A Highly Selective Vanadium Catalyst for Benzylic C–H Oxidation

Ji-Bao Xia, Kevin W. Cormier and Chuo Chen*

Electronic Supplementary Information

General Information

All reactions were performed in glassware under argon. Organic solutions were concentrated by rotary evaporator at ca. 30 mmHg. Flash column chromatography was performed as described by Still (Still, W. C.; Kahn, M.; Mitra, A. *J. Org. Chem.* **1978**, *43*, 2923–2925), employing EMD silica gel 60 (230–400 mesh ASTM). TLC analyses were performed on EMD 250 μm Silica Gel 60 F_{254} plates and visualized by quenching of UV fluorescence (λ_{max}= 254 nm), or by staining ceric ammonium molybdate. ^{1}H and ^{13}C NMR spectra were recorded on a Varian Inova-500 or Inova-400. Chemical shifts for ^{1}H and ^{13}C NMR spectra are reported in ppm (δ) relative to the ^{1}H and ^{13}C signals in the solvent ($CDCl_3$: δ 7.26, 77.00 ppm; DMSO-d_6: δ 2.50 ppm; CD_3CN: δ 1.94 ppm) and the multiplicities are presented as follows: s = singlet, d = doublet, t = triplet, m = multiplet. Mass spectra were acquired on an Agilent 1200 LC-MS or VG 70-VSE. Data collection on 70-VSE (purchased in part with a grant from the Division of Research Resources, National Institutes of Health RR 04648) was serviced by the Mass Spectrometry Laboratory at the University of Illinois at Urbana-Champaign. Gas Chromatography (GC) was performed on an Agilent 6890N GC.

Ethylbenzene (99.8%), 1-(4-ethylphenyl)ethanone (97%), 1,4-diethylbenzene (97%), 1-phenyloctane (98%), 4-propylanisole (99%), α,α-dimethylbenzenepropanol (97%), and dodecane (analytical standard) were purchased from Sigma Aldrich. 1-Ethyl-4-methoxybenzene (98%), 4-methyl-1,1'-biphenyl (98%), and cumene (99%) were purchased from TCI America. 1-Ethyl-4-fluorobenzene (97%), 1-chloro-4-ethyl-benzene (97%), 4-ethylbenzonitrile (98%), 1-bromo-3-ethylbenzene (98%), 1-bromo-4-*n*-heptylbenzene (97%), (±)-4-phenyl-2-butanol (98%), and 3-phenyl-1-propanol (99%) were purchased from Alfa Aesar. 2-Phenylpropane-2-d_1 (Lot S347P6, certified 98.7% purity by GC and 97.2 atom % D by NMR) was purchased from C/D/N Isotopes Inc.

General Procedure for the Cp_2VCl_2/TBHP-catalyzed benzylic oxidation

To 4 mL vial charged with vanadocene dichloride (2.5 mg, 0.01 mmol, 0.01 equiv) was added *tert*-butyl hydroperoxide (70% in water, 720 μL, 5.0 mmol, 5.0 equiv). The solution was stirred at 30 °C for 30 min before the substrate (1.0 mmol, 1.0 equiv) was added. After reacting at 30 °C for 5 days, the reaction mixture was purified directly by flash column chromatography. Alternatively, the reaction mixture was transferred to a 16 mL vial, diluted with 10 mL ethyl acetate, quenched with solid sodium thiosulfate (700 mg, 5.5 mmol, 5.5 equiv) for 1 h, filtered, washed with ethyl acetate, concentrated, and purified by flash column chromatography.

GC and ^{1}H NMR Analysis of the Crude Reaction Mixtures

We have carefully analyzed the crude ^{1}H NMR spectra of all the oxidation reactions and the GC chromatograms of the oxidation of ethylbenzene. We did not detect any aromatic oxidation products. The GC chromatograms of the oxidation of ethylbenzene after 3 days (Figure S1) and 5 days (Figure S2) and the ^{1}H NMR spectra of the oxidation of ethylbenzene (Figure S3) and phenyloctane (Figure S4) after 5 days are shown below.

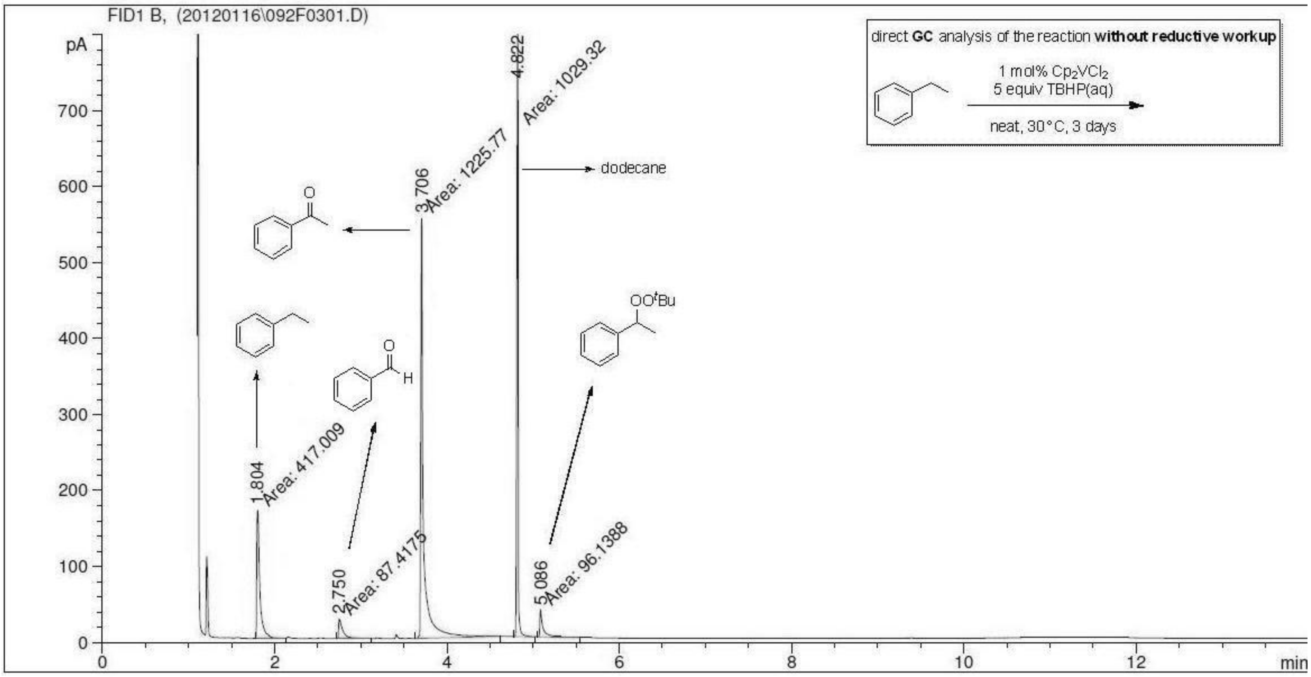


Figure S1 GC chromatogram of the oxidation of ethylbenzene after 3 days

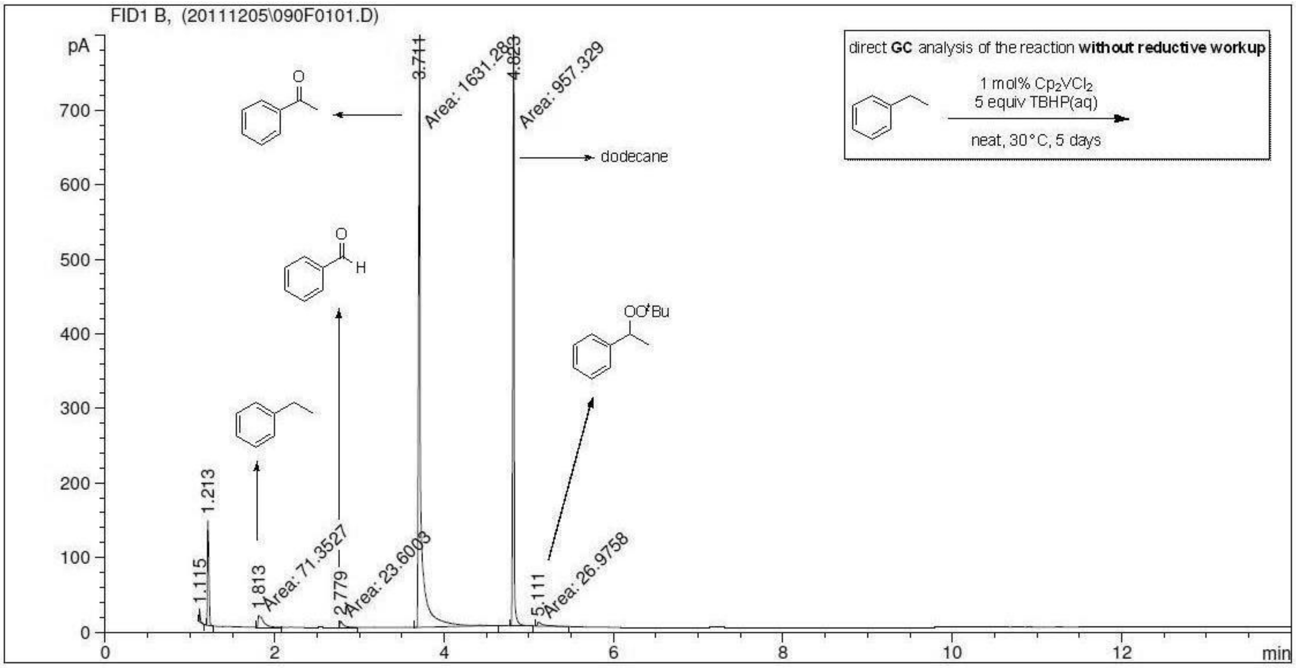


Figure S2 GC chromatogram of the oxidation of ethylbenzene after 5 days

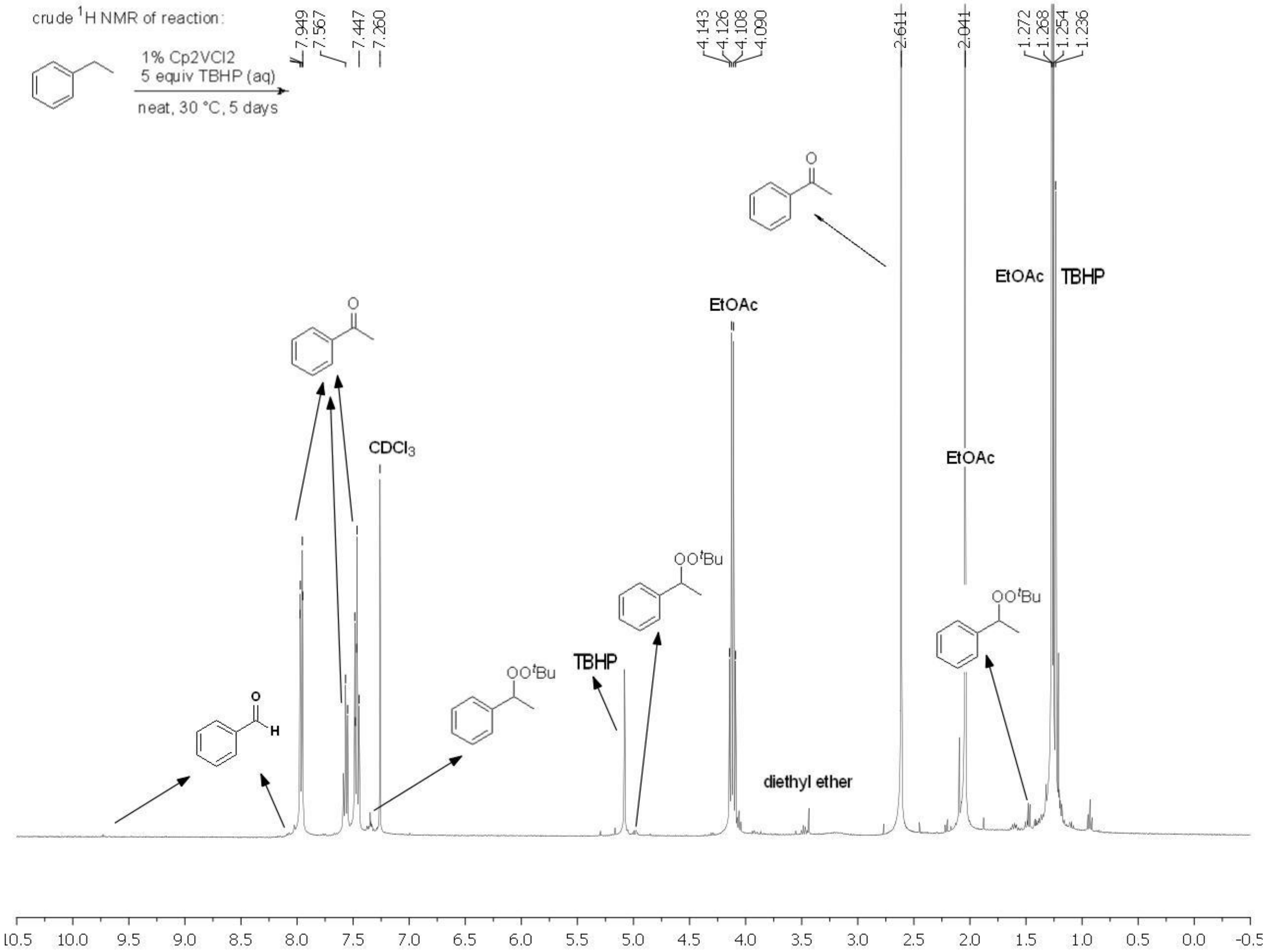


Figure S3 ^{1}H NMR spectrum of the oxidation of ethylbenzene after 5 days

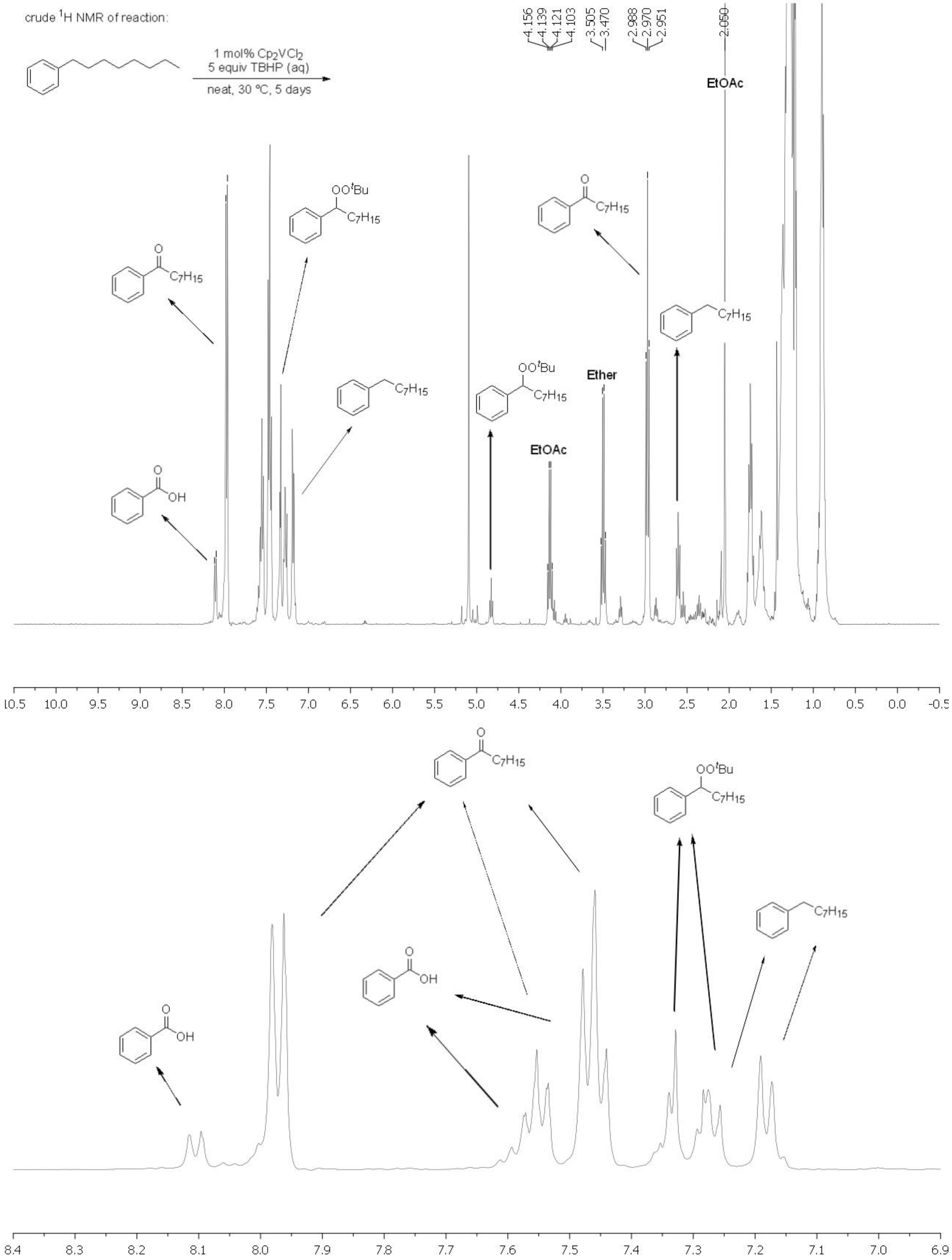
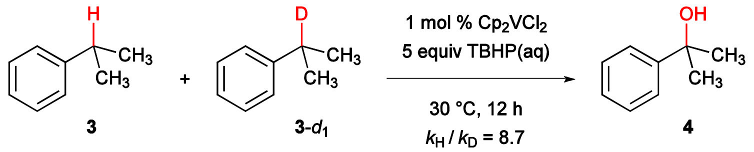


