Electronic Supplementary Information for

Highly Active Copper-Catalysts for Azide-Alkyne Cycloaddition

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Content

General Information

Analytical thin-layer chromatography (TLC) was performed on Merck DC precoated TLC plates with 0.25 mm Kieselgel 60 F_{254}. TLC spots were visualized under UV light at 254 nm. Column chromatography was carried out using silica gel 60 (0.040-0.063 mm) from Merck using hexanes – ethyl acetate eluent mixtures. ^{1}H and ^{13}C NMR spectra were recorded on a Bruker DRX-250 spectrometer and on a Varian VNMRS 600 MHz spectrometer equipped with a HCN triple resonance probe head in $CDCl_3$ or d_6-DMSO. ^{31}P shifts were given relative to ortho-Phosphoric acid 85% as an external standard. Chemical shifts (δ) are expressed in parts per million units, relative to the residual solvent peak (δ = 7.26 ppm for ^{1}H, δ = 77.0 ppm for ^{13}C) where possible or alternatively to $SiMe_4$ (δ = 0.00 ppm) as internal standard. Coupling constants (*J*) are given in Hz and multiplicities are designated as s (singlet), d (doublet), t (triplet), q (quartet), sept (septet), m (multiplet) or broad (br). Combination gas chromatography and low resolution mass spectrometry was obtained on an Agilent 6890N gas Chromatograph (30 m x 0.25 mm column with 0.25 μm HP-5MS coating, He carrier gas) and Agilent 5973 Mass Spectrometer (Ion source: EI+, 70 eV, 230 ^{o}C, interface: 300 ^{o}C). High resolution mass spectra were recorded on an Agilent Technologies 6210 Time of Flight Mass Spectrometer. IR spectra were obtained on a Bruker IFS55 spectrometer on a single-reflexion diamond ATR unit. Samples for melting point determination were recrystallyzed from toluene or hexanes. Melting points were determined in capillary tubes with a Büchi apparatus and are uncorrected.

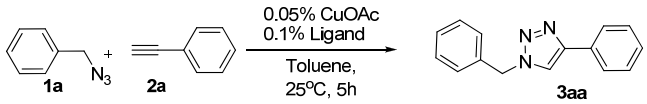
Starting acetylenes are commercially available. Acetylene **2g**[1] and **2h**[2] were prepared using literature procedures. Azides (**1e,f**) were obtained from commercial sources (Aldrich, Fluka) and used without further purification. Compounds **1k**[3] and **1l**[4] were prepared using literature procedures.

Optimization Studies

All optimization studies were performed in screw capped 4 ml glass vials. Solid reactants (Cu-salt, ligands, bases) were measured first, then solvent was added followed by the phenylacetylene (0.25 mmol, 27.5 μl) and benzyl azide (0.25 mmol, 31.1 μl). The reactions were stirred at 25^{o}C, and samples were taken, diluted and analyzed with GC, GC-MS.

Ligand Screening

Solutions of the copper complexes were made in a 10.00mL flask with DCM using 0.025mmol CuOAc and 0.05mmol monodentate or 0.025mmol bidentate ligand. In a 4mL screw capped vial the phenylacetylene (0.5 mmol) and the benzyl azide (0.5 mmol) was dissolved in 200μl DCM, then 50μl solution of the catalyst mixture was added. Samples were taken after 5 hours, diluted with DCM and analyzed by GC.

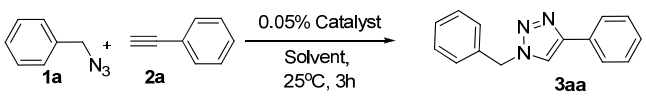


Entry	Phosphane	Conversion [%] [a]
1	Ph_3P[b]	100
2	(4-Fluorophenyl)$_3$P	43
3	(4-Methoxyphenyl)$_3$P	48
4	Cy_3P	64
5	XPhos[c]	0
6	BINAP	38
7	Dppe	68
8	Dppp[d]	100
9	Dppb	10

[a] Conversions were determined by GC. [b] Conversion after 3 hours. [c] 2-Dicyclohexylphosphino-2',4',6'-triisopropylbiphenyl. [d] Conversion after 4 hours.

Solvent effect

In a 4mL screw capped vial the copper(I) complex (0.0001mmol), terminal acetylene (0.25 mmol) and the azide (0.25 mmol) was dissolved in 250 µL solvent. The reactions were stirred at 25°C. Samples were taken after 3 hours, diluted with DCM and analyzed by GC. (In parentheses: conversion with 0.05% copper salt after 3 hours)



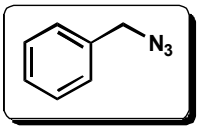
Solvent	1% CuOAc Conversion [%]	1% Cu(I)-butyrate Conversion [%]	0.05% $CuNO_3(PPh_3)_2$ Conversion [%]	0.05% $CuOAc(PPh_3)_2$ Conversion [%]	0.05% $C_3H_7COOCu(PPh_3)_2$ Conversion [%]
THF	8	4	0	0	0
EtOH/water	31	36	0	0	0
Hexane	0	3	12	12	12
MeCN	60	70	14	26	63

Chloroform	86	80	45	61	96
Toluene	45	87	50	83	96
DCE	99	98	32	92	100
DCM	99 (49)	99 (78)	84	100	100

Catalyst Loading

In a 4mL screw capped vial the terminal acetylene (0.25 mmol) and the azide (0.25 mmol) was dissolved in 200 μL DCM. 10.00mL Solution of the catalyst was prepared, dissolving 16.9mg (0.025mmol) of $C_3H_7COOCu(PPh_3)_2$ in DCM. For the reactions 50μL of the catalyst solution was used.

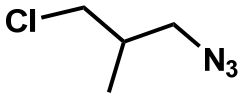
Preparation of azides



Benzyl azide.[5]

In 500 ml round bottomed flask we measured 11.9 ml (100 mmol) benzyl bromide and 400 ml acetone-water mixture (3:1 ratio). During stirring sodium azide (13.0 g, 200 mmol) was added in small portions. The reaction mixture was stirred for 15 min at 25°C. The product was diluted with 400 ml dichloromethane and extracted with water and brine. The organic phase was dried over $MgSO_4$, and then the solvent was evaporated. –the crude product was purified with vacuum distillation (73 °C-on 14 mbar-on). Yield: 11.3g, 84.9 mmol 85% MS (EI, 70eV) m/z (% relative intensity, ion): 133(30, [M^+]), 133(30), 104(60), 91(100), 77(65), 65(20), 51(40).

4-Nitrobenzylazide,[6] **4-iodobenzylazide**[7] and **4-bromobenzylazide**[8] were prepared using the procedure described above. The azides were analyzed with GC-MS and NMR.



2-Azido-1-chloropropane. Sodium azide (923 mg, 0.0142 mol) was added to a solution of 1-bromo-3-chloro-2-methyl-propane (1.17mL, 1.705g, 0.01mol) in DMSO (20 mL). After 20 h of stirring at room temperature, 30 mL of water was added, followed by extraction with diethyl ether (50 mL x 3). The organic phase was washed with H_2O (50 mL x 2) and then dried ($MgSO_4$) and concentrated under reduced pressure to give pure 1-azido-3-chloro-2-methyl-propane (**10a**) as colorless oil (1.123 g, 84 %). ^{1}H NMR (250 MHz, $CDCl_3$): δ = 3.53-3.34 (m, 4H), 2.16-2.01 (m, 1H), 1.05 (d, 3H, *J* = 7.0 Hz) ppm. ^{13}C NMR (62.5 MHz, $CDCl_3$):

δ = 54.1, 47.4, 35.6, 15.5 ppm. MS (EI, 70 eV): *m/z* (%): 137 (5), 133(15). 90 (15). 77 (45), 70(40), 56 (100), 49 (70).

Butyl azide,[9] Ethyl-5-azidopentanoate,[10] and **6-azidohex-1-ene[11]** were prepared using the procedure described above. The azides were analyzed with GC-MS and NMR.

Preparation of Copper-complexes

Copper(I)-acetate.[12] In 50 ml round bottomed flask was flushed with argon, then copper(II)acetate (0,61 g 3,3 mmol) was placed, then abs. MeCN (16 ml) and 4mL acetic acid – aceticacid anhydride (4:1) mixture was added, followed by copper foil (1,53 g, 24,1 mmol). The deep green reaction mixture was stirred until it become colorless (typically 48 hours). The colorless solution was added to 45 ml abs. diethyl ether (previously deoxygenated). The white precipitate was filtered quickly and washed with argon. The product was stored under argon in a dark container.

Bis-triphenylphosphano-copper(I)-acetate.[13] In a 10 mL round bottomed flask copper(I)-acetate (0.123 g, 1.0 mmol) and PPh_3 (1.115 g, 4.25 mmol) in 6 mL toluene were stirred for 30 min at 25°C under argon. The white crystalline product was filtered, washed with ether and dried in vacuum. Mp.: 170-173 °C White crystals. 363 mg (0.940 mmol), yield: 94 %

Copper(II)-butyrate.[14] In a 25 mL round bottomed flask basic copper(II)-carbonate (2.21 g, 10 mmol) was refluxed in butyric acid (8.81 g, 100mmol) for 6 hours. After cooling to room temperature, the deep green crystalline product was filtered and dried under vacuum. 1.581 g (6.65 mmol) yield: 66 %.

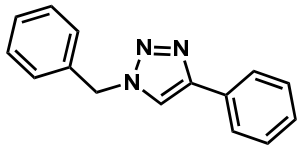
Copper(I)-butyrate.[12] The procedure for the preparation of CuOAc was used. Starting from 0.594 g (2.5 mmol) copper(II)-butyrate, 235 mg (1.55 mmol) Cu(I)-butyrate was obtained as white crystals. Yield: 62 %

Bis-triphenylphosphano-copper(I)-butyrate. In a 10 mL round bottomed flask copper(I)-butyrate (0.117 g, 0.77 mmol) and PPh_3 (0.87 g, 3.32 mmol) in 4 mL toluene were stirred for 30 min at 25°C under argon. The white crystalline product was filtered, washed with ether and dried in vacuum. Mp.: 179-183 °C. White crystals. 332 mg (0.493 mmol), yield: 64 %. ^{1}H NMR (600 MHz, $CDCl_3$): δ = 7.33-7.31 (m, 20H), 7.23-7.20 (m, 15H), 2.20 (t, 2H, *J* = 7.2 Hz), 1.65-1.59 (m, 2H), 0.89 (t, 2H, *J* = 7.2 Hz) ppm. ^{13}C NMR (150 MHz, $CDCl_3$): δ = 181.6, 133.8 (d, *J* = 14.25 Hz), 132.9 (d, *J* = 29.85

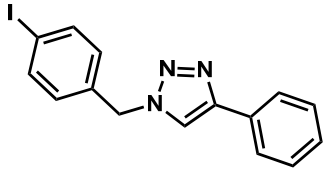
Hz), 129.6, 128.5 (d, J = 7.8 Hz), 39.1, 19.9, 14.2 ppm. ^{31}P (242.85MHz, $CDCl_3$): δ = -2.07 ppm. IR (ATR): 3054, 2949, 1549, 1477, 1430, 1407, 1305, 1180, 1092 cm^{-1}.

Synthesis of Triazoles

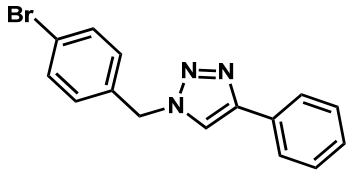
In a 4mL screw capped vial the terminal acetylene (0.5 mmol) and the azide (0.5 mmol) was measured. 10.00mL DCM solution of the catalyst was prepared, dissolving 33.8mg (0.05mmol) of $C_3H_7COOCu(PPh_3)_2$ in the solvent. For the reactions usually 50μL of the catalyst solution was used, and the total volume of the solvent was 300 μL. The reaction was stirred at room temperature (28°C) for the indicated time. Then the solvent was evaporated affording the crude product. The products usually proved to be pure enough, but further purifications such as recrystallyzation of the solids from toluene or silicagel column chromatography afforded purified product.



