Supporting Information

Claisen-Type Condensation of Vinylogous Acyl Triflates

Shin Kamijo* and Gregory B. Dudley*

Department of Chemistry and Biochemistry, Florida State University, Tallahassee, Florida 32306

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General Information

^{1}H NMR and ^{13}C NMR spectra were recorded on a Varian 300 (300 MHz) spectrometer using $CDCl_3$ as a solvent. The chemical shifts (δ) are reported in parts per million (ppm) relative to the chloroform peak (7.26 ppm for ^{1}H NMR, 77.0 ppm for ^{13}C NMR). The coupling constants (*J*) were reported in Hertz (Hz). IR spectra were recorded on a Perkin-Elmer FTIR Paragon 1000 spectrometer on NaCl discs. Mass spectra were recorded on a JEOL JMS600H spectrometer. All chemicals were used as received unless otherwise noted. The purifications of the compounds were performed by flash chromatography using silica gel F-254 (230-499 mesh particle size). Triflates **1** were prepared from the corresponding 1,3-dione according to our published procedure.[1] Triflates **1c** and **1e** were obtained from 4,4-dimethylcyclohexane-1,3-dione in a ca. 1:1 ratio and separated by silica gel chromatography.

Standard Procedure for the Claisen-Type Condensation of the Triflate (1) with Acetophenone (2a)

To a THF solution (2 mL) of acetophenone **2a** (0.14 mL, 1.2 mmol) was added LiHMDS (1.1 mL, 1.1 mmol; 1.0 M solution in THF) at –78 °C under Ar atmosphere. After stirred for 30 min at –78 °C, 2-methyl-3-(trifluoromethanesulfonyloxy)-2-cyclohexenone (**1a**) (93 μL, 0.50 mmol) was added to the resultant solution. The mixture was stirred at -78 °C for 10 min, at 0 °C for 10 min, at rt for 30 min, and then at 60 °C for 30 min. Saturated aqueous NH_4Cl solution was added to quench the reaction and the mixture was extracted with ether. The organic layer was washed with water,

[1] Kamijo, S; Dudley, G. B. *J. Am. Chem. Soc.* **2005**, *127*, 5028–5029.

dried over $MgSO_4$, filtered, and concentrated. The residue was purified on a silica gel column chromatography (hexanes/ether = 100/1 - 20/1) to give 1-phenyl-1,3-dioxo-7-nonyne (**3a**) in 85% yield (96 mg).

Analytical Data

Most of the 1,3-diketones were obtained as a mixture of keto- and enol-forms, therefore spectra data for the major isomer is mainly reported here.

1-phenyl-1,3-dioxo-7-nonyne (3a) [141726-24-1]: pale yellow oil; enol:keto = 9.7:1; enol-form: ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.78 (3H, t, *J* = 2.5 Hz), 1.86 (2H, apparent quintet, *J* = 7.1 Hz), 2.23 (2H, tq, *J* = 6.9, 2.5 Hz), 2.55 (2H, t, *J* = 7.5 Hz), 6.19 (1H, s), 7.41-7.54 (3H, m), 7.88 (2H, m); assignable peaks of keto-form: δ 1.74 (3H, t, *J* = 2.5 Hz), 2.15 (2H, tq, *J* = 6.8, 2.5 Hz), 2.71 (2H, t, *J* = 7.1 Hz), 4.10 (2H, s); ^{13}C NMR (75 MHz, $CDCl_3$) δ 3.4, 18.3, 24.8, 38.1, 76.5, 78.0, 96.2, 126.9, 128.5, 132.1, 134.8, 183.0, 196.3; IR (neat) 3448 (br), 1719, 1613 (br), 1454, 1267, 1136, 765, 696 cm^{-1}; HRMS (EI) Calcd for $C_{15}H_{16}O_2$ (M^+) 228.1150. Found 228.1130.

2,4-dioxo-8-decyne (3b): yellow oil; enol:keto = 4.7:1; enol-form: ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.78 (3H, t, *J* = 2.5 Hz), 1.78 (2H, apparent quintet, *J* = 7.3 Hz), 2.05 (3H, s), 2.18 (2H, tq, *J* = 6.9, 2.5 Hz), 2.39 (2H, t, *J* = 7.5 Hz), 5.51 (1H, s); assignable peaks of keto-form: δ 2.24 (3H, s), 2.63 (2H, t, *J* = 7.2 Hz), 3.59 (2H, s); ^{13}C NMR (75 MHz, $CDCl_3$) δ 3.4, 18.2, 24.08, 24.84, 37.0, 76.4, 78.1, 99.8, 191.0, 193.6; IR (neat) 1725, 1707, 1612 (br), 1435, 1234, 1134 cm^{-1}; HRMS (FAB) Calcd for $C_{10}H_{14}O_2Na$ (M^+) 189.0892. Found 189.0881.

ethyl 3-oxo-7-nonynoate (3c): pale yellow oil; ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.28 (3H, t, *J* = 7.0 Hz), 1.76 (3H, t, *J* = 2.5 Hz), 1.76 (2H, apparent quintet, *J* = 7.0 Hz), 2.17 (2H, tq, *J* = 6.8, 2.5 Hz), 2.39 (2H, t, *J* = 7.2 Hz), 3.45 (2H, s), 4.19 (2H, q, *J* = 7.0 Hz); ^{13}C NMR (75 MHz, $CDCl_3$) δ 3.3, 14.0, 17.8, 22.5, 41.6, 49.3, 61.2, 76.43, 77.9, 167.0, 202.35; IR (neat) 1745, 1714, 1651, 1415, 1242, 1027 cm^{-1}; HRMS (FAB) Calcd for $C_{11}H_{16}O_3Na$ (M^+) 219.0097. Found 219.0097.