Figure S4 ^{1}H NMR spectra of the oxidation of phenyloctane after 5 days

Kinetic Isotope Effect Study



A mixture of cumene (**3**) (99%, 60.1 mg, 0.5 mmol, 0.5 equiv) and *d*-cumene (**3**-*d*$_1$) (99%, 60.6 mg, 0.5 mmol, 0.5 equiv) was oxidized with vanadocene dichloride (2.5 mg, 0.01 mmol, 0.01 equiv) and *tert*-butyl hydroperoxide (70% in water, 720 μL, 5.0 mmol, 5.0 equiv) according to the general procedure. The sample of cumene (**3**) contained ca. 0.015% **3**-*d*$_1$ based on natural abundance, and the sample of *d*-cumene (**3**-*d*$_1$) contained 2.8% **3** based on ^{1}H NMR according to C/D/N Isotopes (2.6% according to our analysis). After 12 h, the crude reaction mixture was homogenized by adding ether (40 mL) followed by the external standard dodecane (101.8 mg, 0.6 mmol, 0.6 equiv). Four aliquotes (500 μL each) were taken and analyzed by GC to determine the reaction conversion (Table S1). A flame ionization detector (FID) was used in the GC analysis and the relative response factor of cumene (**3**) and dodecane has been determined for quantitative analysis (Figure S5). The remaining crude reaction mixture was concentrated and purified directly without workup by flash column chromatography (pentane) to recover **3** and **3**-*d*$_1$, which was analyzed by ^{1}H NMR to determine the deuterium content (Figure S6). The ^{1}H NMR spectrum was recorded in CD_3CN with ^{13}C decoupling to remove satellite signals. The signals were collected at 90° pulse (10.7 μs) and with 8 × [longest T1 (7.5 s)] as the relaxation delay (d1 = 60 s) and an acquisition time of 2.56 s (nt = 256). The data was processed with baseline correction and zero filling. The ratio of **3** and **3**-*d*$_1$ was determined by comparing the integration of the benzylic peak (1H, **3** only) and the aromatic peaks (5H, **3** and **3**-*d*$_1$) (Figure S6). The error of the ^{1}H NMR integration was determined to be 0.3% based on the ^{1}H NMR of **3**/**3**-*d*$_1$ before reaction (Table S2). Assuming that the catalyst concentration did not change significantly over this period of time, the KIE value was then calculated to be 8.7 according to the following equations.

$$\frac{d[\mathrm{H}]}{dt} = -k_{\mathrm{H}}[\mathrm{cat}^*][\mathrm{H}]$$

$$\int_0^t \frac{d[\mathrm{H}]}{[\mathrm{H}]} = \int_0^t -k_{\mathrm{H}}[\mathrm{cat}^*]dt \approx -k_{\mathrm{H}}\, c \int_0^t dt$$

$$ln\frac{[\mathrm{H}]_t}{[\mathrm{H}]_0} = -k_{\mathrm{H}}ct$$

$$\frac{d[\mathrm{D}]}{dt} = -k_{\mathrm{D}}[\mathrm{cat}^*][\mathrm{D}]$$

$$\int_0^t \frac{d[\mathrm{D}]}{[\mathrm{D}]} = \int_0^t -k_{\mathrm{D}}[\mathrm{cat}^*]dt \approx -k_{\mathrm{D}}\, c \int_0^t dt$$

$$ln\frac{[\mathrm{D}]_t}{[\mathrm{D}]_0} = -k_{\mathrm{D}}ct$$

$$\frac{k_{\mathrm{H}}}{k_{\mathrm{D}}} = \frac{ln\left({[\mathrm{H}]_t}/{[\mathrm{H}]_0}\right)}{ln\left({[\mathrm{D}]_t}/{[\mathrm{D}]_0}\right)}$$

Table S1 Determination of the kinetic isotope effects.

Remaining amount of **3**/**3**-d_1				**3**:**3**-d_1 (mol ratio)		KIE
Run	Result	Average	Standard error	Before reaction	After reaction	
1	76.2%	77.0%	0.6%	0.514 : 0.486	0.311 : 0.459	8.7
2	77.5%					
3	76.9%					
4	77.4%					

Table S2 Determination of the error in the ^{1}H NMR measurement of deuterium content.

	Weight	MW	mmol	D content	Corrected mmol	NMR analysis	% error
3	60.1 mg	120.19	0.500	0.015%	0.514	0.515	0.3%
3-d_1	60.6 mg	121.20	0.500	97.2%	0.486	0.485	

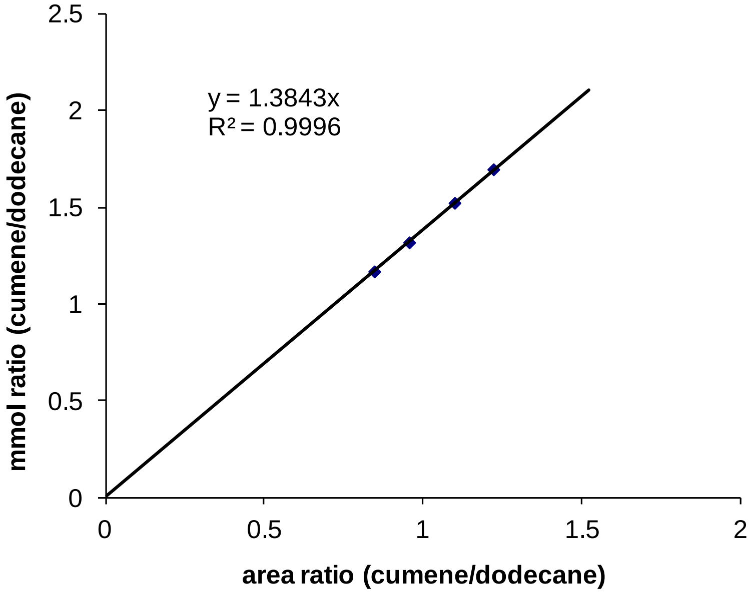


Figure S5 Relative GC response factor of cumene (**3**) and dodecane

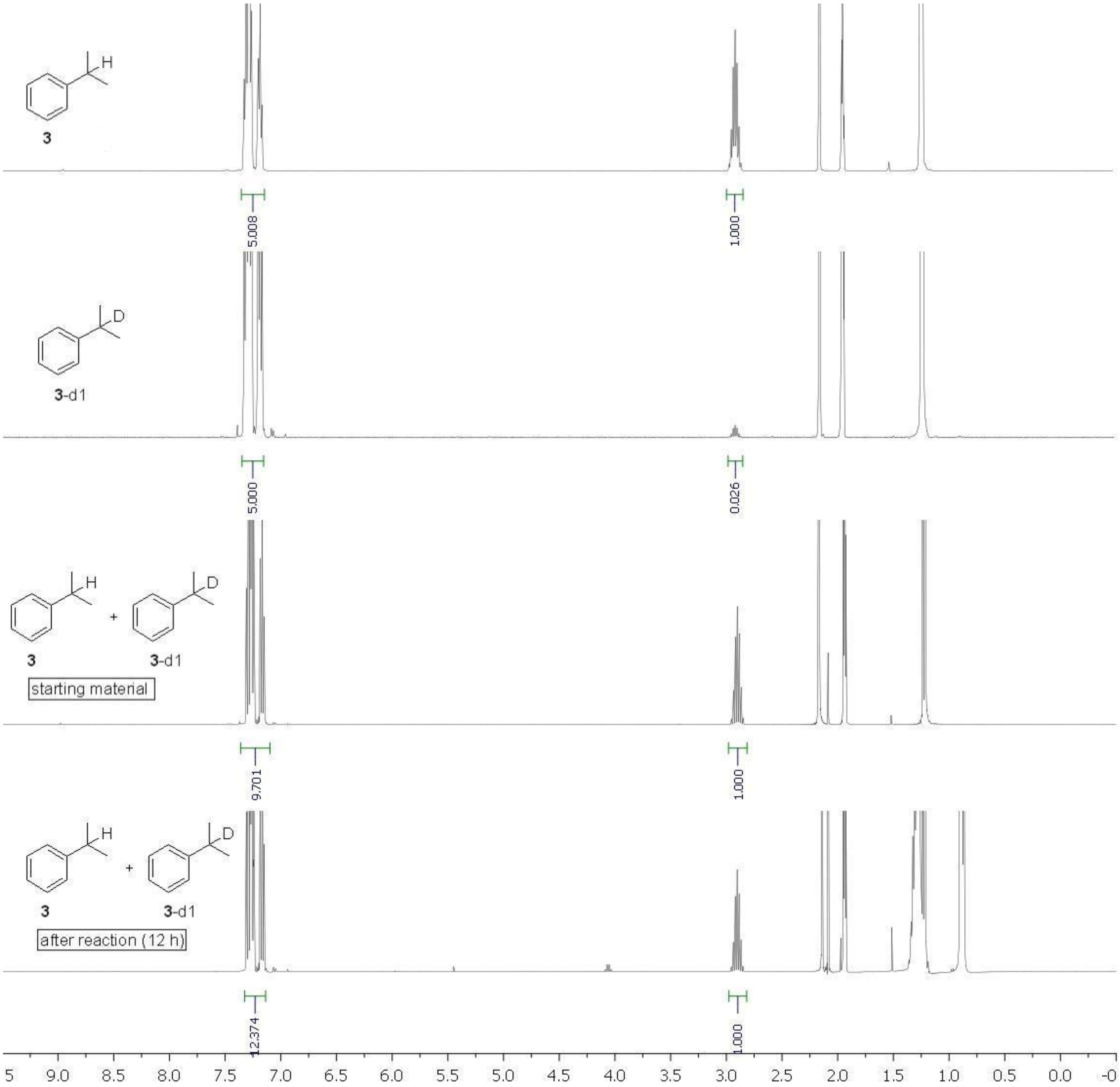
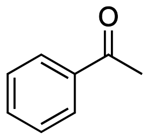
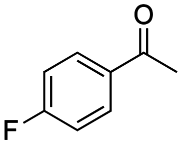


Figure S6 ^{1}H NMR spectra of the KIE study

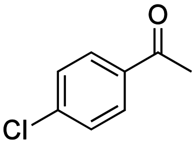
Characterization Data



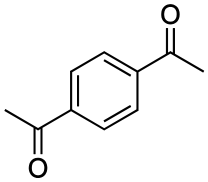
Acetophenone. Oxidation of ethylbenzene (105.2 mg, 1.0 mmol, 1.0 equiv) according to the general procedure and purified directly by flash column chromatography (7% diethyl ether/pentane) gave acetophenone (108 mg, 90% yield) as a colorless oil. ^{1}H NMR (400 MHz, CDCl$_3$) δ 7.95-7.97 (m, 2H), 7.55-7.59 (m, 1H), 7.45-7.48 (m, 2H), 2.61 (s, 3H); MS(ESI)$^+$ calcd for C_8H_9O (M+H)$^+$ 121.1, found 121.1.



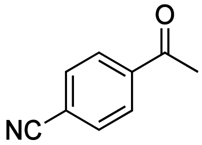
1-(4-Fluorophenyl)ethanone. Oxidation of 1-ethyl-4-fluorobenzene (124.1 mg, 1.0 mmol, 1.0 equiv) according to the general procedure and purified directly by flash column chromatography (7% diethyl ether/pentane) gave 1-(4-fluorophenyl)ethanone (125 mg, 91% yield) as a colorless oil. ^{1}H NMR (400 MHz, CDCl$_3$) δ 7.97-8.00 (m, 2H), 7.11-7.15 (m, 2H), 2.59 (s, 3H); MS(ESI)$^+$ calcd for C_8H_8FO (M+H)$^+$ 139.0, found 139.1.



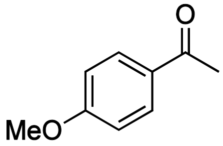
1-(4-Chlorophenyl)ethanone. Oxidation of 1-chloro-4-ethylbenzene (138.0 mg, 1.0 mmol, 1.0 equiv) according to the general procedure and purified by flash column chromatography (2% ethyl acetate/hexanes) gave 1-(4-chlorophenyl)ethanone (131 mg, 86% yield) as a colorless oil. ^{1}H NMR (400 MHz, CDCl$_3$) δ 7.89 (d, J = 8.5 Hz, 2H), 7.43 (d, J = 8.5 Hz, 2H), 2.59 (s, 3H); MS(ESI)$^+$ calcd for C_8H_8ClO (M+H)$^+$ 155.0, found 155.1.



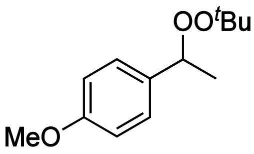
1,1'-(1,4-Phenylene)diethanone. Oxidation of 1-(4-ethylphenyl)ethanone (148.2 mg, 1.0 mmol, 1.0 equiv) according to the general procedure and purified by flash column chromatography (15% ethyl acetate/hexanes) to give 1,1'-(1,4-phenylene)diethanone (144 mg, 89% yield) as a white solid. ^{1}H NMR (400 MHz, CDCl$_3$) δ 8.03 (s, 4H), 2.65 (s, 6H); MS(ESI)$^+$ calcd for $C_{10}H_{11}O_2$ (M+H)$^+$ 163.1, found 163.1.



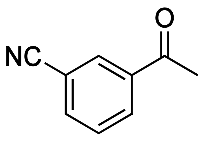
4-Acetylbenzonitrile. Oxidation of 4-ethylbenzonitrile (129.7 mg, 1.0 mmol, 1.0 equiv) according to the general procedure and purified by flash column chromatography (10% ethyl acetate/hexanes) gave 4-acetylbenzonitrile (110 mg, 77% yield) as a colorless oil. ^{1}H NMR (400 MHz, CDCl$_3$) δ 8.04 (d, J = 8.4 Hz, 2H), 7.78 (d, J = 8.4 Hz, 2H), 2.65 (s, 3H); MS(ESI)$^+$ calcd for C_9H_8NO (M+H)$^+$ 146.1, found 146.2.



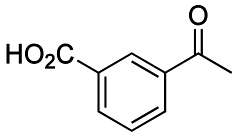
1-(4-Methoxyphenyl)ethanone. Oxidation of 1-ethyl-4-methoxybenzene (136.2 mg, 1.0 mmol, 1.0 equiv) according to the general procedure and purified by flash column chromatography (5% ethyl acetate/hexanes) gave 1-(4-methoxyphenyl)-ethanone (81 mg, 54% yield) as a colorless oil, and 1-(1-(*tert*-butylperoxy)ethyl)-4-methoxybenzene (65 mg, 29% yield) as a colorless oil. ^{1}H NMR (400 MHz, CDCl$_3$) δ 7.93 (d, J = 8.7 Hz, 2H), 6.93 (d, J = 8.7 Hz, 2H), 3.87 (s, 3H), 2.55 (s, 3H); MS(ESI)$^+$ calcd for $C_9H_{11}O_2$ (M+H)$^+$ 151.1, found 151.2.



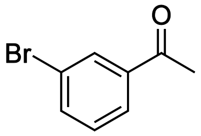
1-(1-(*tert*-Butylperoxy)ethyl)-4-methoxybenzene. ^{1}H NMR (400 MHz, CDCl$_3$) δ 7.29 (d, J = 8.3 Hz, 2H), 6.88 (d, J = 8.3 Hz, 2H), 4.95 (q, J = 6.5 Hz, 1H), 3.80 (s, 3H), 1.48 (d, J = 6.5 Hz, 3H), 1.21 (s, 9H); ^{13}C NMR (100 MHz, CDCl$_3$): δ 20.1, 26.5, 55.2, 80.0, 81.1, 113.6, 128.1, 134.0, 159.2; MS(ESI)$^+$ calcd for $C_{13}H_{20}O_3Na$ (M+Na)$^+$ 247.1, found 247.2.



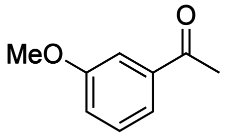
3-Acetylbenzonitrile. Oxidation of 3-ethylbenzonitrile (131.2 mg, 1.0 mmol, 1.0 equiv) according to the general procedure and purified by flash column chromatography (20% ethyl acetate/hexanes) gave 3-acetylbenzonitrile (123 mg, 85% yield) as a white solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.24 (s, 1H), 8.18 (d, *J* = 7.9 Hz, 1H), 7.85 (d, *J* = 7.7 Hz, 1H), 7.62 (dd, *J* = 7.9, 7.7 Hz, 1H), 2.64 (s, 3H); MS(ESI)$^+$ calcd for C_9H_8NO $(M+H)^+$ 146.1, found 146.1.



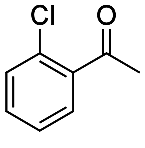
3-Acetylbenzoic acid. Oxidation of 3-ethylbenzoic acid (151.0 mg, 1.0 mmol, 1.0 equiv) according to the general procedure and purified by flash column chromatography (5% methanol/dichloromethane) gave 3-acetylbenzoic acid (150 mg, 91% yield) as a white solid. ^{1}H NMR (400 MHz, DMSO-d_6) δ 13.35 (brs, 1H), 8.45 (s, 1H), 8.17-8.20 (m, 2H), 7.67 (dd, *J* = 7.7, 7.7 Hz, 1H), 2.63 (s, 3H); MS(ESI)$^+$ calcd for $C_9H_9O_3$ $(M+H)^+$ 165.0, found 165.1.