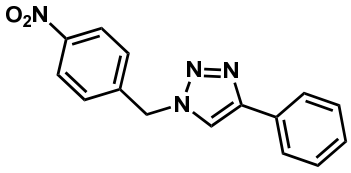
1-Benzyl-4-phenyl-1*H*-1,2,3-triazole.[15] (3aa). 0.05% $C_3H_7COOCu(PPh_3)_2$ was used. White solid. 116mg (0.495mmol), 99% yield, Mp.: 128-129 °C. ^{1}H NMR (250 MHz, $CDCl_3$): δ = 7.82 (d, 2H, J = 6.75 Hz), 7.69 (s, 1H), 7.42 – 7.26 (m, 8H), 5.53 (s, 2H) ppm. ^{13}C NMR (62.5 MHz, $CDCl_3$): δ = 148.0, 134.6, 130.4, 128.9, 128.6, 128.5, 128.0, 127.0, 127.0, 125.5, 119.5 ppm. MS (EI, 70 eV): *m/z* (%): 235 (20, $[M^+]$). 220(70), 205(100), 176(75), 151(20), 102(15), 88(20).



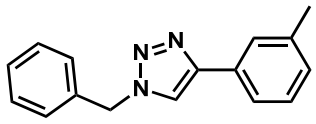
1-(4-iodobenzyl)-4-phenyl-1H-1,2,3-triazole (3ba). 0.1% $C_3H_7COOCu(PPh_3)_2$ was used. White crystals. Yield: 153 mg (0.425 mmol), 85%. Mp.154-156: °C. ^{1}H NMR (250 MHz, d_6-DMSO): δ = 8.63 (s, 1H), 7.86 (d, 2 H, J = 7.5 Hz), 7.77 (d, 2 H, J = 8.25 Hz), 7.43 (t, 2 H, J = 7.25 Hz); 7.37 (d, 1 H, J = 7.25 Hz), 7.17 (d, 2 H, J = 8.25 Hz), 5.62 (s, 2H) ppm. ^{13}C NMR (62.5 MHz, d_6-DMSO): δ = 146.6, 137.5, 135.7, 130.5; 130.1; 128.8; 127.9; 125.1; 121.5; 94.4; 52.4 ppm. IR (ATR): 3082, 2922, 1483, 1442, 1404, 1221, 1077, 1049, 1007 cm^{-1}.MS (EI, 70 eV): *m/z* (%): 361(8, $[M^+]$), 332 (10), 230 (8), 217 (30), 206 (25), 116 (100), 89 (70). HRMS: *m/z* $[M + H]^+$ calcd for $C_{15}H_{13}IN_3$: 362.0149; found: 362.0144.



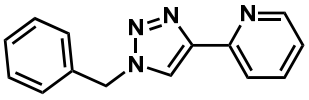
1-(4-bromobenzyl)-4-phenyl-1H-1,2,3-triazole[16] (3ca). 0.1% $C_3H_7COOCu(PPh_3)_2$ was used. White crystals. Yield: 142mg (0.455 mmol), 91%. Mp.: 151-152°C. ^{1}H NMR (250 MHz, d_6-DMSO): δ = 8.65 (s, 1H), 7.87 (d, 2 H, *J* = 7.5 Hz), 7.61 (d, 2 H, *J* = 8.25 Hz), 7.43 (t, 2 H, *J* = 7.25 Hz); 7.35-7.30 (m, 3 H), 5.64 (s, 2H) ppm. ^{13}C NMR (62.5 MHz, $CDCl_3$): δ = 146.5, 135.3, 131.6, 130.5, 130.0, 128.8, 127.8, 125.0, 121.5, 121.3, 52.2 MS (EI, 70 eV): *m/z* (%): 313, 315 (5, [M^+]), 207(10), 169 (10), 171(10), 116 (100), 89 (30).



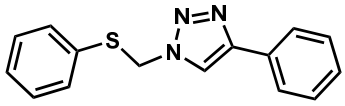
1-(4-nitrobenzyl)-4-phenyl-1H-1,2,3-triazole.[17] (3da). 0.1% $C_3H_7COOCu(PPh_3)_2$ was used. White solid. 122 mg (0.435 mmol), 87% yield, Mp.: 140-142 °C. ^{1}H NMR (250 MHz, d_6-DMSO): δ = 8.70 (s, 1H), 8.26 (d, 2H, *J* = 8.25 Hz), 7.87 (d, 2H, *J* = 7.75 Hz), 7.59 (d, 2H, *J* = 8.5 Hz), 7.44 (t, 2H, *J* = 8.0 Hz), 7.35 (d, 1H), 5.85 (s, 2H) ppm. ^{13}C NMR (62.5 MHz, $CDCl_3$): δ = 147.6, 147.2, 143.7, 130.9, 129.3, 129.3, 128.4, 125.6, 124.3, 122.4, 52.5 ppm. MS (EI, 70 eV): *m/z* (%): 281(8, [M^+]), 281(8), 207(30), 116(100), 106(25), 89(35).



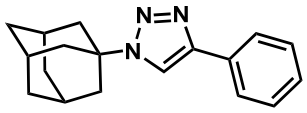
1-benzyl-4-m-tolyl-1H-1,2,3-triazole (3ab). 0.05% $C_3H_7COOCu(PPh_3)_2$ was used. White crystals. 117 mg (0.47 mmol), 94% yield, Mp.: 144-146 °C. ^{1}H NMR (250 MHz, $CDCl_3$): δ = 7.67 (s, 2H), 7.60 (d, 1H, *J* = 7.5 Hz), 7.41-7.26 (m, 6H), 7.15 (d, 1H, *J* = 7,5 Hz), 5.55 (s, 2H), 2.38 (s, 3H) ppm. ^{13}C NMR (62.5 MHz, $CDCl_3$): δ = 138.4, 134.6, 130.3, 129.0, 128.8, 128.6, 128.0, 127.9, 126.3, 122.7, 119.4, 77.5, 77.0, 76.5, 54.0, 21.3 ppm. MS (EI, 70 eV): *m/z* (%): 249(10, [M^+]), 220(25), 130(100), 91(75), 77(15).



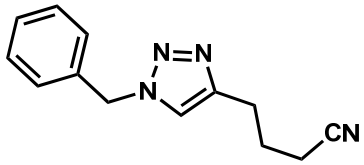
1-Benzyl-4-pyridyl-1*H*-1,2,3-triazole.[18] (3ac). 0.05% $C_3H_7COOCu(PPh_3)_2$ was used. Light brown crystals. 110 mg (0.465 mmol), 93% yield, Mp.: 110-112 °C. ^{1}H NMR (250 MHz, $CDCl_3$): δ = 8.48 (s, 1H), 8.13 (d, 1H, *J* = 8.0 Hz), 8.03 (s, 1H), 7.71 (t, 1H), 7.28 (d, 5H, *J* = 10.5 Hz), 7.15 (t, 1H), 5.51 (s, 2H) ppm. ^{13}C NMR (62.5 MHz, $CDCl_3$): δ = 150.0, 149.1, 148.5, 136.6, 134.2, 128.9, 128.6, 128.0, 122.6, 121.8, 119.9, 54.1 ppm. MS (EI, 70 eV): *m/z* (%): 236 (5, [M^+]), 207(55), 117(50), 91(95), 65(20).



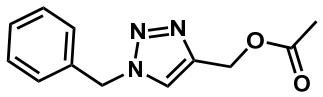
4-Phenyl-1-((phenylthio)methyl)-1*H*-1,2,3-triazole (3ea). 0.1% $C_3H_7COOCu(PPh_3)_2$ was used. White crystals. 128 mg (0.48 mmol), 96% yield, Mp.: 89-91 °C. R_f = 0.42 (hexanes−ethyl acetate, 3:1). ^{1}H NMR (250 MHz, $CDCl_3$): δ = 7.81-7.78 (m, 3 H), 7.44-7.30 (m, 8 H), 5.62 (s, 2 H). ^{13}C NMR (62.5 MHz, $CDCl_3$): δ = 147.9, 132.0, 131.7, 130.1, 129.3, 128.7, 128.5, 128.1, 125.5, 119.0, 53.7. IR(ATR): ν_{max} 3121, 3060, 2101, 1481, 1439, 1191, 1076, 740, 690 cm^{-1}. MS (EI, 70 eV): *m/z* (%): 267 (8) [M^+], 238 (35), 130 (100), 123 (18), 116 (15), 109 (29), 103 (69), 77 (55), 65 (18). HRMS: *m/z* $[M + H]^+$ calcd for $C_{15}H_{14}N_3S$: 268.0903 ; found: 268.0901.



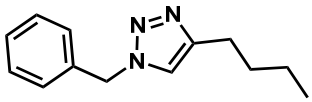
1-(1-Adamantyl)-4-phenyl-1*H*-1,2,3-triazole[19] (3fa). 0.15% $C_3H_7COOCu(PPh_3)_2$ was used. White solid. 128 mg (0.46 mmol), 92% yield. Mp.: 203-204 °C (dec). R_f = 0.57 (hexanes−ethyl acetate, 3:1). ^{1}H NMR (250 MHz, $CDCl_3$): δ = 7.75-7.79 (m, 3 H), 7.19-7.36 (m, 3 H), 2.21 (br s, 9 H), 1.73 (br s, 6 H). ^{13}C NMR (62.5 MHz, $CDCl_3$): δ = 146.7, 131.1, 128.7, 127.8, 125.6, 116.0, 59.5, 43.0, 35.9, 29.4. MS (EI, 70 eV): *m/z* (%): 279 (9) [M^+], 223 (12), 181 (8), 135 (100), 116 (20), 102 (15), 93 (31), 79 (36), 67 (12).



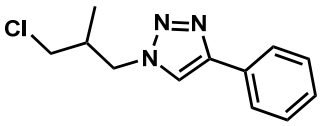
4-(1-benzyl-1H-1,2,3-triazol-4-yl)butanenitrile (3ad). 0.1% $C_3H_7COOCu(PPh_3)_2$ was used. White solid. 110 mg (0.49 mmol), 98% yield. ^{1}H NMR (250 MHz, $CDCl_3$): δ = 7.313-7.29 (m, 3 H), 7.21-7.18(m, 3 H), 5.43 (s, 2H), 2.77 (t, 2H, *J* = 7.0 Hz), 2.34 (t, 2 H, *J* = 7.25 Hz), 1.99 (t, 2H, *J* = 7.0 Hz). ^{13}C NMR (62.5 MHz, $CDCl_3$): δ = 134.6, 129.1, 128.7, 128.0, 119.3, 54.1, 24.4, 24.2, 16.4. IR (ATR): 3113, 3065, 2940, 2247, 1556, 1497, 1448, 1311, 1214, 1175, 1129, 1057, 858 cm^{-1}. MS (EI, 70 eV): *m/z* (%): 226 (5, [M$^+$]), 187 (9), 144 (8), 130 (8), 104 (8), 91 (100), 65 (15). HRMS: *m/z* [M + H]$^+$ calcd for $C_{13}H_{15}N_4$: 227.1291 ; found: 227.1295



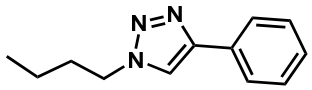
(1-benzyl-1H-1,2,3-triazol-4-yl)methyl acetate (3ae). 0.05% $C_3H_7COOCu(PPh_3)_2$ was used. Yellow oil. Yield: 114 mg (0.495 mmol), 99%. ^{1}H NMR (250 MHz, $CDCl_3$): δ = 7.53 (s, 1H), 7.32-7.21 (m, 5H), 5.46 (s, 2H), 5.11 (s, 2H), 1.98 (s, 3H) ppm. ^{13}C NMR (62.5 MHz, $CDCl_3$): δ = 170.6, 142.9, 134.2, 128.9, 128.6, 127.9, 123.5, 57.3 53.9, 20.6 ppm. IR (ATR): 3127, 1731, 1496, 1445, 1388, 1368, 1330, 1258, 1216, 1125, 1033, 995 cm^{-1}. MS (EI, 70 eV): *m/z* (%):231(1, [M$^+$]), 188(10), 161(10), 91(100), 65(10). HRMS: *m/z* [M + H]$^+$ calcd for $C_{12}H_{14}N_3O_2$: 232.1081; found: 232.1080.



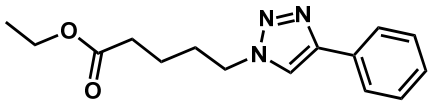
1-benzyl-4-butyl-1H-1,2,3-triazole[20] (3af). 0.15% $C_3H_7COOCu(PPh_3)_2$ was used. White crystals. 100 mg (0.433 mmol), 93% yield, Mp.: 55-56 ^{o}C. ^{1}H NMR (250 MHz, $CDCl_3$): δ = 7.32 (m, 3H), 7.29 (m, 3H), 5.44 (s, 2H), 2.65 (t, 2H, *J* = 7.5 Hz), 1.65-1.56 (m, 2H), 1.39-1.27 (m, 2H), 0.87 (t, 3H, *J* = 7.25 Hz) ppm. ^{13}C NMR (62.5 MHz, $CDCl_3$): δ = 134.9, 128.8, 128.3, 128.0, 127.7, 120.4, 53.7, 31.3, 25.2, 22.1, 13.6 ppm. MS (EI, 70 eV): *m/z* (%): 215(0, [M$^+$]), 173(15), 104(10), 91(100), 65(25).