1-(methylsufonyl)-2-oxo-6-octyne (3d): pale yellow oil; ^{1}H NMR (300 MHz, $CDCl_3$) δ

1.77 (3H, t, *J* = 2.5 Hz), 1.78 (2H, apparent quintet, *J* = 7.0 Hz), 2.20 (2H, tq, *J* = 6.8, 2.5 Hz), 2.84 (2H, t, *J* = 7.0 Hz), 3.04 (3H, s), 4.04 (2H, s); ^{13}C NMR (75 MHz, $CDCl_3$) δ 3.3, 17.7, 22.2, 41.4, 43.4, 64.5, 76.8, 77.6, 199.24; IR (neat) 1715, 1311, 1147 cm^{-1}; HRMS (ESI) Calcd for $C_9H_{14}O_3SNa$ (M^+) 225.0561. Found 225.0554.

di(2-oxo-6-octynyl)sulfone (3d'): white solid; ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.64 (6H, t, *J* = 2.5 Hz), 1.64 (4H, apparent quintet, *J* = 7.0 Hz), 2.19 (4H, tq, *J* = 6.8, 2.5 Hz), 2.75 (4H, t, *J* = 7.2 Hz), 4.30 (4H, s); ^{13}C NMR (75 MHz, $CDCl_3$) δ 3.4, 17.7, 22.1, 43.4, 62.5, 77.1, 77.5, 199.2; IR (CCl_4) 1713, 1326, 1130 cm^{-1}; HRMS (ESI) Calcd for $C_{16}H_{22}O_4SNa$ (M^+) 333.1136. Found 333.1149.

1-(dimethylphosphonato)-2-oxo-6-octyne (3e):[2] yellow oil; ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.75 (2H, apparent quintet, *J* = 7.0 Hz), 1.76 (3H, t, *J* = 2.5 Hz), 2.16 (2H, tq, *J* = 6.9, 2.5 Hz), 2.73 (2H, t, *J* = 7.2 Hz), 3.10 (2H, d, ^2J(H,P) = 22 Hz), 3.78 (6H, d, ^3J(H, P) = 11 Hz); ^{13}C NMR (75 MHz, $CDCl_3$) δ 3.3, 17.8, 22.6, 41.3 (^1J(C,P) = 128 Hz), 42.8, 52.9 (^2J(C,P) = 6.5 Hz), 76.3, 78.0, 201.4; IR (neat) 1711, 1449, 1253, 1024 cm^{-1}; HRMS (EI) Calcd for $C_{10}H_{17}O_4P$ (M^+) 232.0864. Found 232.0860.

1-phenyl-1,3-dioxo-7-octyne (3f): yellow oil; enol:keto = 8.8:1; enol-form: ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.92 (2H, apparent quintet, *J* = 7.1 Hz), 2.00 (1H, t, *J* = 2.5 Hz), 2.30 (2H, td, *J* = 7.2, 2.5 Hz), 2.58 (2H, t, *J* = 7.5 Hz), 6.19 (1H, s), 7.41-7.52 (3H, m), 7.88 (2H, m); assignable peaks of keto-form: δ 1.83 (2H, apparent quintet, *J* = 7.0 Hz), 2.24 (2H, td, *J* = 6.9, 2.5 Hz), 2.75 (2H, t, *J* = 7.2 Hz), 4.11 (2H, s); ^{13}C NMR (75 MHz, $CDCl_3$) δ 17.8, 24.1, 37.7, 69.1, 83.3, 96.2, 126.9, 128.5, 132.2, 134.7, 183.0, 195.9; IR (neat) 3299, 2117, 1715, 1651, 1269, 760, 693 cm^{-1}; HRMS (ESI) Calcd for $C_{14}H_{14}O_2Na$ (M^+) 237.0891. Found 237.0892.

1-phenyl-1,3-dioxo-5,5-dimethyl-7-octyne (3h): pale yellow oil; enol:keto = 22.2:1; enol-form: ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.13 (6H, s), 2.09 (1H, t, *J* = 2.7 Hz), 2.26 (2H, d, *J* = 2.7 Hz), 2.43 (2H, s), 6.21 (1H, s), 7.43-7.55 (3H, m), 7.89 (2H, m);

[2] Turet, L.; Marko, I. E.; Tinant, B.; Declercq, J.-P.; Touilaux, R. *Tetrahedron Lett.* **2002**, *43*, 6591–6596.

