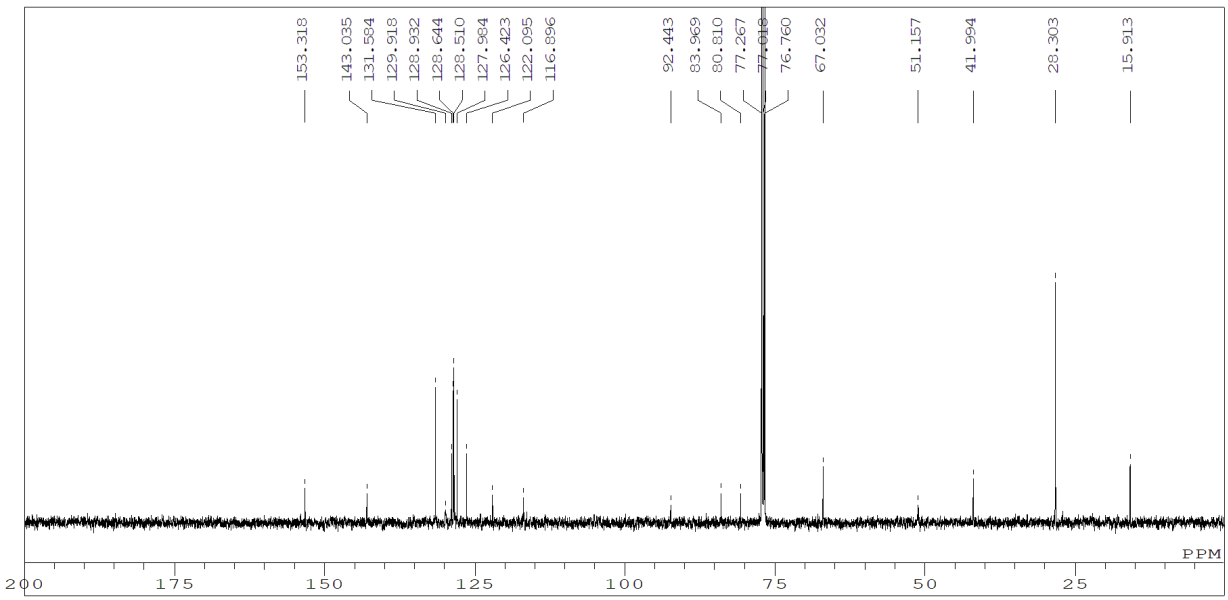
***tert*-Butyl ((5*S*,6*R*,*Z*)-7-hydroxy-6-methyl-1,5-diphenylhept-3-en-1-yn-3-yl)carbamate (2a)**



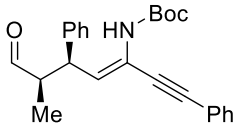
^{1}H-NMR (500 MHz, $CDCl_3$)



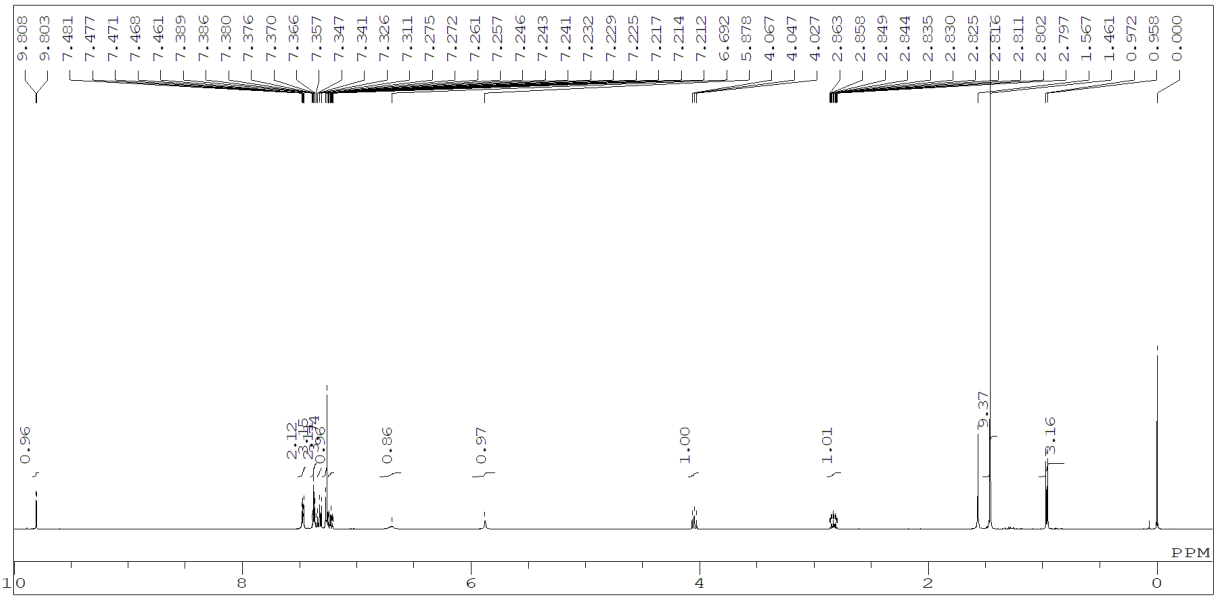
^{13}C-NMR (125 MHz, $CDCl_3$)



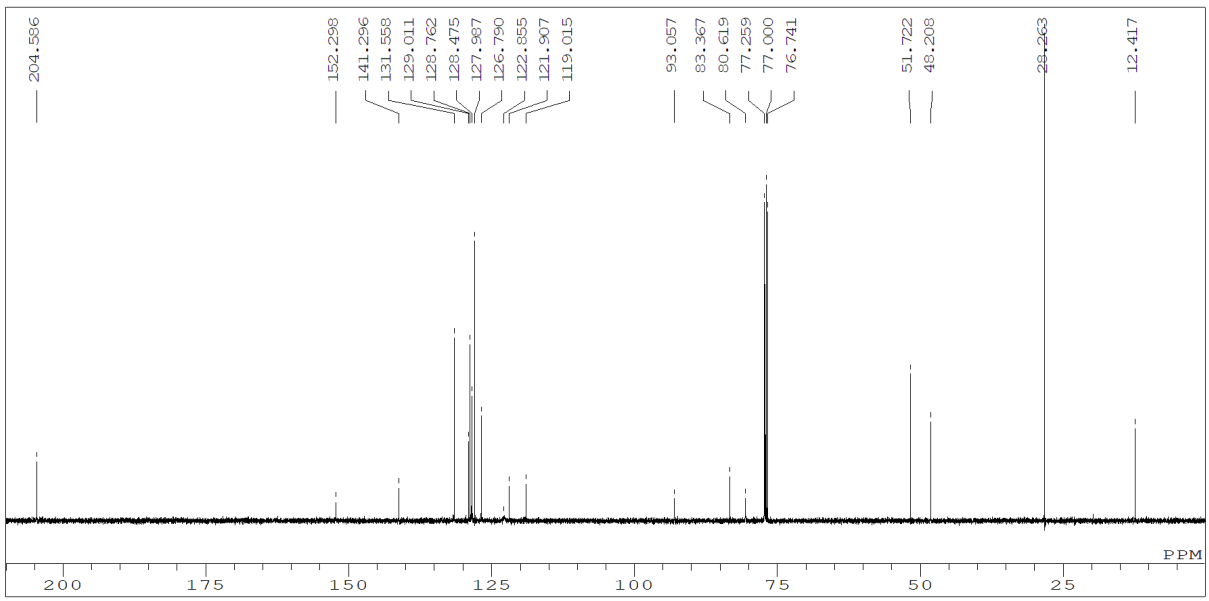
***tert*-Butyl ((5*S*,6*R*,*Z*)-6-methyl-7-oxo-1,5-diphenylhept-3-en-1-yn-3-yl)carbamate**



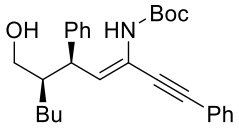
^{1}H-NMR (500 MHz, $CDCl_3$)



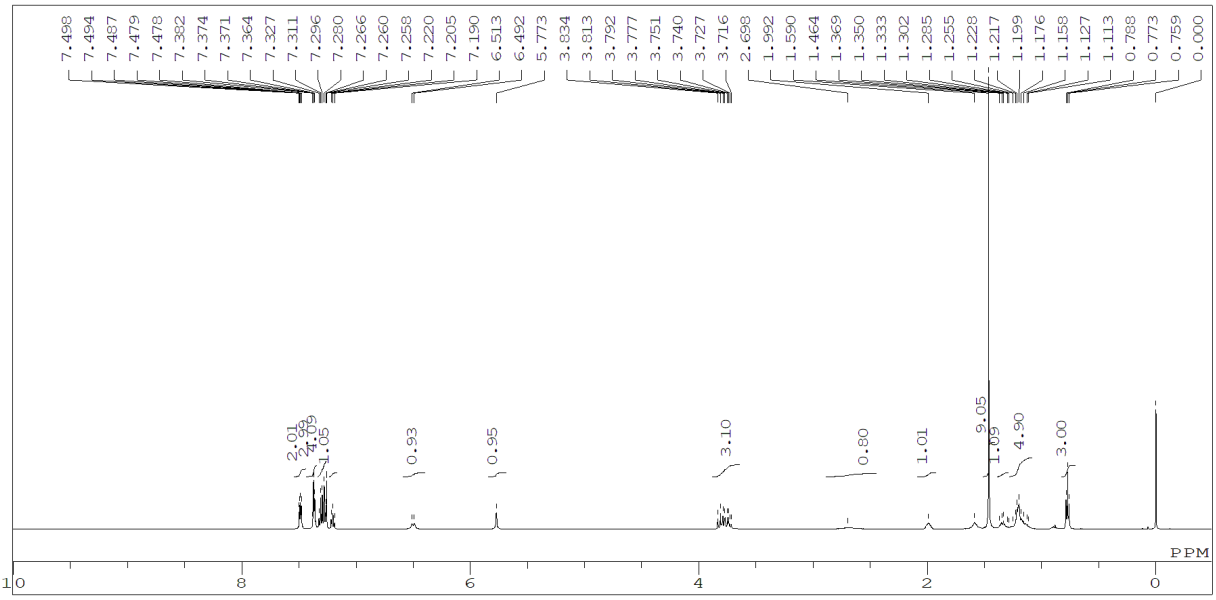
^{13}C-NMR (125 MHz, $CDCl_3$)



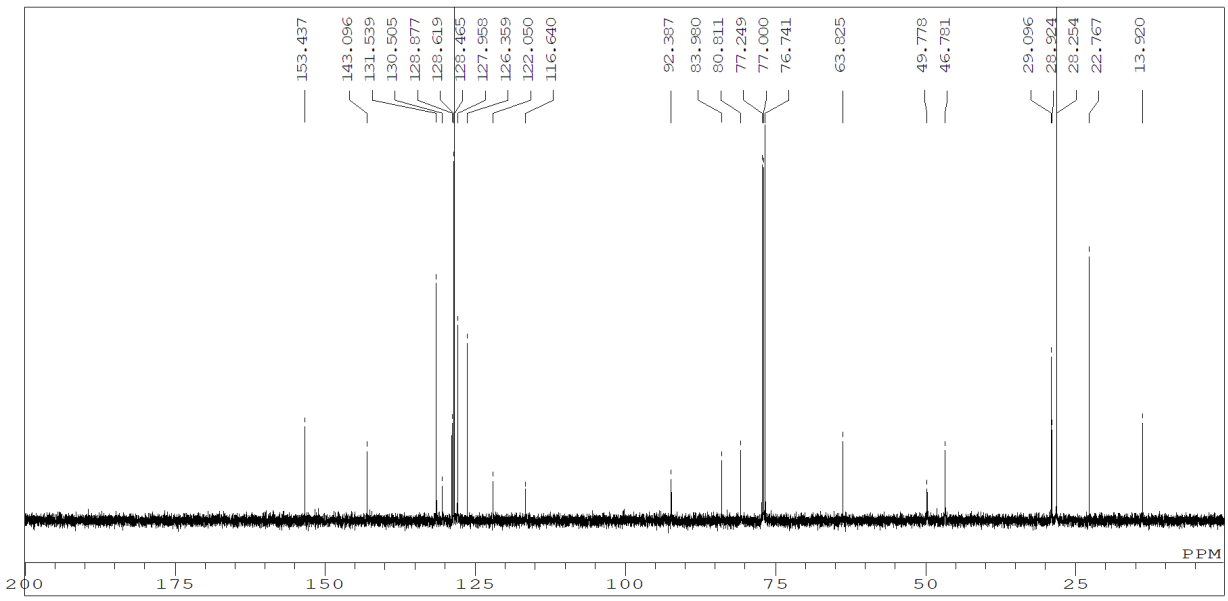
***tert*-Butyl ((5*S*,6*R*,*Z*)-6-(hydroxymethyl)-1,5-diphenyldec-3-en-1-yn-3-yl)carbamate (2b)**



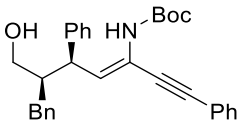
^{1}H-NMR (500 MHz, $CDCl_3$)



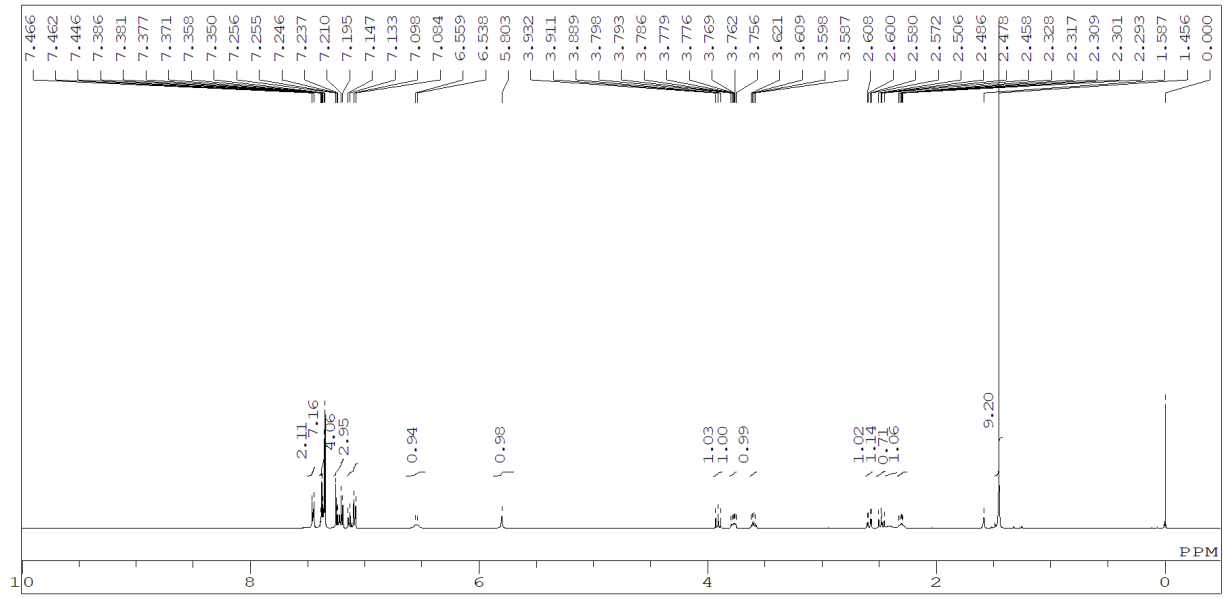
^{13}C-NMR (125 MHz, $CDCl_3$)