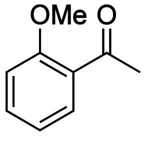
1-(3-Bromophenyl)ethanone. Oxidation of 1-bromo-3-ethylbenzene (186.0 mg, 1.0 mmol, 1.0 equiv) according to the general procedure and purified directly by flash column chromatography (5% diethyl ether/pentane) gave 1-(3-bromophenyl)ethanone (179 mg, 90% yield) as a colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.08 (dd, *J* = 1.2, 1.6 Hz, 1H), 7.88 (d, *J* = 7.8 Hz, 1H), 7.69 (dd, *J* = 0.8, 7.9 Hz, 1H), 7.35 (dd, *J* = 7.9, 7.8 Hz, 1H), 2.60 (s, 3H); MS(ESI)$^+$ calcd for C_8H_8BrO $(M+H)^+$ 199.0, found 199.0.



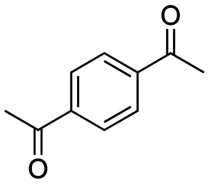
1-(3-Methoxyphenyl)ethanone. Oxidation of 1-ethyl-3-methoxybenzene (133.0 mg, 1.0 mmol, 1.0 equiv) according to the general procedure and purified directly by flash column chromatography (5% diethyl ether/pentane) gave 1-(3-methoxyphenyl)ethanone (117 mg, 80% yield) as a colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.53-5.55 (m, 1H), 7.48-7.49 (m, 1H), 7.37 (dd, *J* = 8.0, 7.6 Hz, 1H), 7.10-7.13 (m, 1H), 3.86 (s, 3H), 2.60 (s, 3H); MS(ESI)$^+$ calcd for $C_9H_{11}O_2$ $(M+H)^+$ 151.1, found 151.1.



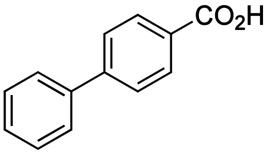
1-(2-Chlorophenyl)ethanone. Oxidation of 1-chloro-2-ethylbenzene (140.2 mg, 1.0 mmol, 1.0 equiv) according to the general procedure and purified directly by flash column chromatography (3% diethyl ether/pentane) gave 1-(2-chlorophenyl)ethanone (80 mg, 52% yield) as a colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.55 (dd, *J* = 1.6, 7.6 Hz, 1H), 7.30-7.41 (m, 3H), 2.65 (s, 3H); MS(ESI)$^+$ calcd for C_8H_8ClO $(M+H)^+$ 155.0, found 155.1.



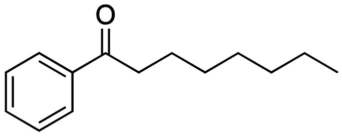
1-(2-Methoxyphenyl)ethanone. Oxidation of 1-ethyl-2-methoxybenzene (138.0 mg, 1.0 mmol, 1.0 equiv) according to the general procedure and purified directly by flash column chromatography (3% diethyl ether/pentane) gave 1-(2-methoxyphenyl)ethanone (103 mg, 68% yield) as a colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.73 (dd, *J* = 1.8, 7.7 Hz, 1H), 7.44-7.49 (m, 1H), 6.96-7.01 (m, 2H), 3.91 (s, 3H), 2.61 (s, 3H); MS(ESI)$^+$ calcd for $C_9H_{11}O_2$ $(M+H)^+$ 151.1, found 151.1.



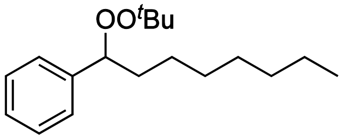
1,1'-(1,4-Phenylene)diethanone. Oxidation of 1,4-diethylbenzene (133.8 mg, 1.0 mmol, 1.0 equiv) according to the general procedure but with 2 mol % vanadocene dichloride (5.0 mg, 0.02 mmol, 0.02 equiv) and 10 equiv *tert*-butyl hydroperoxide (70% in water, 1440 μL, 10.0 mmol, 10.0 equiv), and purified by flash column chromatography (15% ethyl acetate/hexanes) gave 1,1'-(1,4-phenylene)diethanone (140 mg, 86% yield) as a white solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.03 (s, 4H), 2.65 (s, 6H); MS(ESI)$^+$ calcd for $C_{10}H_{11}O_2$ $(M+H)^+$ 163.1, found 163.1.



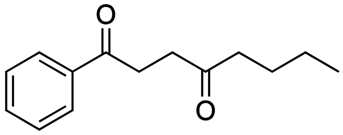
[1,1'-Biphenyl]-4-carboxylic acid. Oxidation of 4-methyl-1,1'-biphenyl (168.5 mg, 1.0 mmol, 1.0 equiv) according to the general procedure and purified by flash column chromatography (4% ethyl acetate/hexanes) gave [1,1'-biphenyl]-4-carboxylic acid (108 mg, 54% yield) as a white solid. In a separate run with an addition of acetonitrile (0.2 mL) as solvent, the acid product was isolated in 60% yield. ^{1}H NMR (400 MHz, DMSO-d_6) δ 12.99 (brs, 1H), 8.02 (d, J = 8.2 Hz, 2H), 7.80 (d, J = 8.2 Hz, 2H), 7.73 (d, J = 7.6 Hz, 2H), 7.50 (dd, J = 7.6, 7.6 Hz, 2H), 7.40-7.44 (m, 1H); MS(ESI)$^+$ calcd for $C_{13}H_{11}O_2$ (M+H)$^+$ 199.1, found 199.2.



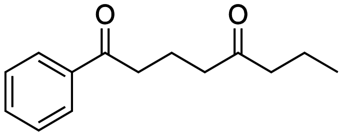
1-Phenyloctan-1-one. Oxidation of 1-phenyloctane (190.3 mg, 1.0 mmol, 1.0 equiv) according to the general procedure and purified by flash column chromatography (1→4% ethyl acetate/hexanes) gave 1-phenyloctan-1-one (116 mg, 57% yield) as a colorless oil, (1-(*tert*-butylperoxy)octyl)benzene (26 mg, 9% yield) as a colorless oil, 1-phenyloctane-1,4-dione (7 mg, 3% yield) as a colorless oil, 1-phenyloctane-1,5-dione (2 mg, 1% yield) as a colorless oil, 1-phenyloctane-1,6-dione (2 mg,1% yield) as a colorless oil, benzoic acid (11 mg, 10% yield), and recovered 1-phenyloctane (25 mg, 13% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.96-7.94 (m, 2H), 7.52-7.56 (m, 1H), 7.43-7.46 (m, 2H), 2.95 (t, J = 7.4 Hz, 2H), 1.70-1.77 (m, 2H), 1.26-1.35 (m, 8H), 0.88 (t, J = 6.6 Hz, 3H); MS(ESI)$^+$ calcd for $C_{14}H_{21}O$ (M+H)$^+$ 205.2, found 205.1.



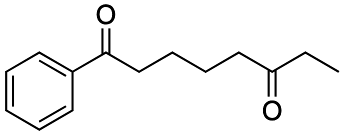
(1-(*tert*-Butylperoxy)octyl)benzene. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.27-7.36 (m, 5H), 4.82 (t, J = 6.9 Hz, 1H), 1.86-1.91 (m, 1H), 1.61-1.67 (m, 1H), 1.21-1.27 (m, 10H), 1.21 (s, 9H), 0.88 (t, J = 6.9 Hz, 3H); ^{13}C NMR (125 MHz, $CDCl_3$): δ 14.1, 22.6, 25.9, 26.5, 29.1, 29.6, 31.8, 35.1, 80.1, 86.1, 126.9, 127.4, 128.1, 141.9; MS(ESI)$^+$ calcd for $C_{18}H_{31}O_2$ (M+H)$^+$ 279.2, found 279.2.



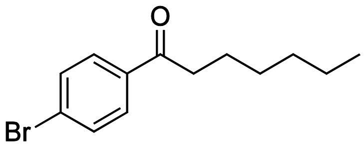
1-Phenyloctane-1,4-dione. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.97-7.99 (m, 2H), 7.55-7.58 (m, 1H), 7.44-7.48 (m, 2H), 3.28 (t, J = 6.3 Hz, 2H), 2.86 (t, J = 6.3 Hz, 2H), 2.53 (t, J = 7.5 Hz, 2H), 1.57-1.63 (m, 2H), 1.32-1.37 (m, 2H), 0.92 (t, J = 7.3 Hz, 3H); MS(ESI)$^+$ calcd for $C_{14}H_{19}O_2$ (M+H)$^+$ 219.1, found 219.1.



1-Phenyloctane-1,5-dione. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.95-7.97 (m, 2H), 7.54-7.58 (m, 1H), 7.44-7.48 (m, 2H), 3.01 (t, J = 7.0 Hz, 2H), 2.54 (t, J = 7.0 Hz, 2H), 2.39 (t, J = 7.4 Hz, 2H), 2.00-2.04 (m, 2H), 1.55-1.63 (m, 2H), 0.91 (t, J = 7.4 Hz, 3H); MS(ESI)$^+$ calcd for $C_{14}H_{19}O_2$ (M+H)$^+$ 219.1, found 219.0.

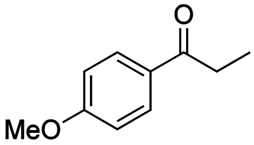


1-Phenyloctane-1,6-dione. ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.94-7.96 (m, 2H), 7.54-7.57 (m, 1H), 7.45-7.48 (m, 2H), 2.99 (t, J = 7.1 Hz, 2H), 2.47 (t, J = 7.3 Hz, 2H), 2.43 (q, J = 7.4 Hz, 2H), 1.65-1.77 (m, 4H), 1.05 (t, J = 7.3 Hz, 3H); MS(ESI)$^+$ calcd for $C_{14}H_{19}O_2$ (M+H)$^+$ 219.1, found 219.1.

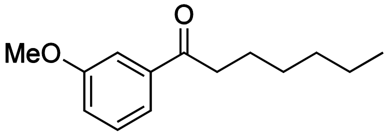


1-(4-Bromophenyl)heptan-1-one. Oxidation of 1-bromo-4-heptylbenzene (254.6 mg, 1.0 mmol, 1.0 equiv) according to the general procedure and purified by flash column chromatography (2% ethyl acetate/hexanes) gave 1-(4-bromophenyl)heptan-1-one (137 mg, 51%

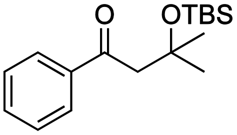
yield) as a white solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.82 (d, J = 8.5 Hz, 2H), 7.60 (d, J = 8.5 Hz, 2H), 2.92 (t, J = 7.4 Hz, 2H), 1.68-1.75 (m, 2H), 1.29-1.39 (m, 6H), 0.89 (t, J = 6.7 Hz, 3H); MS(ESI)$^+$ calcd for $C_{13}H_{18}BrO$ $(M+H)^+$ 269.0, found 269.1.



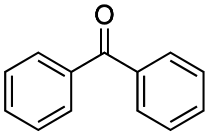
1-(4-Methoxyphenyl)propan-1-one. Oxidation of 1-methoxy-4-propylbenzene (150.0 mg, 1.0 mmol, 1.0 equiv) according to the general procedure and purified by flash column chromatography (2% ethyl acetate/hexanes) gave 1-(4-methoxyphenyl)propan-1-one (81 mg, 49% yield) as a colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.95 (d, J = 8.9 Hz, 2H), 6.93 (d, J = 8.9 Hz, 2H), 3.86 (s, 3H), 2.95 (q, J = 7.3 Hz, 2H), 1.21 (t, J = 7.3 Hz, 3H); MS(ESI)$^+$ calcd for $C_{10}H_{13}O_2$ $(M+H)^+$ 165.1, found 165.1.



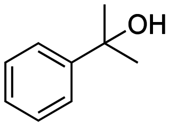
1-(3-Methoxyphenyl)heptan-1-one. Oxidation of 1-heptyl-3-methoxybenzene (205.8 mg, 1.0 mmol, 1.0 equiv) according to the general procedure and purified by flash column chromatography (5% ethyl acetate/hexanes) gave 1-(3-methoxyphenyl)heptan-1-one (113 mg, 50% yield) as a white solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.53 (d, J = 7.8 Hz, 1H), 7.49 (d, J = 2.0 Hz, 1H), 7.36 (dd, J = 7.8, 8.0 Hz, 1H), 7.09 (dd, J = 2.0, 8.0 Hz, 1H), 3.85 (s, 3H), 2.94 (t, J = 7.4 Hz, 2H), 1.69-1.76 (m, 2H), 1.31-1.39 (m, 6H), 0.89 (t, J = 6.7 Hz, 3H); MS(ESI)$^+$ calcd for $C_{14}H_{21}O_2$ $(M+H)^+$ 221.1, found 221.1.



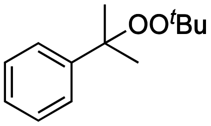
3-((*tert*-Butyldimethylsilyl)oxy)-3-methyl-1-phenylbutan-1-one. Oxidation of 2-methyl-4-phenylbutan-2-ol (165.0 mg, 1.0 mmol, 1.0 equiv) according to the general procedure and purified by flash column chromatography (5→15% ethyl acetate/hexanes) gave an inseparable mixture of recovered starting material and the benzylic oxidation product 3-hydroxy-3-methyl-1-phenylbutan-1-one (121 mg), and benzoic acid (11 mg, 9% yield). This mixture was dissolved in methylene chloride (3 mL) and treated with *tert*-butyldimethylsilyl trifluoromethanesulfonate (211.4 mg, 0.8 mmol) and 2,6-lutidine (186 μL, 1.6 mmol) to afford 3-((*tert*-butyldimethylsilyl)oxy)-3-methyl-1-phenylbutan-1-one (146 mg, 50% yield for two steps) as a colorless oil, and 3-((*tert*-butyldimethylsilyl)oxy)-3-methyl-1-phenylbutane (45 mg, 16% yield) as a colorless oil after flash column chromatography (1→5% ethyl acetate/hexanes). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.96 (d, J = 7.6 Hz, 2H), 7.50 (dd, J = 7.3, 7.3 Hz, 1H), 7.41 (dd, J = 7.6, 7.3 Hz, 2H), 3.09 (s, 2H), 1.40 (s, 6H), 0.73 (S, 9H), 0.03 (s, 6H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 2.1, 17.8, 25.6, 30.3, 51.7, 73.6, 128.3, 128.6, 132.6, 138.4, 199.2; MS(ESI)$^+$ calcd for $C_{17}H_{28}O_2SiNa$ $(M+Na)^+$ 315.2, found 315.1.



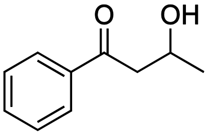
Benzophenone. Oxidation of diphenylmethane (165.0 mg, 1.0 mmol, 1.0 equiv) according to the general procedure and purified by flash column chromatography (2% ethyl acetate/hexanes) gave benzophenone (170 mg, 95% yield) as a white solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.81 (d, J = 7.2 Hz, 4H), 7.59 (dd, J = 7.4, 7.3 Hz, 2H), 7.49 (dd, J = 7.7, 7.5 Hz, 4H); MS(ESI)$^+$ calcd for $C_{13}H_{11}O$ $(M+H)^+$ 183.1, found 183.1.



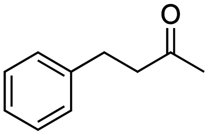
2-Phenylpropan-2-ol. Oxidation of cumene (120.0 mg, 1.0 mmol, 1.0 equiv) according to the general procedure and purified directly by flash column chromatography (3→50% diethyl ether/pentane) gave 2-phenylpropan-2-ol (105 mg, 77% yield) as a colorless oil and (2-(*tert*-butylperoxy)propan-2-yl)benzene (26 mg, 13% yield) as a colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.49 (d, J = 8.0 Hz, 2H), 7.34 (dd, J = 8.0, 7.2 Hz, 2H), 7.22-7.26 (m, 1H), 1.96 (brs, 1H), 1.58 (s, 6H); MS(EI)$^+$ calcd for $C_9H_{12}O$ $(M)^+$ 136.1, found 136.1.



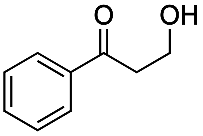
(2-(*tert*-Butylperoxy)propan-2-yl)benzene. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.47 (d, *J* = 7.4 Hz, 2H), 7.31-7.35 (m, 2H), 7.21-7.26 (m, 1H), 1.57 (s, 6H), 1.23 (s, 9H); MS(EI)$^+$ calcd for $C_{13}H_{20}O_2$ (M)$^+$ 208.1, found 208.2.



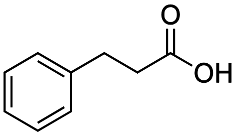
3-Hydroxy-1-phenylbutan-1-one. Oxidation of 4-phenylbutan-2-ol (150.2 mg, 1.0 mmol, 1.0 equiv) according to the general procedure for 3 days and purified by flash column chromatography (10→30% ethyl acetate/hexanes) gave 3-hydroxy-1-phenylbutan-1-one (43 mg, 26% yield) as a colorless oil, 1-phenylbutane-1,3-dione (16 mg, 11%) as a colorless oil, and benzoic acid (22 mg, 18% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.94 (d, *J* = 7.4 Hz, 2H), 7.57 (m, 1H), 7.46 (m, 2H), 4.36-4.44 (m, 1H), 3.40 (brs, 1H), 3.16 (dd, *J* = 2.9, 17.7 Hz, 1H), 3.04 (dd, *J* = 8.8, 17.7 Hz, 1H), 1.29 (d, *J* = 6.4 Hz, 3H); MS(ESI)$^+$ calcd for $C_{10}H_{13}O_2$ (M+H)$^+$ 165.1, found 165.1.