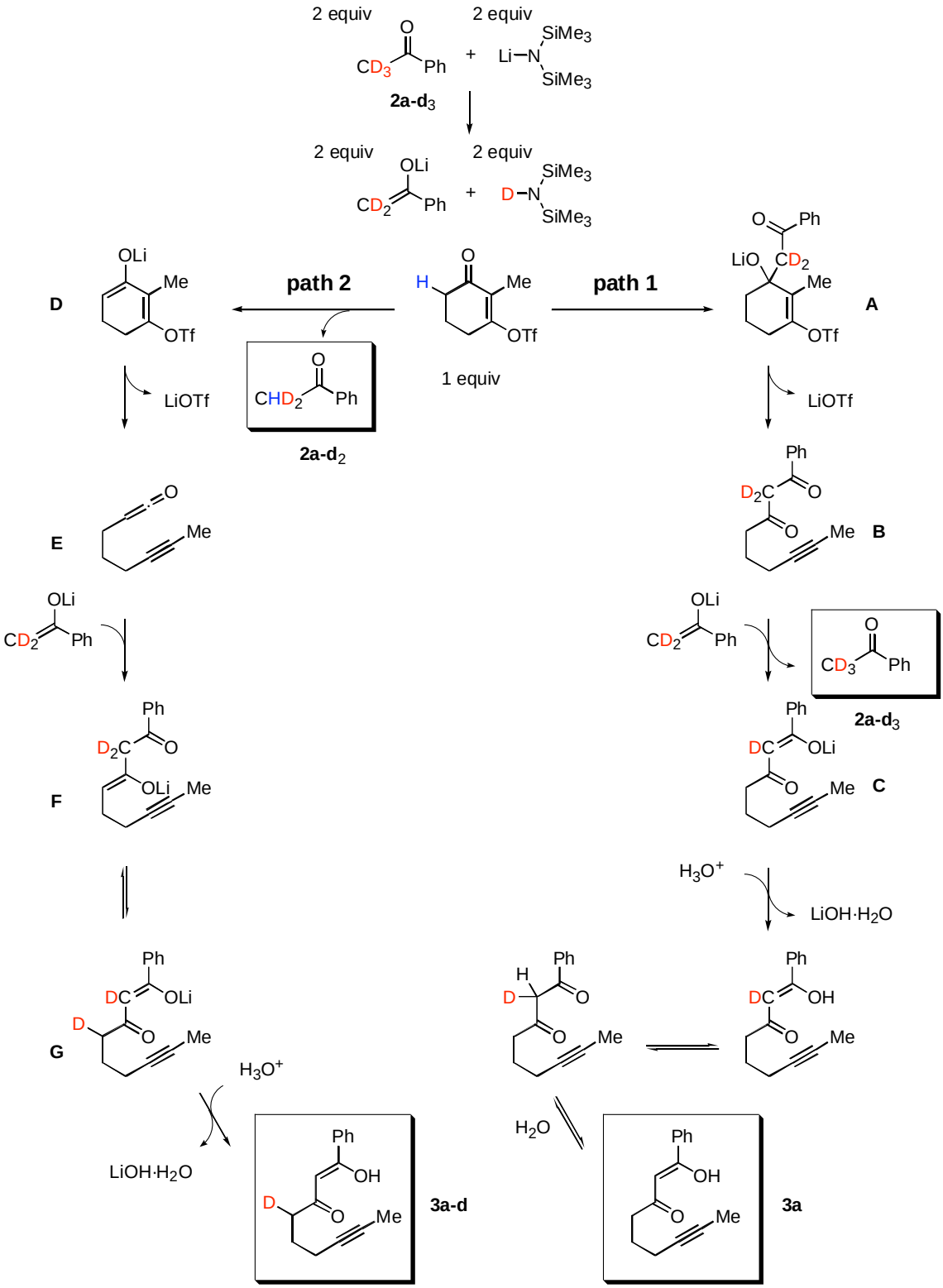
assignable peaks of keto-form: δ 4.08 (2H, s); ^{13}C NMR (75 MHz, $CDCl_3$) δ 27.2, 31.9, 34.5, 48.9, 70.7, 82.0, 98.1, 127.1, 128.5, 132.3, 135.2, 185.1, 193.1; IR (neat) 3301, 2115, 1651, 1274, 1182, 762, 699 cm^{-1}; HRMS (ESI) Calcd for $C_{16}H_{18}O_2Na$ (M^+) 265.1205. Found 265.1198.

1-phenyl-1,3-dioxo-6,6-dimethyl-7-octyne (3i): pale yellow oil; enol:keto = 11.7:1; enol-form: ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.26 (6H, s), 1.80 (2H, virtual t, *J* = 8.4 Hz), 2.14 (1H, s), 2.63 (2H, virtual t, *J* = 8.4 Hz), 6.21 (1H, s), 7.42-7.59 (3H, m), 7.88 (2H, m); assignable peaks of keto-form: δ 1.73 (2H, virtual t, *J* = 7.9 Hz), 2.79 (2H, virtual t, *J* = 7.9 Hz), 4.13 (2H, s); ^{13}C NMR (75 MHz, $CDCl_3$) δ 28.9, 30.7, 35.7, 38.3, 68.7, 90.5, 96.0, 126.8, 128.53, 128.59, 132.1, 134.7, 182.4, 197.4; IR (neat) 3298, 2107, 1721, 1613, 1262, 766, 688 cm^{-1}; HRMS (ESI) Calcd for $C_{16}H_{18}O_2Na$ (M^+) 265.1204. Found 265.1202.

1-phenyl-1,3-dioxo-8-nonyne (3j): pale yellow oil; enol:keto = 8.3:1; enol-form: ^{1}H NMR (300 MHz, $CDCl_3$) δ 1.61 (2H, apparent quintet, *J* = 7.4 Hz), 1.82 (2H, apparent t, *J* = 7.5 Hz), 1.96 (1H, t, *J* = 2.7 Hz), 2.25 (2H, td, *J* = 7.0, 2.7 Hz), 2.46 (2H, t, *J* = 7.5 Hz), 6.18 (1H, s), 7.40-7.56 (3H, m), 7.88 (2H, m); assignable peaks of keto-form: δ 1.93 (1H, t, *J* = 2.6 Hz), 2.19 (2H, td, *J* = 7.2, 2.6 Hz), 2.62 (2H, t, *J* = 7.2 Hz), 4.09 (2H, s); ^{13}C NMR (75 MHz, $CDCl_3$) δ 18.1, 24.6, 27.8, 38.5, 68.6, 83.8, 95.9, 126.8, 128.5, 132.1, 134.8, 183.3, 196.3; IR (neat) 3299, 2116, 1715, 1275, 764, 692 cm^{-1}; HRMS (ESI) Calcd for $C_{15}H_{16}O_2Na$ (M^+) 251.1048. Found 251.1038.