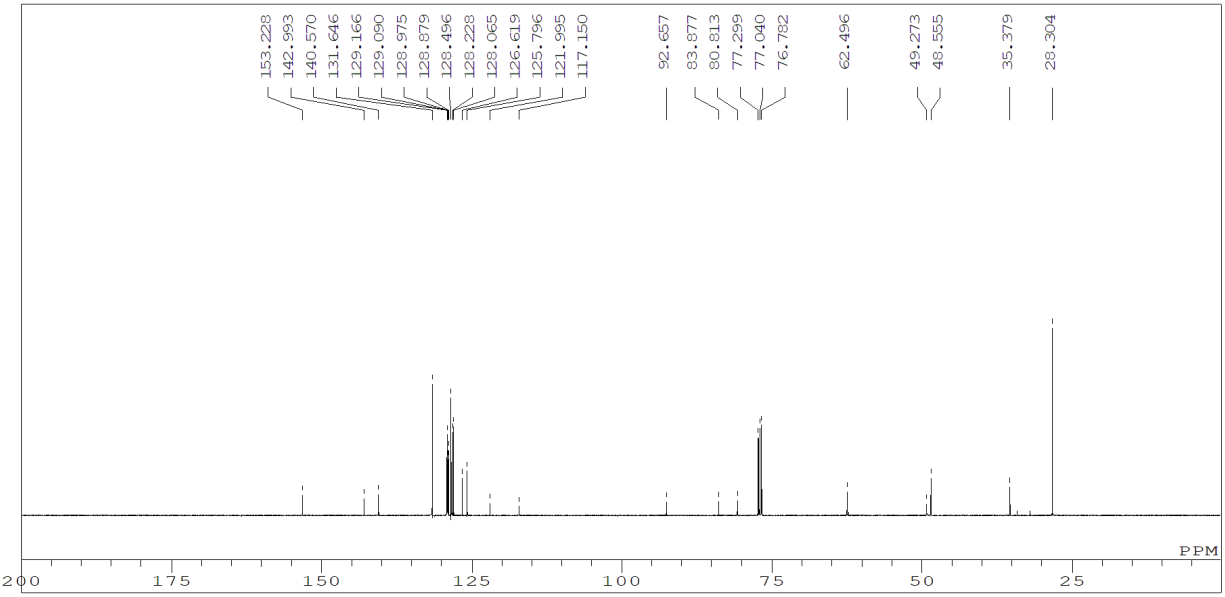
***tert*-Butyl ((5*S*,6*R*,*Z*)-6-benzyl-7-hydroxy-1,5-diphenylhept-3-en-1-yn-3-yl)carbamate (2c)**



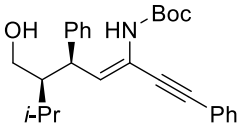
^{1}H-NMR (500 MHz, $CDCl_3$)



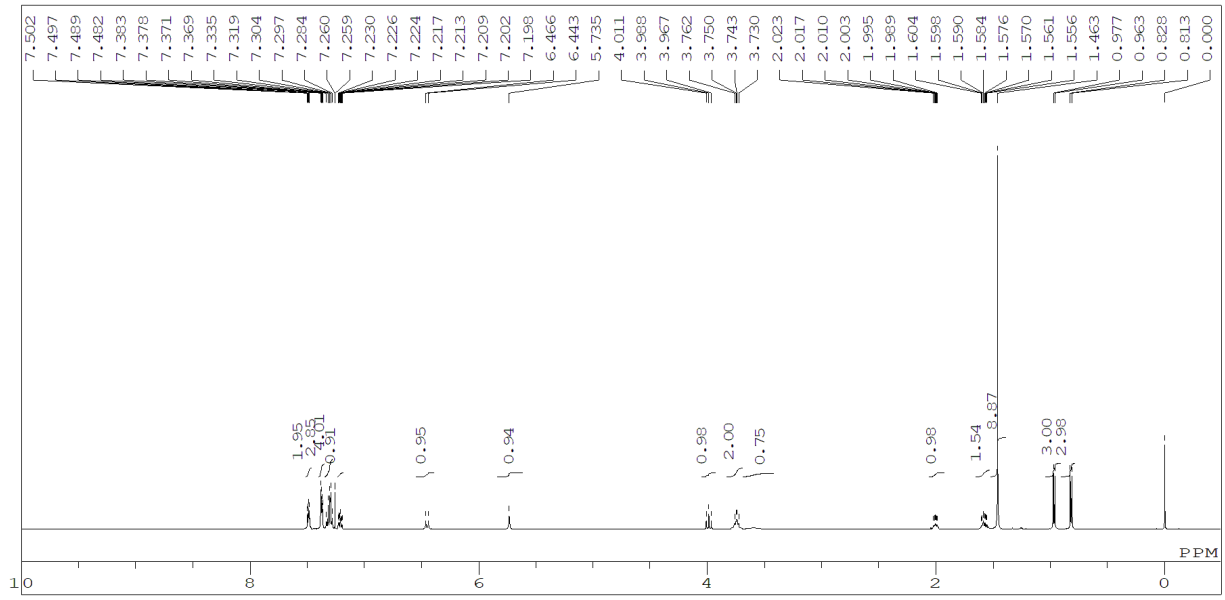
^{13}C-NMR (125 MHz, $CDCl_3$)



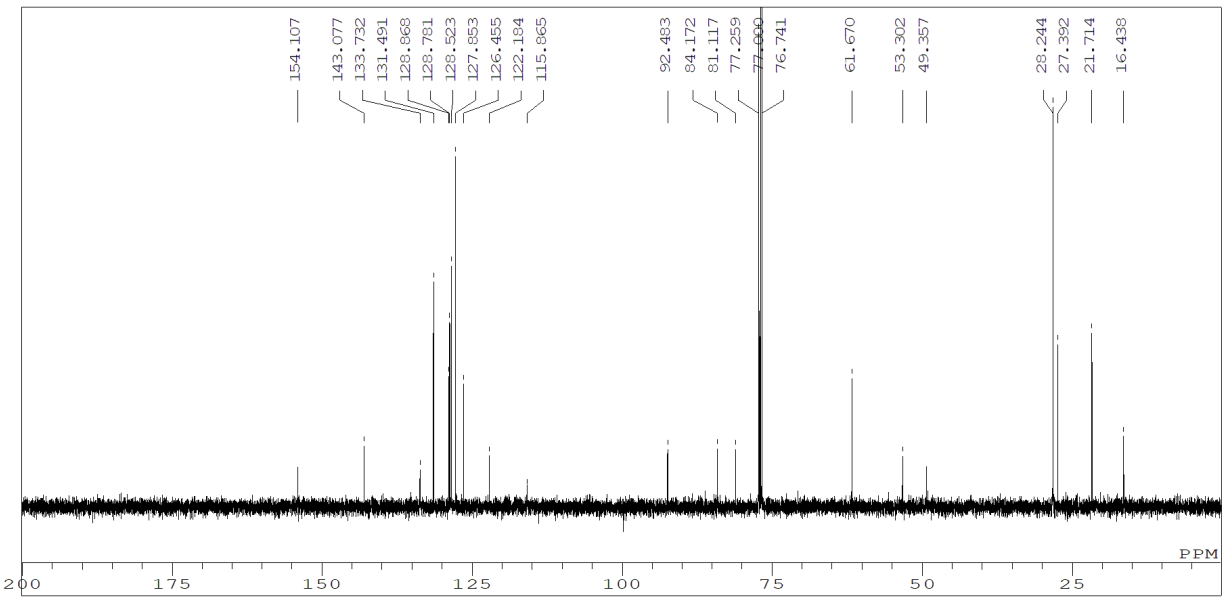
***tert*-Butyl ((5*S*,6*R*,*Z*)-6-(hydroxymethyl)-7-methyl-1,5-diphenyloct-3-en-1-yn-3-yl)carbamate (2d)**



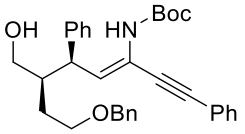
^{1}H-NMR (500 MHz, $CDCl_3$)



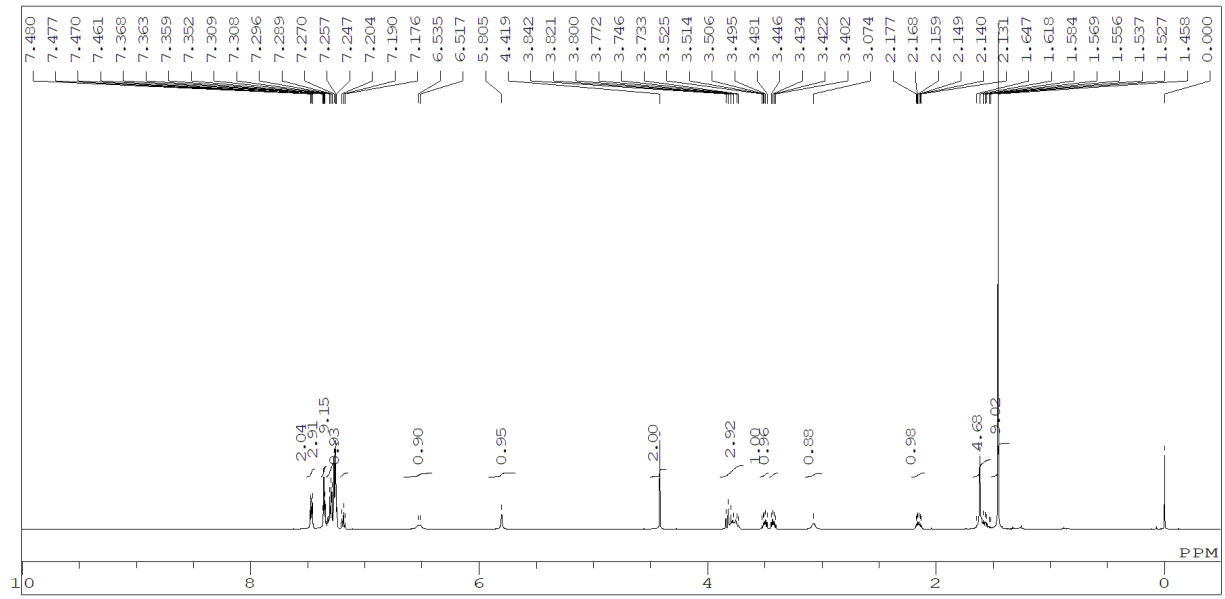
^{13}C-NMR (125 MHz, $CDCl_3$)



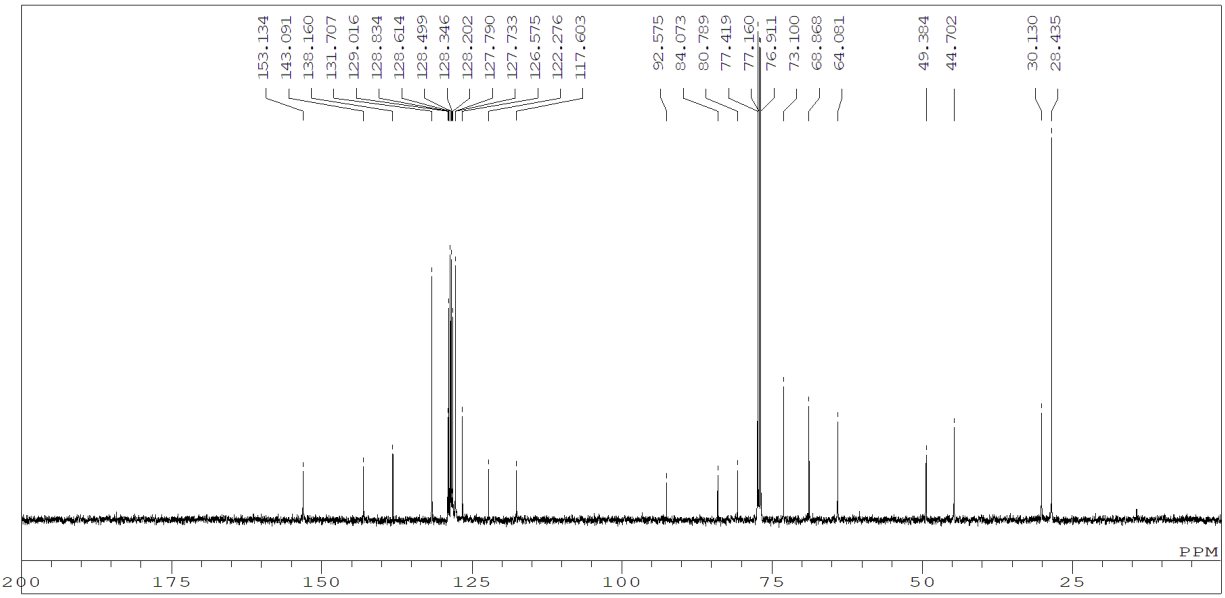
***tert*-Butyl ((5*S*,6*R*,*Z*)-8-(benzyloxy)-6-(hydroxymethyl)-1,5-diphenyloct-3-en-1-yn-3-yl)carbamate (2e)**



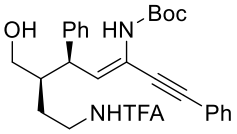
^{1}H-NMR (500 MHz, $CDCl_3$)



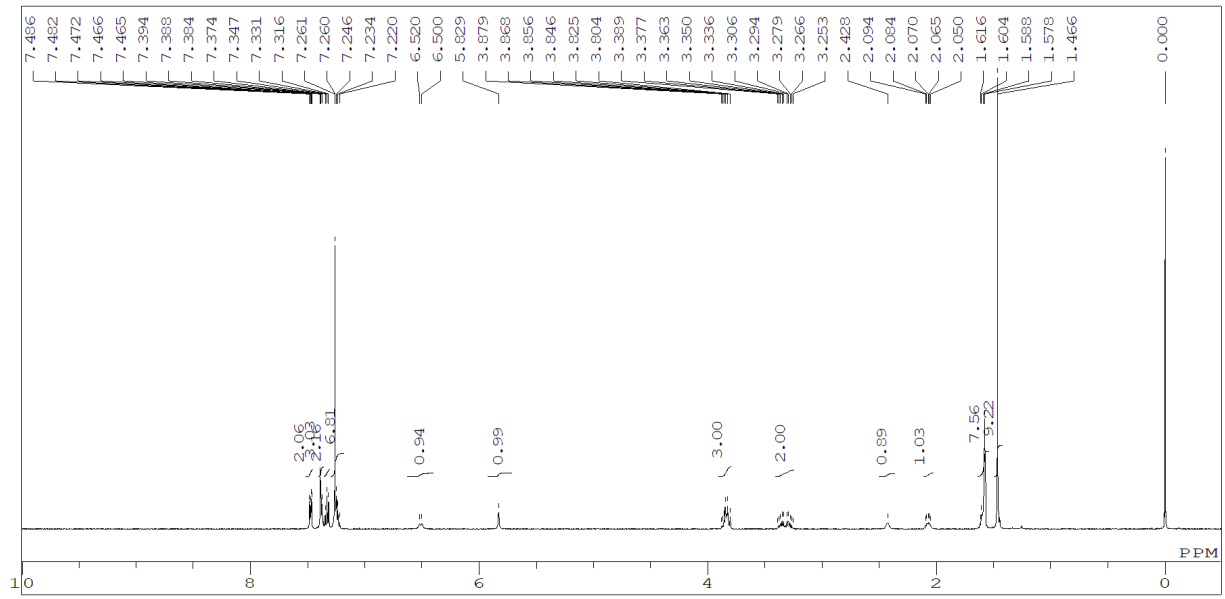
^{13}C-NMR (125 MHz, $CDCl_3$)



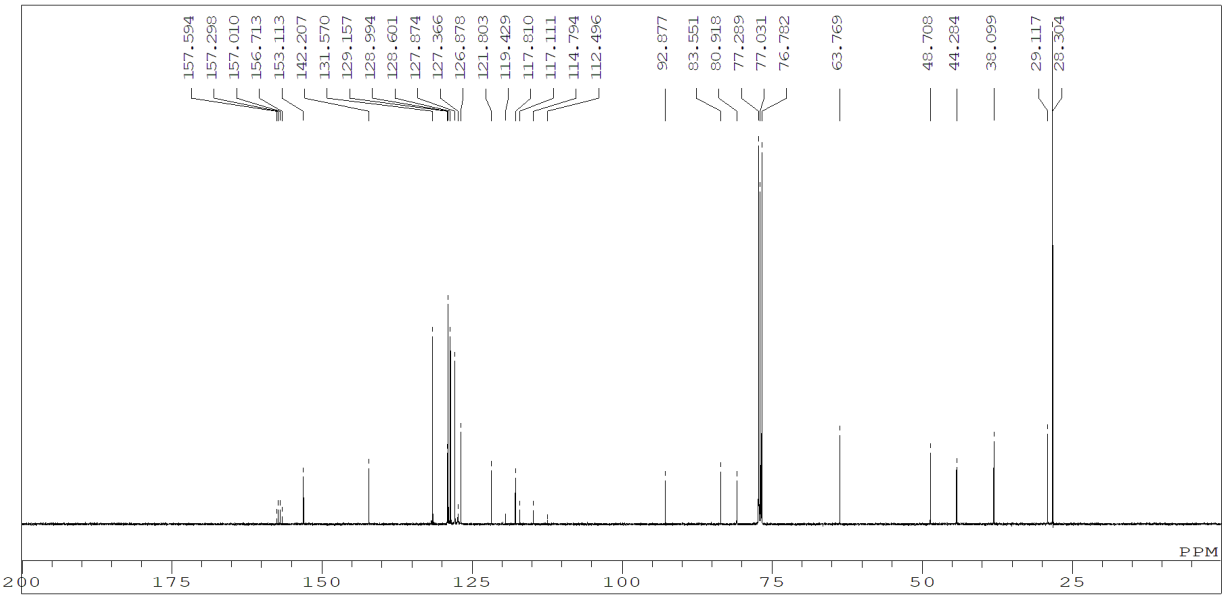
***tert*-Butyl ((5*S*,6*R*,*Z*)-6-(hydroxymethyl)-1,5-diphenyl-8-(2,2,2-trifluoroacetamido)oct-3-en-1-yn-3-yl)carbamate (2f)**