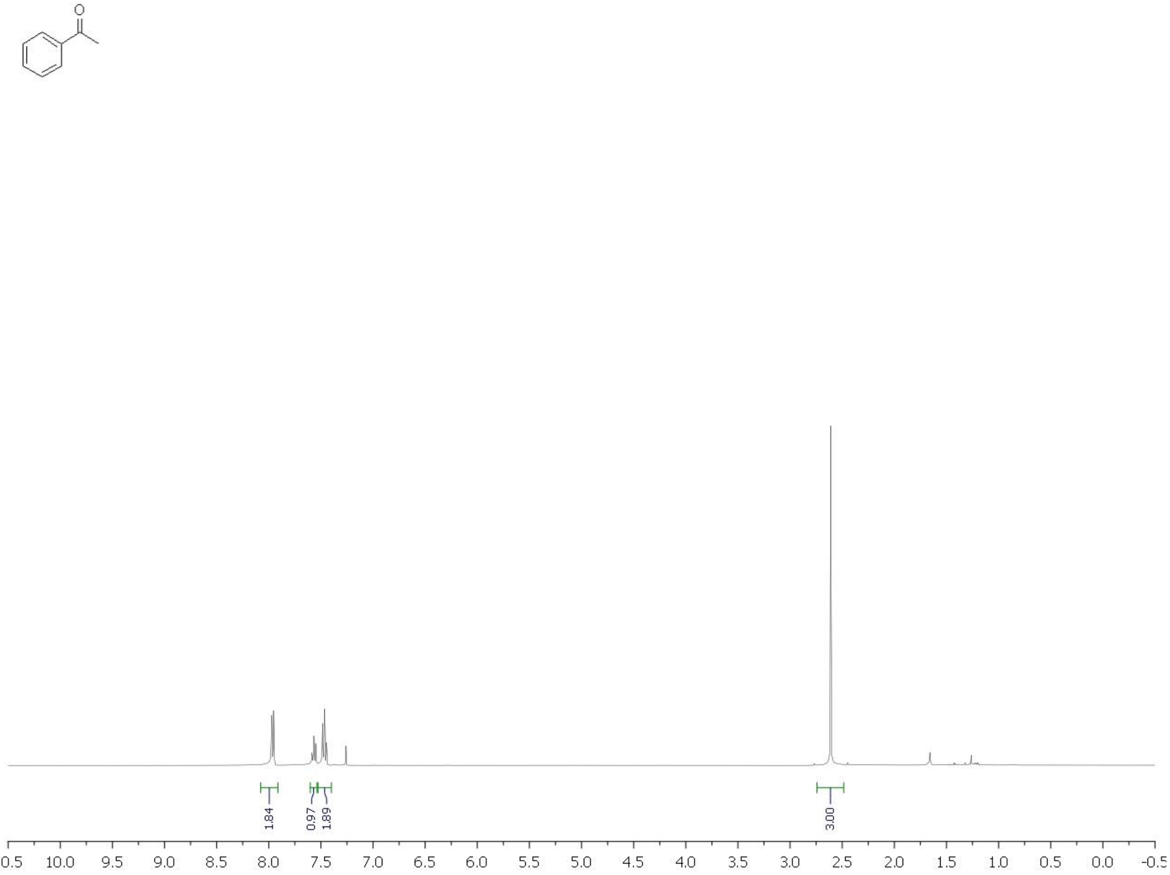
4-Phenylbutan-2-one. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.26-7.31 (m, 2H), 7.18-7.21 (m, 3H), 2.90 (d, *J* = 7.6 Hz, 2H), 2.77 (d, *J* = 7.6 Hz, 2H), 2.14 (s, 3H); MS(ESI)$^+$ calcd for $C_{10}H_{13}O$ (M+H)$^+$ 149.1, found 149.1.



3-Hydroxy-1-phenylpropan-1-one. Oxidation of 3-phenylpropan-1-ol (136.2 mg, 1.0 mmol, 1.0 equiv) according to the general procedure for 3 days and purified by flash column chromatography (10→25% ethyl acetate/hexanes) gave 3-hydroxy-1-phenylpropan-1-one (51 mg, 34% yield) as a colorless oil, 3-phenylpropanoic acid (13 mg, 9%) as a colorless oil, and benzoic acid (15 mg, 12% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.97 (d, *J* = 7.8 Hz, 2H), 7.59 (dd, *J* = 7.3, 7.5 Hz, 1H), 7.48 (dd, *J* = 7.8, 7.5 Hz, 2H), 4.03-4.04 (m, 2H), 3.24 (t, *J* = 5.3 Hz, 3H), 2.68 (brs, 1H); MS(ESI)$^+$ calcd for $C_9H_{11}O_2$ (M+H)$^+$ 151.1, found 151.1.