Possible Mechanistic Pathways and Deuterium-Labeling Experiment

(1) Possible Mechanistic Pathways for the Formation of **3a**



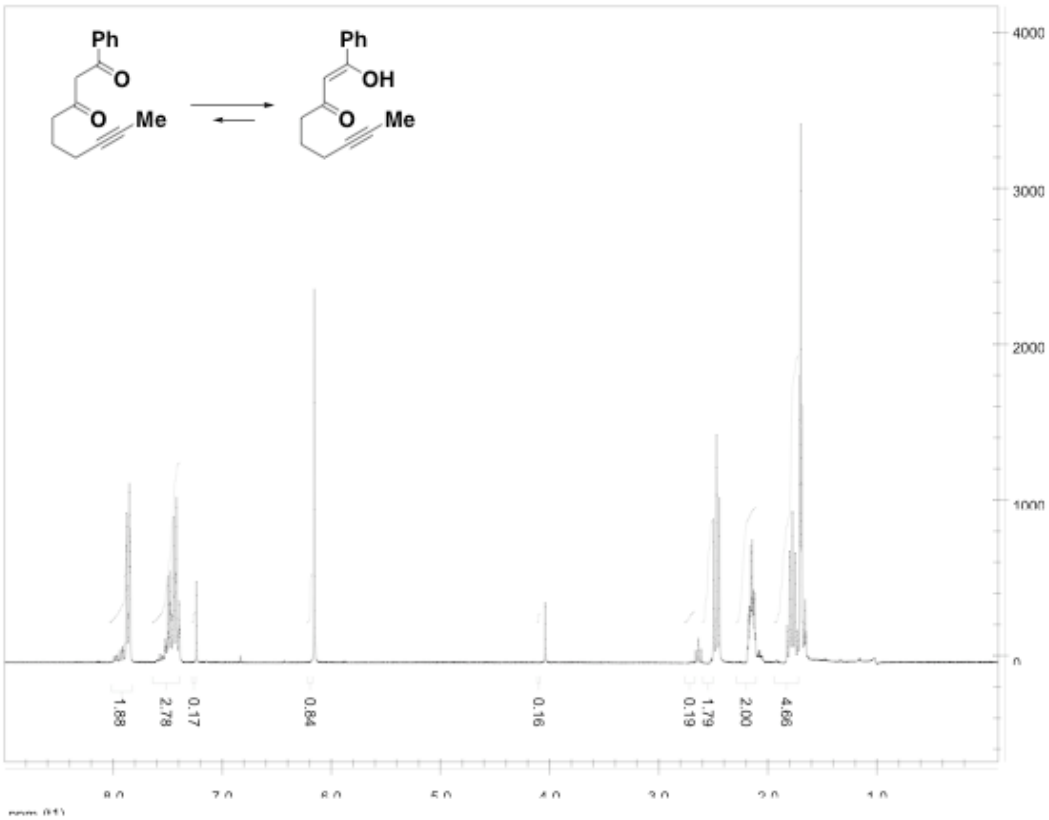
The mechanistic pathway we proposed in the text (Scheme 1) goes along with **path 1** in the above scheme, in which the reaction is initiated by nucleophilic 1,2-addition of the lithium enolate of acetophenone **2a** to the carbonyl group of triflate **1a**.

An alternative mechanistic pathway could be proposed as shown in **path 2**, where the reaction would start with abstraction of the acidic proton of the triflate **1a** to form the intermediate **D**. The Grob-type fragmentation then would lead the formation of the ketene intermediate **E**. Addition of another molecule of the lithium enolate of **2a** and proton transfer would yield the most stable lithium enolate of the 1,3-diketone **G** through the intermediate **F**. Aqueous workup and keto-enol equilibrium in the presence of proton source would furnish the final product **3a**.

We expected that a deuterium-labeling experiment would give us an insight into the mechanistic pathway for the present Claisen-type condensation, and conducted the reaction using the vinylogous carboxylic acid triflates **1a** and acetophenone-*methyl-*d_3 **2a-d$_3$**. The resultant compounds were the corresponding 1,3-diketone **3a** without noticeable deuteration and recovery of **2a-d$_3$**. These products are consistent with expectations based on **path 1**, and they are inconsistent with material that would be formed via **path 2**. Accordingly, we favor the mechanism outlined in **path 1**.

(2) Deuterium-Labeling Experiment Using the Triflate **1a** and Acetophenone-*methyl-*d_3 **2a-d$_3$**