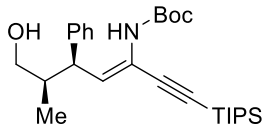
^{1}H-NMR (500 MHz, $CDCl_3$)



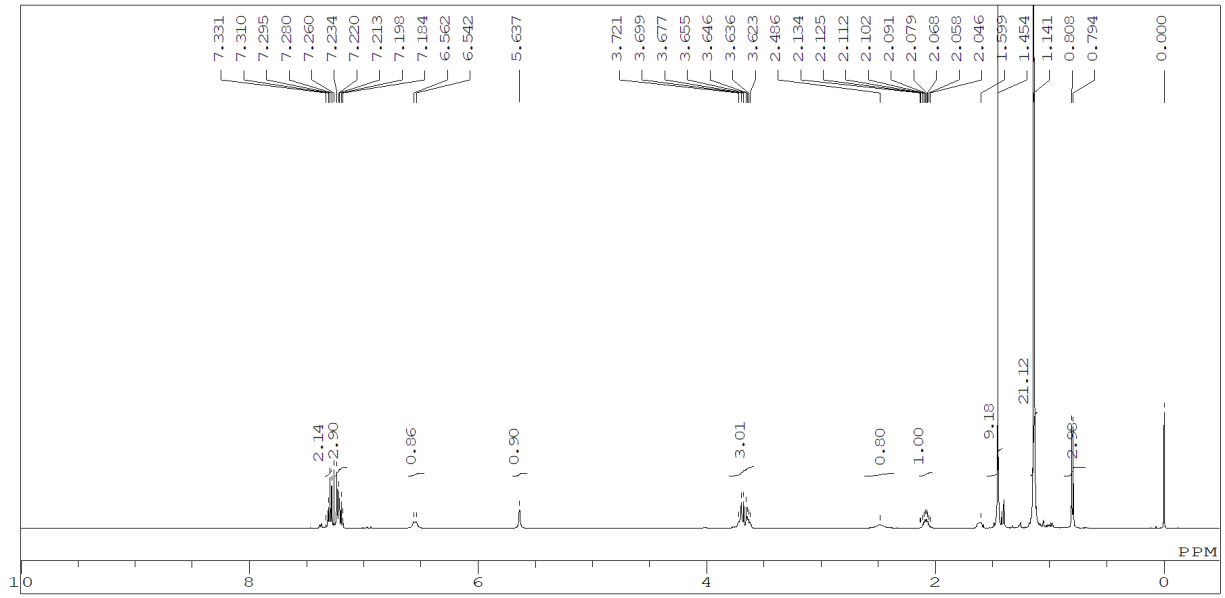
^{13}C-NMR (125 MHz, $CDCl_3$)



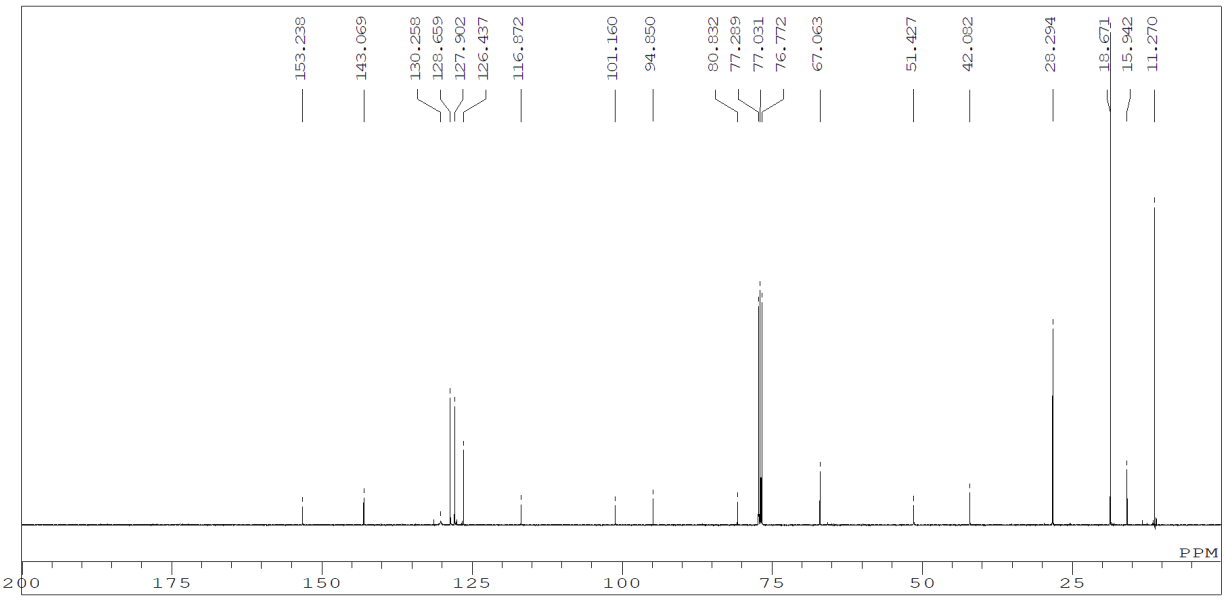
***tert*-Butyl ((5*S*,6*R*,*Z*)-7-hydroxy-6-methyl-5-phenyl-1-(triisopropylsilyl)hept-3-en-1-yn-3-yl)carbamate (2g)**



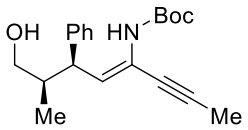
^{1}H-NMR (500 MHz, $CDCl_3$)



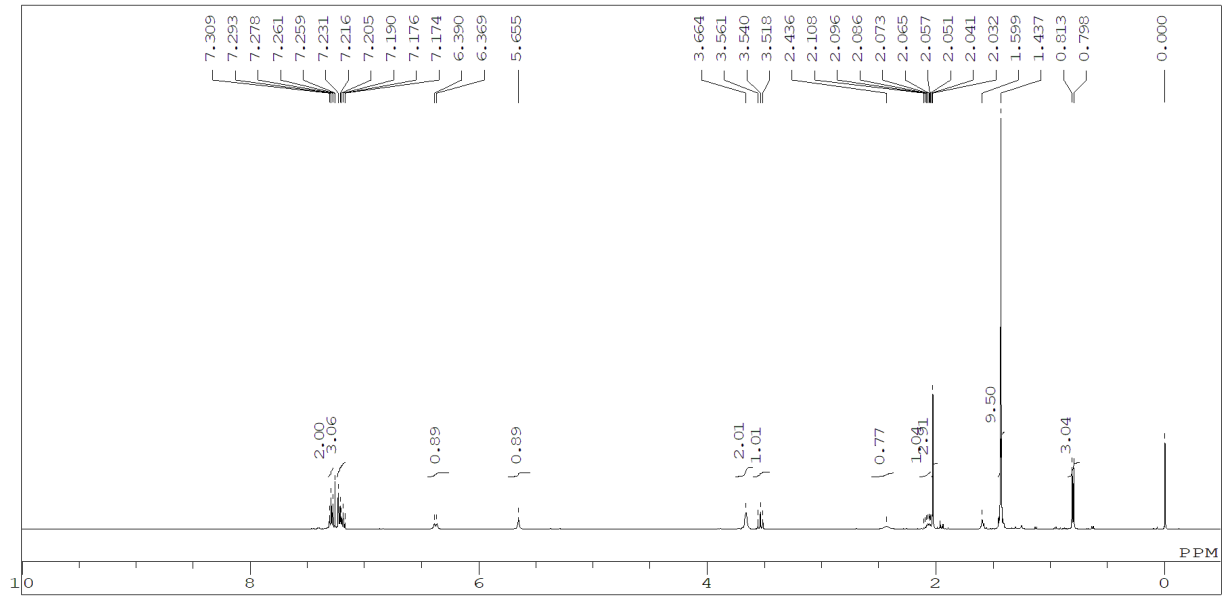
^{13}C-NMR (125 MHz, $CDCl_3$)



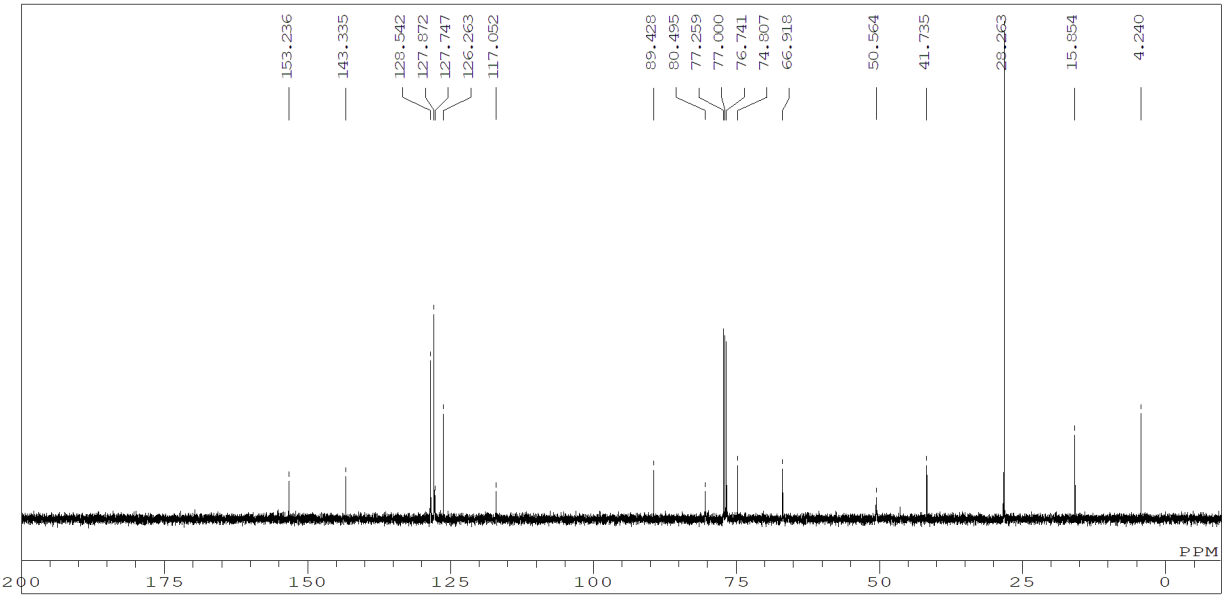
***tert*-Butyl ((6*S*,7*R*,*Z*)-8-hydroxy-7-methyl-6-phenyloct-4-en-2-yn-4-yl)carbamate (2h)**



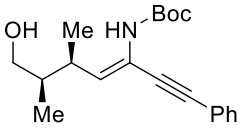
^{1}H-NMR (500 MHz, $CDCl_3$)



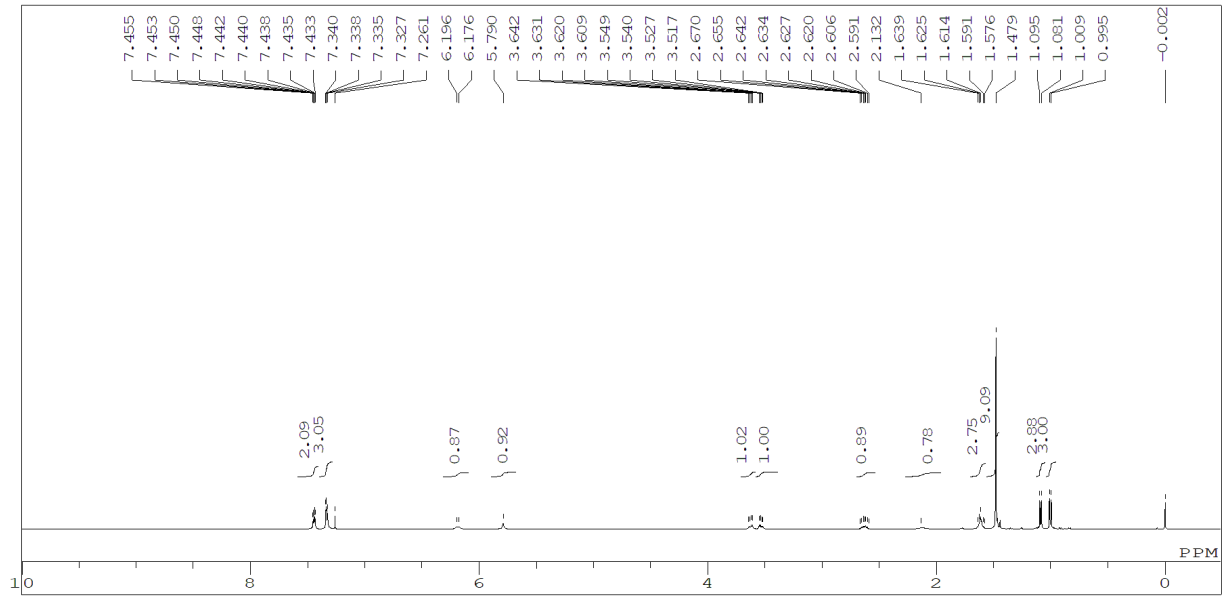
^{13}C-NMR (125 MHz, $CDCl_3$)



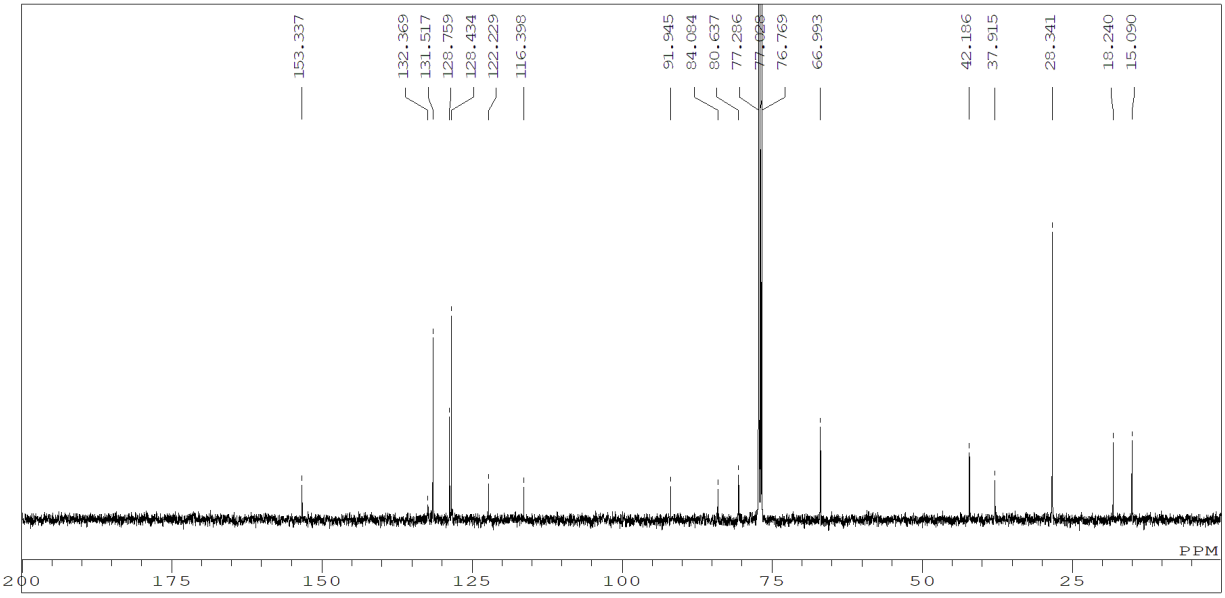
***tert*-Butyl ((5*S*,6*R*,*Z*)-7-hydroxy-5,6-dimethyl-1-phenylhept-3-en-1-yn-3-yl)carbamate (2i)**



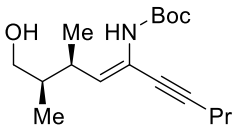
^{1}H-NMR (500 MHz, $CDCl_3$)