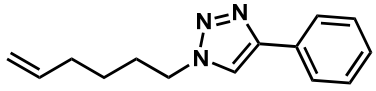
1-(3-Chloro-2-methylpropyl)-4-phenyl-1*H*-1,2,3-triazole (3ga). 0.05% $C_3H_7COOCu(PPh_3)_2$ was used. White crystals. 99 mg (0.45 mmol), 90% yield, Mp.: 51-55 °C. ^{1}H NMR (250 MHz, $CDCl_3$): δ = 7.75-7.72 (m, 3H), 7.34-719 (m, 3H), 4.34-4.19 (m, 2H), 3.35 (d, 2H, *J* = 5.0), 2.48-2.41 (m, 1H), 0.98 (2, 3H, *J* = 6.8) ppm. ^{13}C NMR (62.5 MHz, $CDCl_3$): δ = 147.4, 130.3, 128.7, 128.0, 125.5, 120.4, 52.3, 47.2, 36.0, 15.3 ppm. IR (ATR): 3121, 2975, 1483, 1464, 1436, 1277, 1222, 1079, 1042 cm^{-1}. MS (EI, 70 eV): *m/z* (%): 235 (9) [M^+], 172 (13), 158 (6), 145 (6), 130 (47), 117 (100), 103 (41), 89 (31), 77 (24), 63 (21), 55 (25). HRMS: *m/z* $[M + H]^+$ calcd for $C_{12}H_{15}ClN_3$: 236.0949; found: 236.0951.



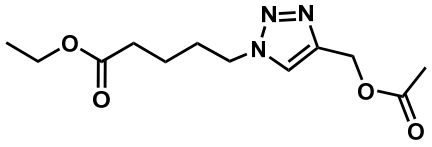
1-butyl-4-phenyl-1H-1,2,3-triazole[21] (3ha). 0.05% $C_3H_7COOCu(PPh_3)_2$ was used. White crystals. 94 mg (0.47 mmol), 94% yield, Mp.: 46-47 °C. ^{1}H NMR (250 MHz, $CDCl_3$): δ = 7.74 (d, 2H, *J* = 7.0 Hz), 7.67 (s, 1H), 7.32-7.17 (m, 3H), 4.26 (t, 2H, *J* = 7.0 Hz), 1.83-1.71 (m, 2H), 1.31-1.16 (m, 2H), 0.85 (t, 3H, *J* = 7.0 Hz) ppm. ^{13}C NMR (62.5 MHz, $CDCl_3$): δ = 147.4, 130.6, 128.6, 127.8, 125.4, 119.4, 49.8, 32.0, 19.4, 13.2 ppm. MS (EI, 70 eV): *m/z* (%): 201(10, [M^+]), 172(10), 130(20), 117(100), 103(20), 89(25).



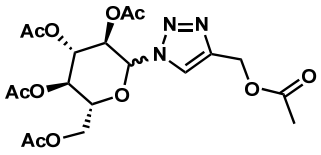
Ethyl-5-(4-phenyl-1*H*-1,2,3-triazol-1-yl)-pentanoate (3ia). 0.05% $C_3H_7COOCu(PPh_3)_2$ was used. White crystals. 131 mg (0.48 mmol), 96% yield, Mp.: 52-53 °C. R_f = 0.61 (hexanes−ethyl acetate, 1:1). ^{1}H NMR (MHz, $CDCl_3$): δ = 7.79 (m, 3H), 7.38-7.23 (m, 3H), 4.35 (t, 2H, *J* = 7.0 Hz), 4.10-4.01 (m, 2H), 2.31 (t, 2H, *J* = 7.25 Hz) 1.97-1.85 (m, 2H), 1.66-1.54 (m, 2H), 1.21 (t, 3H, *J* = 7.25 Hz) ppm. ^{13}C NMR (62.5 MHz, $CDCl_3$): δ = 172.7, 147.4, 130.4, 128.6, 127.8, 125.4, 119.5, 60.2, 49.7, 33.1, 29.3, 21.5, 13.9 ppm. IR (ATR): 3122, 2933, 1729, 1463, 1378, 1331, 1254, 1186 cm^{-1}. MS (EI, 70 eV): *m/z* (%): 273(15, [M^+]), 273(15), 200(50), 129(60), 116(65), 83(70), 55(100). HRMS: *m/z* $[M + H]^+$ calcd for $C_{15}H_{20}N_3O_2$: 274.1550; found: 274.1549.



1-(hex-5-enyl)-4-phenyl-1H-1,2,3-triazole (3ja). 0.05% $C_3H_7COOCu(PPh_3)_2$ was used. White crystals. 103 mg (0.455 mmol), 91% yield. Mp.: 47-48 ^oC. ^1H NMR (250 MHz, $CDCl_3$): δ = 7.83 (d, 2H, *J* = 8.0 Hz), 7.77 (s, 1H), 7.42-7.26 (m, 3H), 5.81-5.65 (m, 1H), 5.02-4.93 (m, 2H), 4.36 (t, 2H, *J* = 7.0 Hz), 2.10-2.02 (m, 2H), 1.96-1.84 (m, 2H), 1.46-1.34 (m, 2H) ppm. ^{13}C NMR (62.5 MHz, $CDCl_3$): δ = 147.4, 137.5, 130.5, 128.6, 127.8, 125.4, 119.4, 115.0, 49.9, 32.7, 29.4, 25.4 ppm. IR(ATR): ν_{max} 3121, 3082, 2931, 2860, 1642, 1463, 1217, 1078, 911, 761, 693 cm^{-1}. MS (EI, 70 eV): *m/z* (%): 227(15, $[M^+]$), 227(15), 198(20), 117(100), 102(35), 89(45), 55(70). HRMS: *m/z* $[M + H]^+$ calcd for $C_{14}H_{18}N_3$: 228.1495; found: 228.1491.

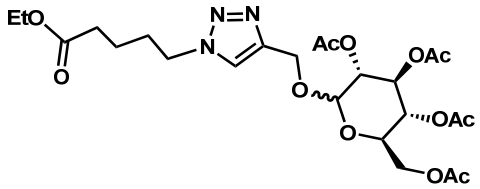


Ethyl 5-(4-(acetoxymethyl)-1H-1,2,3-triazol-1-yl)pentanoate (3ie). 0.05% $C_3H_7COOCu(PPh_3)_2$ was used. Colorless oil, yield: 122 mg (0.456 mmol, 91%). ^1H NMR (250 MHz, $CDCl_3$): δ = 7.61 (s, 1H), 5.12 (s, 1H), 4.32 (t, 2H, *J* = 6.75 Hz), 4.085 (q, 2H, *J* = 7.0 Hz), 2.28 (t, 2H, *J* = 7.25 Hz), 1.99 (s, 3H), 1.96-1.84 (m, 2H), 1.64-1.52 (m, 2H), 1.17 (t, 3H, *J* = 7.25 Hz) ppm. ^{13}C NMR (62.5 MHz, $CDCl_3$): δ = 172.6, 170.5, 142.5, 123.4, 60.1, 57.3, 49.6, 33.1, 29.2, 21.5, 20.5, 13.9 ppm. IR(ATR): ν_{max} 2951, 1732, 1460, 1368, 1218, 961, 599 cm^{-1}. MS (EI, 70 eV): *m/z* (%): 269 (7, $[M^+]$), 226 (25), 199 (25), 154 (25), 108 (40), 101 (80), 84 (100). HRMS: *m/z* $[M + H]^+$ calcd for $C_{12}H_{20}N_3O_4$: 270.1448; found: 270.1451.

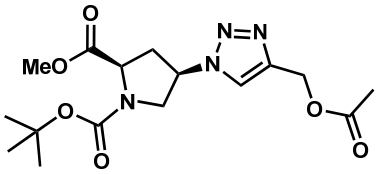


(2R,3R,4S,5R)-2-(acetoxymethyl)-6-(4-(acetoxymethyl)-1H-1,2,3-triazol-1-yl)tetrahydro-2H-pyran-3,4,5-triyl triacetate (3ke) 0.15% $C_3H_7COOCu(PPh_3)_2$ was used. Colorless oil, yield: 118 mg (0.25 mmol, 83 %). IR(ATR): ν_{max} 2943, 2346, 1739, 1434, 1368, 1212, 1098, 1031, 925, 598 cm^{-1}. ^1H NMR (250 MHz, $CDCl_3$): δ = 7.84 (s, 1H), 5.90 (dd, 1H, *J* = 2.5 Hz, *J* = 6.5 Hz), 5.41 (dd, 2H, *J* = 2.5 Hz, *J* = 6.5 Hz), 5.24-5.19 (m, 1H), 5.16 (s, 2H), 4.30 (dd, 1H, *J* = 4.75 Hz, *J* = 12.75 Hz), 4.13 (dd, 1H, *J* = 1.5 Hz, *J* = 12.25 Hz), 4.03-3.98 (m, 1H), 2.03 (s, 6H), 2.01 (s, 3H), 1.98 (s, 3H), 1.82 (s, 3H) ppm.

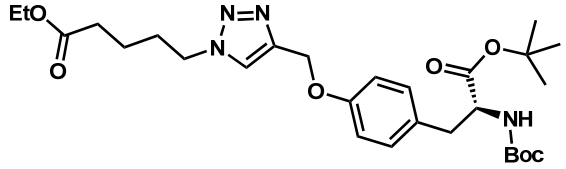
^{13}C NMR (62.5 MHz, $CDCl_3$): δ = 170.6, 170.3, 169.7, 169.2, 168.7, 143.5, 122.1, 85.6, 75.0, 72.5, 70.2, 67.5, 61.4, 57.2, 20.6, 20.5, 20.4, 20.3, 20.0 ppm. HRMS: *m/z* $[M + H]^+$ calcd for $C_{19}H_{26}N_3O_{11}$: 472.1562; found: 472.1563.



((2R,3R,4S,5R)-2-(acetoxymethyl)-6-((1-(5-ethoxy-5-oxopentyl)-1H-1,2,3-triazol-4-yl)methoxy)tetrahydro-2H-pyran-3,4,5-triyl triacetate (3ig). 0.15% $C_3H_7COOCu(PPh_3)_2$ was used. White solid, yield: 63 mg (0.113 mmol, 87%). Mp.: 148-150 ^oC. ^{1}H NMR (250 MHz, $CDCl_3$): δ = 7.47 (s, 1H), 5.17-4.73 (m, 4H), 4.63 (d, 1H, *J* = 8.0 Hz), 4.31 (t, 2H, *J* = 7.0 Hz), 4.193-4.02 (m, 4H), 3.71-3.65 (m, 1H), 2.29 (t, 2H, *J* = 7.0 Hz), 2.03 (s, 3H), 1.99-1.87 (m, 9H), 1.75-1.56 (m, 2H), 1.18 (t, 3H, *J* = 7.5 Hz) ppm. ^{13}C NMR (62.5 MHz, $CDCl_3$): δ = 172.8, 170.6, 170.2, 169.4, 169.3, 137.6, 126.1, 99.9, 72.7, 71.9, 71.2, 62.9, 61.8, 60.4, 49.9, 33.3, 29.6, 21.7, 20.7, 20.6, 20.5, 14.2 ppm. IR(ATR): ν_{max} 2944, 2346, 1738, 1437, 1368, 1213, 1033, 905, 599 cm^{-1}. HRMS: *m/z* $[M + H]^+$ calcd for $C_{24}H_{36}N_3O_{12}$: 558.2294; found: 558.2294.