3-Phenylpropanoic acid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.21-7.33 (m, 5H), 2.97 (t, *J* = 7.8 Hz, 2H), 2.70 (t, *J* = 7.8 Hz, 2H); MS(ESI)$^+$ calcd for $C_9H_{11}O_2$ (M+H)$^+$ 151.1, found 151.1.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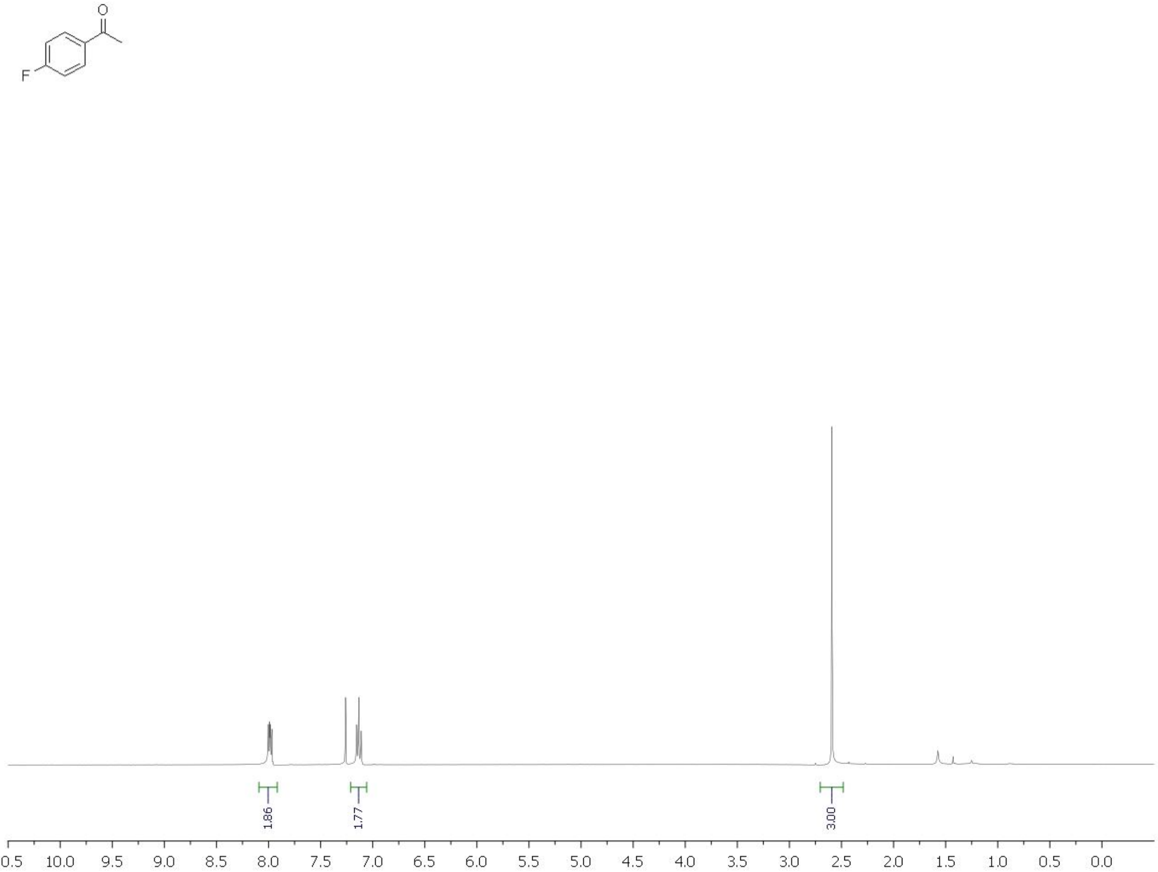
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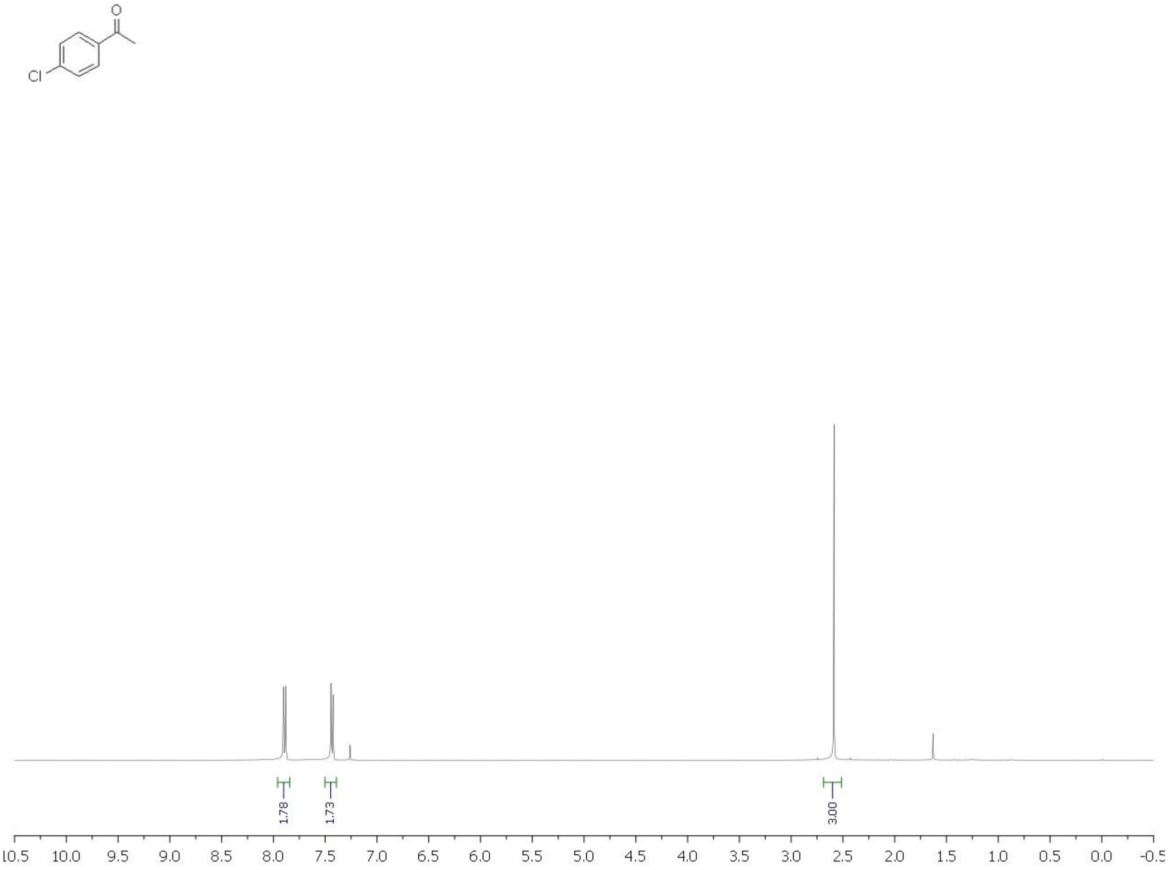
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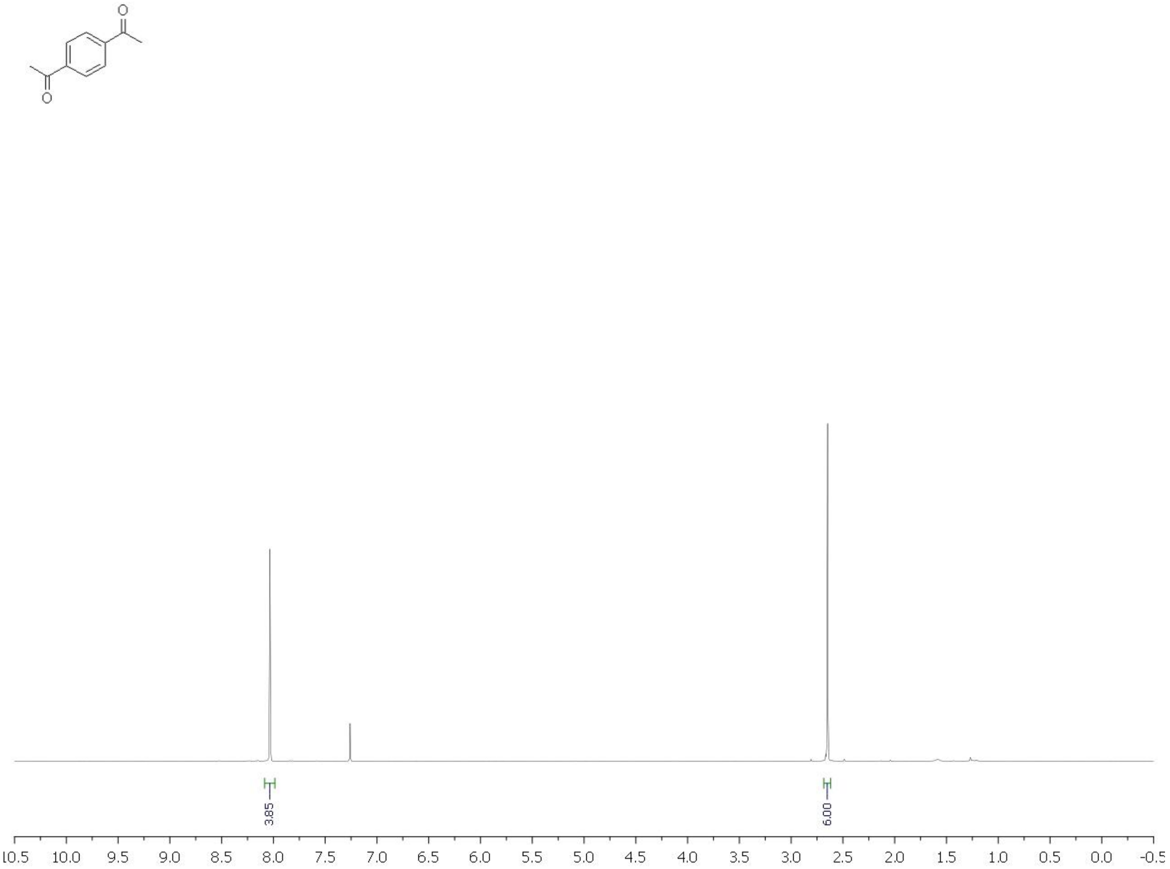
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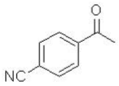
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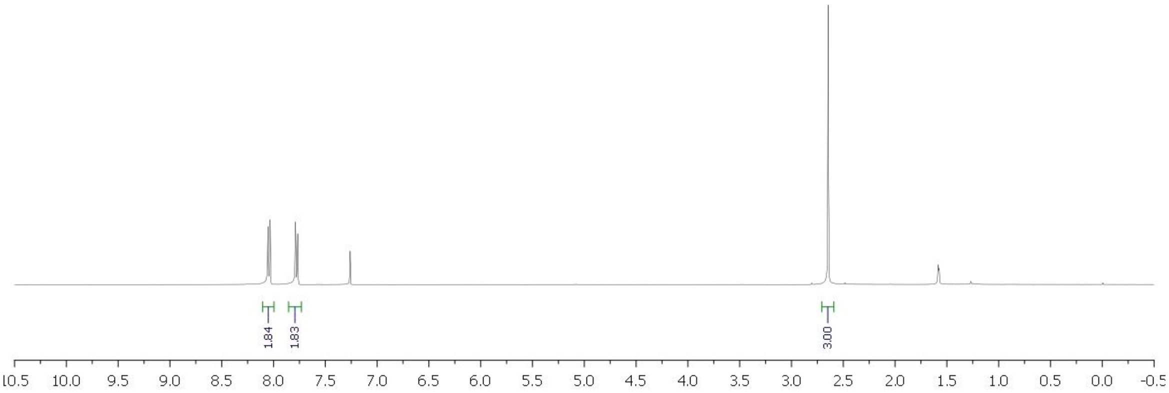
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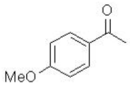
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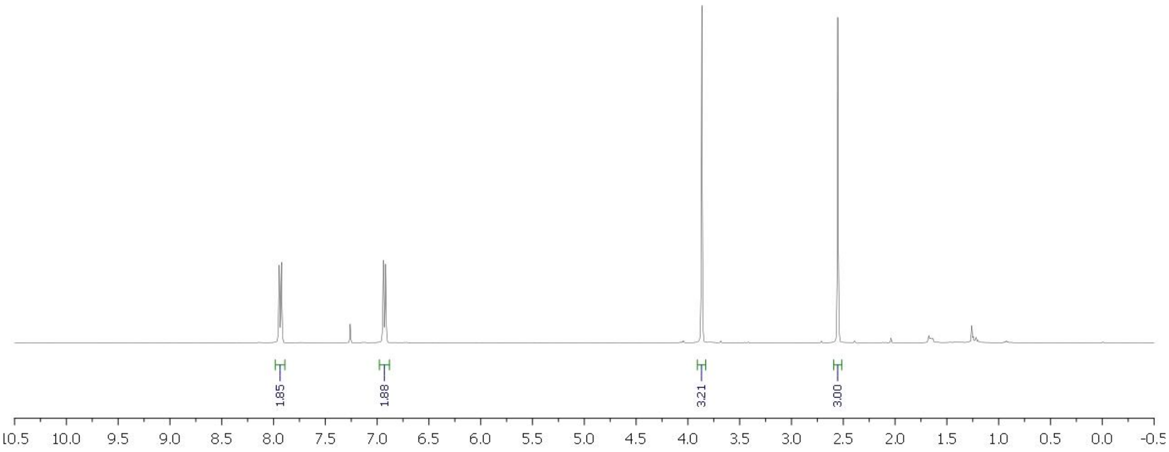
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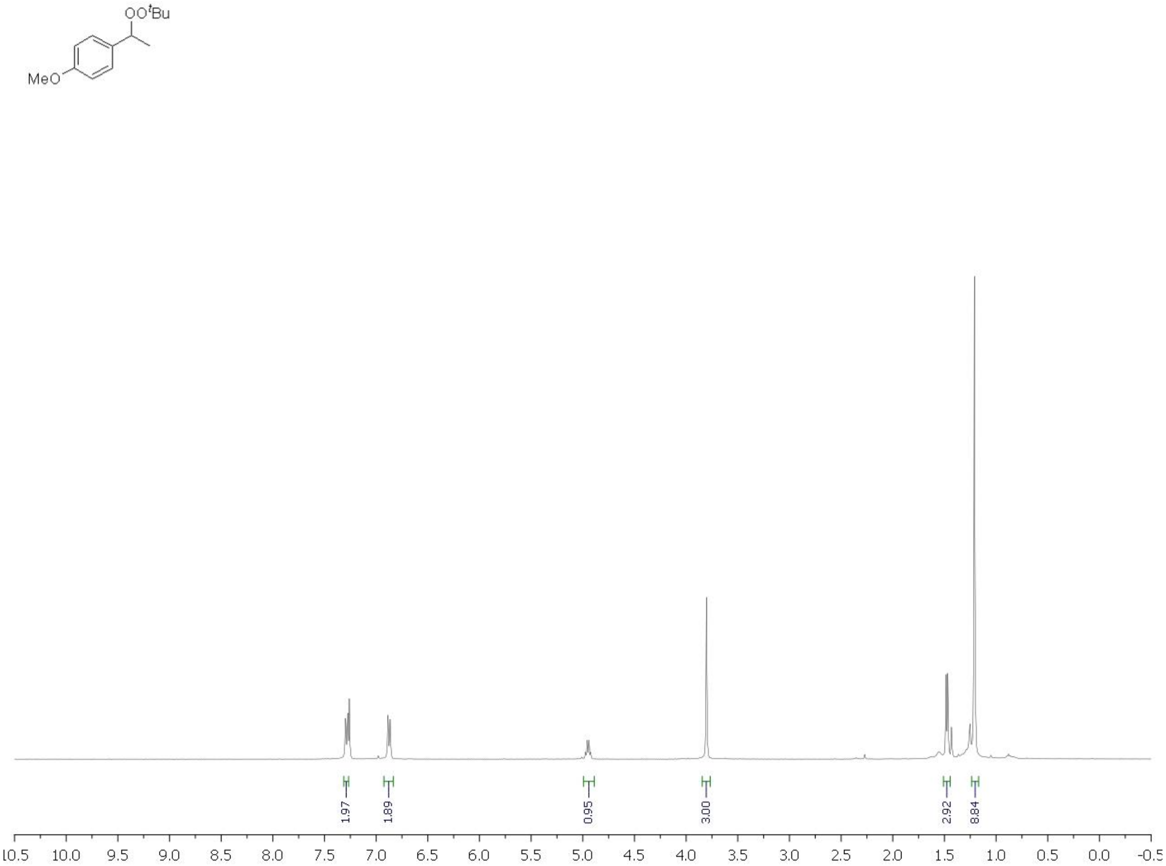
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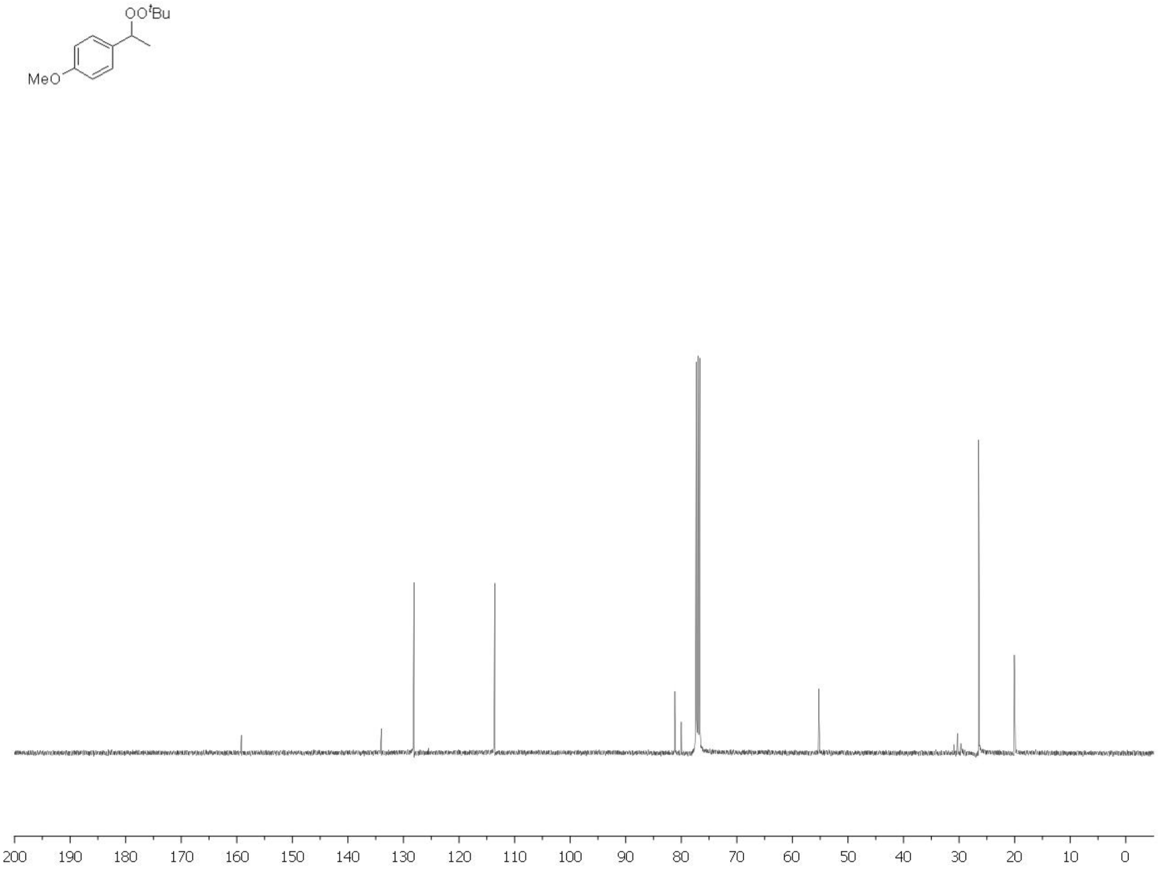
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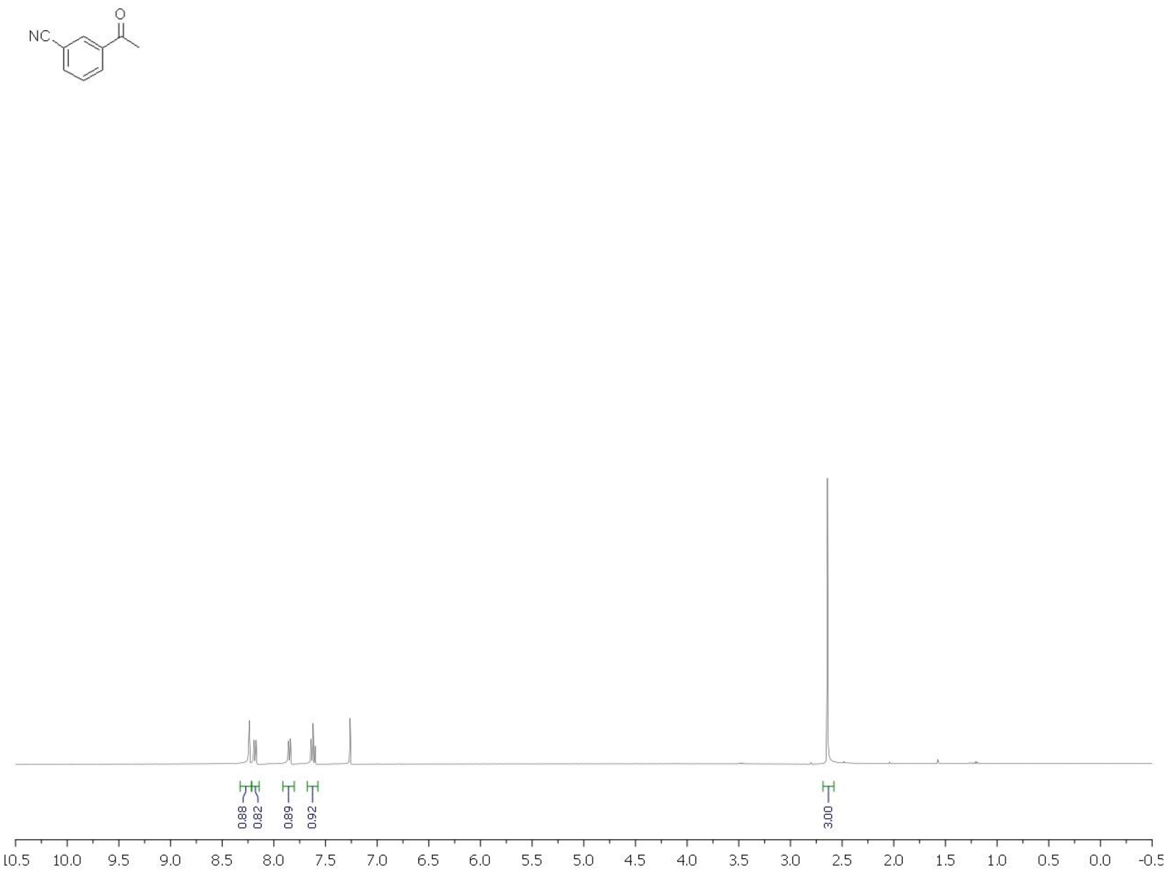