To a THF solution (2 mL) of acetophenone-*methyl-*d_3 **2a-d$_3$** (0.14 mL, 1.2 mmol) was added LiHMDS (1.0 mL, 1.0 mmol; 1.0 M solution in THF) at –78 °C under Ar atmosphere. After stirred for 30 min at –78 °C, 2-methyl-3-(trifluoromethanesulfonyloxy)-2-cyclohexenone (**1a**) (102 mL, 0.55 mmol) was added to the resultant solution. The mixture was stirred at -78 °C for 10 min, at 0 °C for 10 min, at rt for 30 min, and then at 60 °C for 30 min. Saturated aqueous NH_4Cl solution was added to quench the reaction and the mixture was extracted with ether. The organic layer was washed with water, dried over $MgSO_4$, filtered, and concentrated. The residue was purified on a silica gel column chromatography (hexanes/ether = 100/1 - 20/1). 1-Phenyl-1,3-dioxo-7-nonyne (**3a**) was isolated in 45% yield without noticeable deuteration (50 mg) and recovery of **2a-d$_3$** (25 mg, 0.20 mmol) was observed.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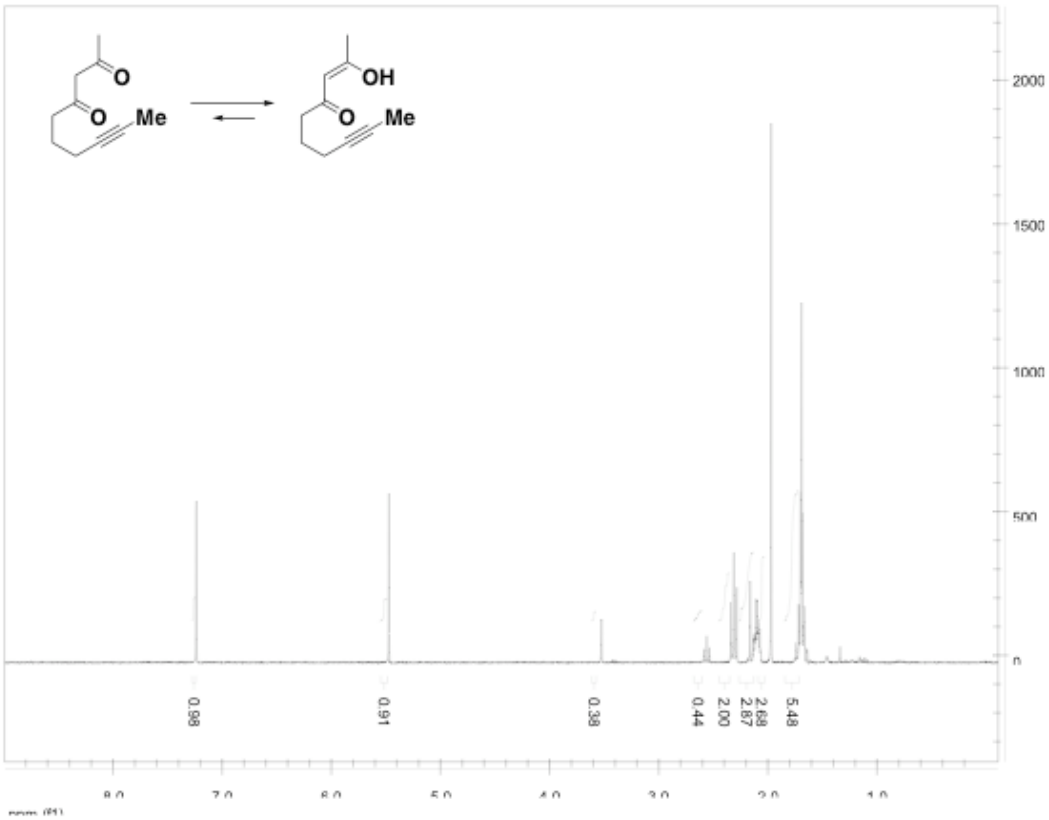
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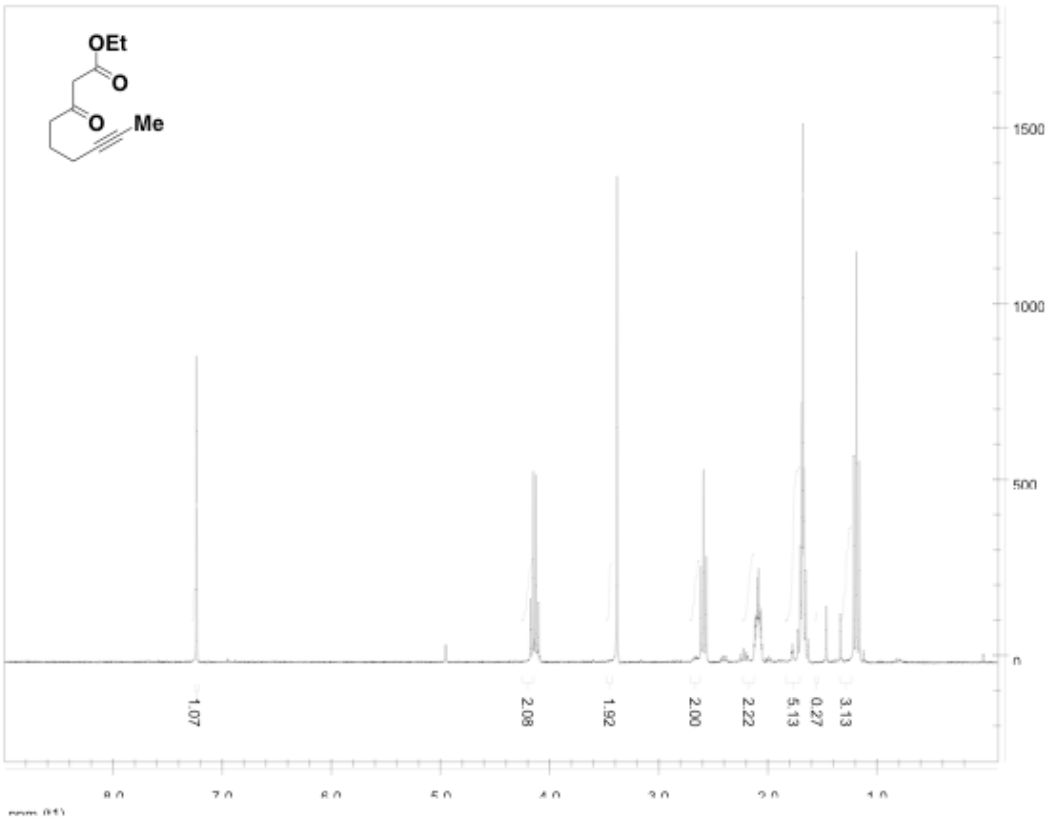
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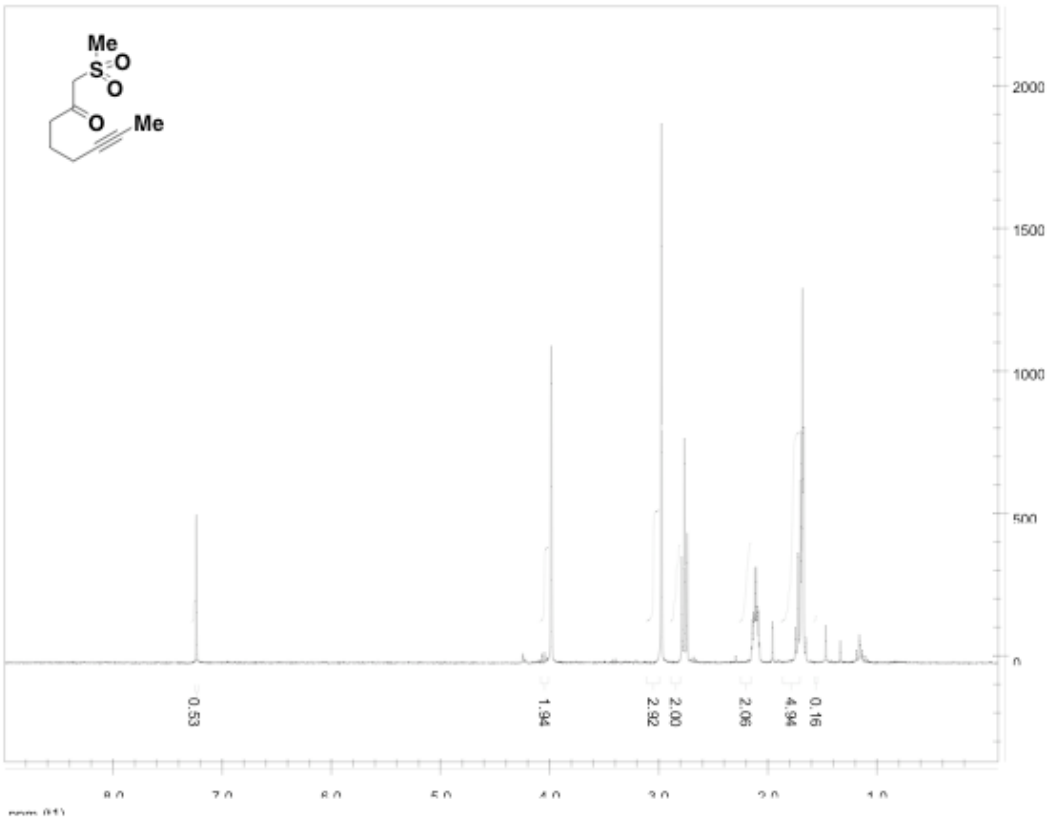
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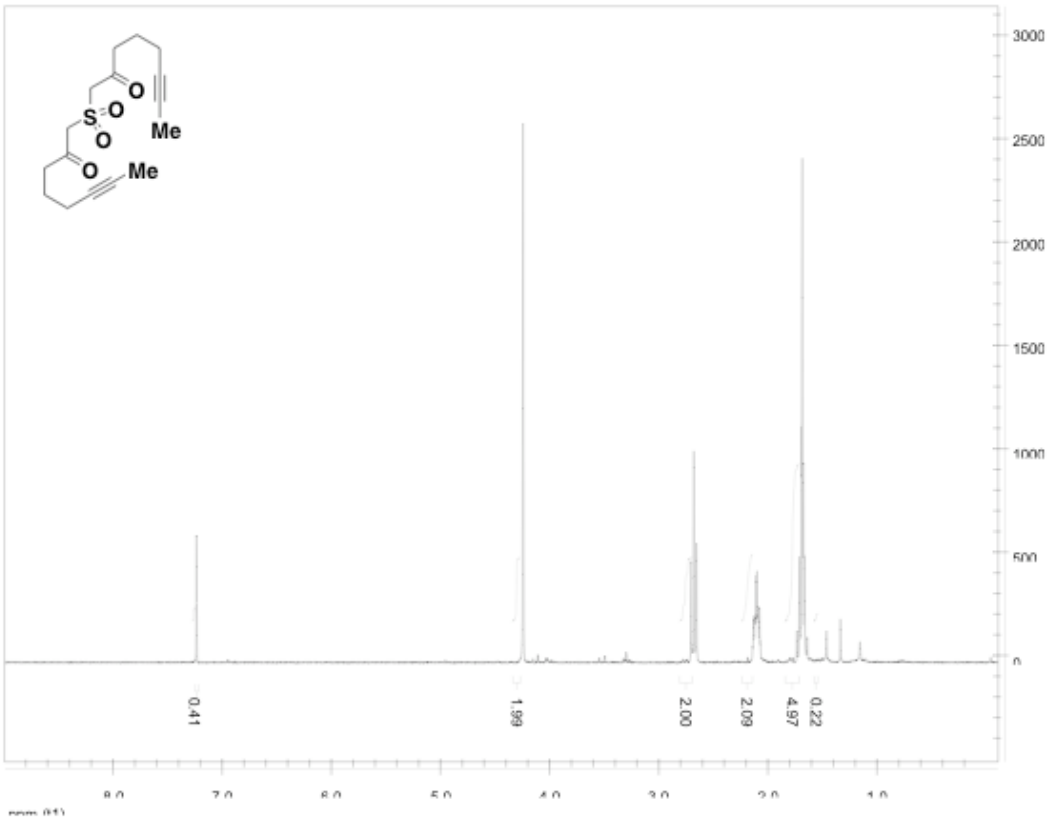
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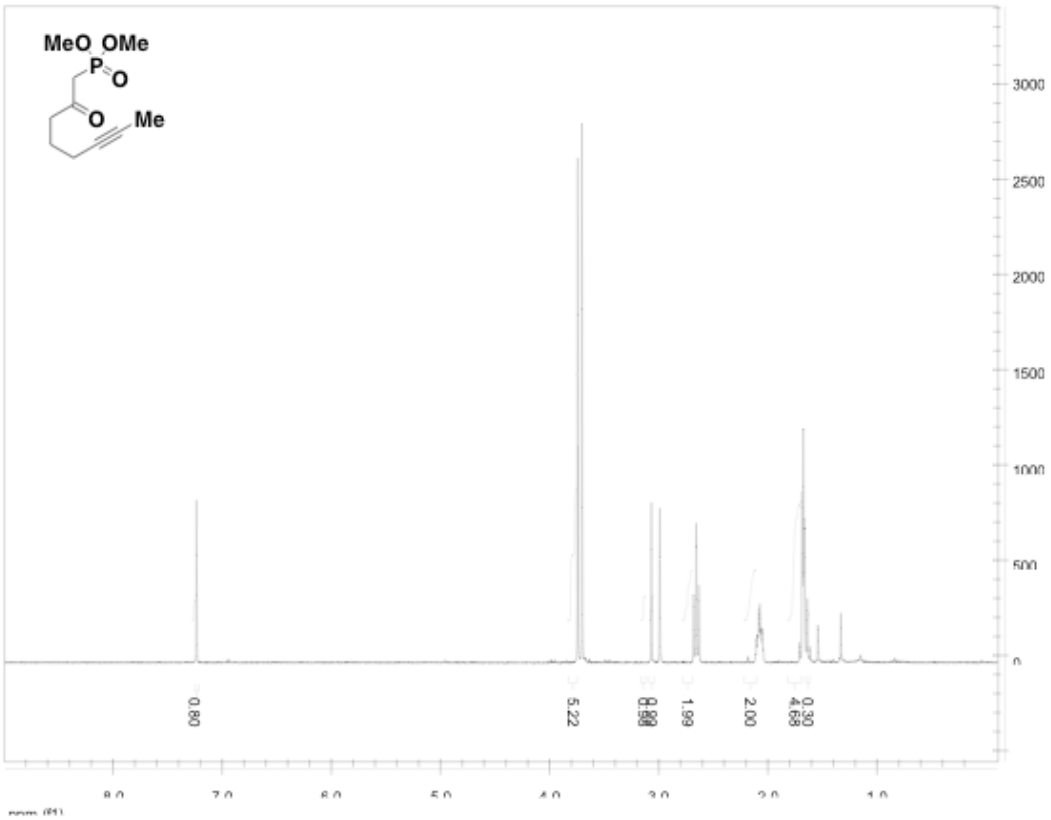