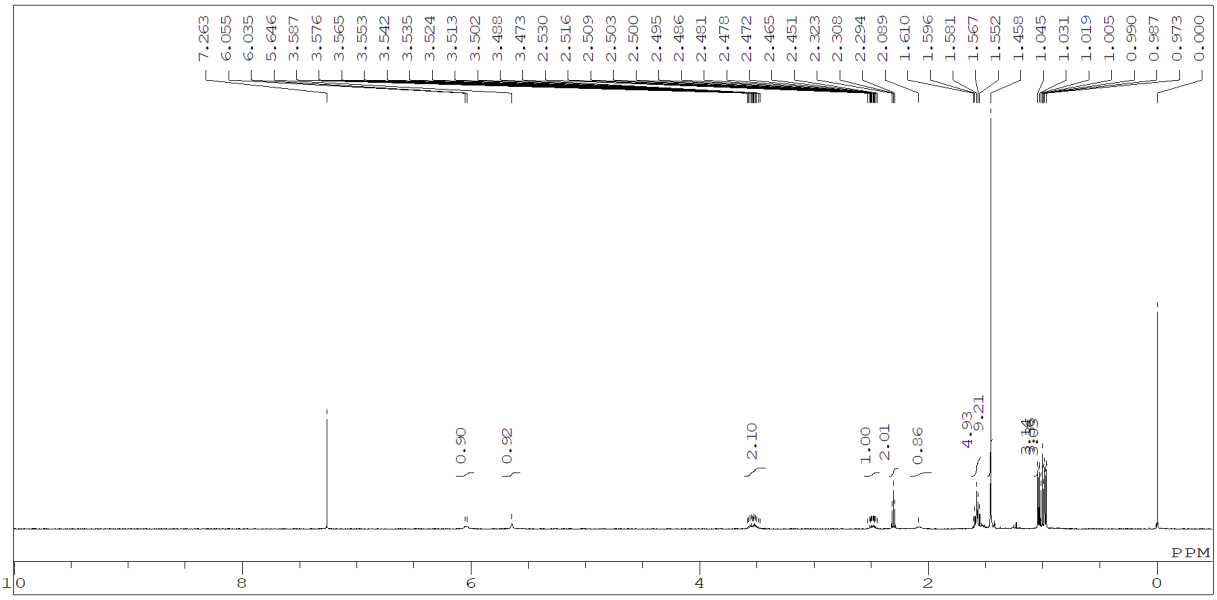
^{13}C-NMR (125 MHz, $CDCl_3$)



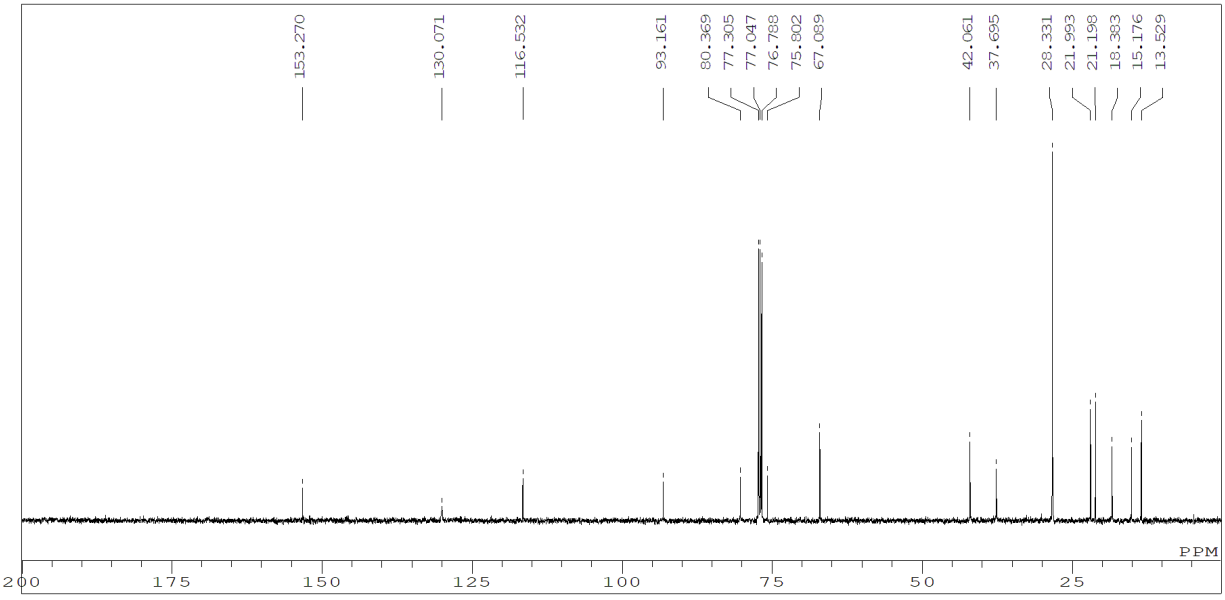
***tert*-Butyl ((2R,3S,Z)-1-hydroxy-2,3-dimethyldec-4-en-6-yn-5-yl)carbamate (2j)**



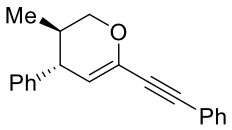
^{1}H-NMR (500 MHz, $CDCl_3$)



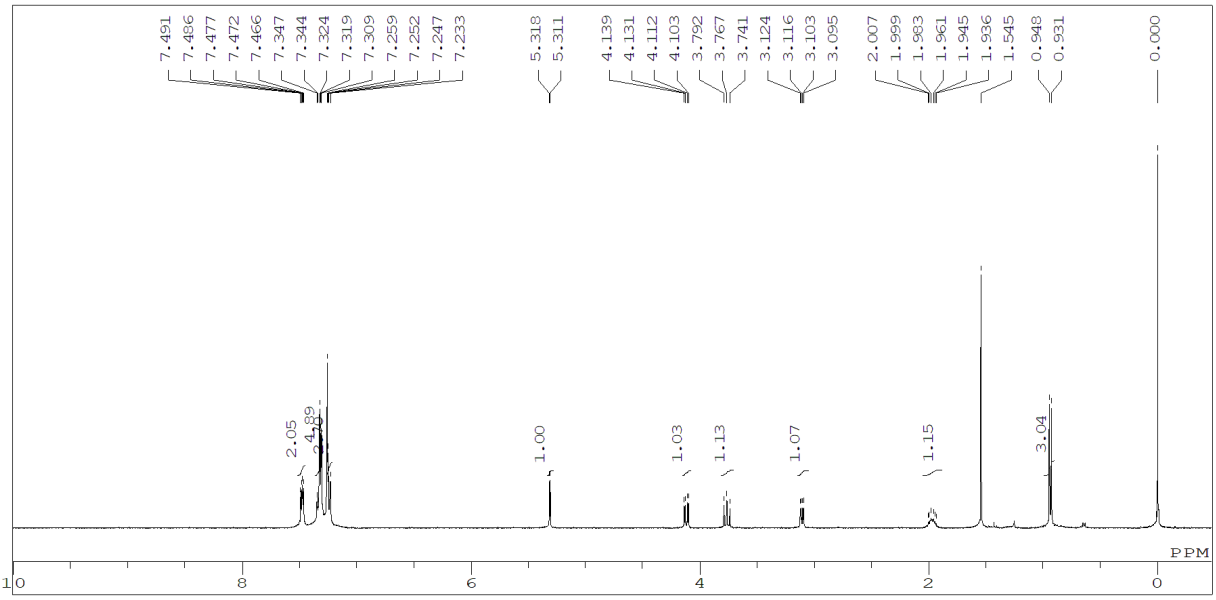
^{13}C-NMR (125 MHz, $CDCl_3$)



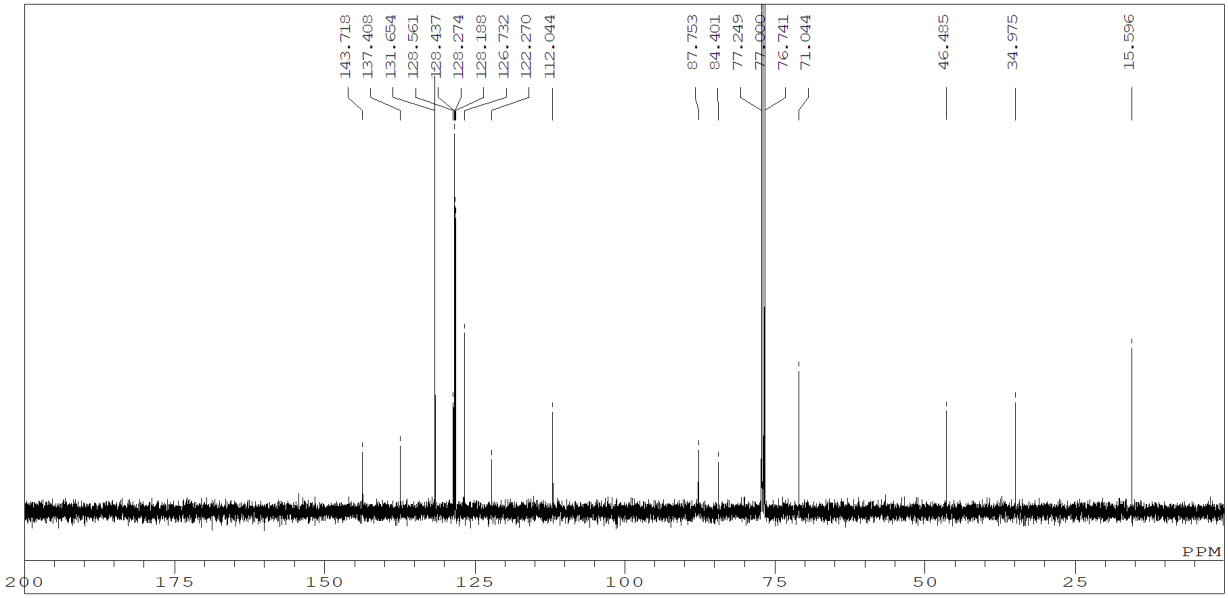
***trans*-9**



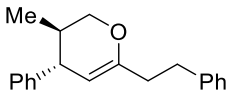
^{1}H-NMR (400 MHz, $CDCl_3$)



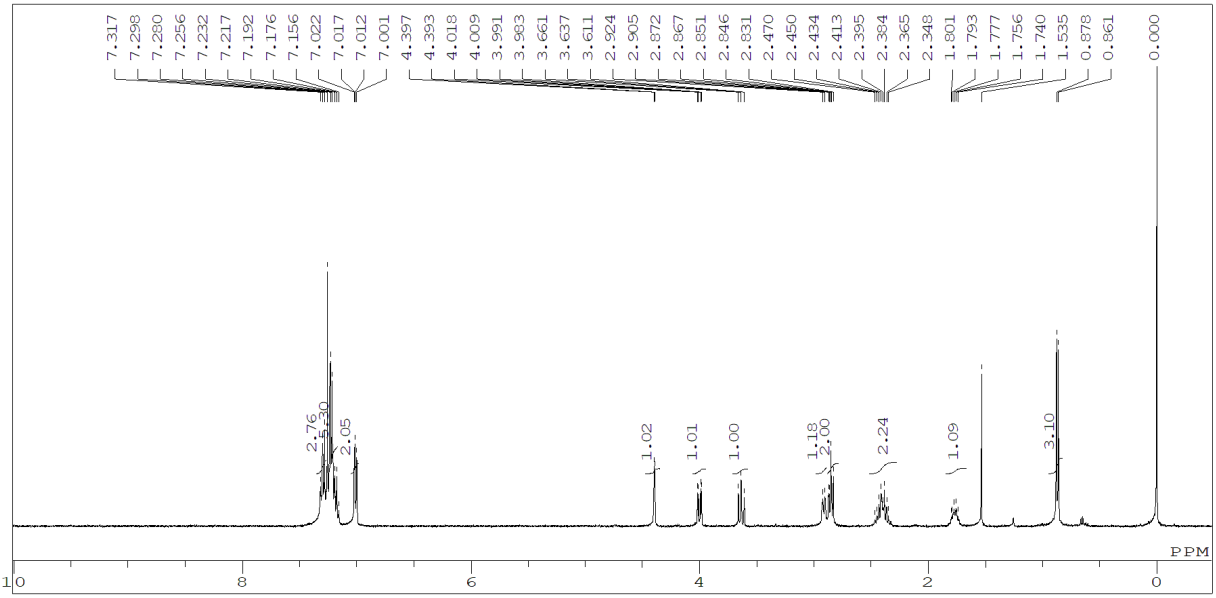
^{13}C-NMR (125 MHz, $CDCl_3$)



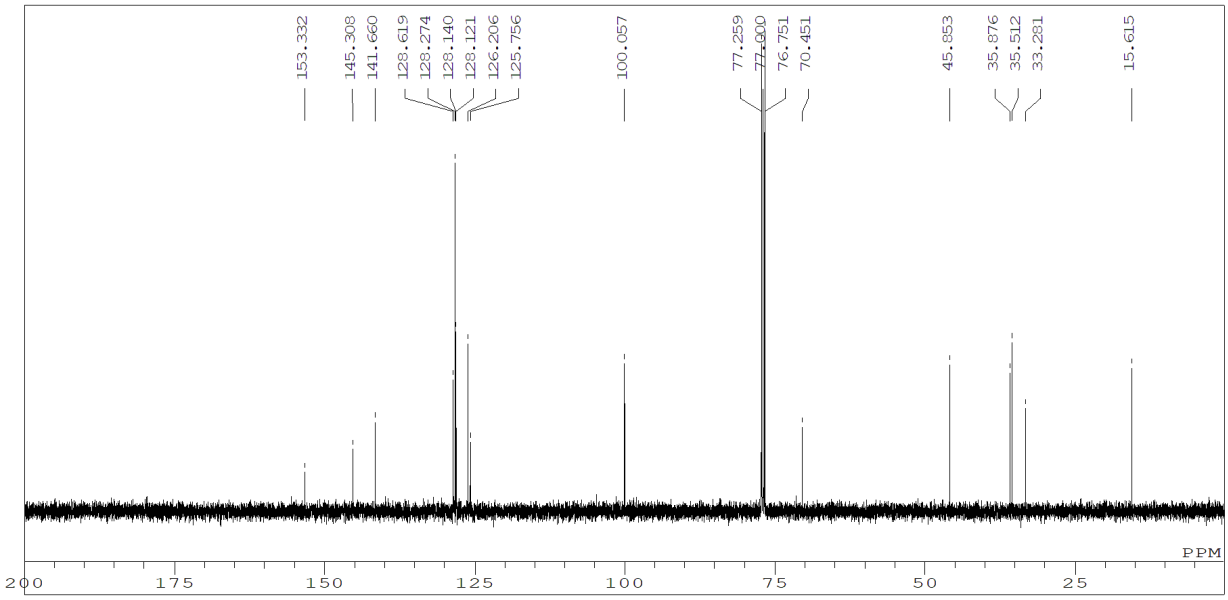
***trans*-10**



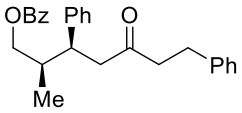
^{1}H-NMR (400 MHz, $CDCl_3$)



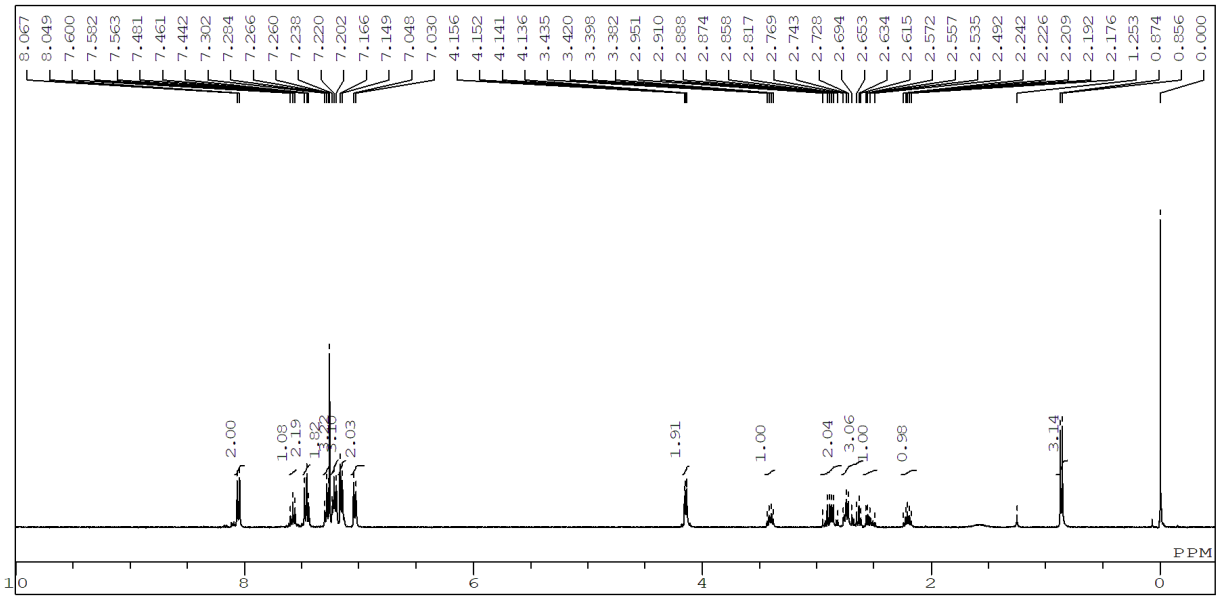
^{13}C-NMR (125 MHz, $CDCl_3$)