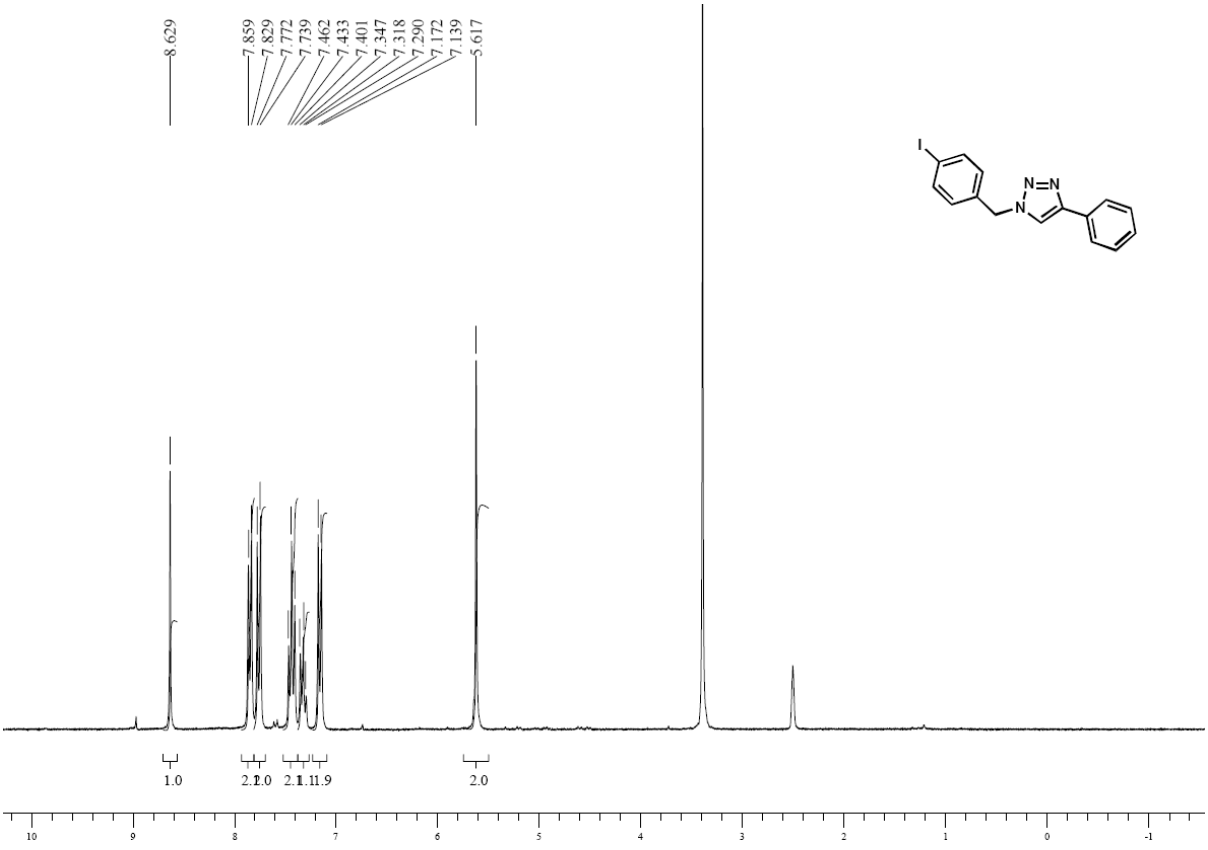
(2R,4R)-1-tert-butyl 2-methyl 4-(4-(acetoxymethyl)-1H-1,2,3-triazol-1-yl)pyrrolidine-1,2-dicarboxylate (3le). 0.15% $C_3H_7COOCu(PPh_3)_2$ was used. Colorless oil, yield: 58 mg (0.157 mmol, 85 %). ^{1}H NMR (250 MHz, $CDCl_3$): δ = 7.70(s, 1H), 5.13 (s, 3H), 4.43-4.34 (m, 1H), 4.14-4.07 (m, 1H), 3.83-3.76 (m, 1H), 3.65 (s, 3H), 2.94-2.82 (m, 1H), 2.61-2.49 (m ,1H), 2.01 (s, 3H), 1.40-1.36 (m, 9H) ppm. ^{13}C NMR (62.5 MHz, $CDCl_3$): δ = 171.9, 170.7, 143.1, 122.5, 81.0, 57.4, 52.3, 51.1, 51.0, 36.1, 28.1, 28.0, 20.7 ppm. IR(ATR): ν_{max} 2976, 1741, 1697, 1394, 1366, 1220, 1156, 1116, 1029, 769 cm^{-1}. HRMS: *m/z* $[M + H]^+$ calcd for $C_{16}H_{25}N_4O_6$: 369.1769; found: 369.1774.

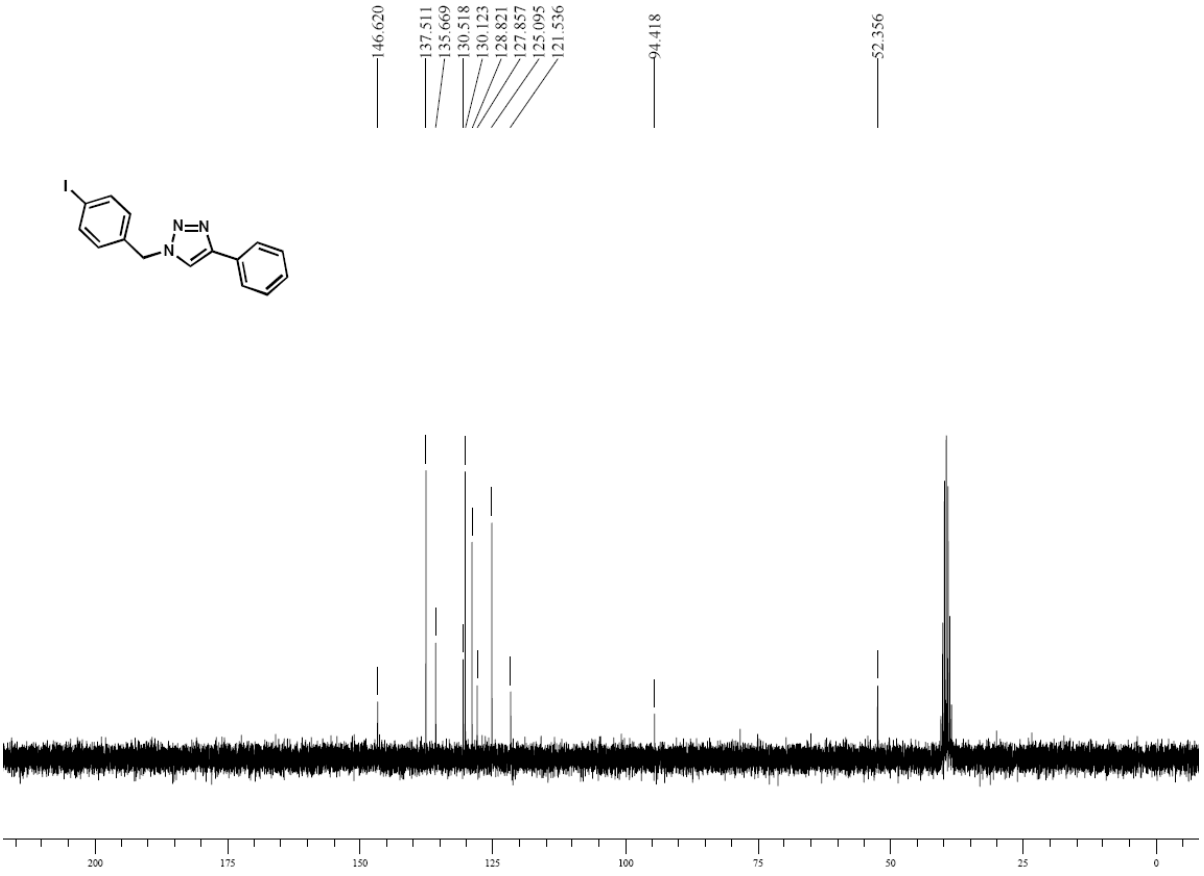


Ethyl 5-(4-((4-(3-tert-butoxy-2-(tert-butoxycarbonylamino)-3-oxopropyl)phenoxy)methyl)-1H-1,2,3-triazol-1-yl)pentanoate (3ih). 0.05% $C_3H_7COOCu(PPh_3)_2$ was used. Colorless oil, yield: 71 mg (0.13 mmol, 96 %). ^{1}H NMR (250 MHz, $CDCl_3$): δ = 7.60 (s, 1H), 7.09 (d, 2H, *J* = 8.5 Hz), 6.91 (d, 2H, *J* = 8.25 Hz), 5.17 (s, 2H), 4.99 (d, 1H, *J* = 8.25 Hz), 4.37 (t, 2H, *J* = 7.25 Hz), 4.16 (q, 2H, *J* = 6.75 Hz), 2.99 (d, 2H, *J* = 5.75 Hz), 2.34 (t, 2H, *J* = 6.75 Hz), 2.02-1.9 (m, 2H), 1.75-1.60 (m, 3H), 1.41 (s, 9H), 1.40 (s, 9H), 1.24 (t, 3H, *J* = 7.0 Hz) ppm. ^{13}C NMR (62.5 MHz, $CDCl_3$): δ = 180.4, 172.8, 170.8, 157.1, 155.0, 130.5, 128.9, 122.5, 114.6, 81.8, 79.5, 62.0, 60.3, 54.9, 49.9, 37.5, 33.3, 29.5, 28.2, 27.9, 21.7, 14.1 ppm. IR(ATR): ν_{max} 3369, 2977, 1711, 1510, 1365, 1242, 1150, 1048, 843 cm^{-1}. HRMS: *m/z* [M + H]$^+$ calcd for $C_{28}H_{43}N_4O_7$: 547.3126; found: 547.3122.