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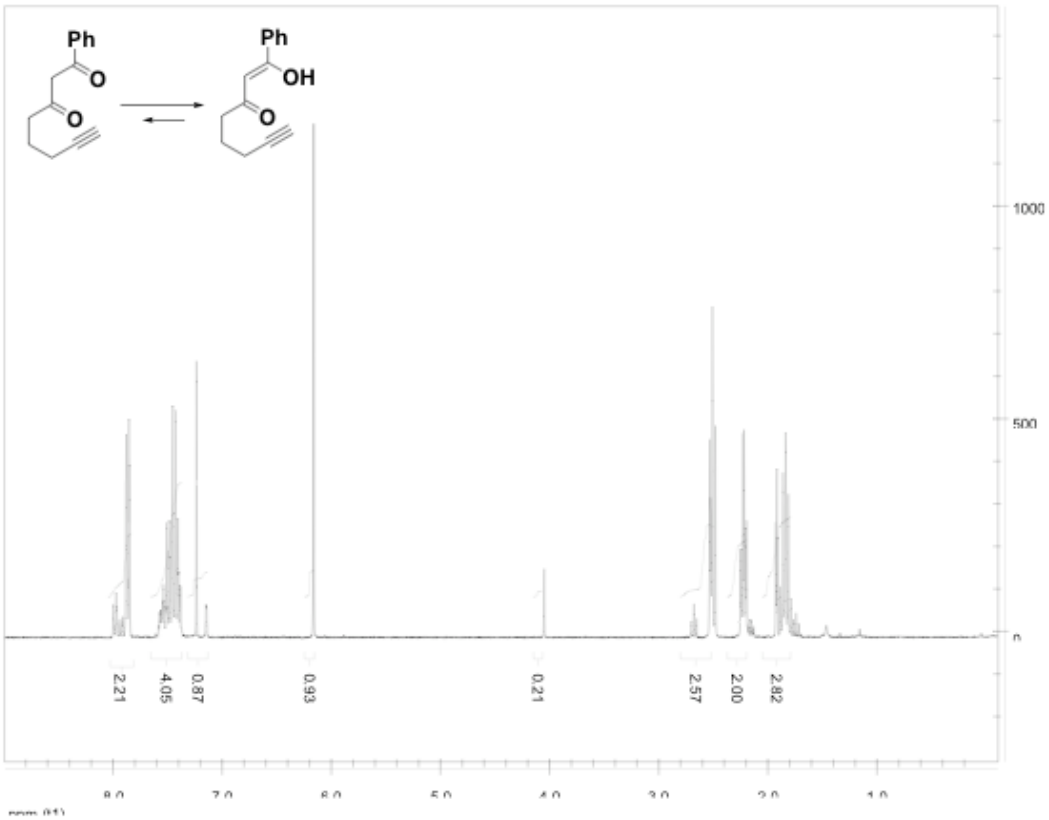
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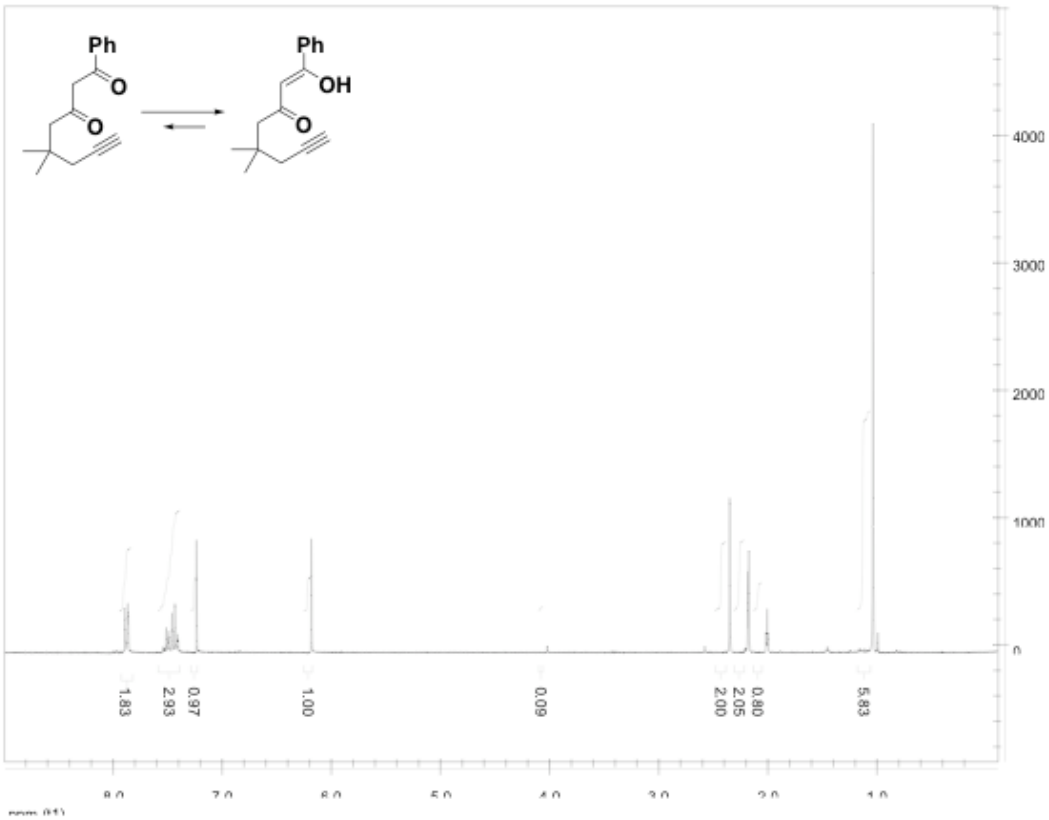
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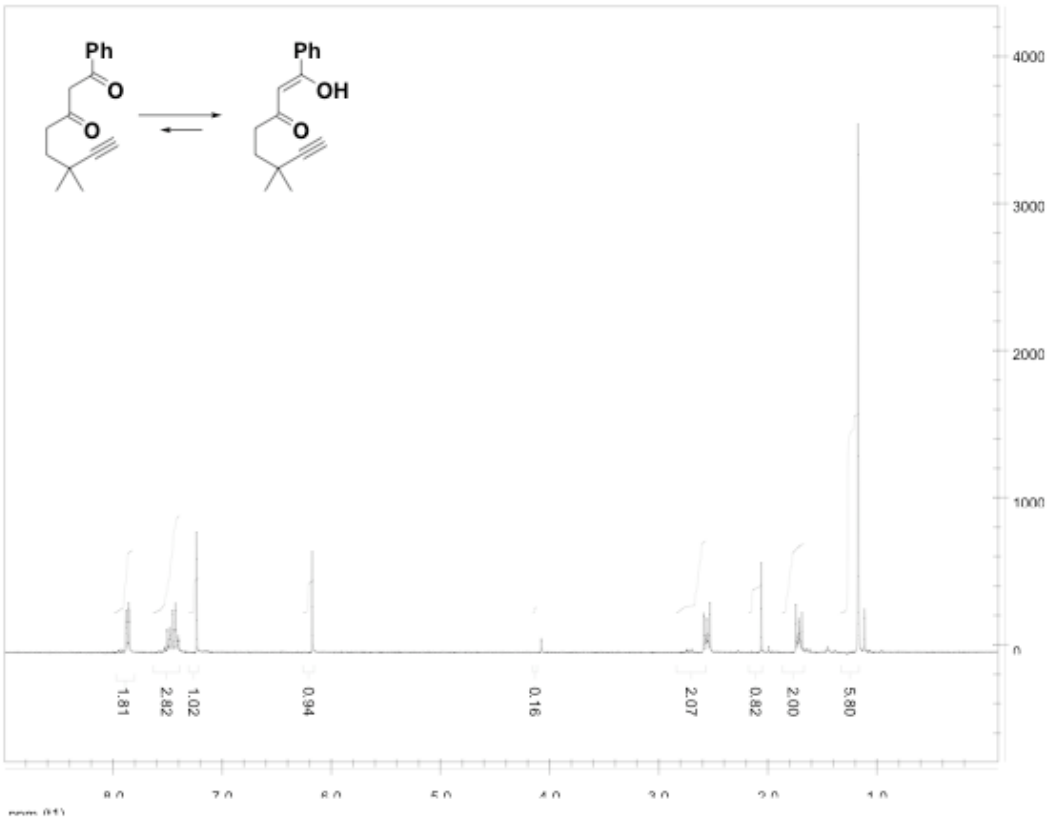
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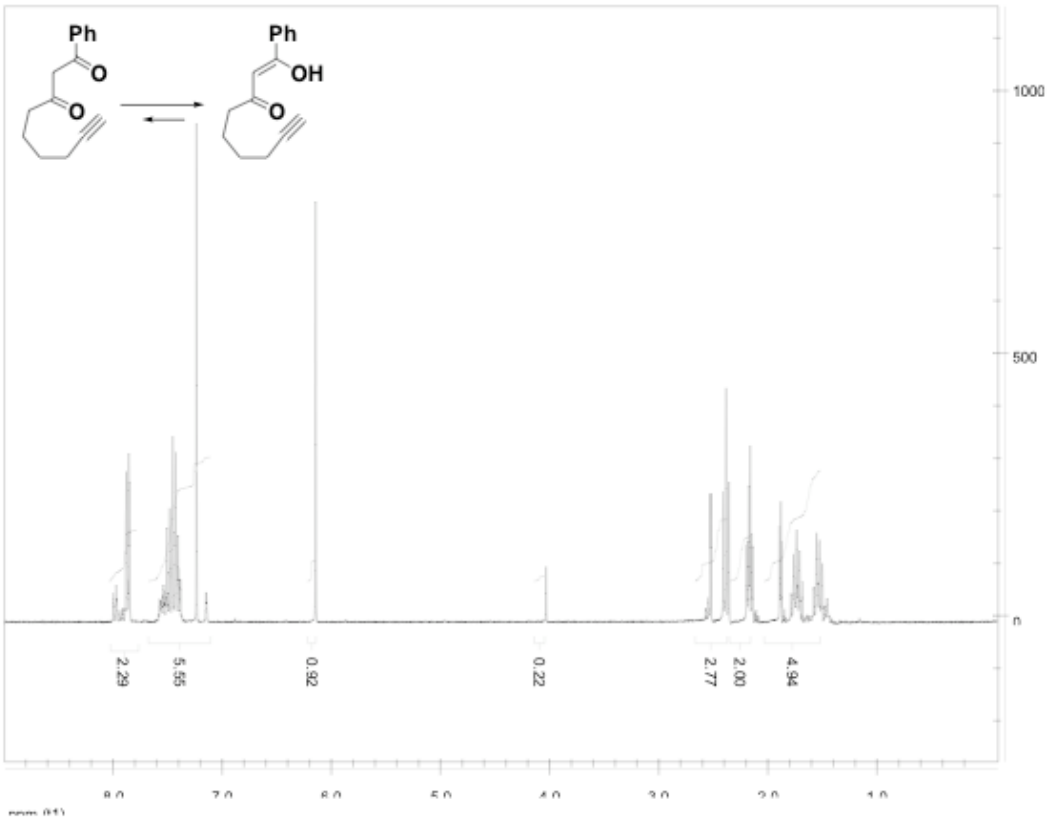
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