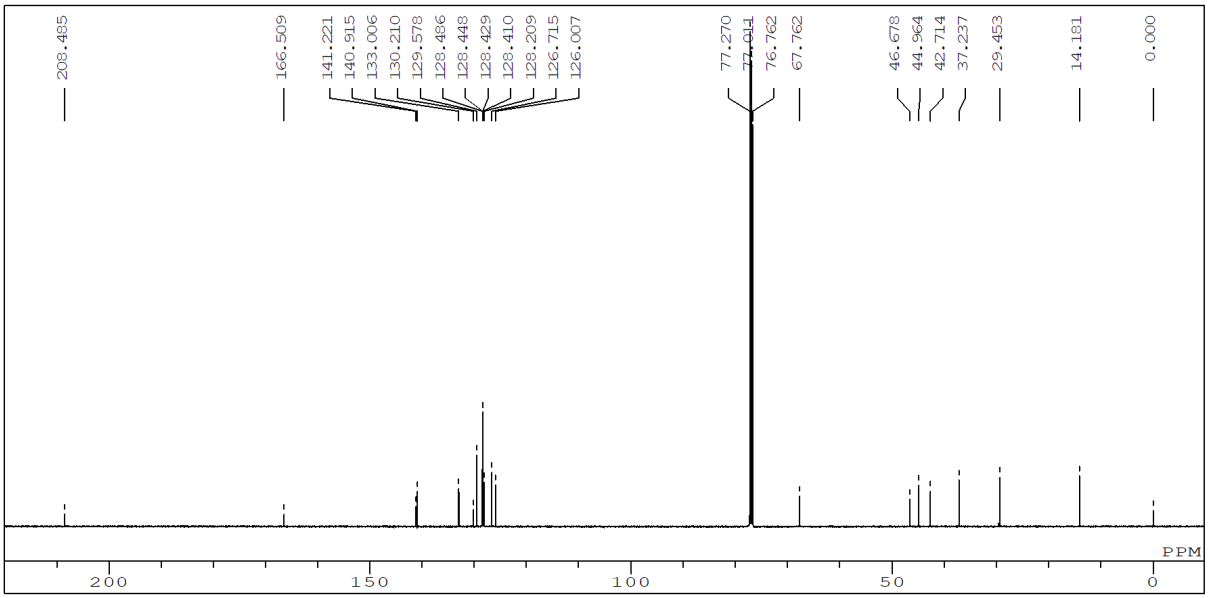
***syn*-S14**



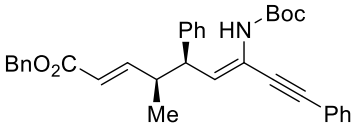
^{1}H-NMR (400 MHz, $CDCl_3$)



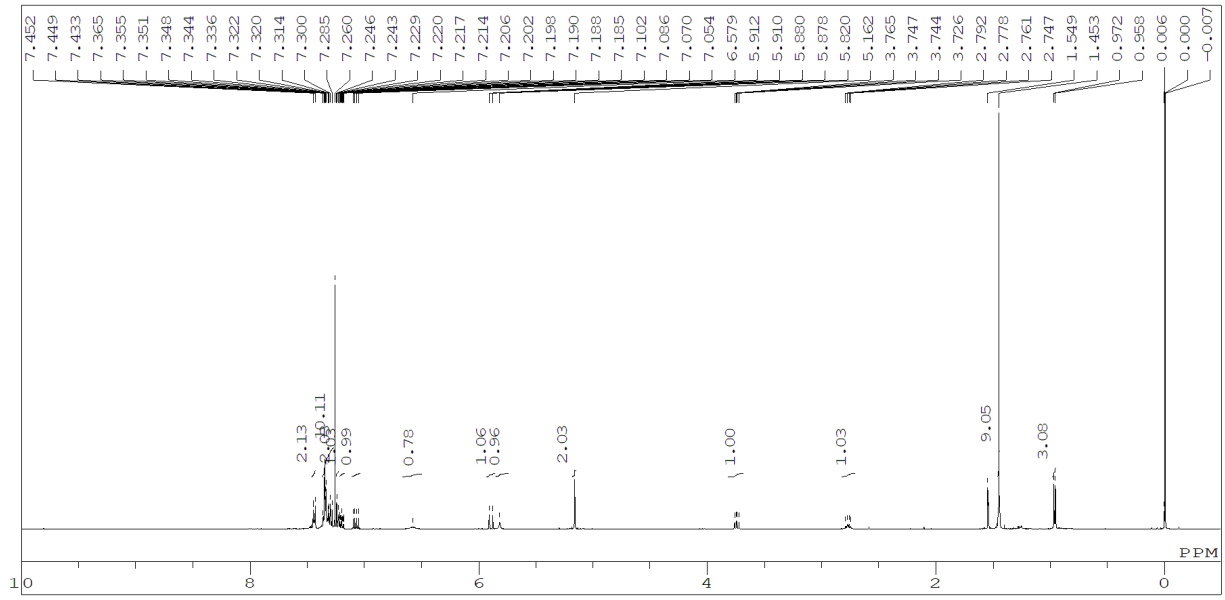
^{13}C-NMR (125 MHz, $CDCl_3$)



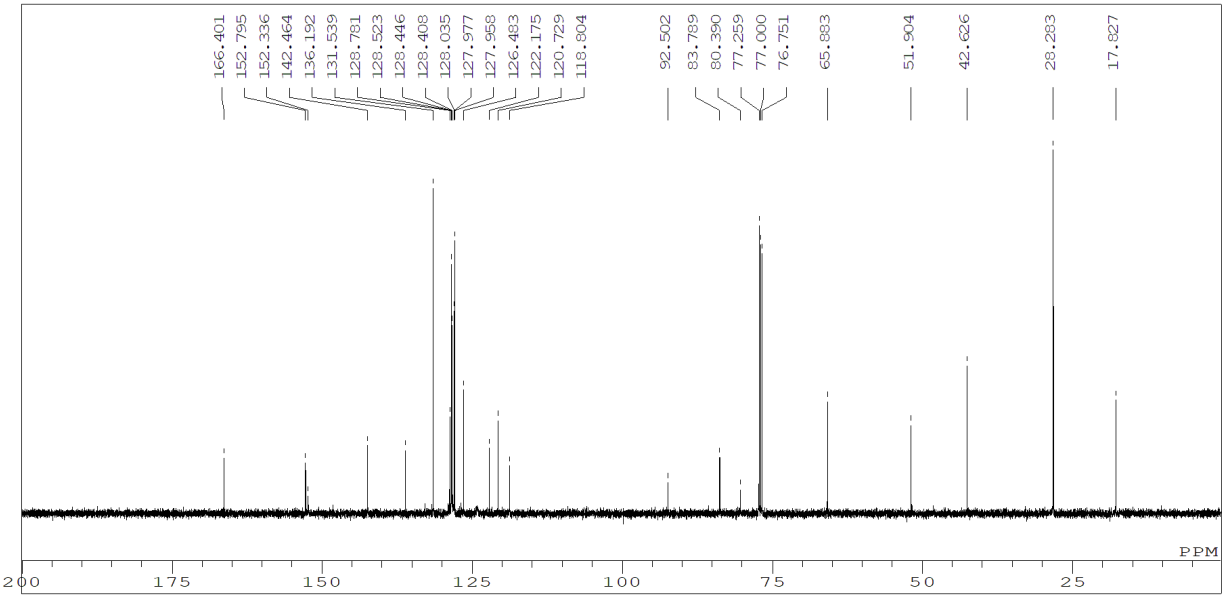
***syn*-S15**



^{1}H-NMR (500 MHz, $CDCl_3$)

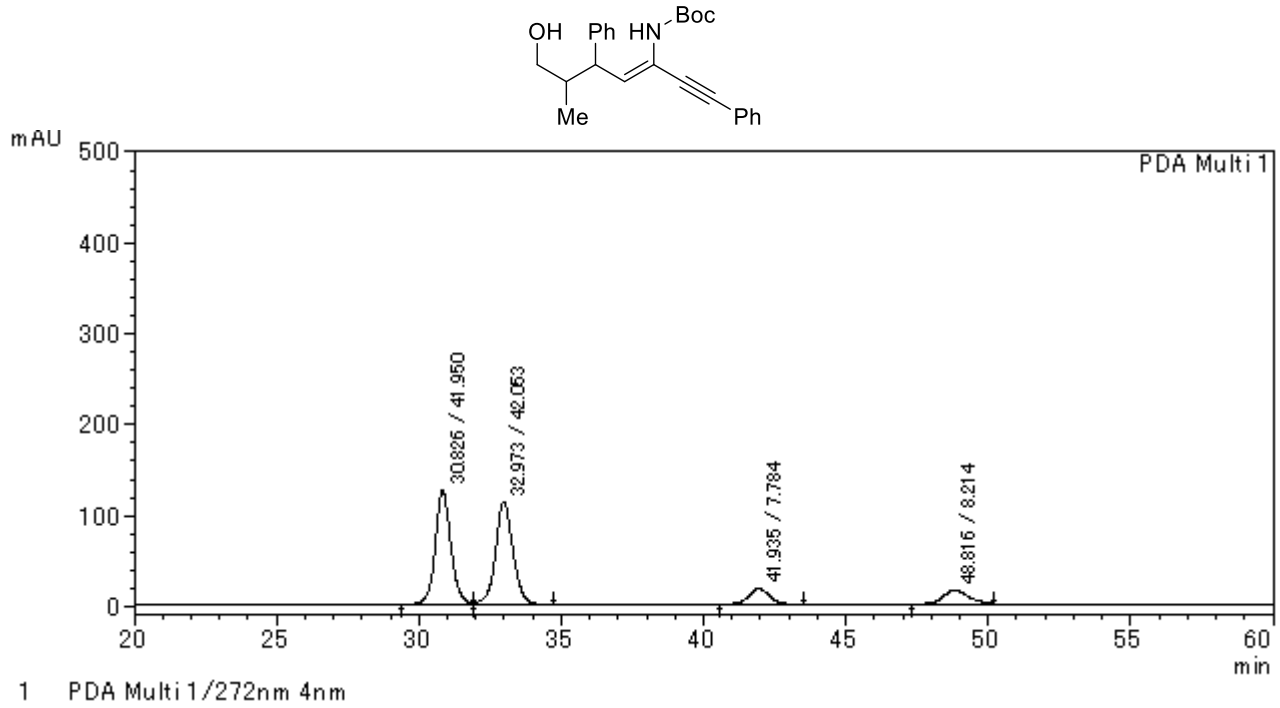


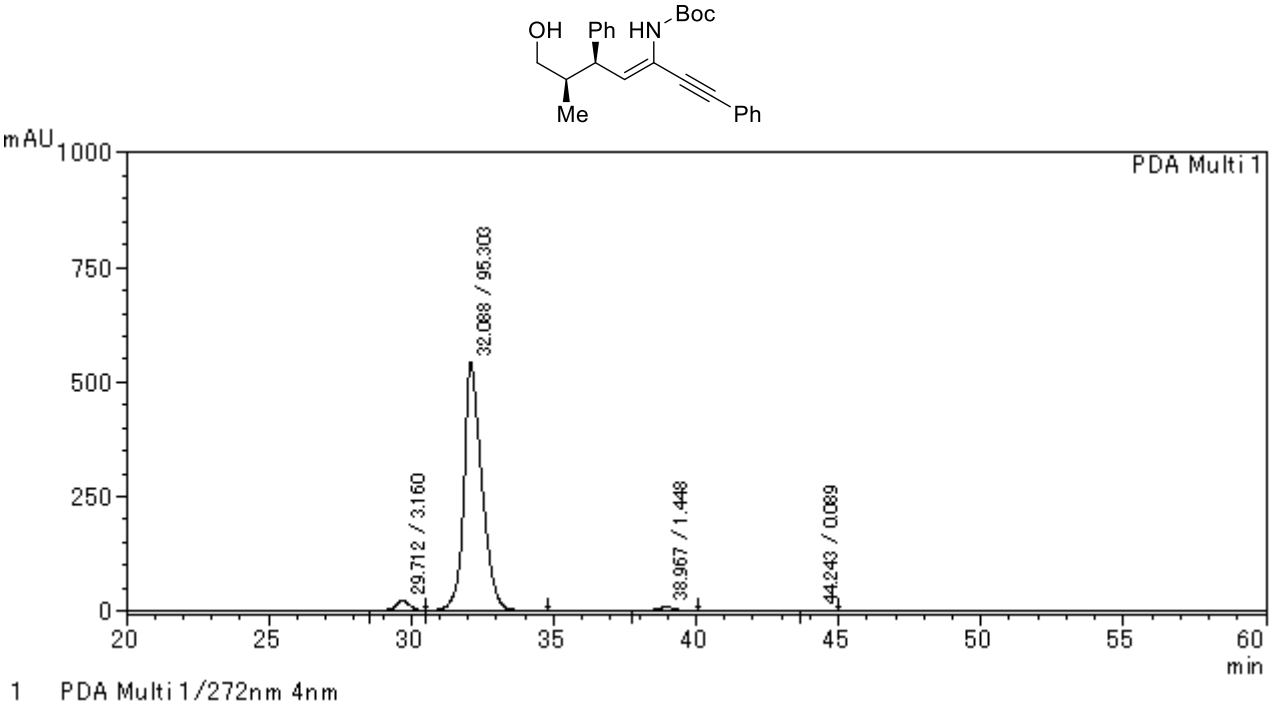
^{13}C-NMR (125 MHz, $CDCl_3$)