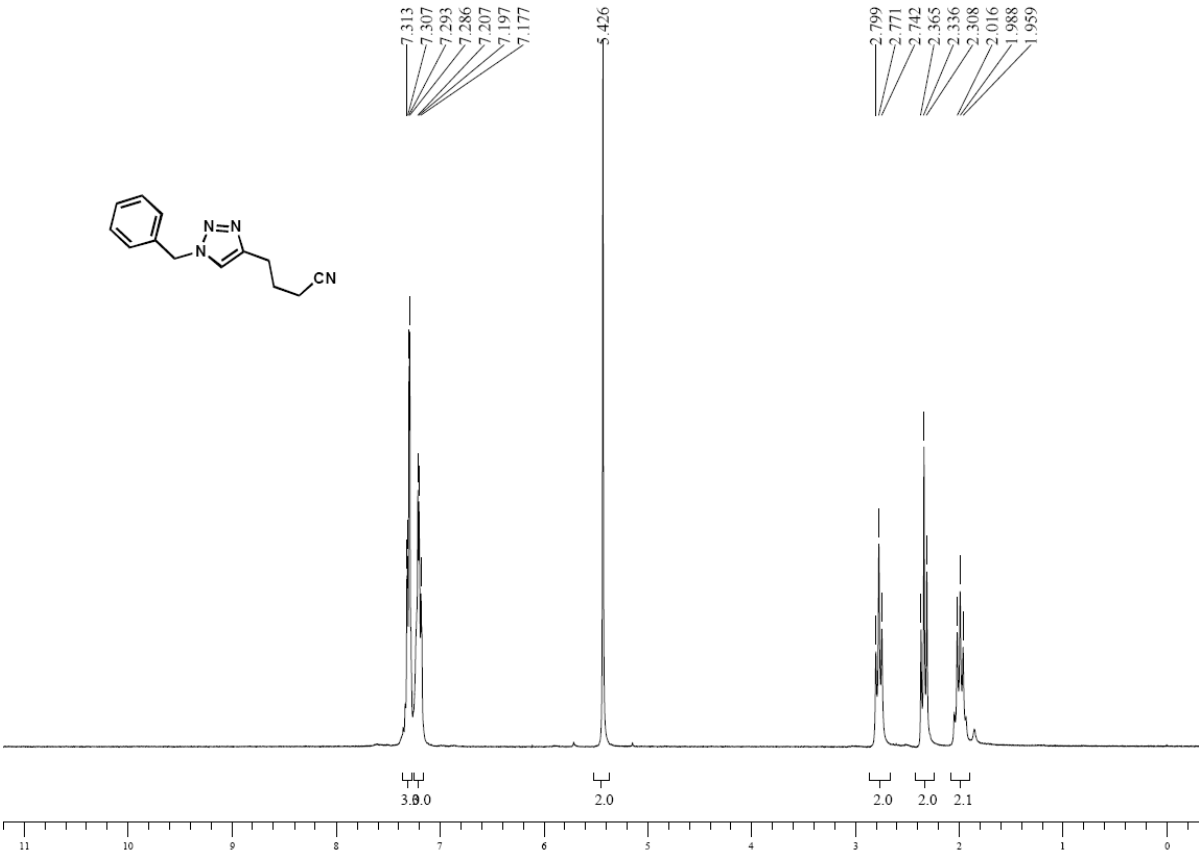
NMR Spectra of new triazole products

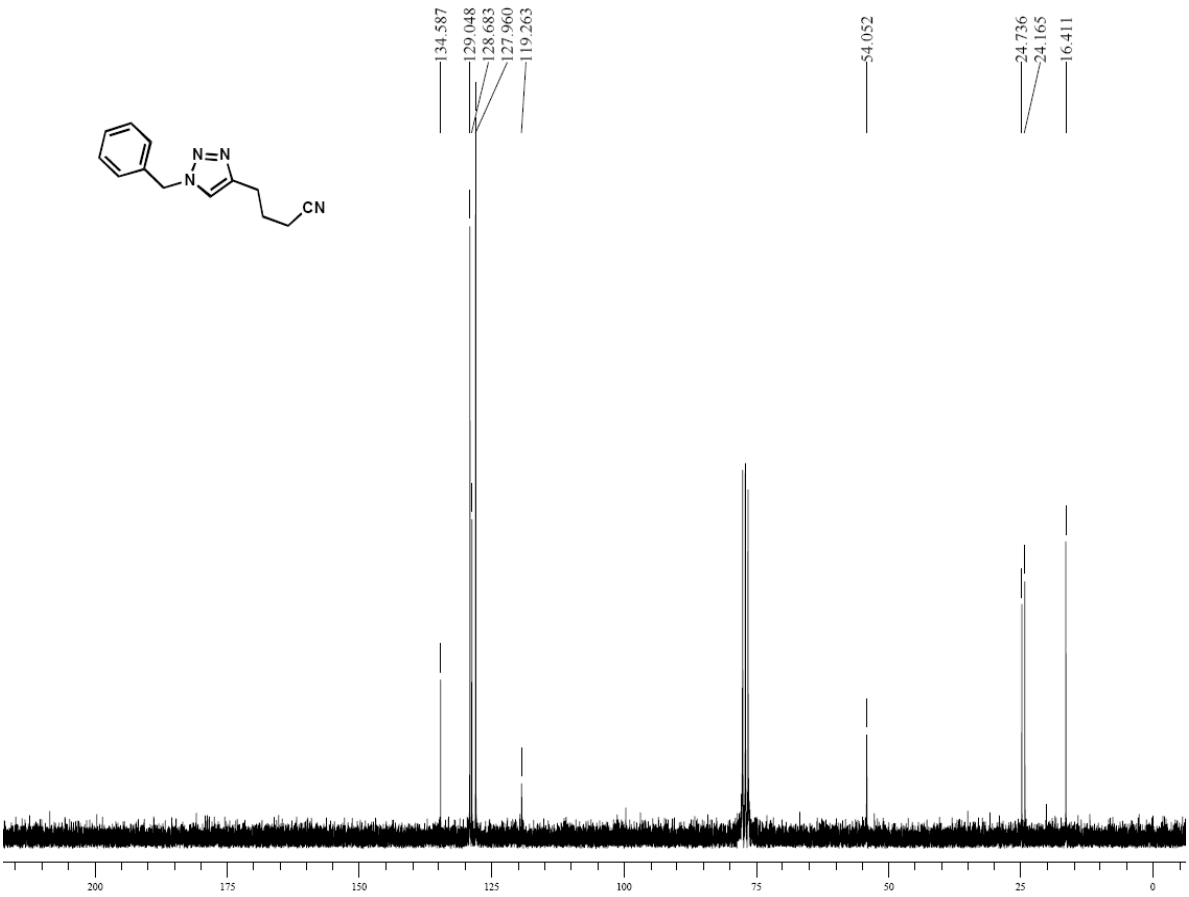
1-(4-iodobenzyl)-4-phenyl-1H-1,2,3-triazole (3ba).



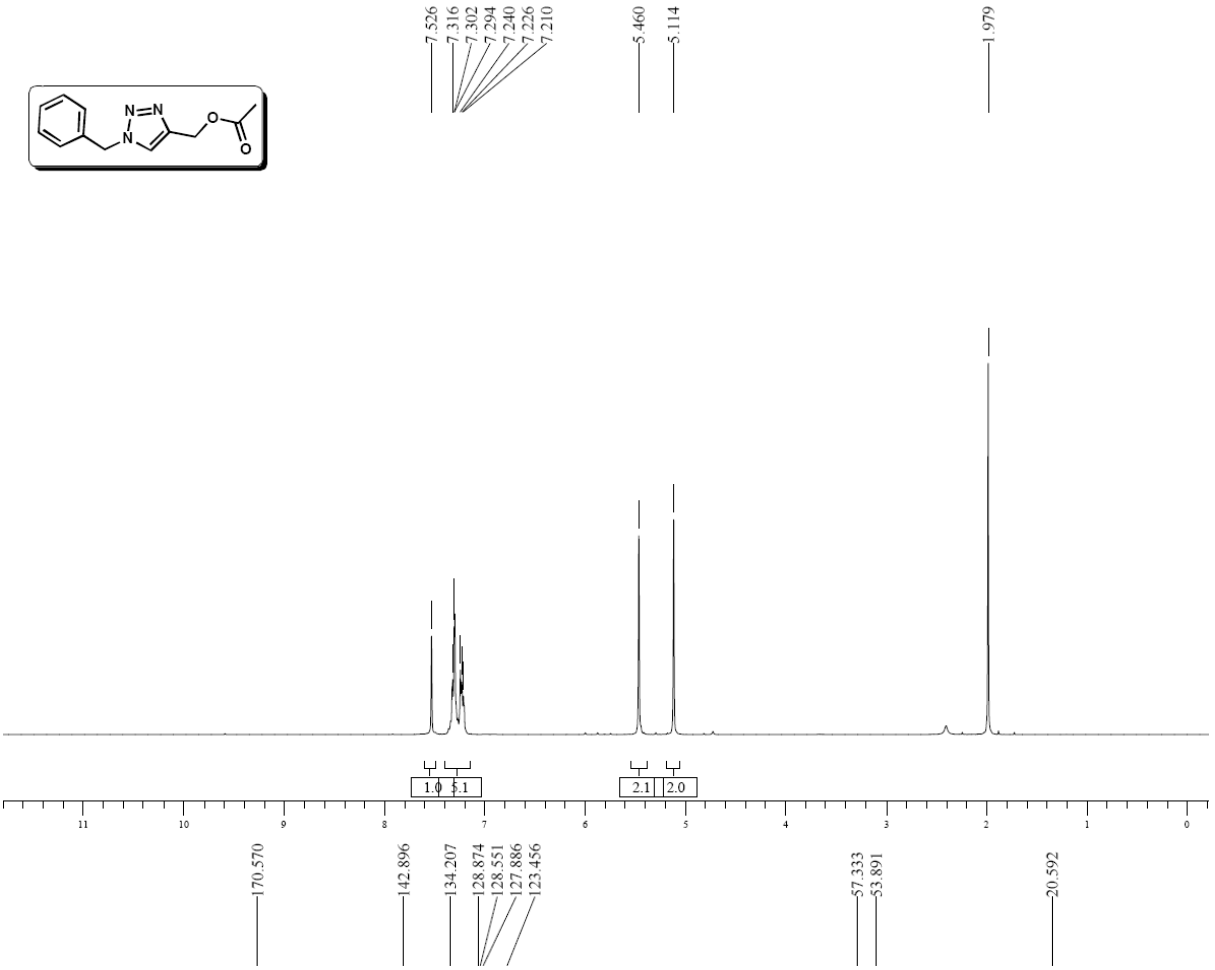


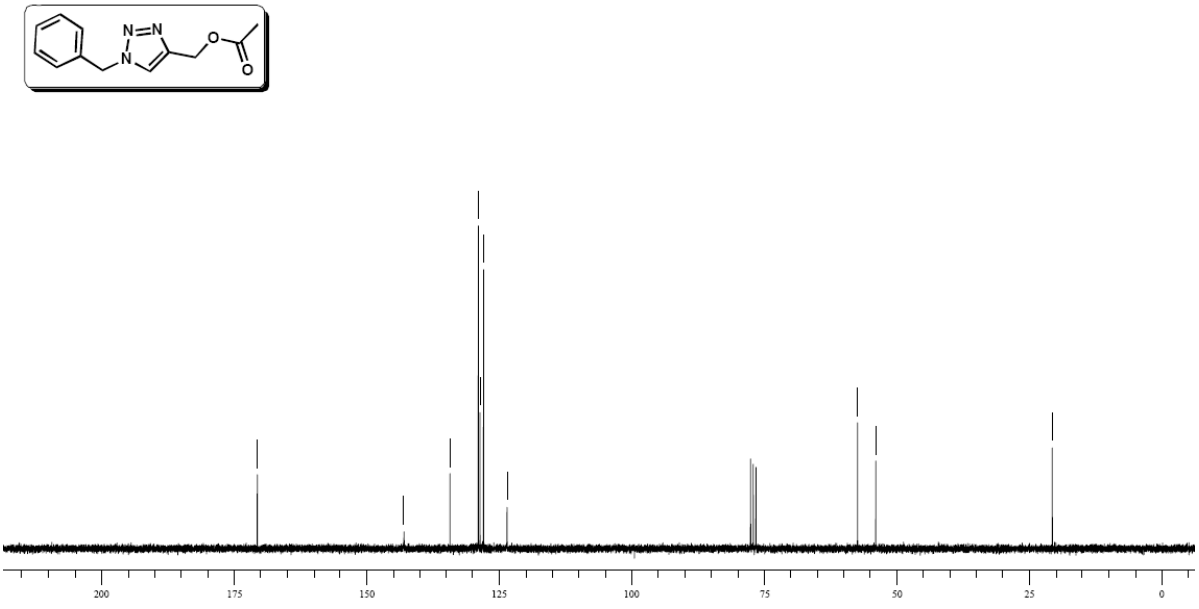
4-(1-benzyl-1H-1,2,3-triazol-4-yl)butanenitrile (3ad).



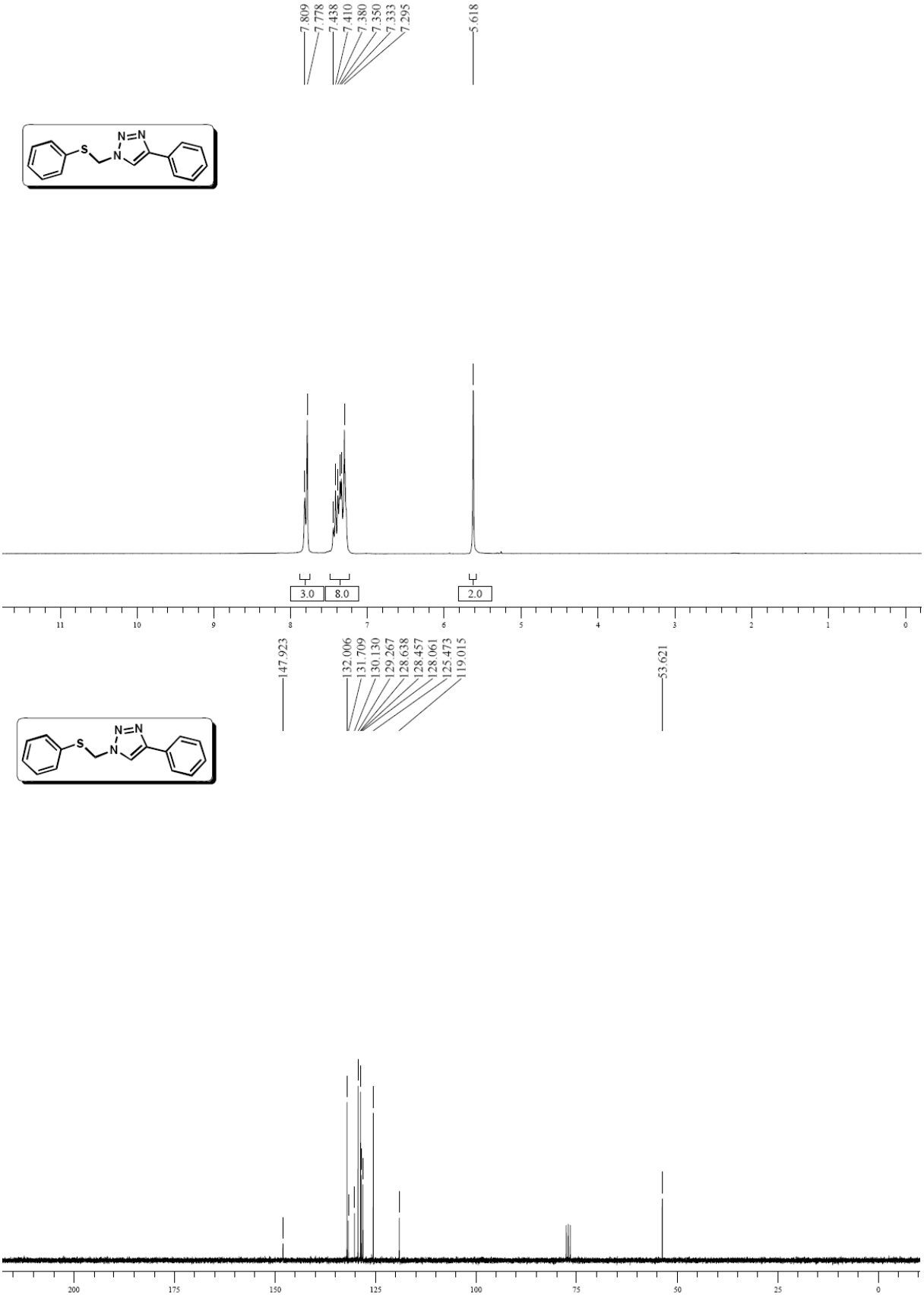


(1-benzyl-1H-1,2,3-triazol-4-yl)methyl acetate (3ae).