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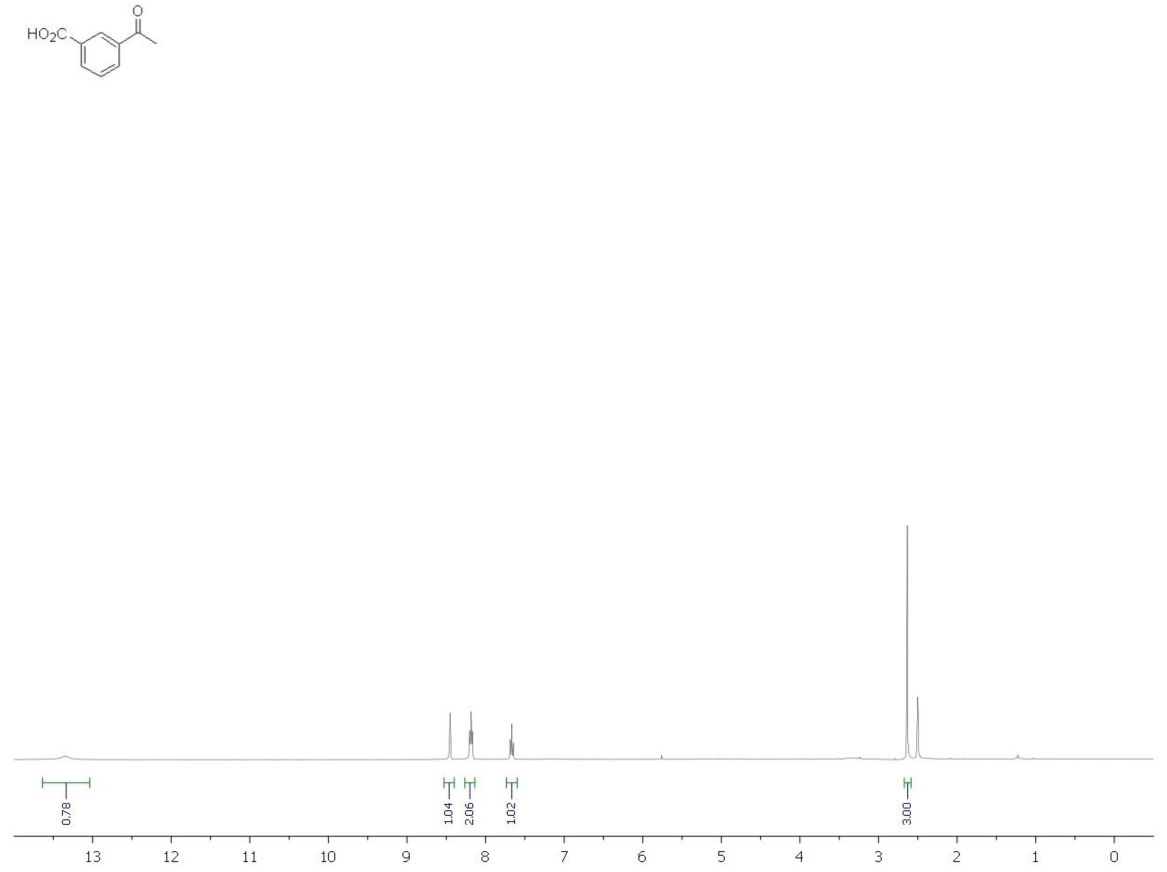
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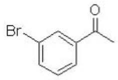
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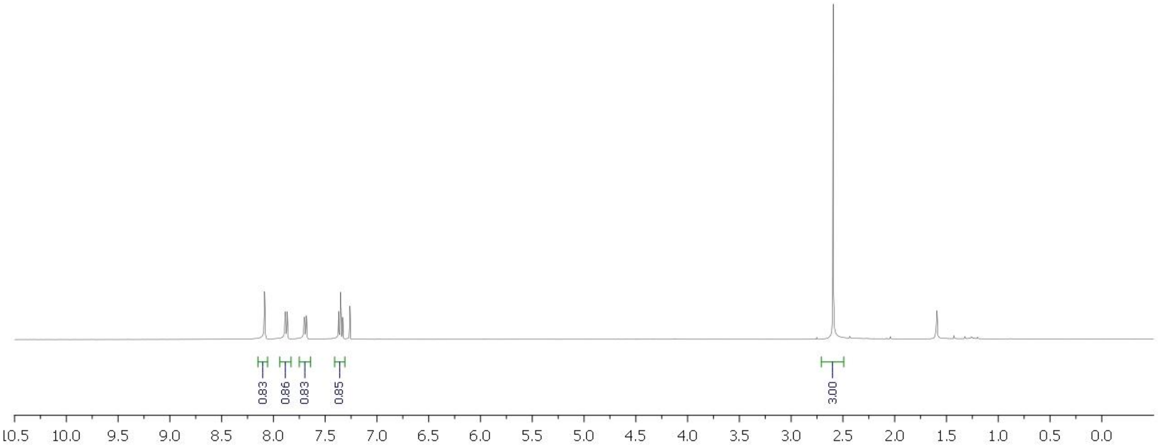
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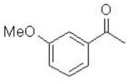
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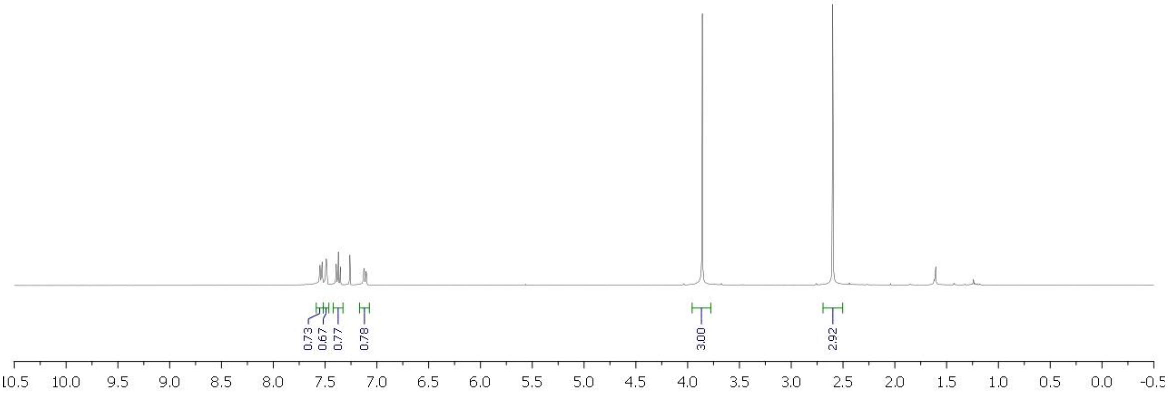
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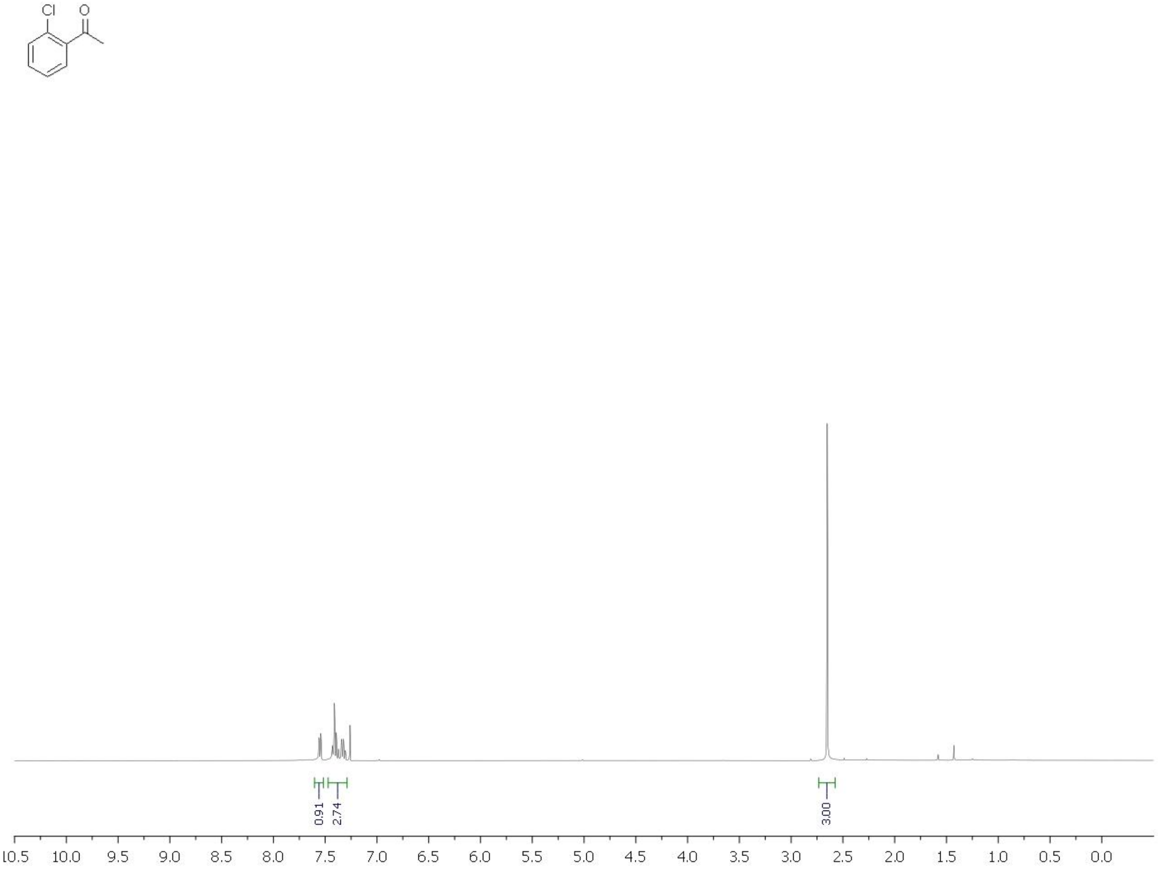
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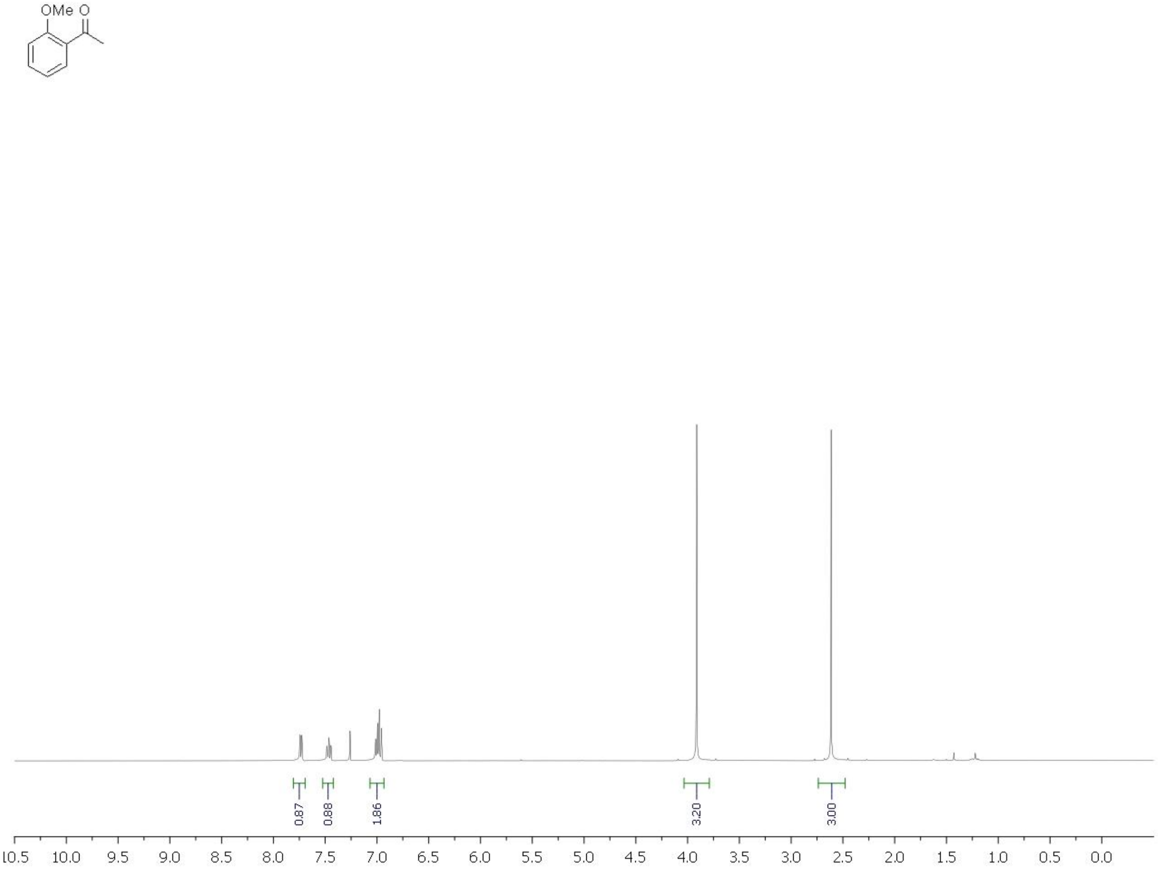
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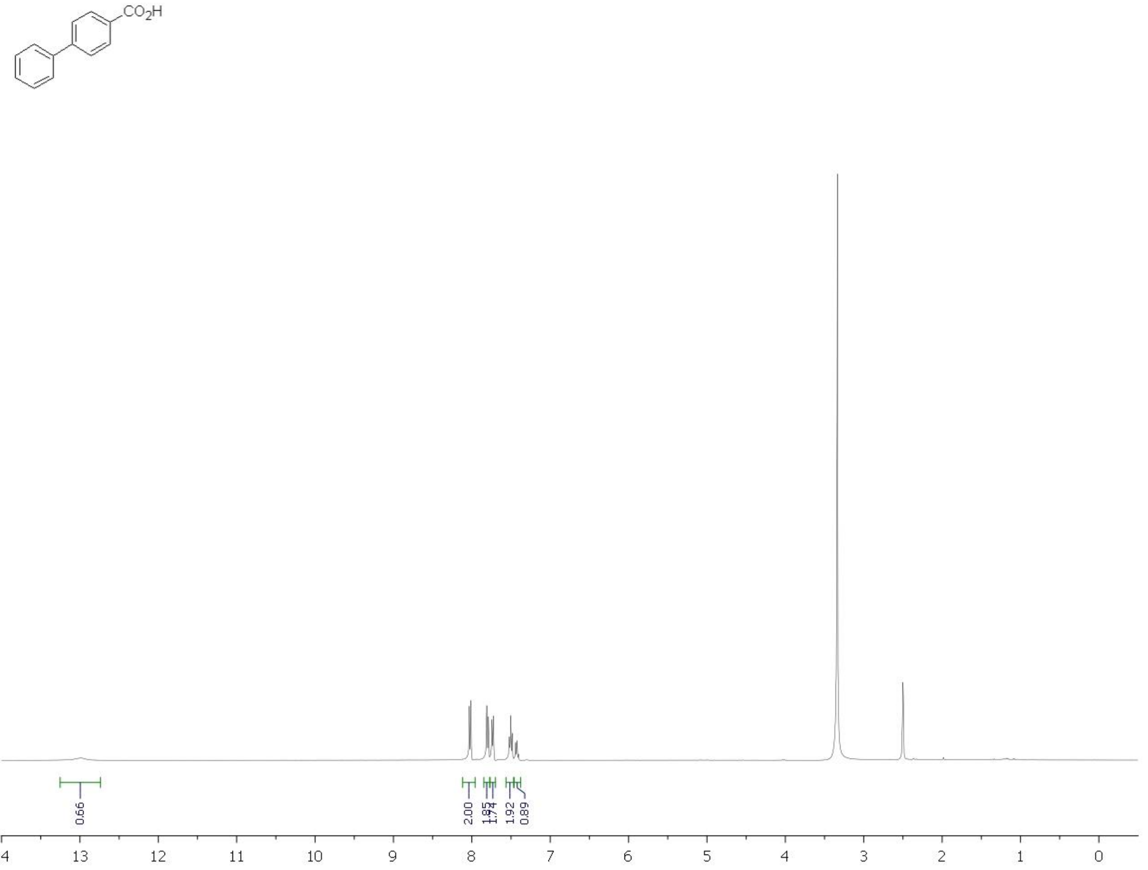
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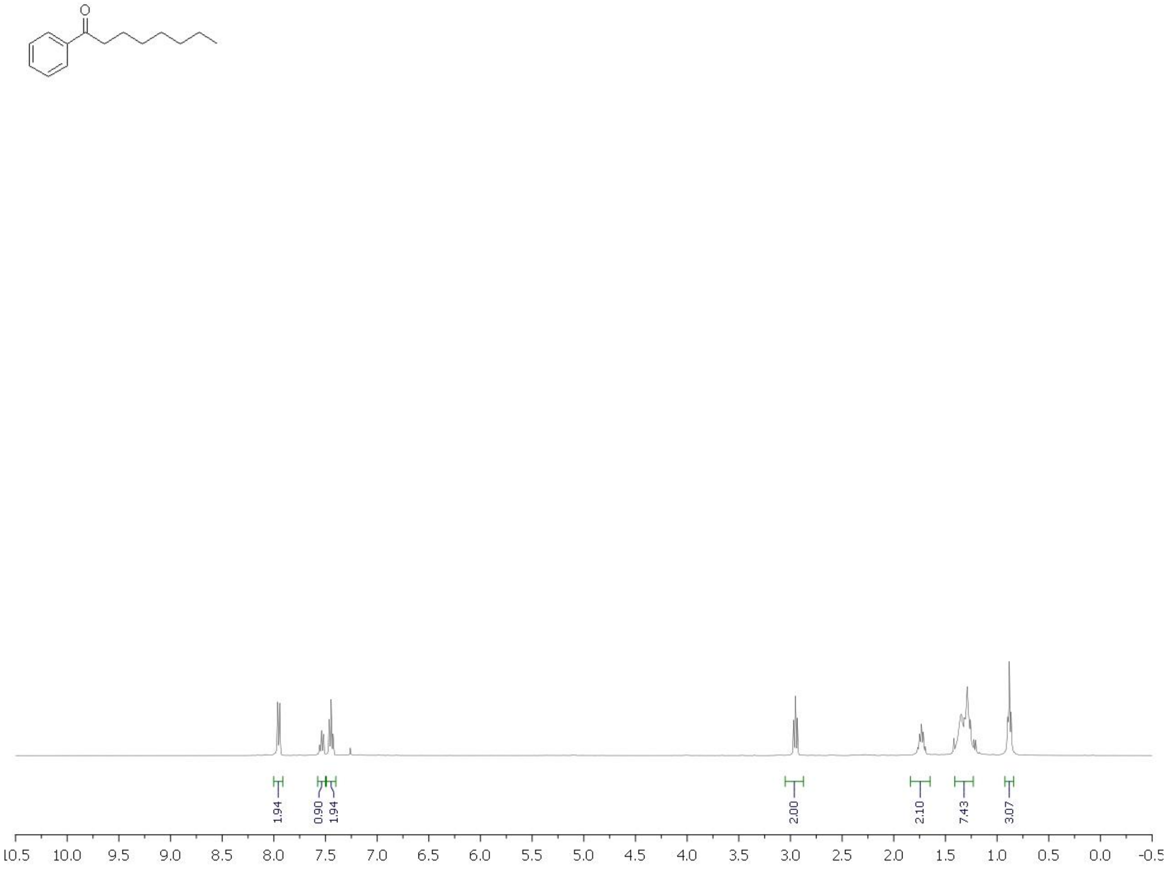
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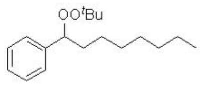
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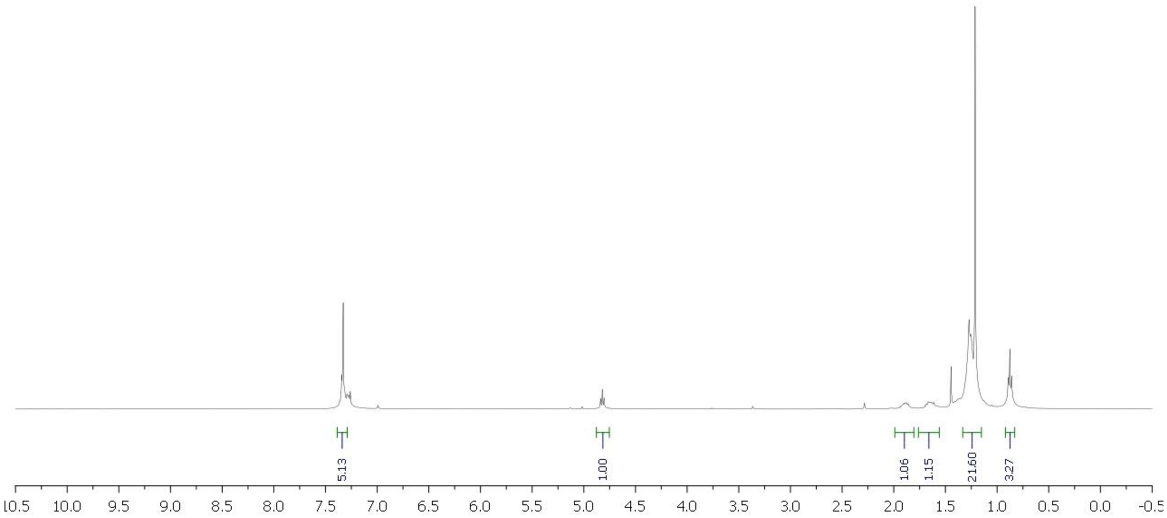
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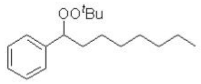
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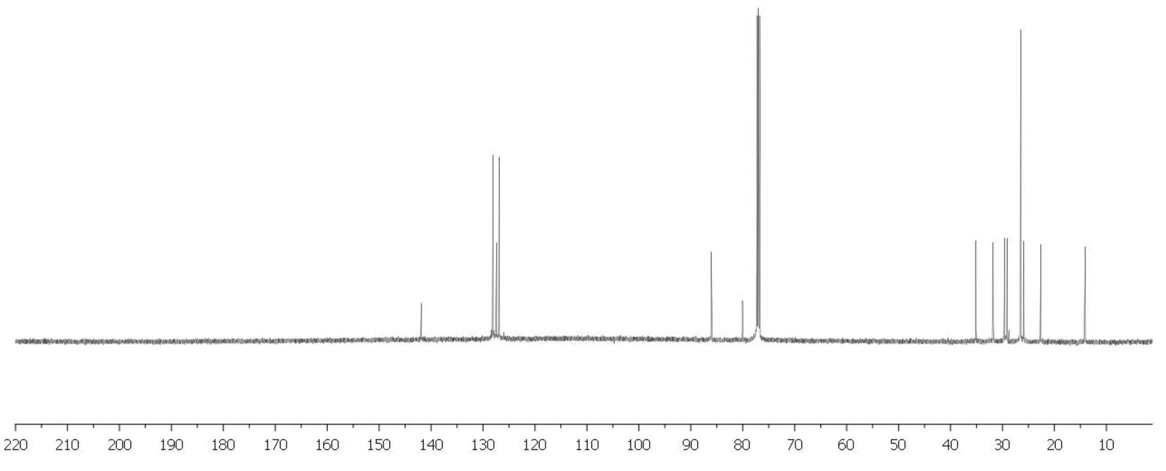