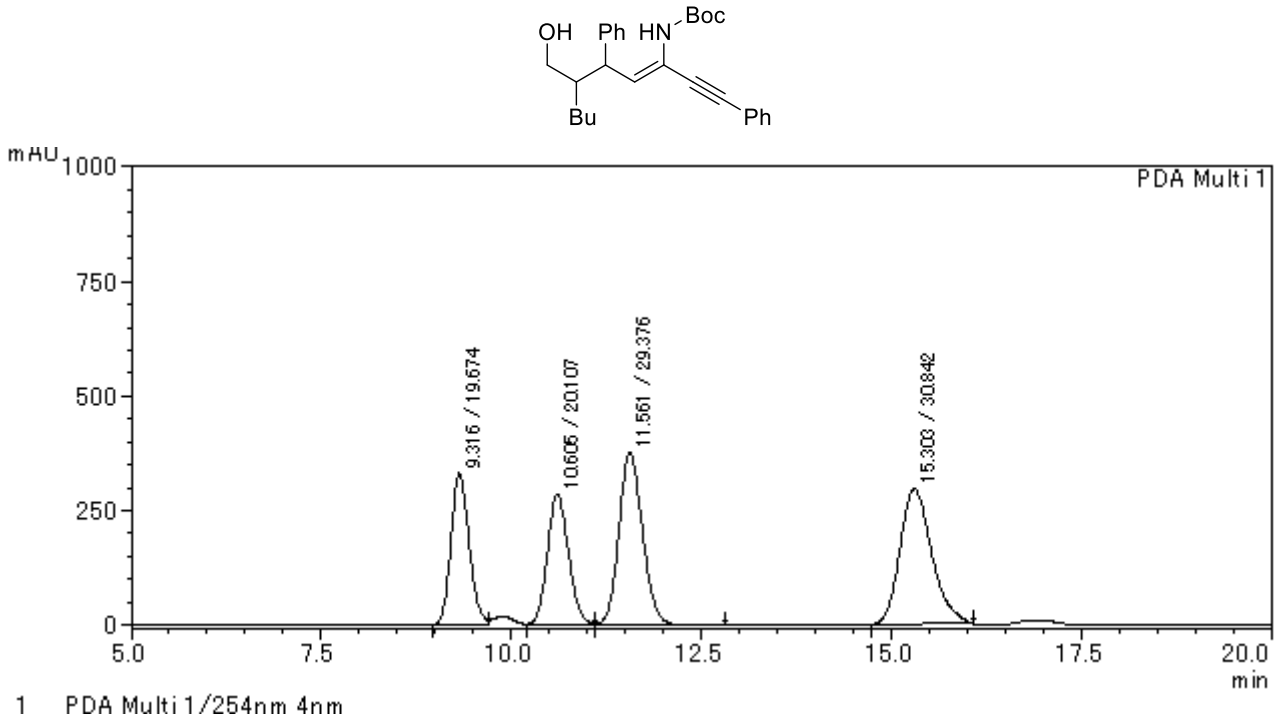
9. HPLC Trace

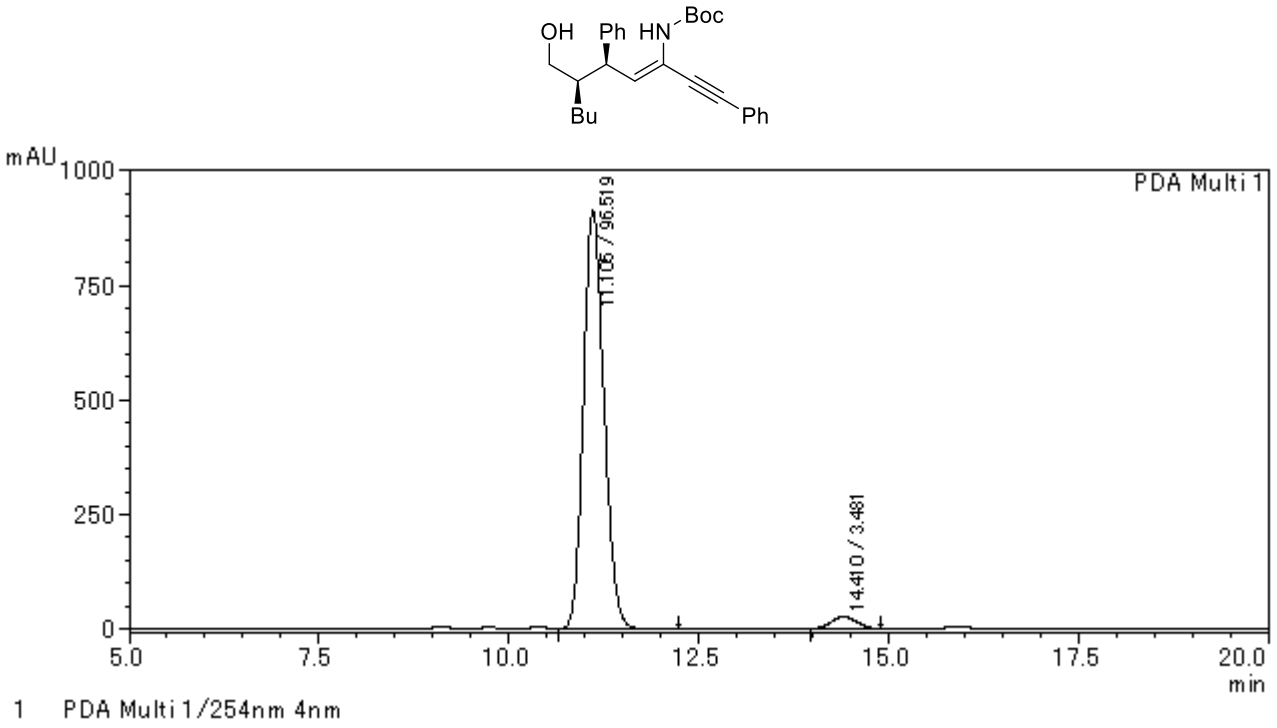
***tert*-Butyl ((5*S*,6*R*,*Z*)-7-hydroxy-6-methyl-1,5-diphenylhept-3-en-1-yn-3-yl)carbamate (2a)**



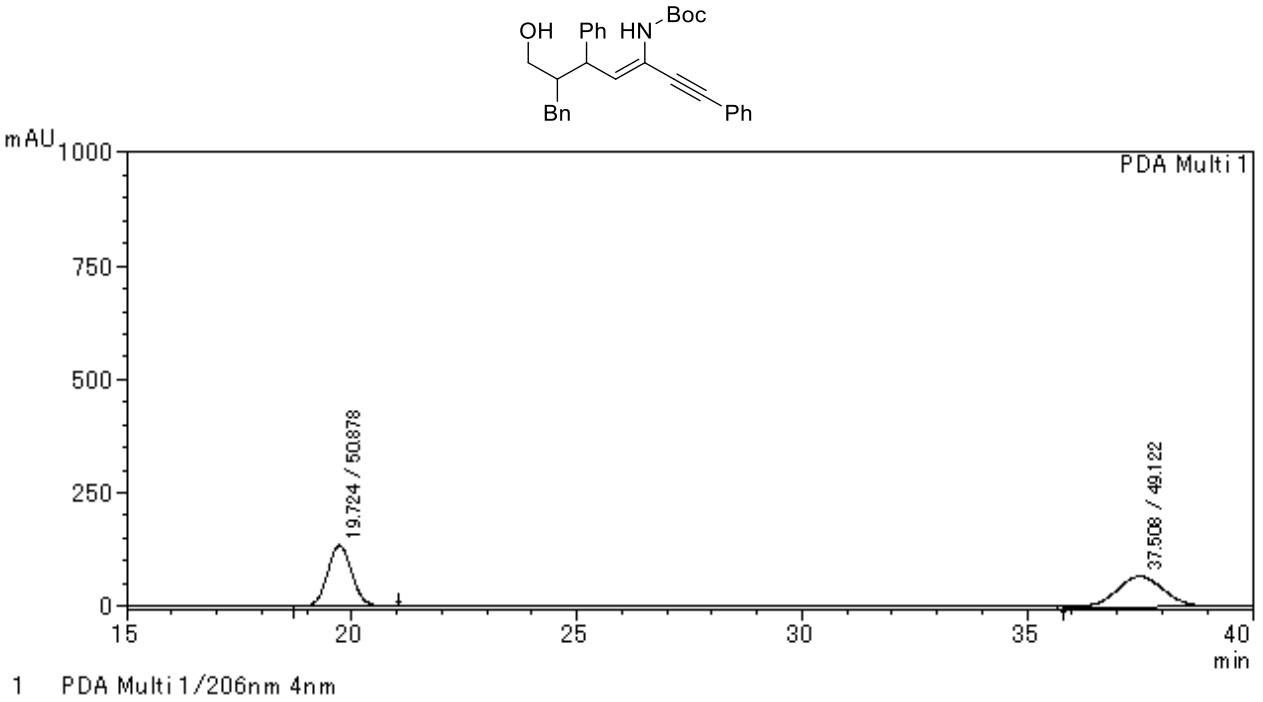


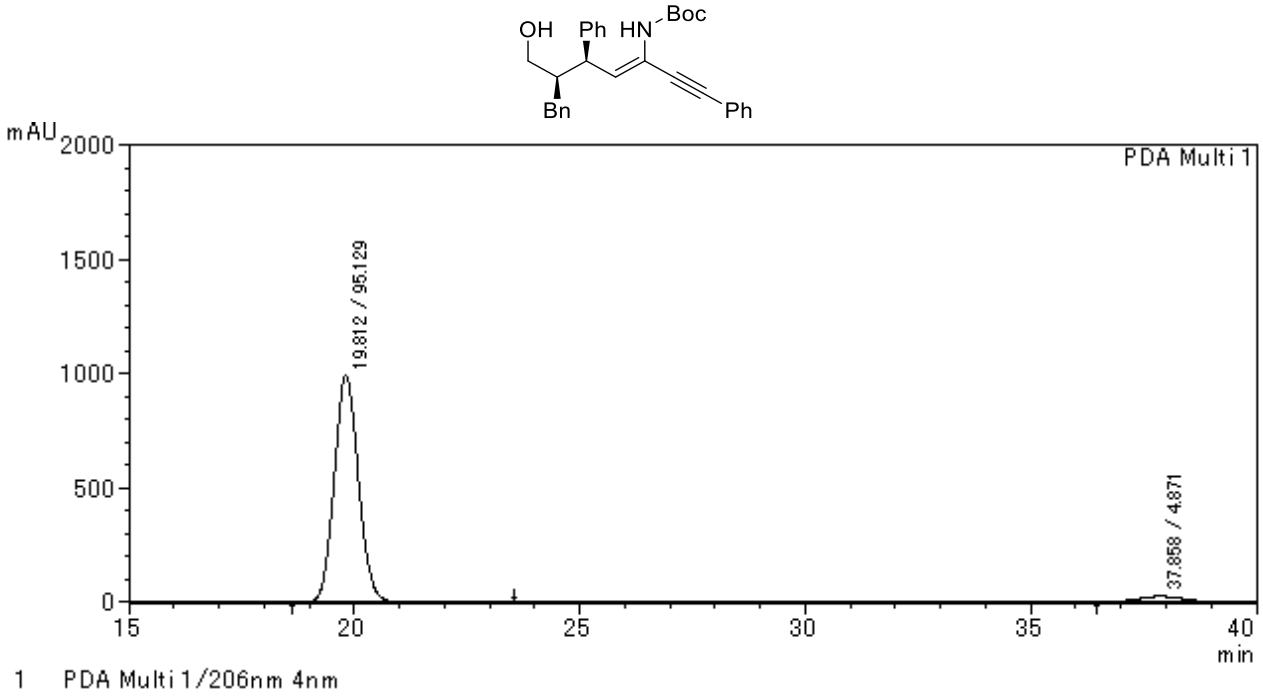
***tert*-Butyl ((5*S*,6*R*,*Z*)-6-(hydroxymethyl)-1,5-diphenyldec-3-en-1-yn-3-yl)carbamate (2b)**



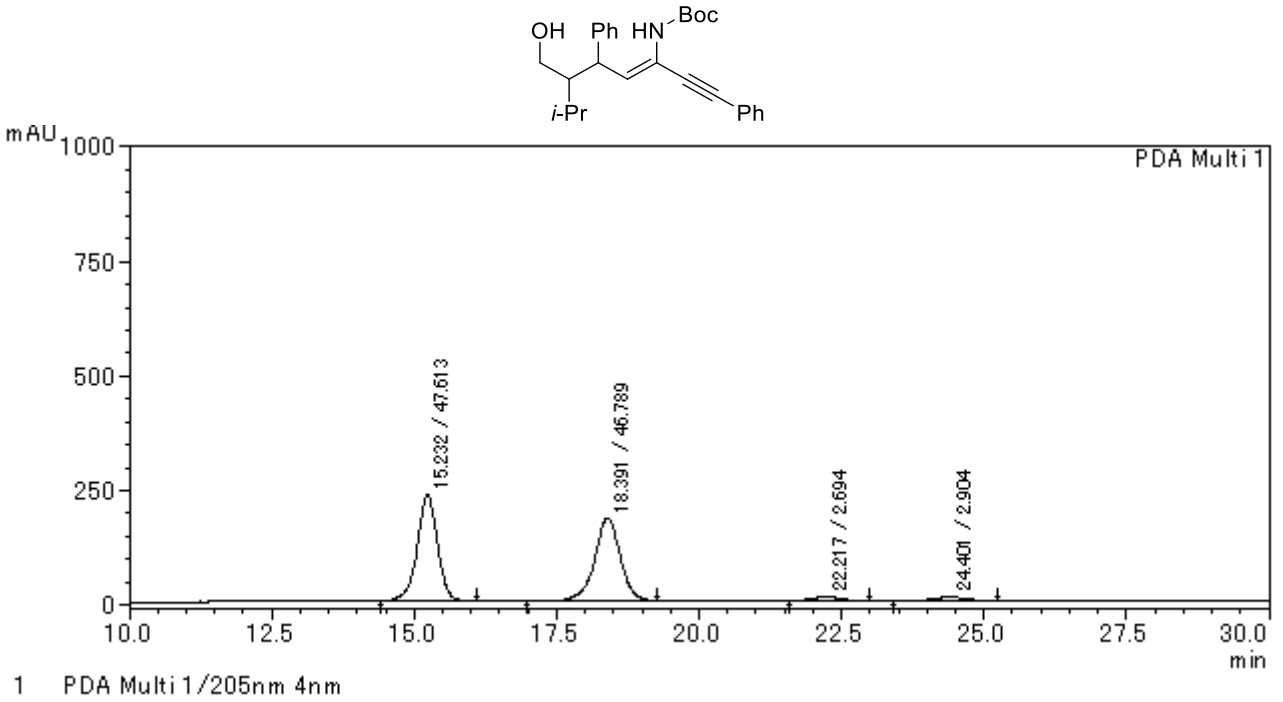


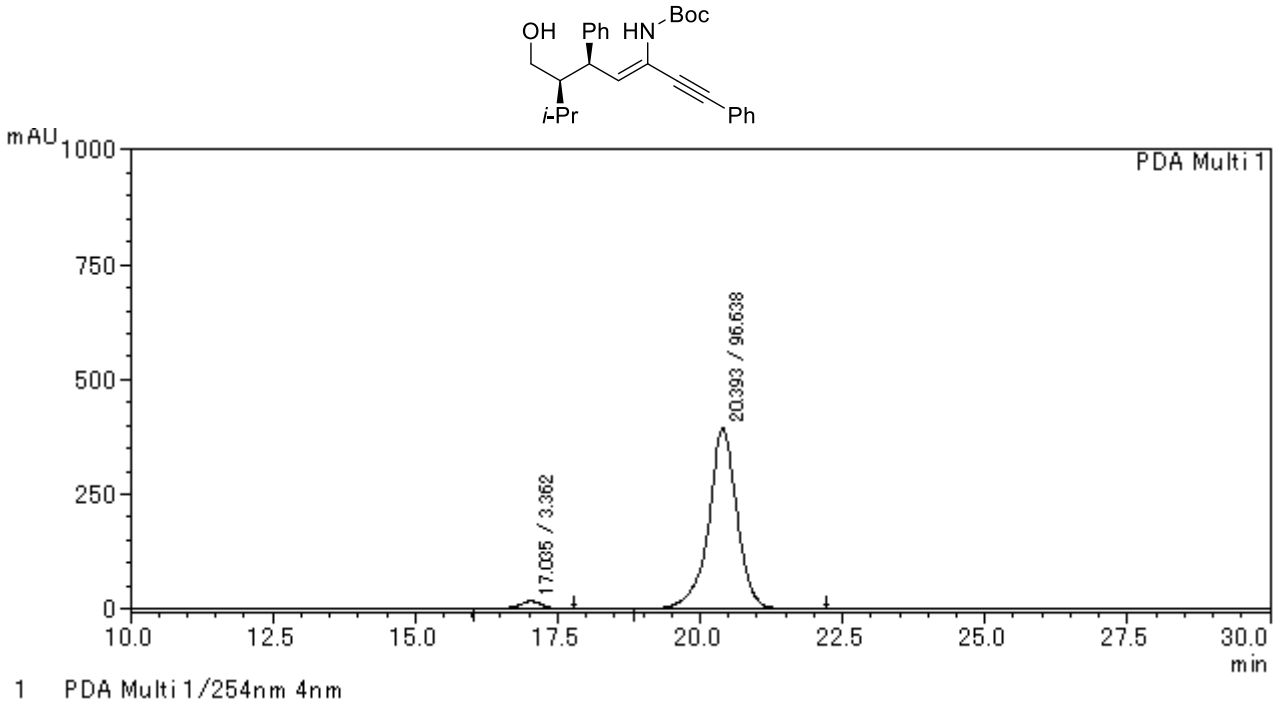
***tert*-Butyl ((5*S*,6*R*,*Z*)-6-benzyl-7-hydroxy-1,5-diphenylhept-3-en-1-yn-3-yl)carbamate (2c)**