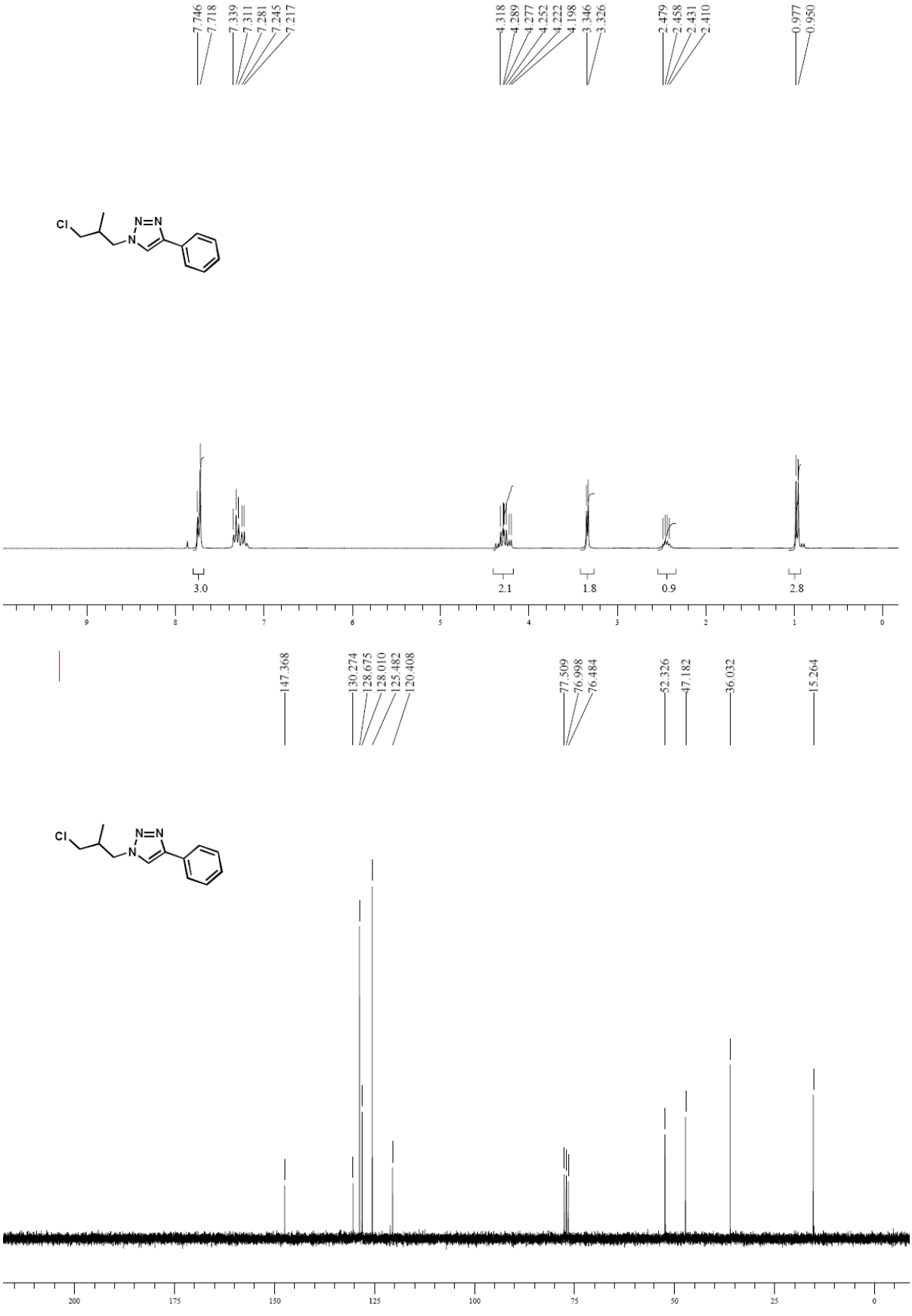




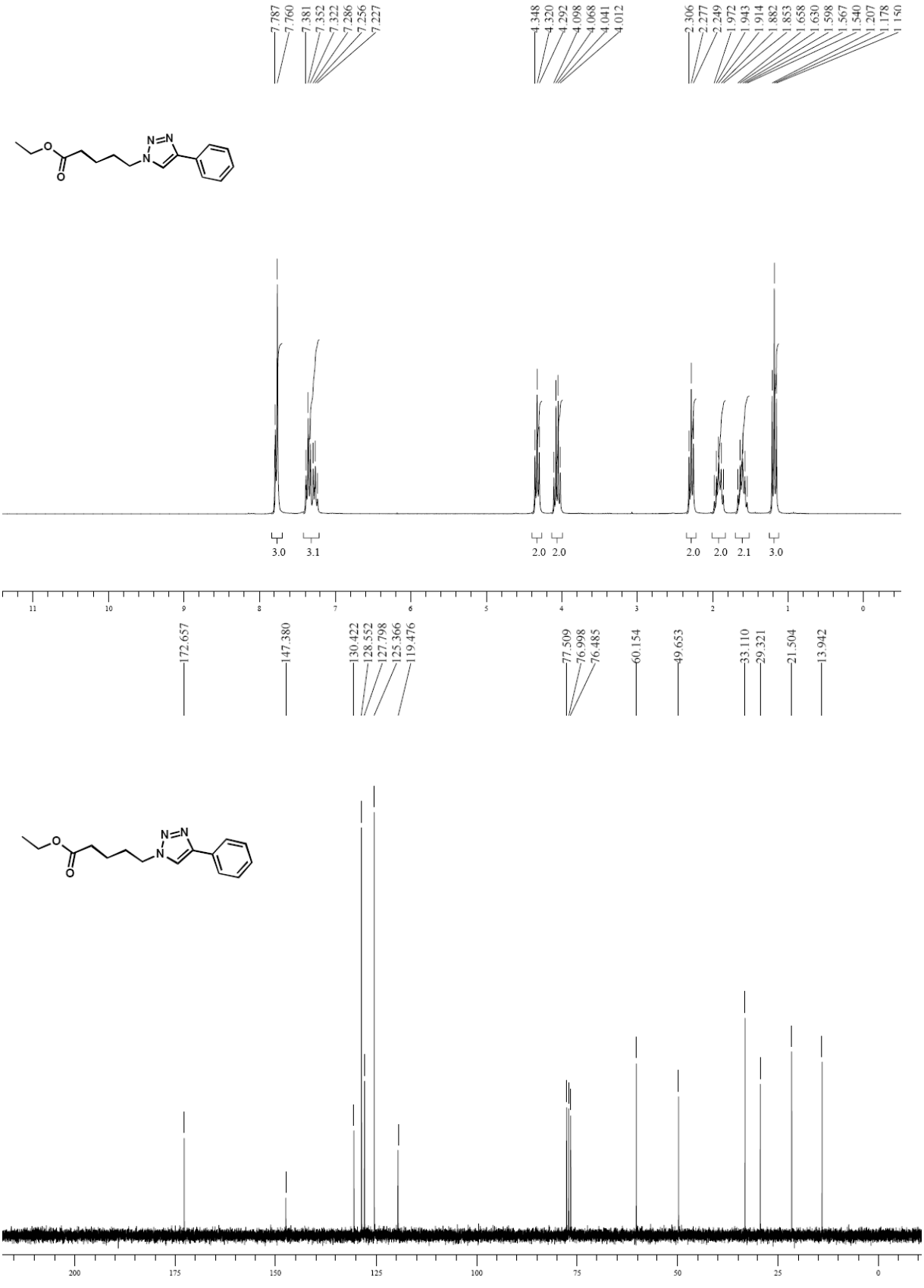
4-Phenyl-1-((phenylthio)methyl)-1*H*-1,2,3-triazole (3ea).



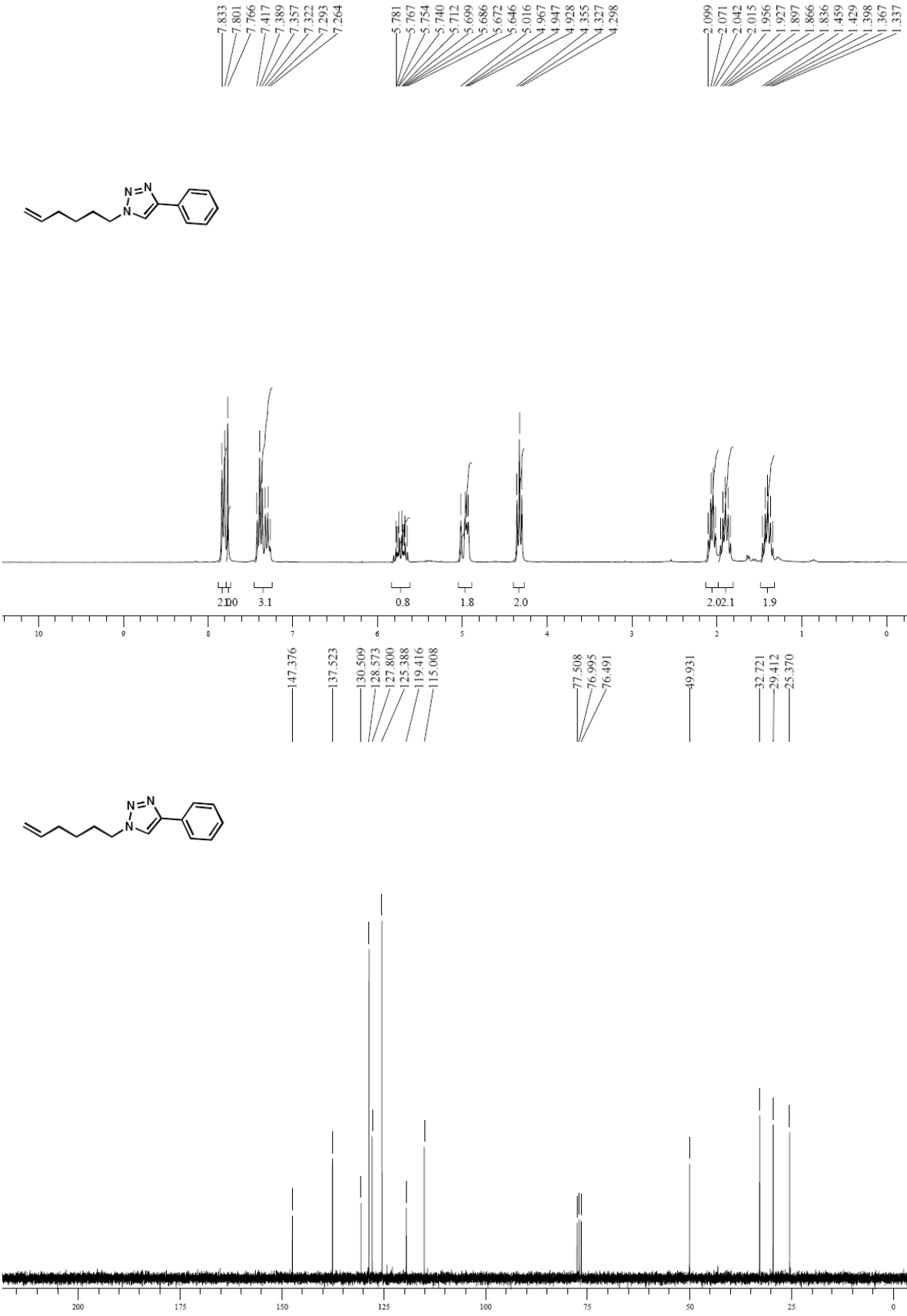
1-(3-Chloro-2-methylpropyl)-4-phenyl-1*H*-1,2,3-triazole (3ga).