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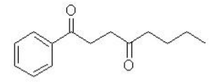
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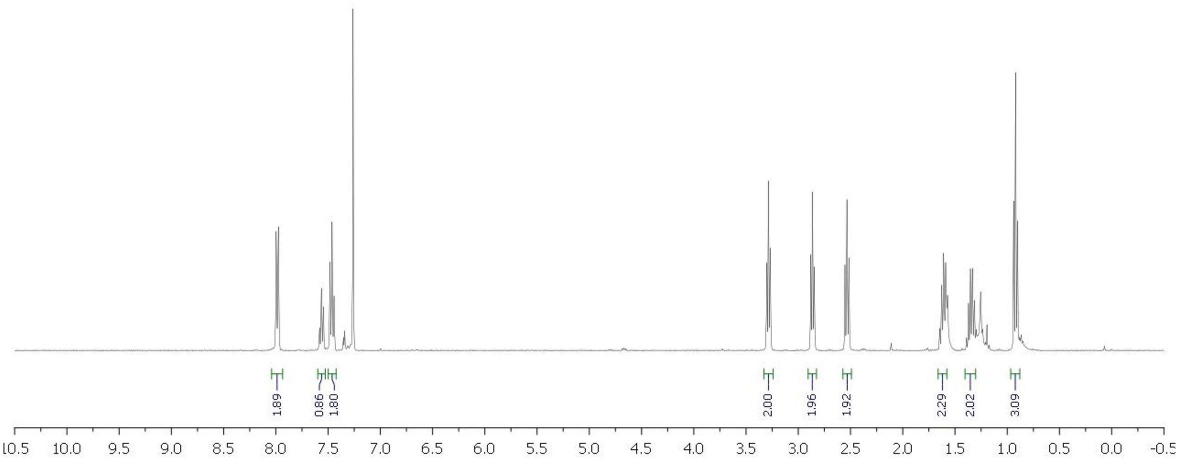
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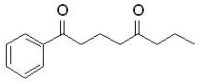
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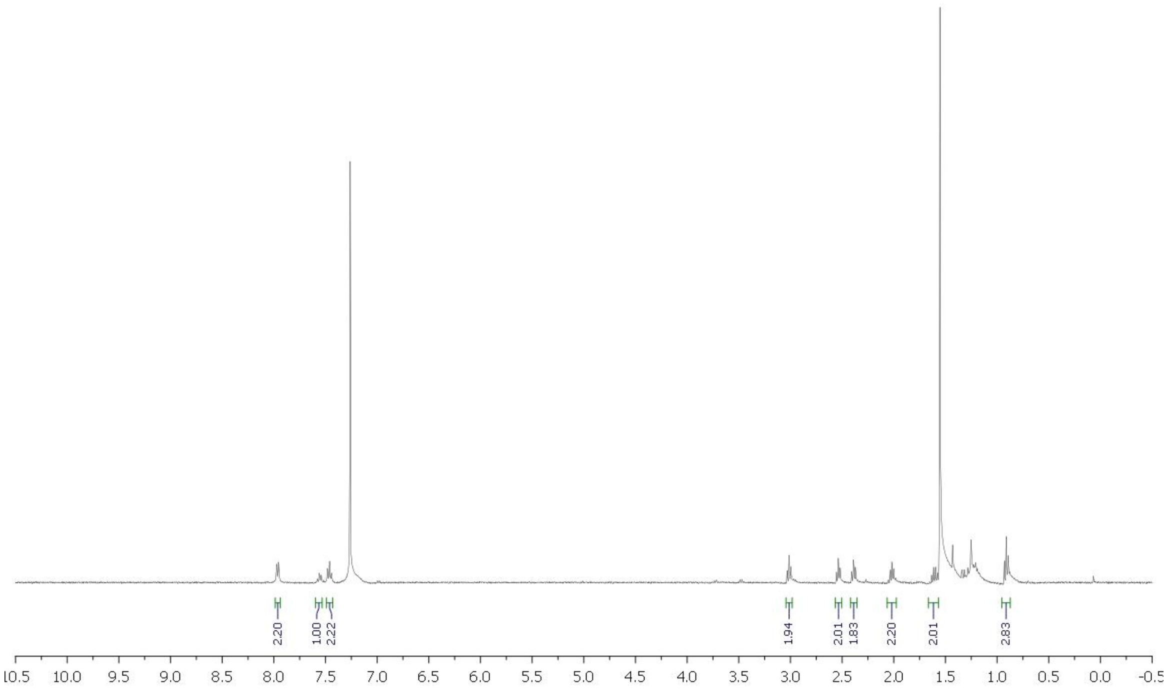
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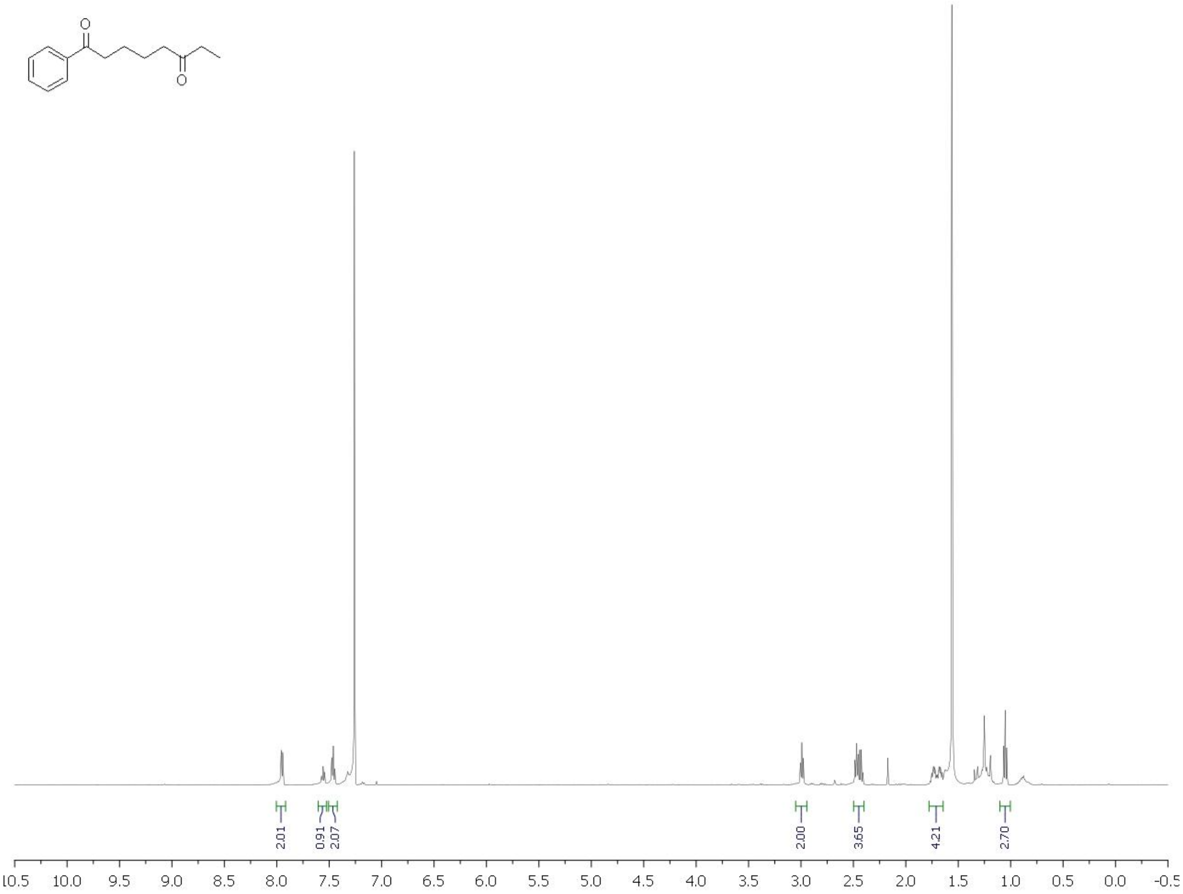
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8.5
8.0
7.5
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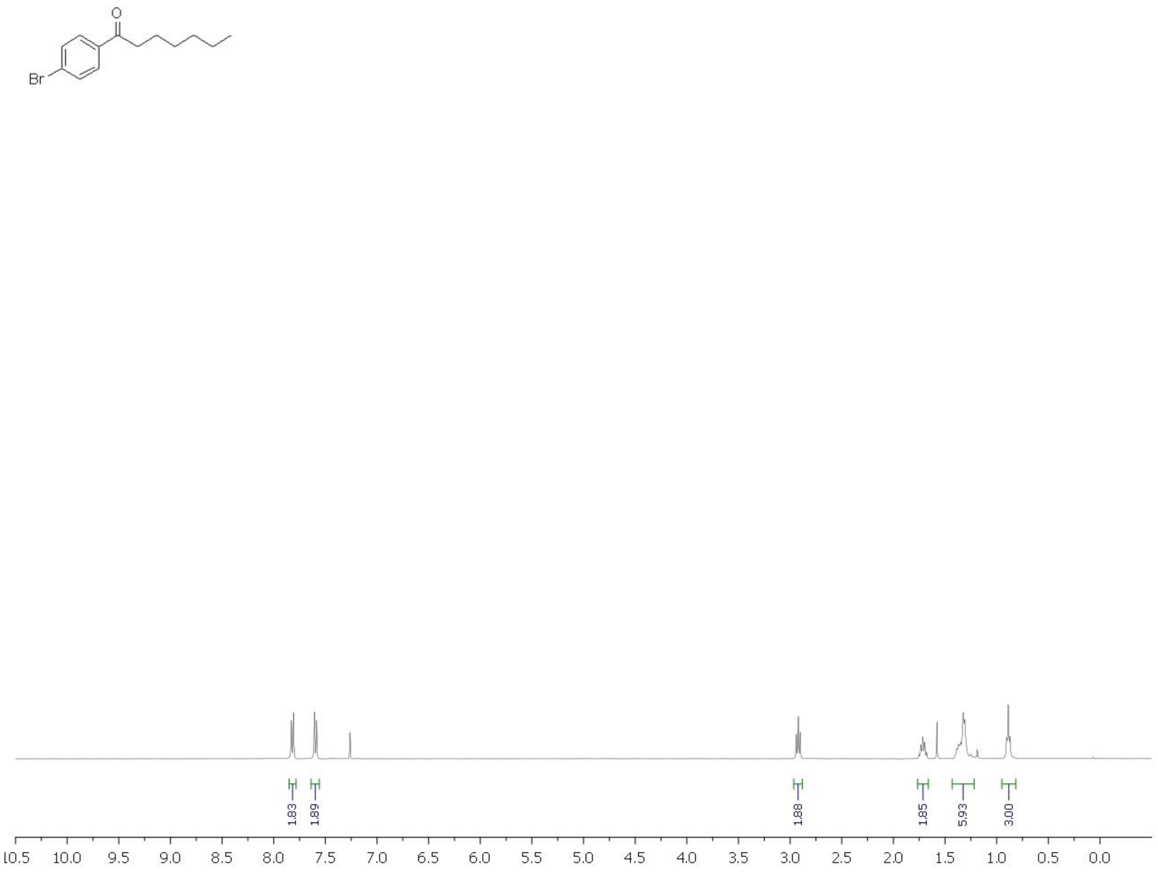
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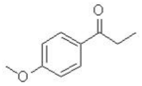
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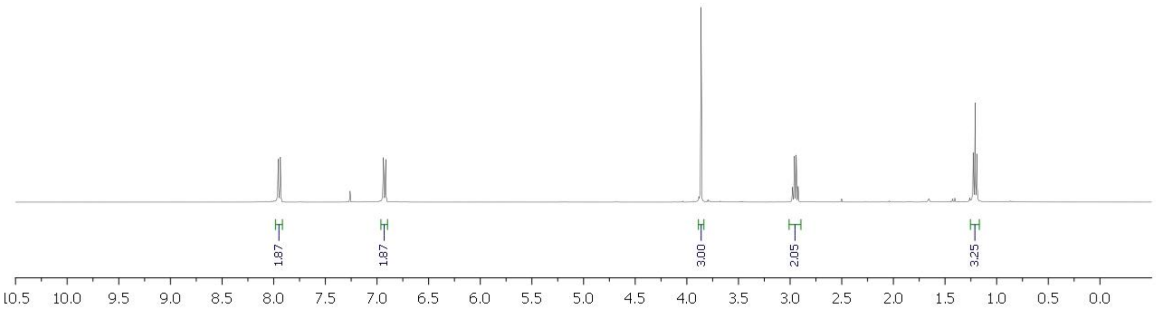
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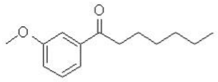
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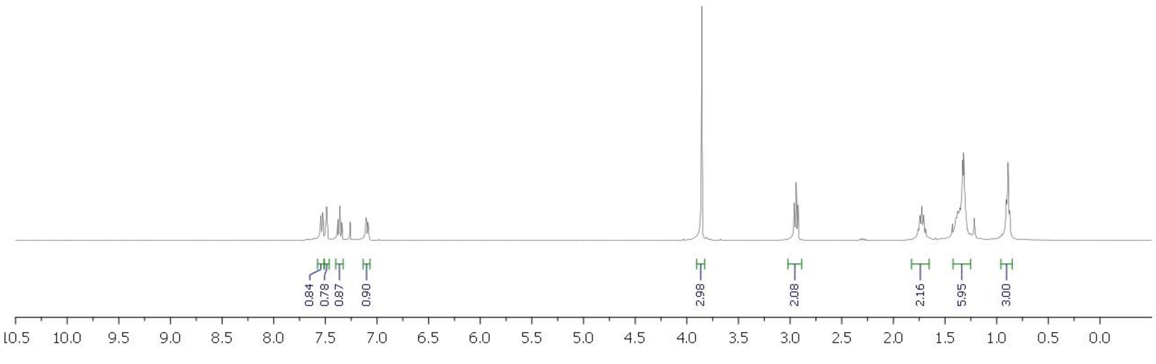
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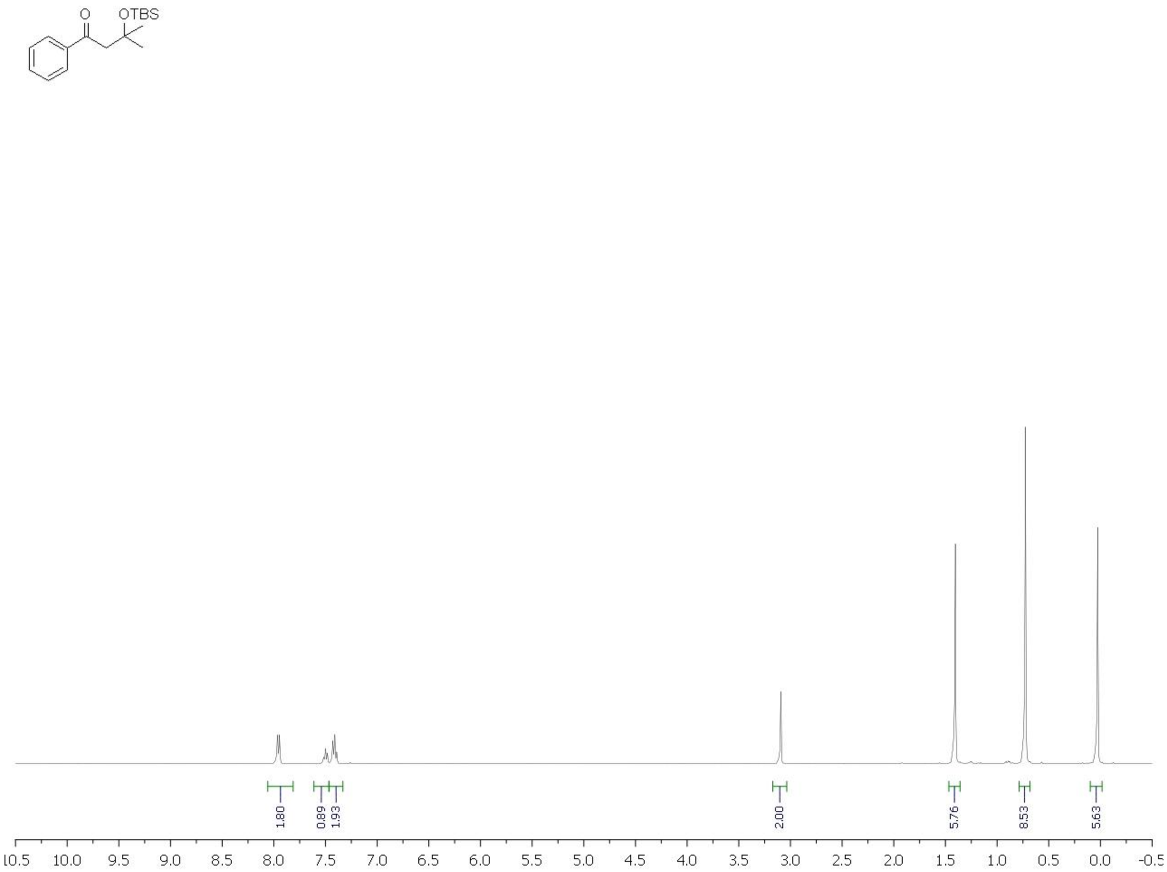