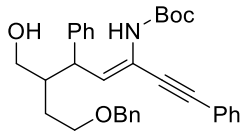


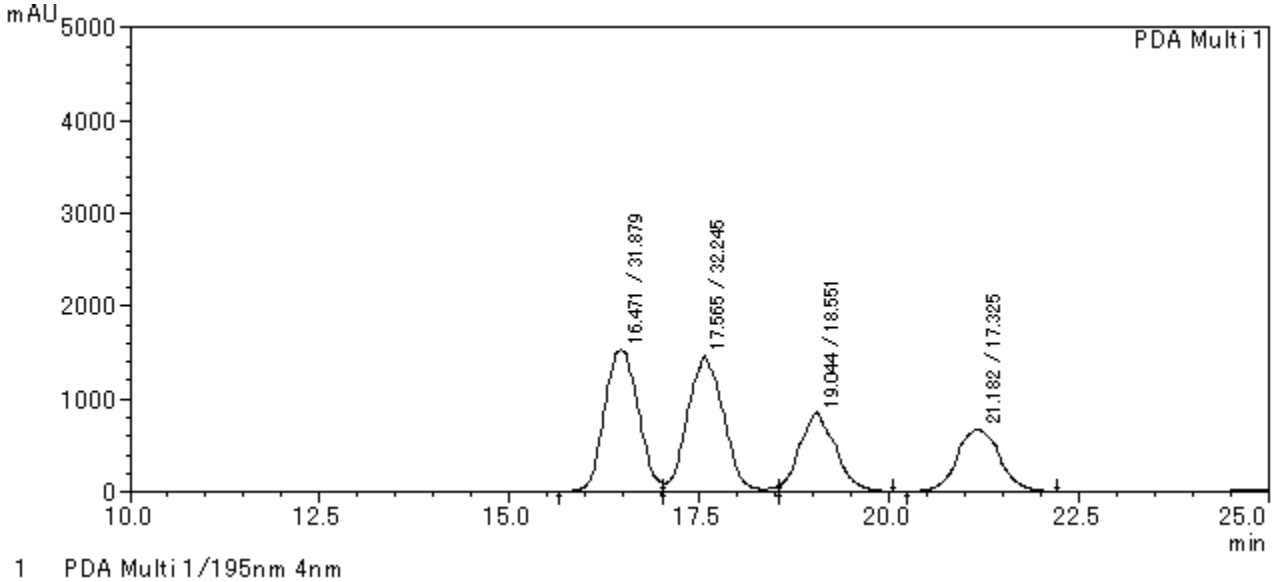
***tert*-Butyl ((5*S*,6*R*,*Z*)-6-(hydroxymethyl)-7-methyl-1,5-diphenyloct-3-en-1-yn-3-yl)carbamate (2d)**



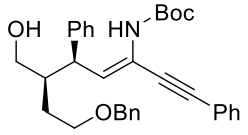


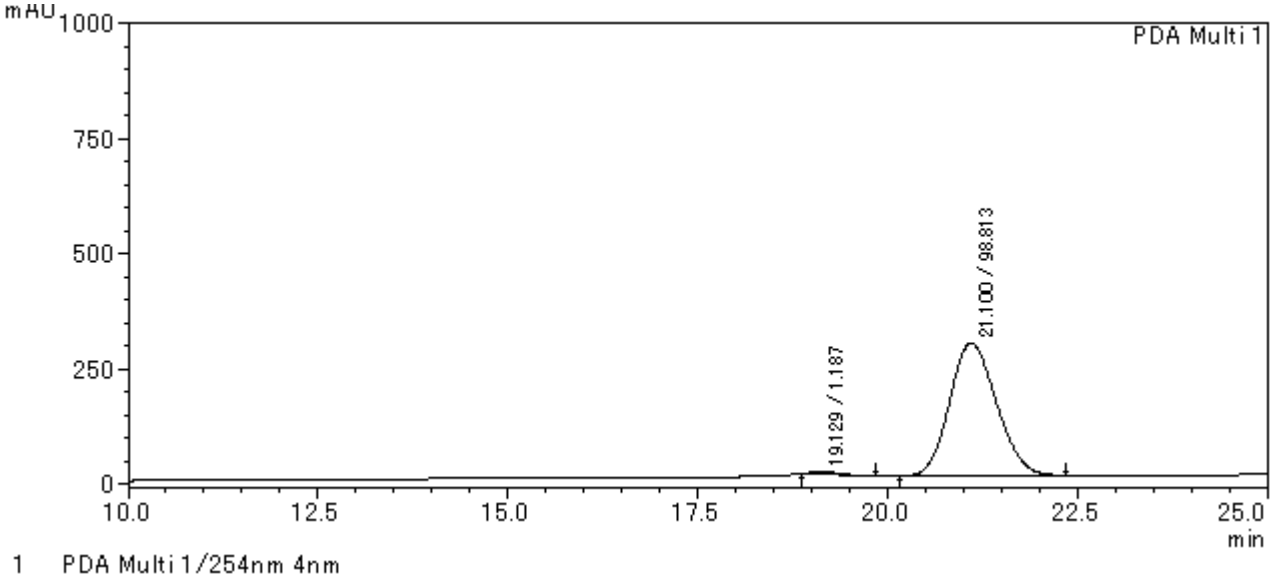
***tert*-Butyl ((5*S*,6*R*,*Z*)-8-(benzyloxy)-6-(hydroxymethyl)-1,5-diphenyloct-3-en-1-yn-3-yl)carbamate (2e)**





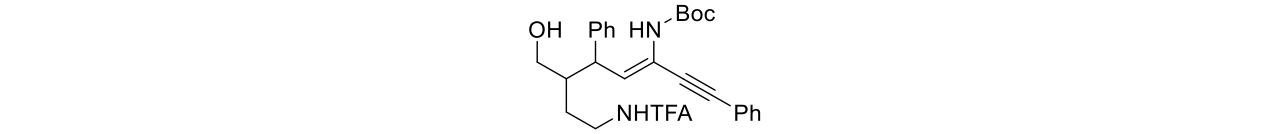
1 PDA Multi 1/195nm 4nm

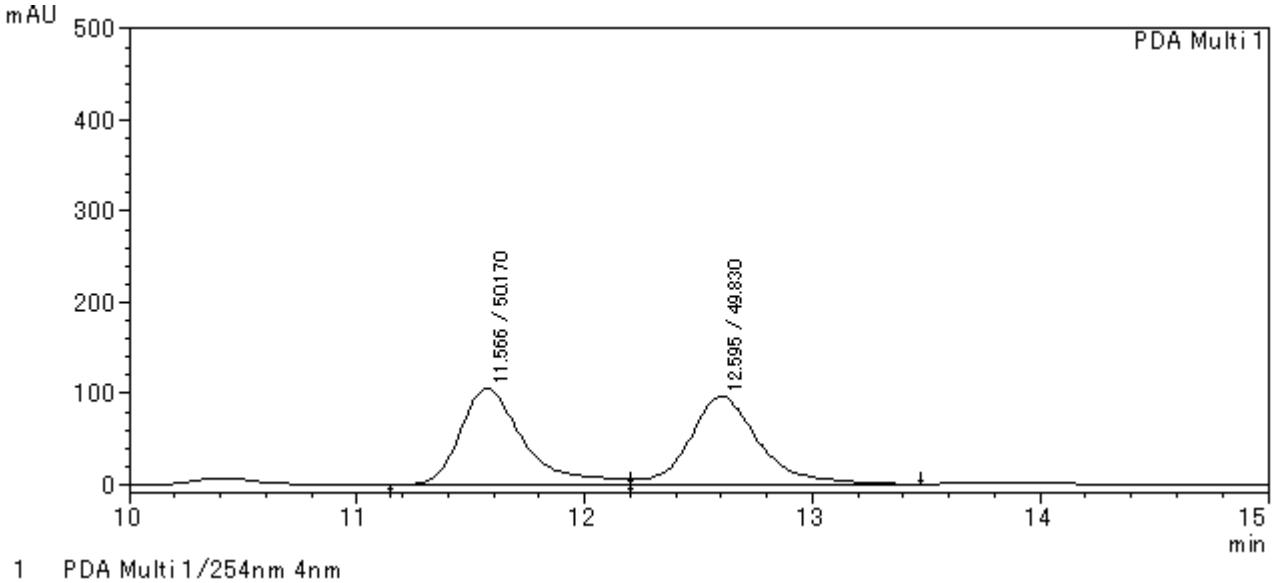




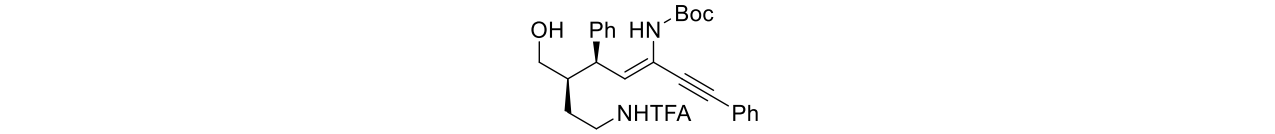
1 PDA Multi 1/254nm 4nm

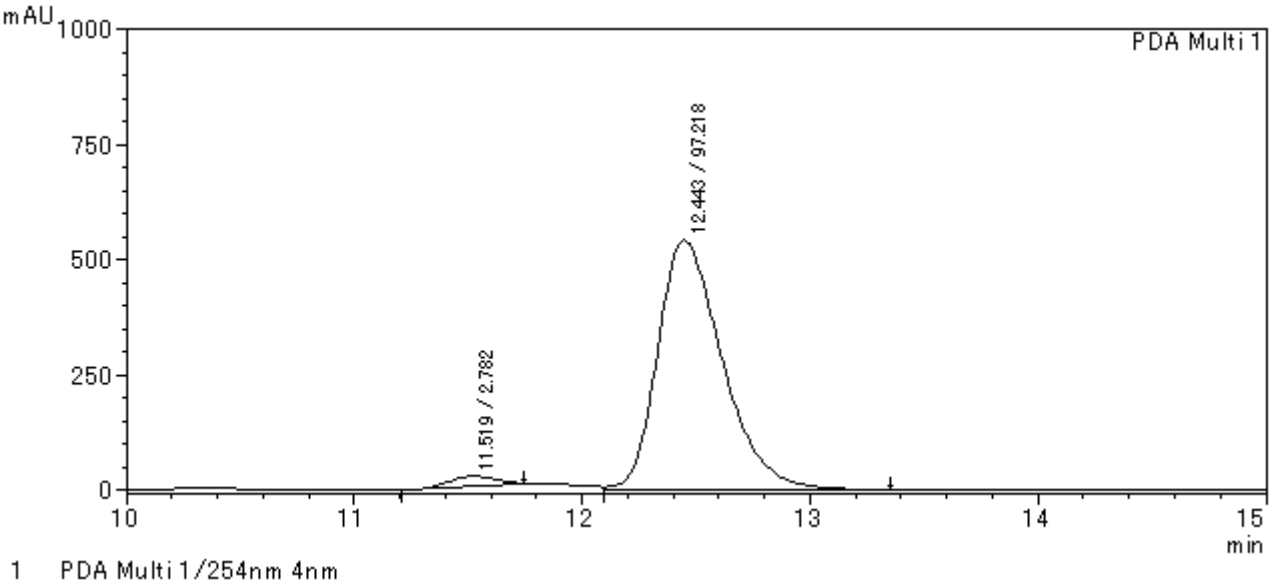
***tert*-Butyl ((5*S*,6*R*,*Z*)-6-(hydroxymethyl)-1,5-diphenyl-8-(2,2,2-trifluoroacetamido)oct-3-en-1-yn-3-yl)carbamate (2f)**