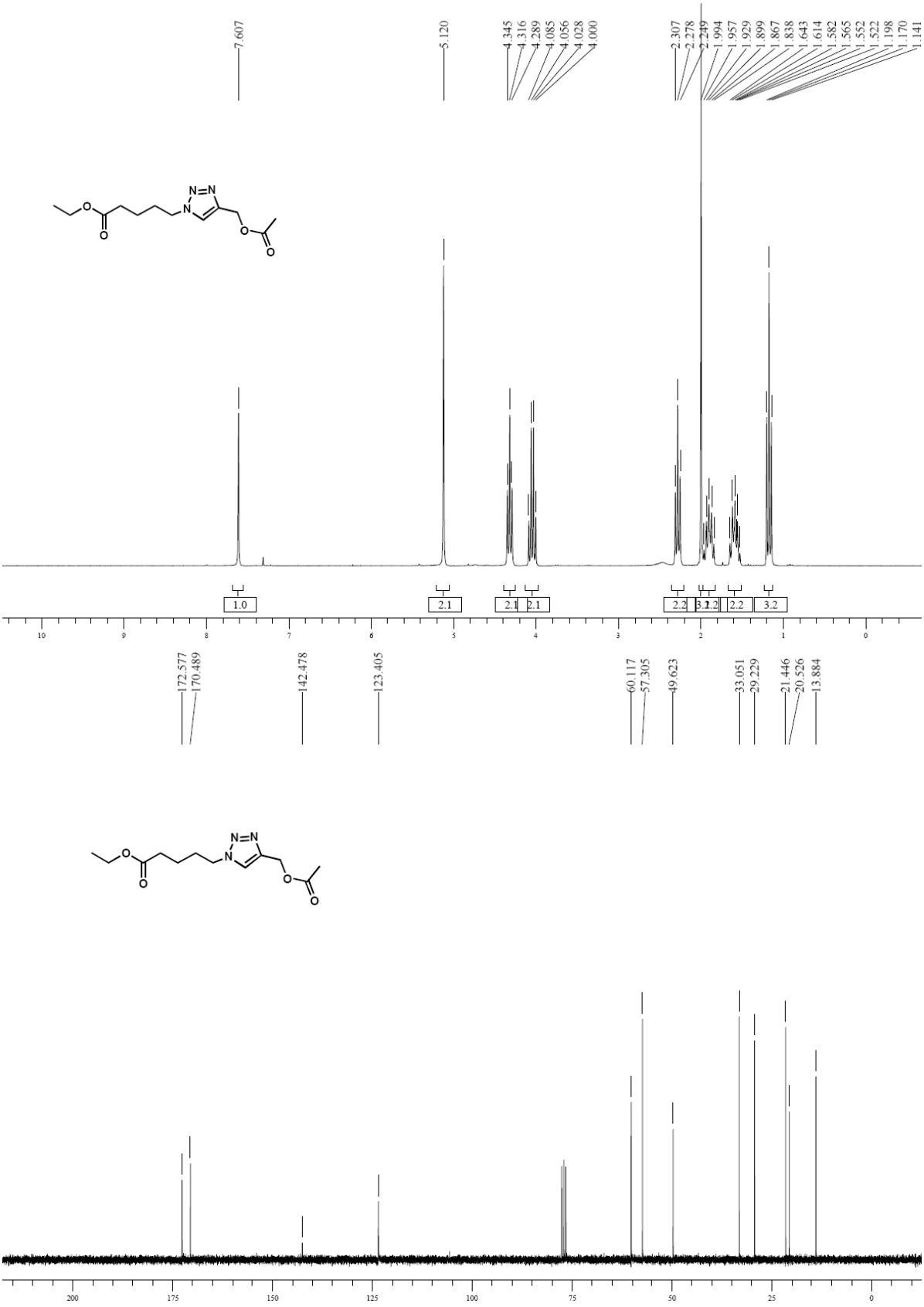
Ethyl-5-(4-phenyl-1*H*-1,2,3-triazol-1-yl)-pentanoate (3ia).



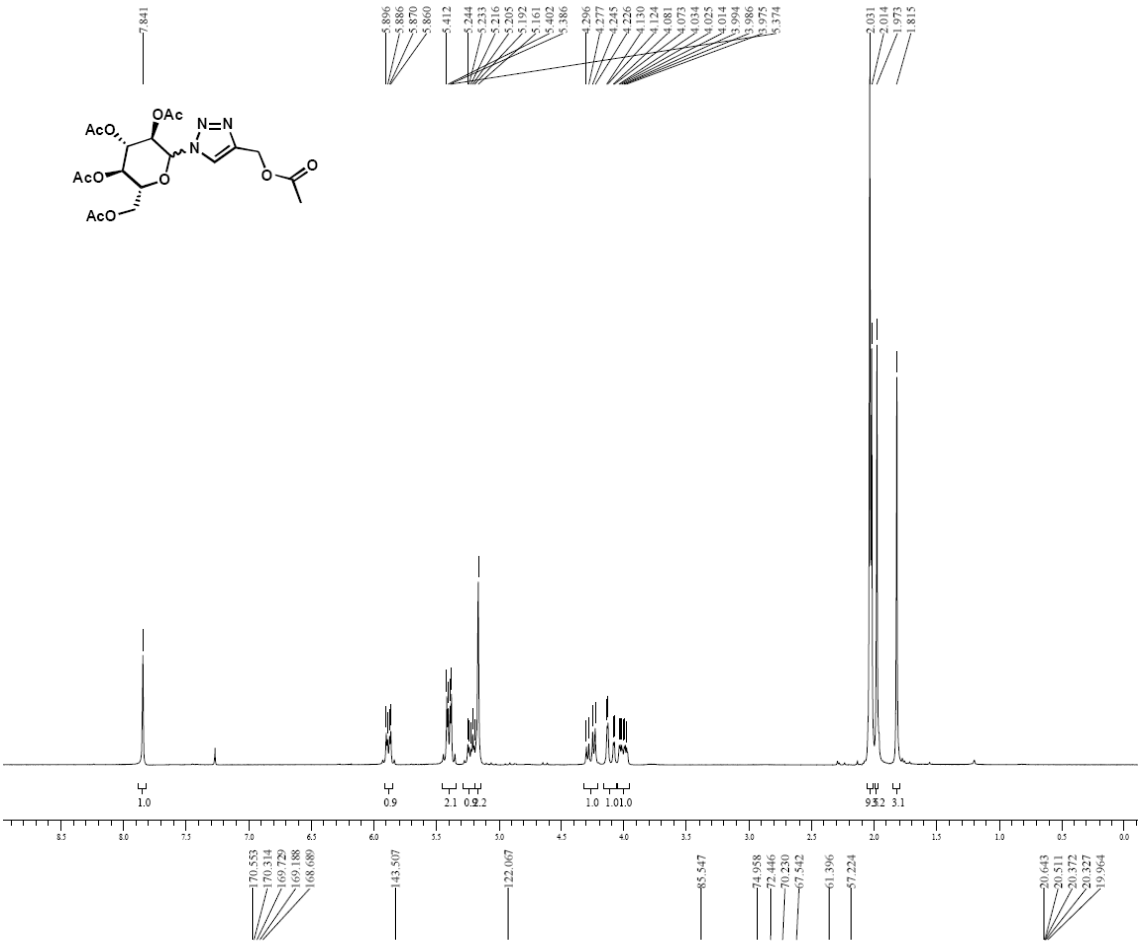
1-(hex-5-enyl)-4-phenyl-1H-1,2,3-triazole (3ja).

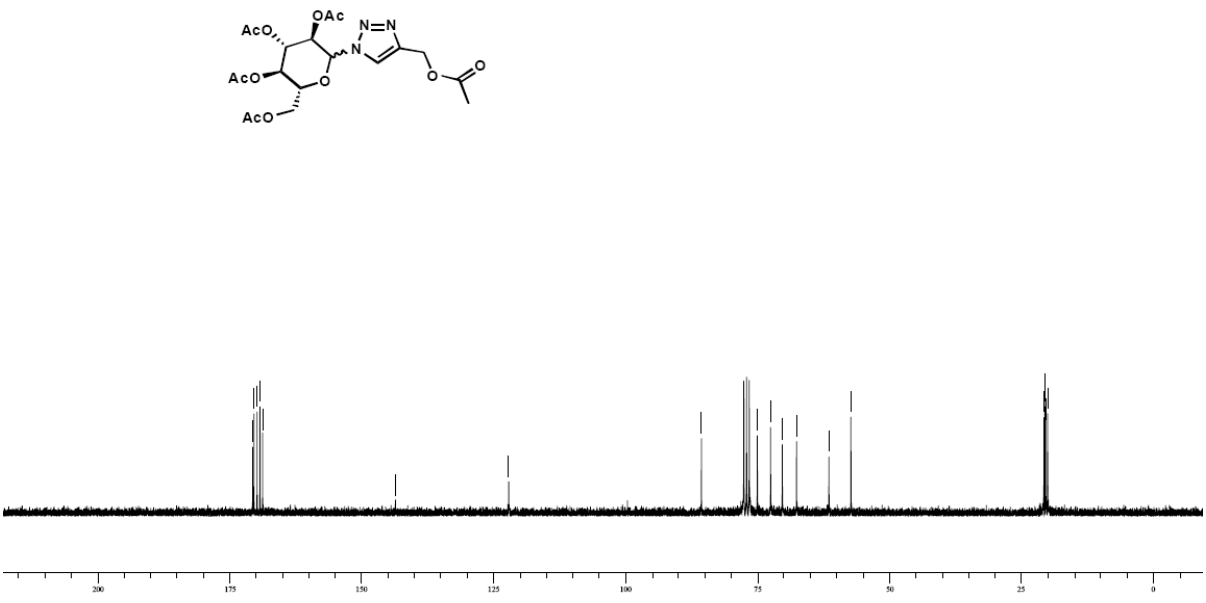


Ethyl 5-(4-(acetoxymethyl)-1H-1,2,3-triazol-1-yl)pentanoate (3ie).