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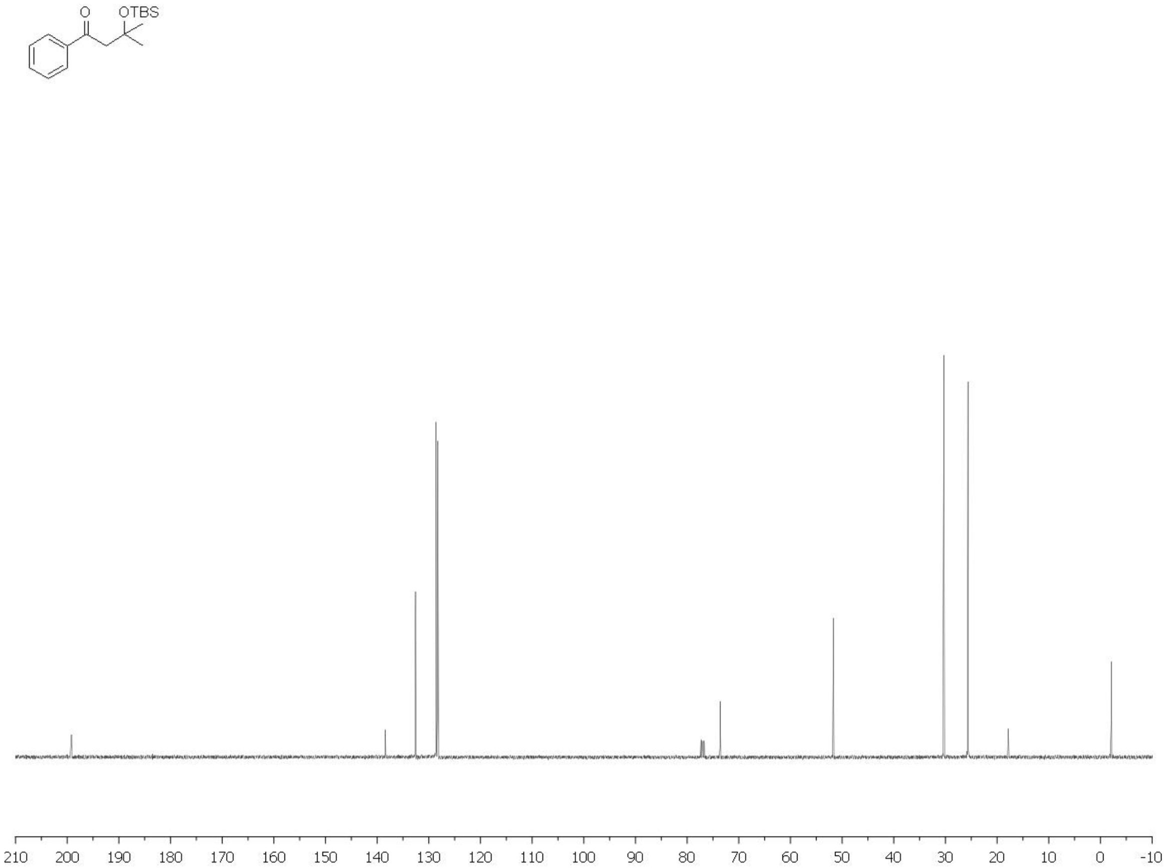
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OTBS
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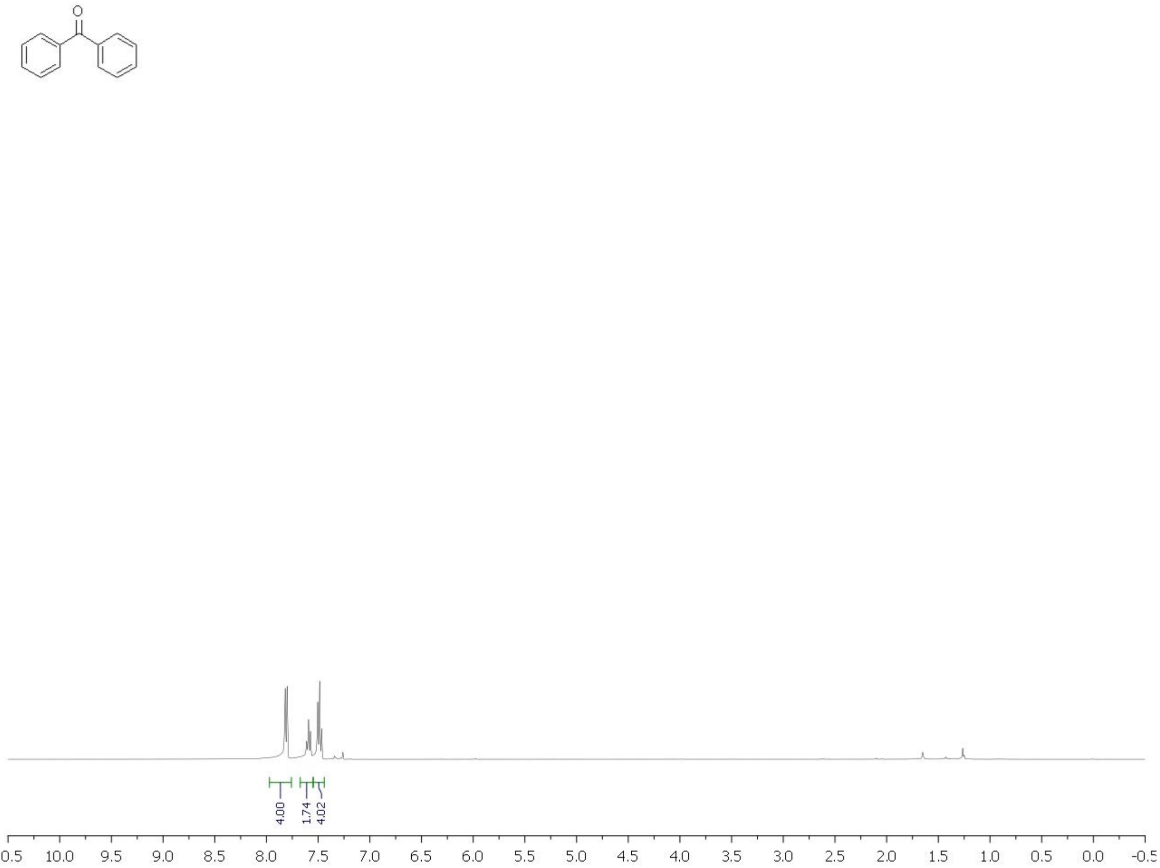
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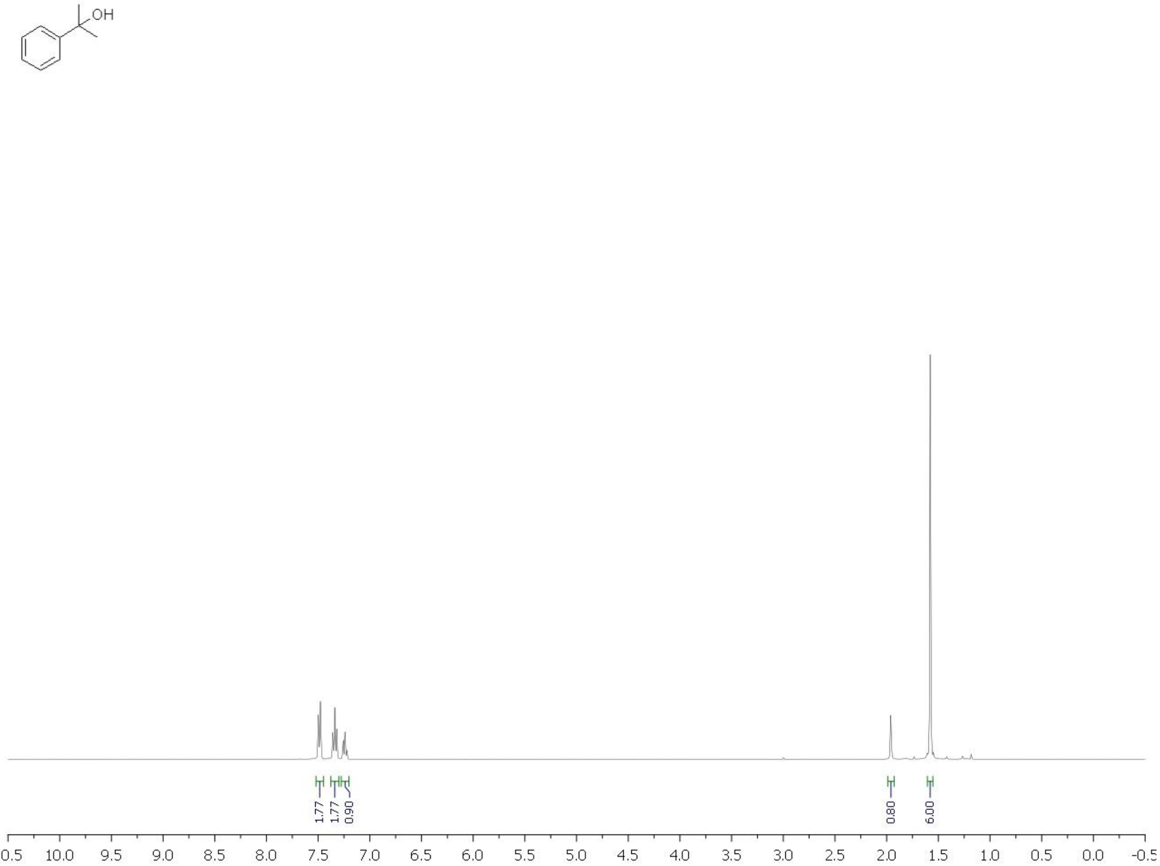
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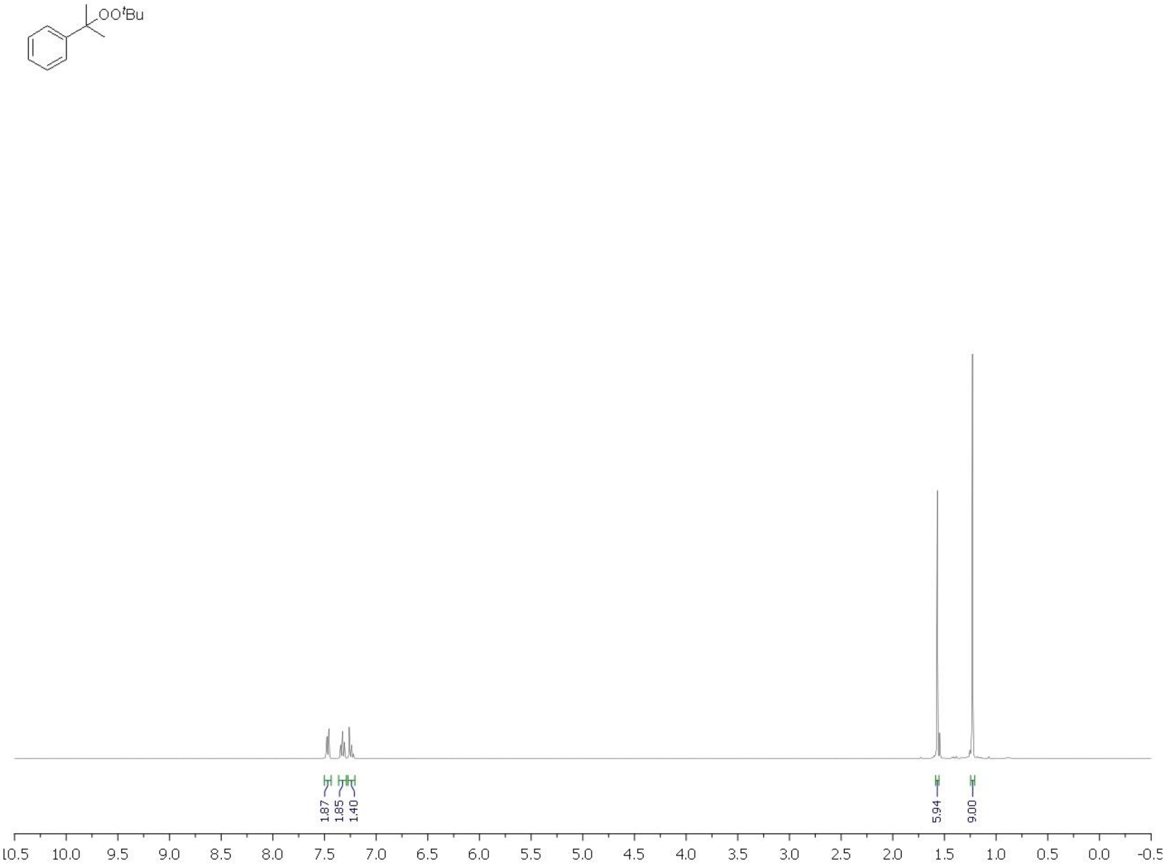
OO^tBu
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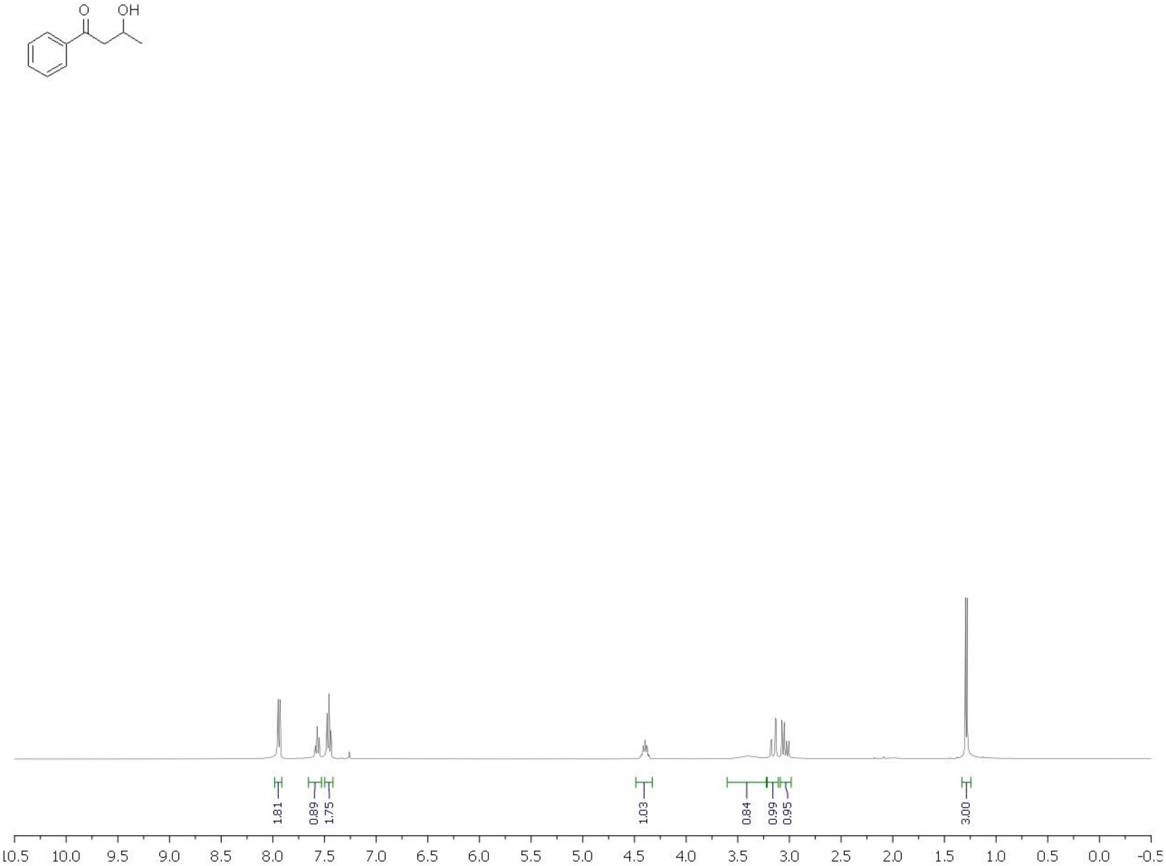
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0.95
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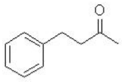
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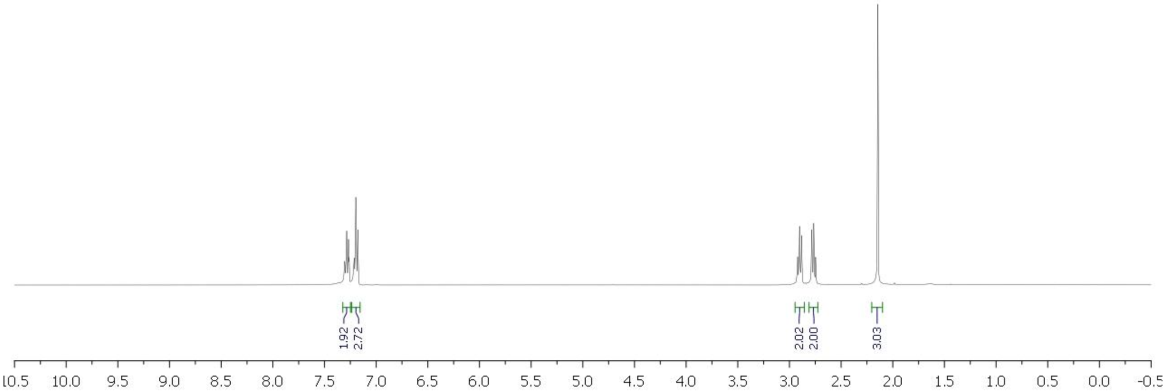
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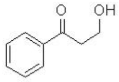
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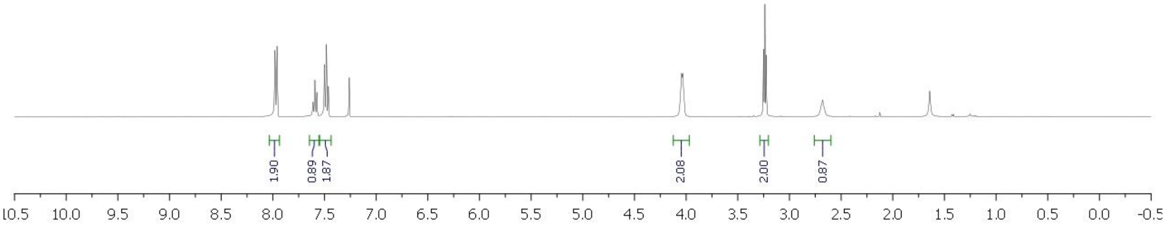
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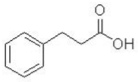
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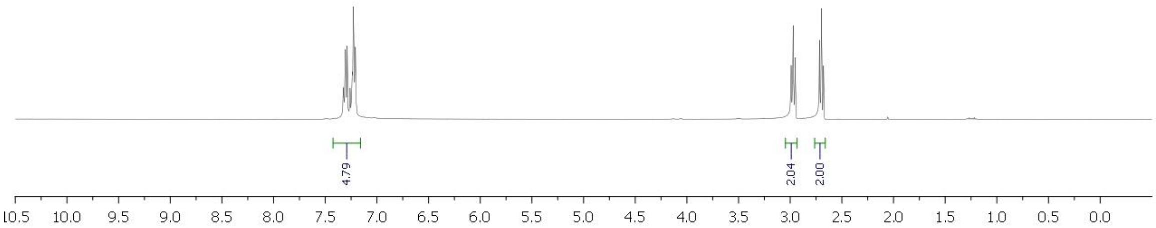
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