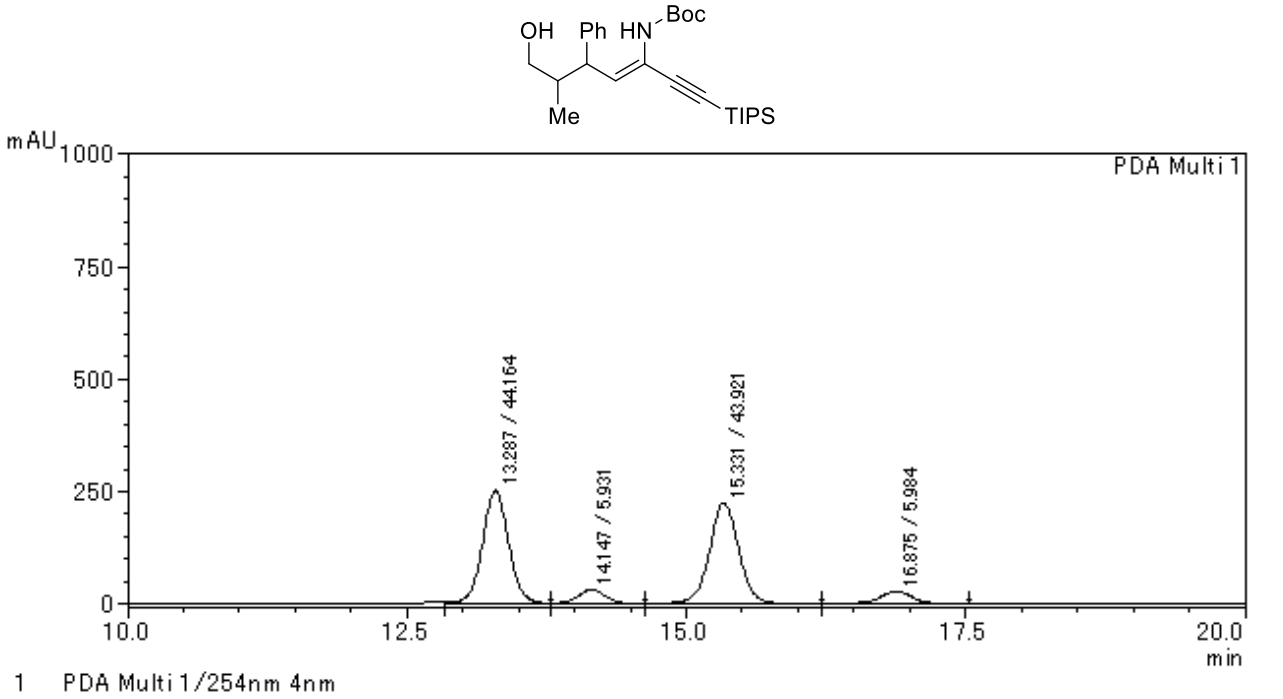
1 PDA Multi 1/254nm 4nm

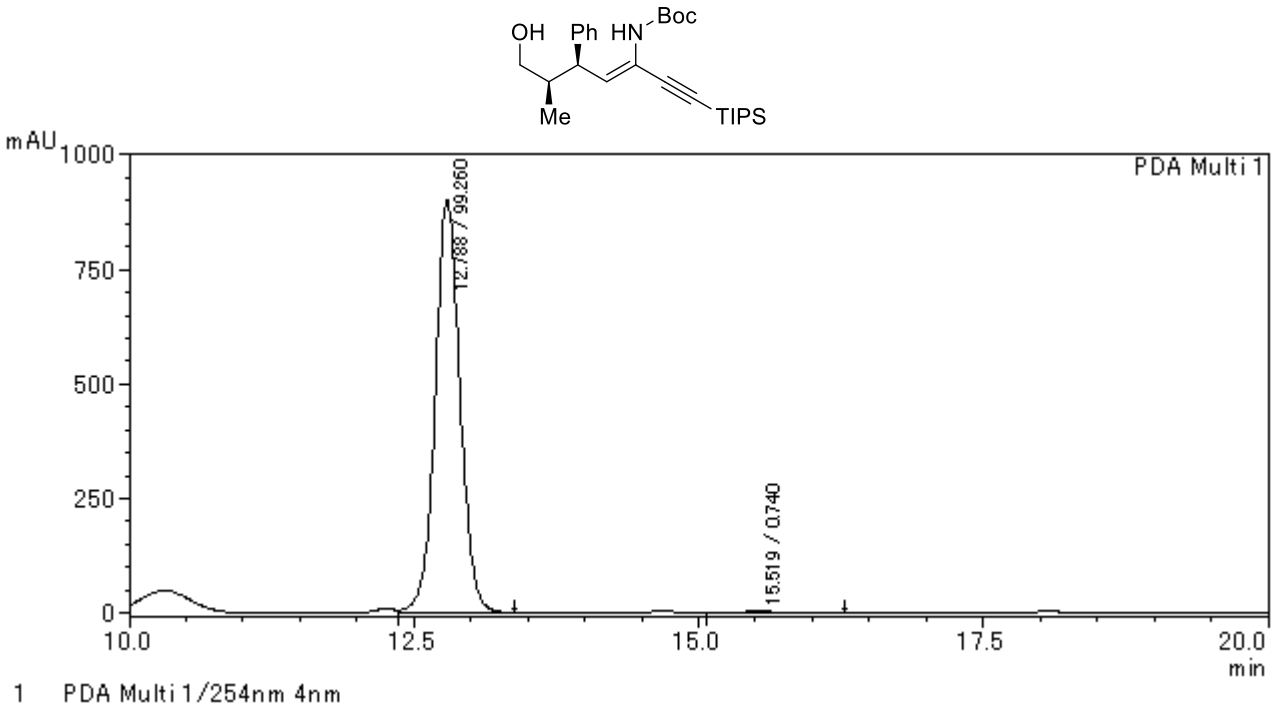




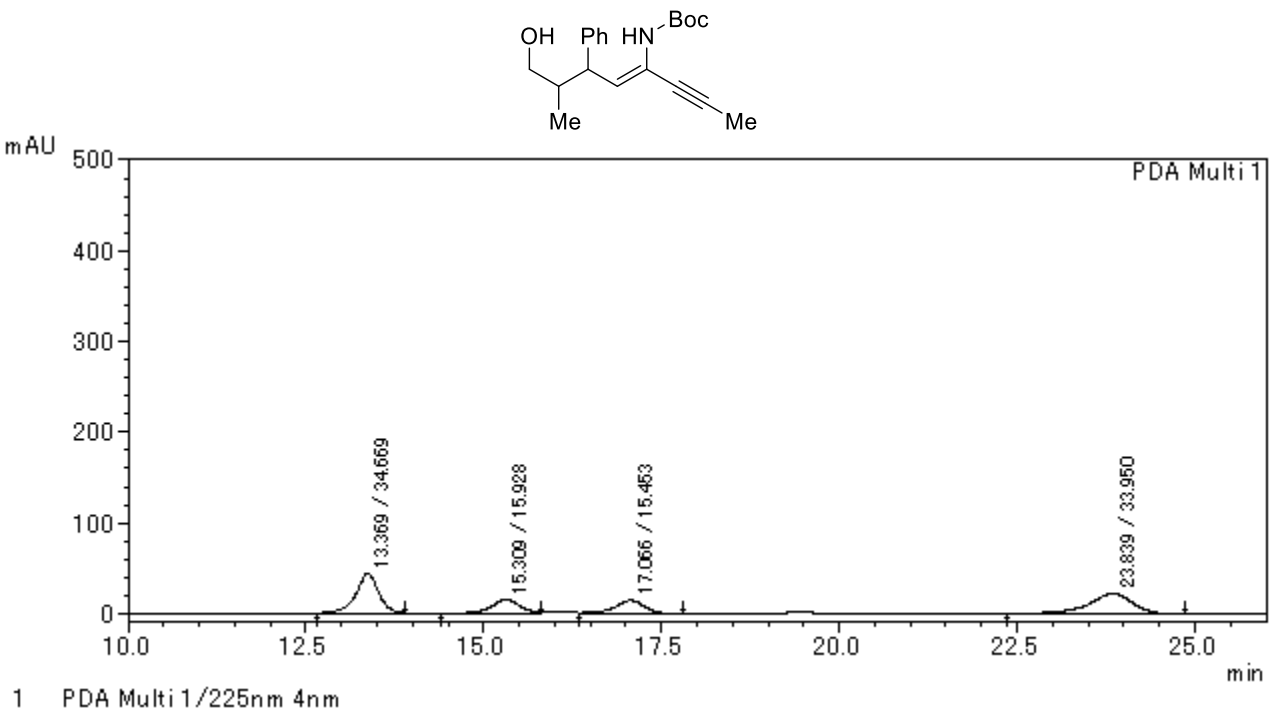
1 PDA Multi 1/254nm 4nm

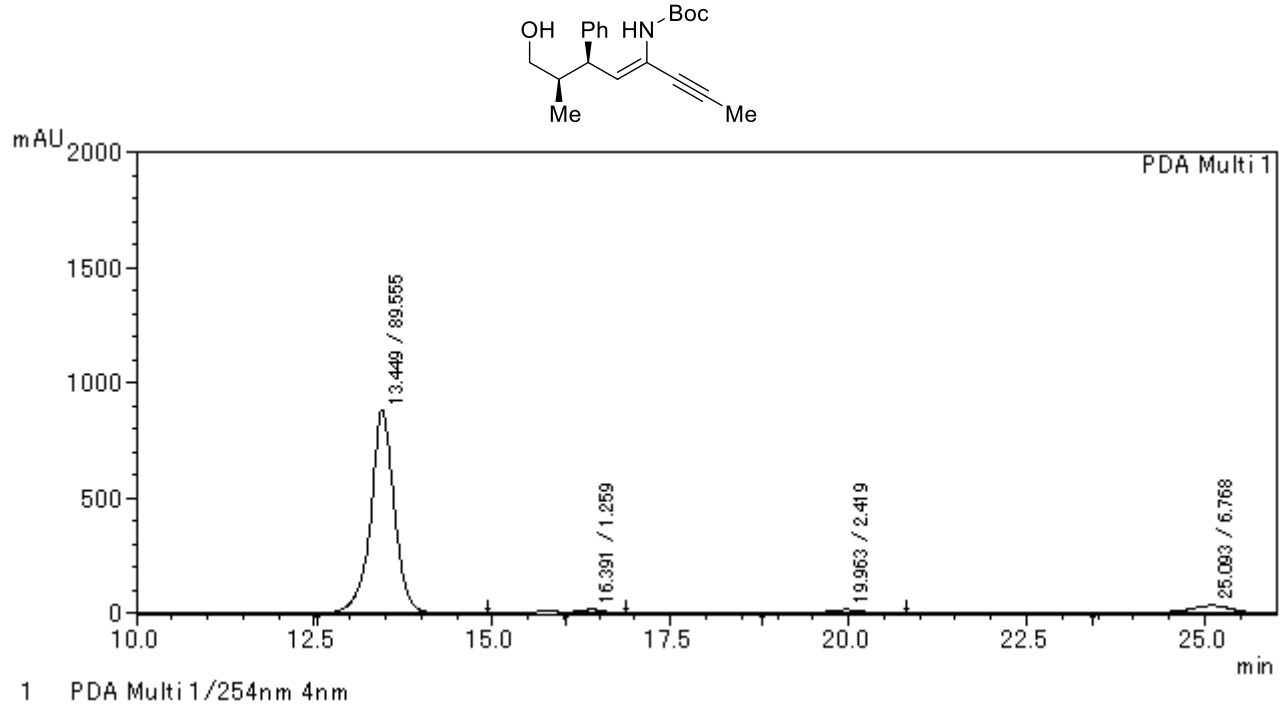
***tert*-Butyl ((5*S*,6*R*,*Z*)-7-hydroxy-6-methyl-5-phenyl-1-(triisopropylsilyl)hept-3-en-1-yn-3-yl)carbamate (2g)**



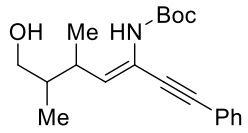


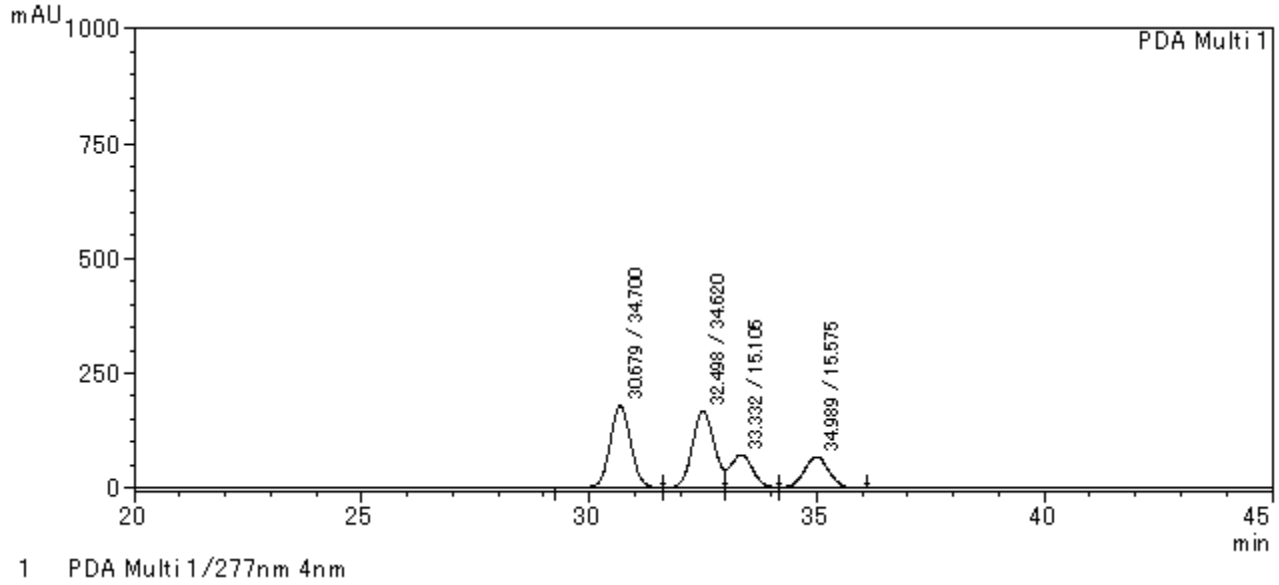
***tert*-Butyl ((6*S*,7*R*,*Z*)-8-hydroxy-7-methyl-6-phenyloct-4-en-2-yn-4-yl)carbamate (2h)**



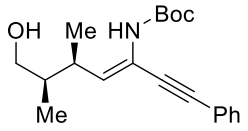


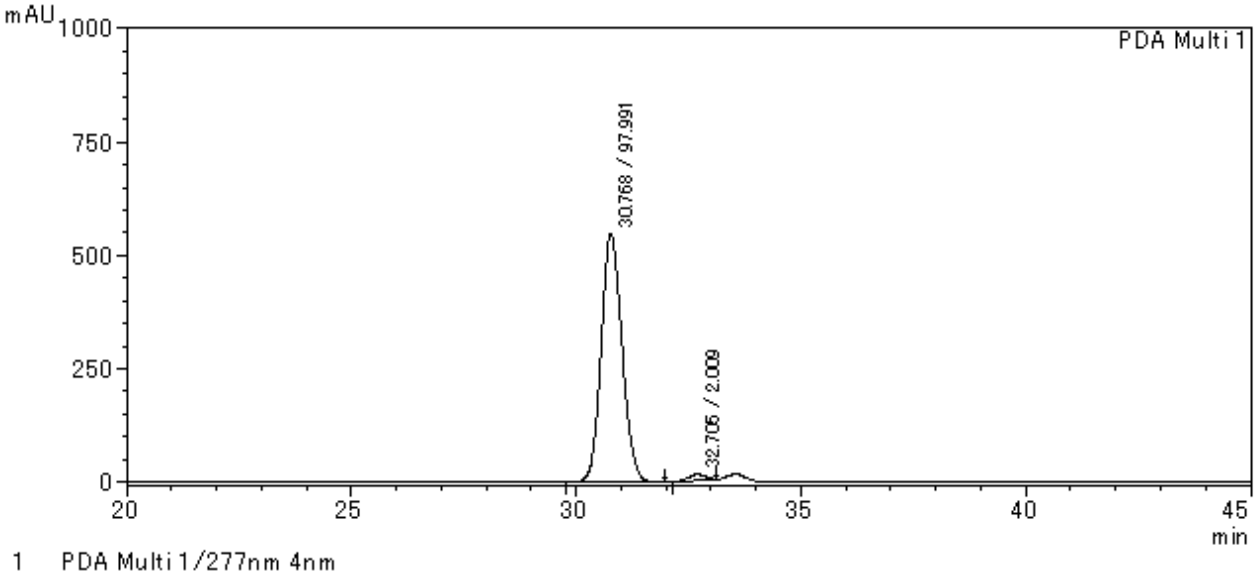
***tert*-Butyl ((5*S*,6*R*,*Z*)-7-hydroxy-5,6-dimethyl-1-phenylhept-3-en-1-yn-3-yl)carbamate (2i)**





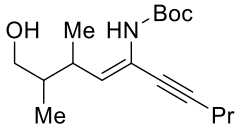
1 PDA Multi 1/277nm 4nm

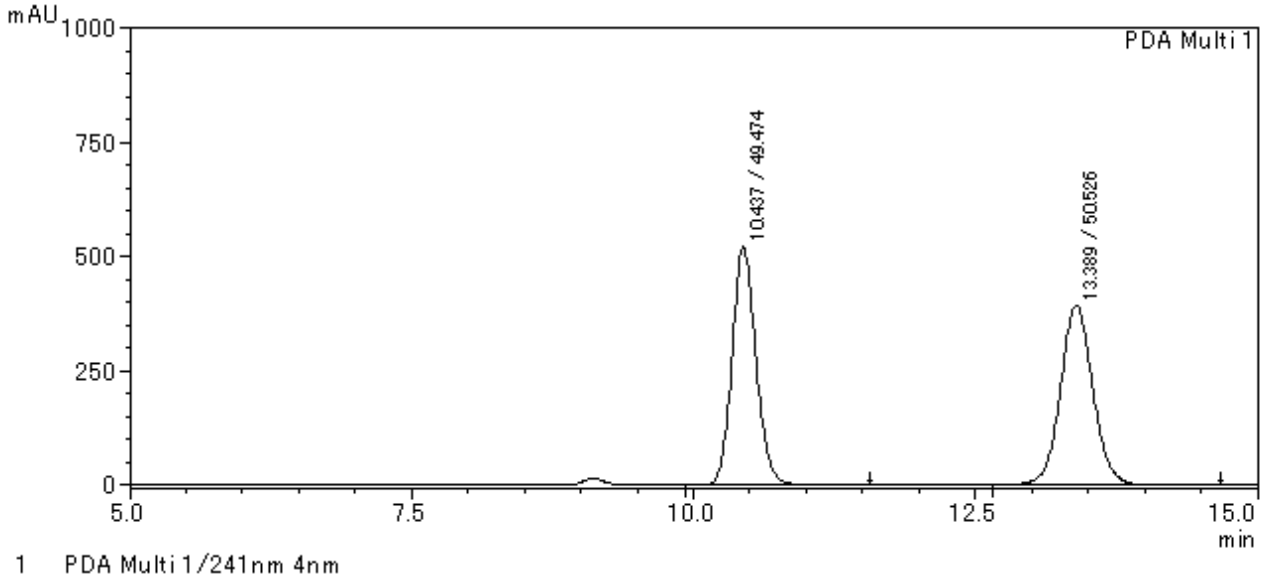




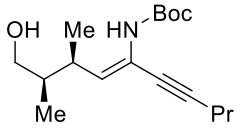
1 PDA Multi 1/277nm 4nm

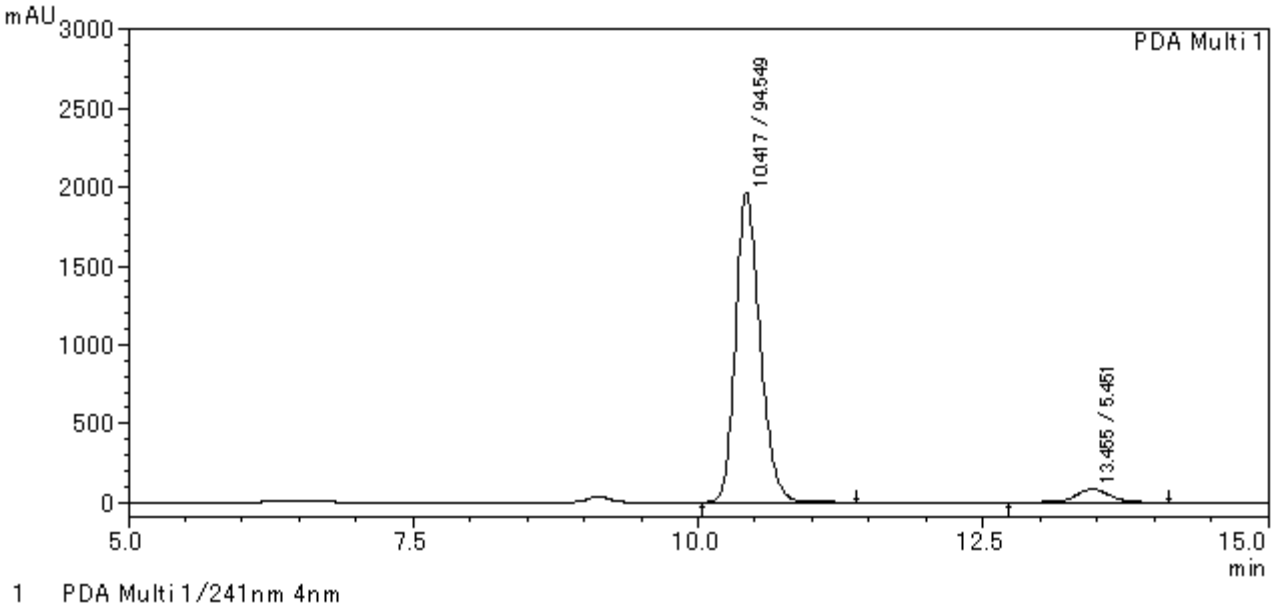
***tert*-Butyl ((2R,3S,Z)-1-hydroxy-2,3-dimethyldec-4-en-6-yn-5-yl)carbamate (2j)**





1 PDA Multi 1/241nm 4nm





1 PDA Multi 1/241nm 4nm