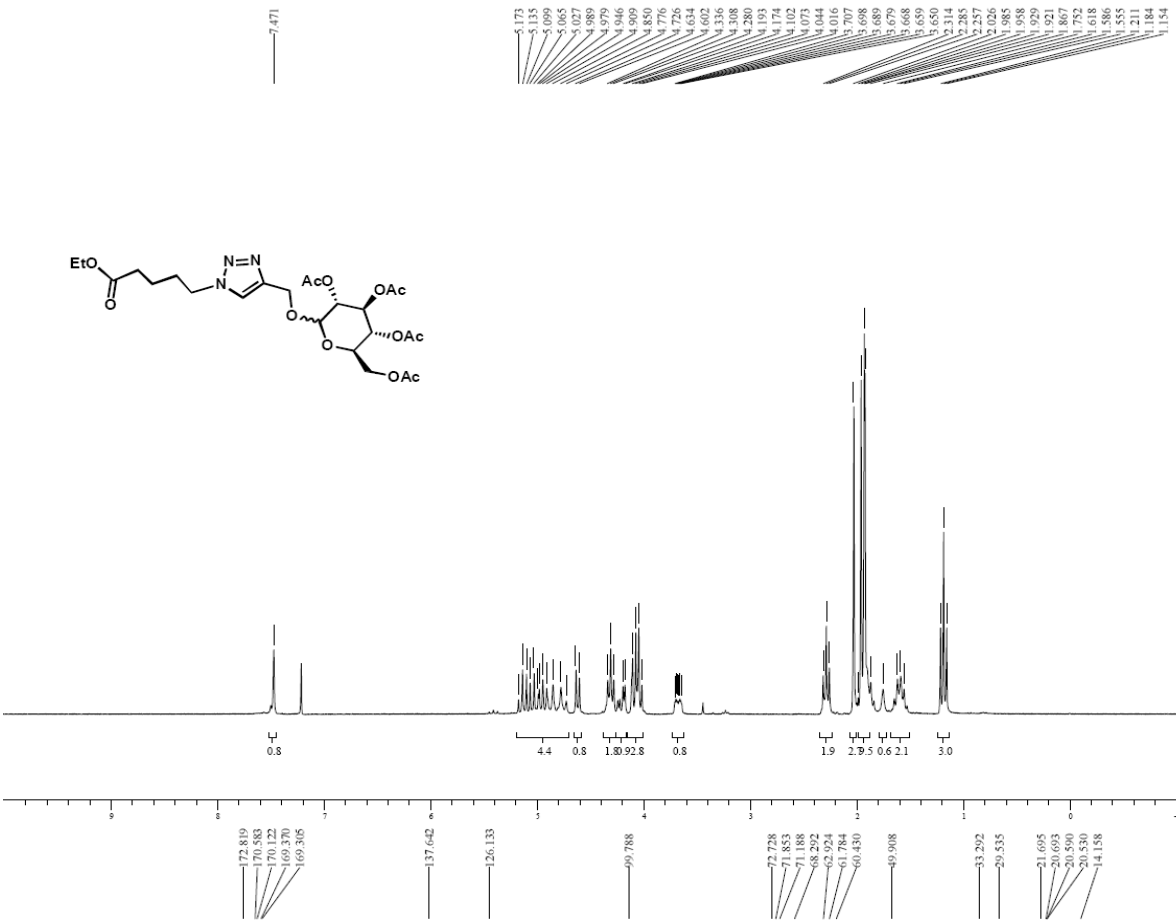


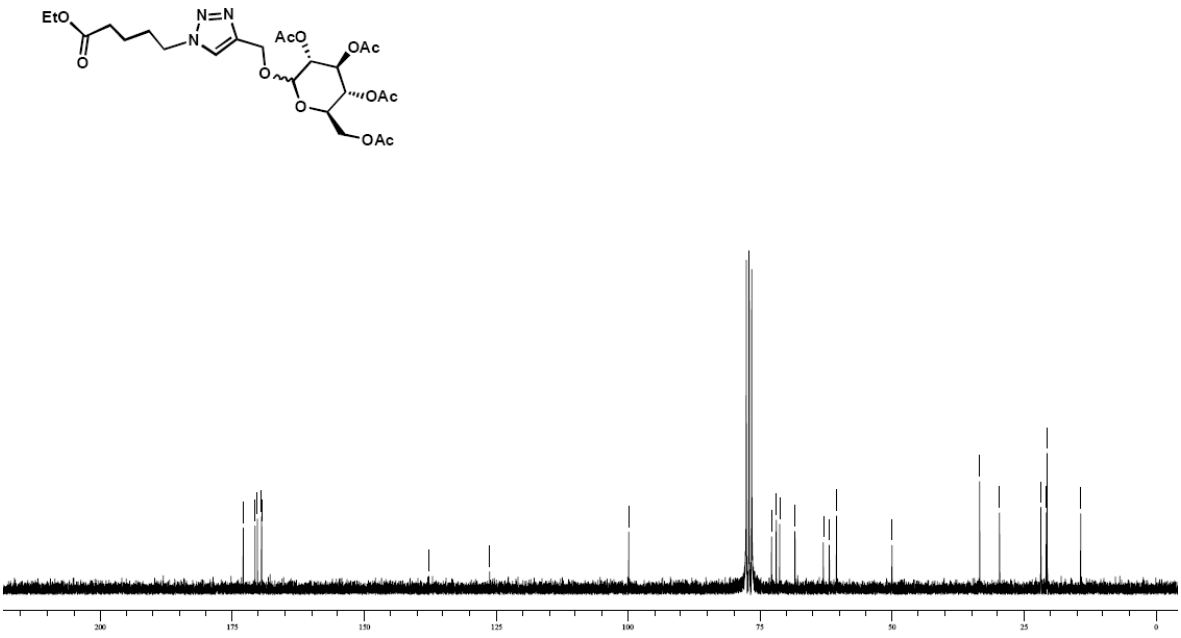
(2R,3R,4S,5R)-2-(acetoxymethyl)-6-(4-(acetoxymethyl)-1H-1,2,3-triazol-1-yl)tetrahydro-2H-pyran-3,4,5-triyl triacetate (3ke)



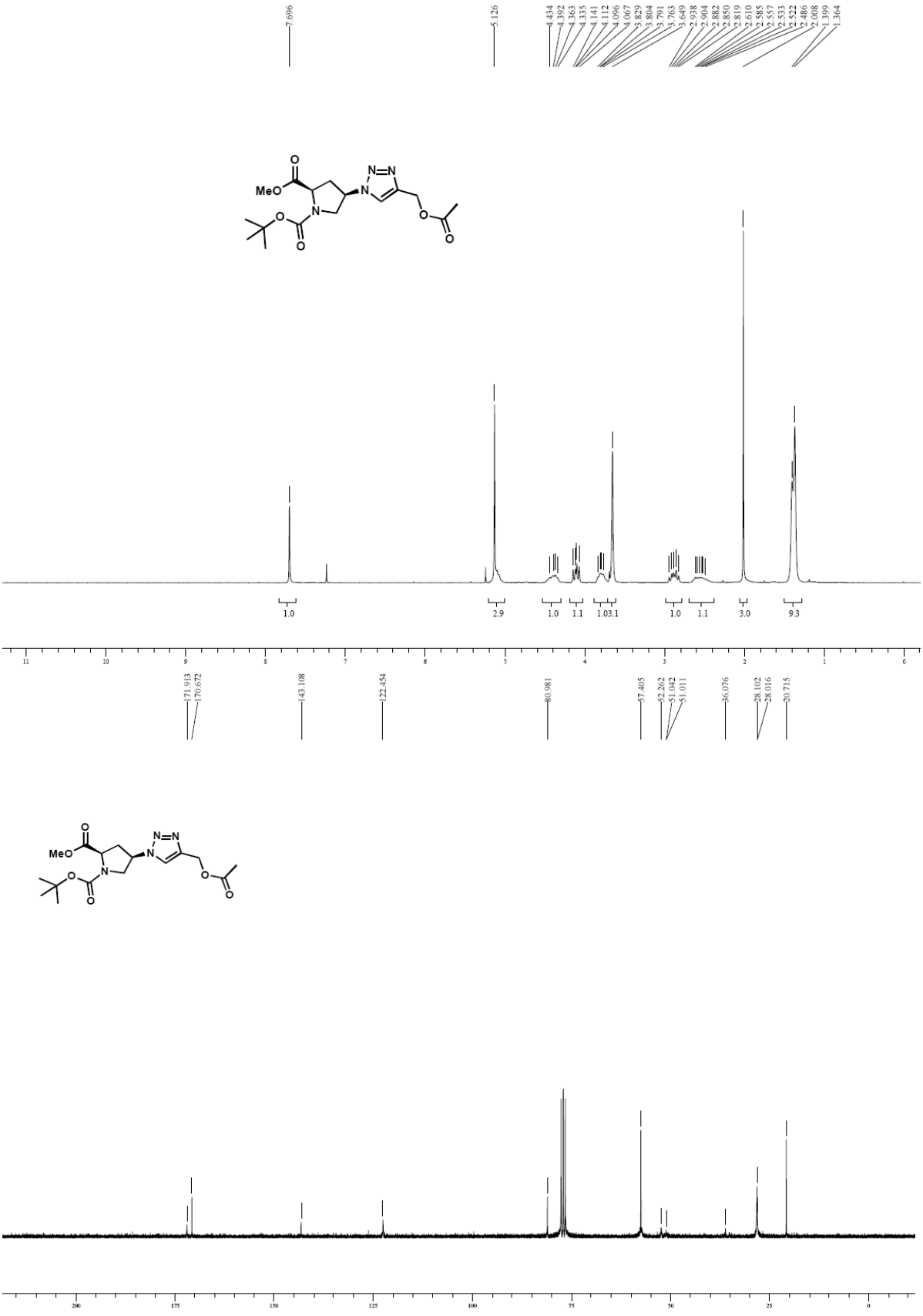


((2R,3R,4S,5R)-2-(acetoxymethyl)-6-((1-(5-ethoxy-5-oxopentyl)-1H-1,2,3-triazol-4-yl)methoxy)tetrahydro-2H-pyran-3,4,5-triyl triacetate (3ig).

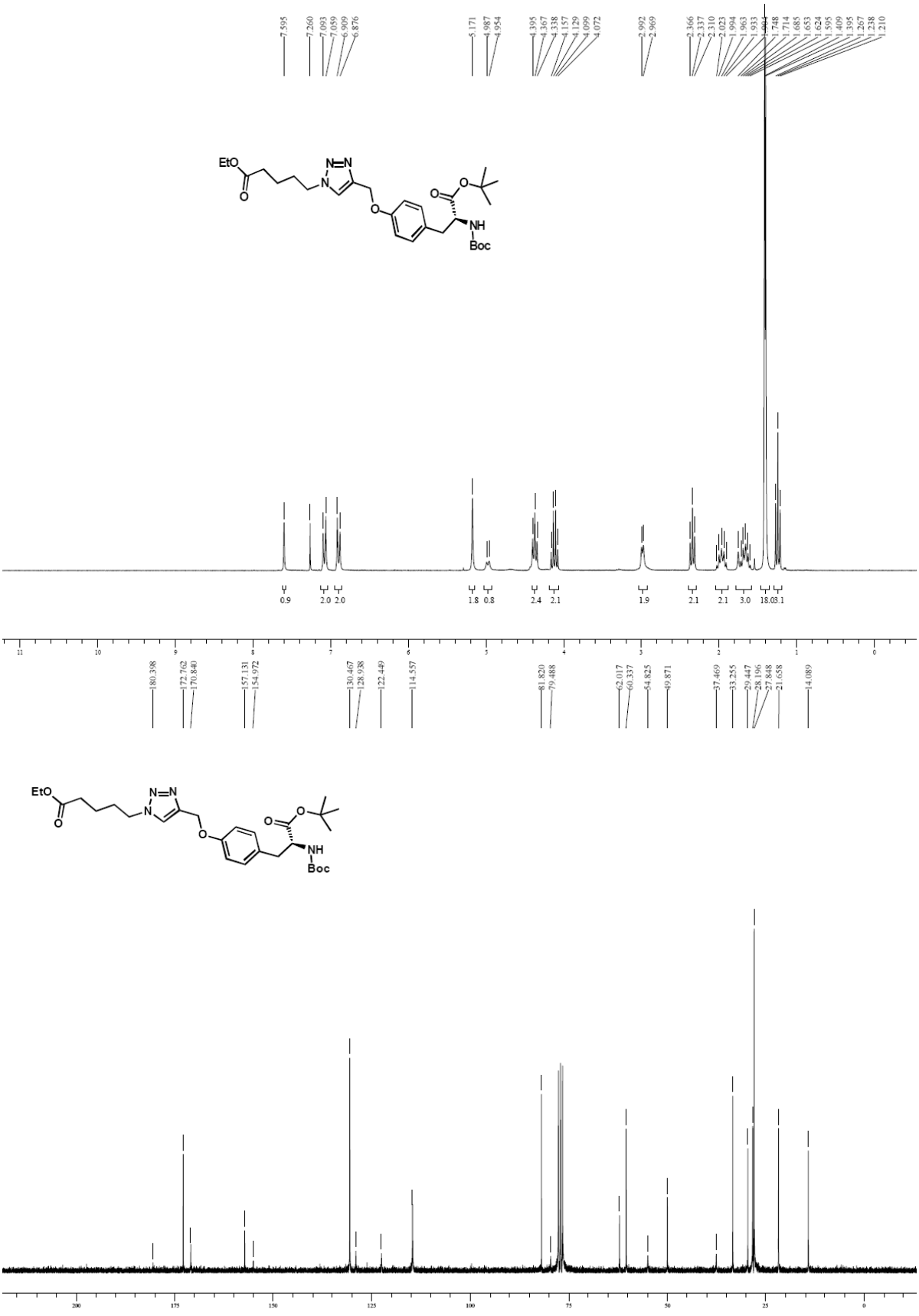




(2R,4R)-1-tert-butyl 2-methyl 4-(4-(acetoxymethyl)-1H-1,2,3-triazol-1-yl)pyrrolidine-1,2-dicarboxylate (3le).



Ethyl 5-(4-((4-(3-tert-butoxy-2-(tert-butoxycarbonylamino)-3-oxopropyl)phenoxy)methyl)-1H-1,2,3-triazol-1-yl)pentanoate (3ih).



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