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Increased Lewis Acidity in Hafnium-Substituted Polyoxotungstates

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General remarks: Reagents and chemicals were purchased from commercial sources and used as received. The lacunary polyoxometalates, $K_9[\alpha_1\text{-}LiP_2W_{17}O_{61}]$[1] and $K_7[\alpha\text{-}PW_{11}O_{39}]$[2] were prepared as reported in the literature. Reactions were carried out under argon, with magnetic stirring. CH_3CN was dried and distilled from CaH_2. Thin-layer chromatography (TLC) was performed on Merck 60F254 silica gel. Merck Geduran SI 60 Å silica gel (40-63 μm) was used for column chromatography. IR spectra were recorded from a Bruker Tensor 27 ATR diamond PIKE spectrophotometer in KBr disk from a Biorad FTS 165 FT-IR spectrometer. ^1H NMR [^{13}C NMR] spectra were recorded at room temperature with a 400 MHz [100 MHz] Bruker AVANCE 400 spectrometer. Chemical shifts are given in ppm, referenced to the residual resonances of the solvents (δ = 7.26 or 77.2, for $CDCl_3$). Coupling constants (*J*) are given in Hertz (Hz). ^{31}P NMR spectra were obtained at 298K in 5 mm o.d. tube at 162 MHz, by use of a Bruker AVANCE 400 at a concentration of 100 mg/0.5 mL. External 85% H_3PO_4 in coaxial tube was used as reference.^{183}W NMR spectrum was recorded in 10 mm o.d. tubes at 12.5 MHz on a Bruker AVANCE II 300 spectrometer equipped with a low-frequency special VSP probehead. Chemical shifts are referenced to WO_4^{2-} (δ = 0 ppm) according to the IUPAC recommendation. They were measured by the substitution method, using a saturated aqueous solution (in D_2O) of dodecatungstosilicic acid ($H_4SiW_{12}O_{40}$) as a secondary standard (δ = –103.8 ppm). pH was measured with Hanna Instrument HI 221 pH meter. Polarograms were recorded in MeCN with $TBABF_4$ as supporting electrolyte on a Radiometer POL150 using a glassy carbon rotating disk electrode, a Pt electrode and a saturated calomel electrode linked by a salt bridge. Mass spectroscopy experiments have been carried out on an electrospray-ion trap instrument (Bruker, Esquire 3000). The 50 pmolμL^{-1} solutions of POMs were infused using a syringue pump (160 μLmin $^{-1}$). The negative ion mode was used with capillary high voltage 3500 V. The orifice/skimmer voltage difference was set to 40 V to avoid decomposition of the POMs. The low-mass-cutoff (LMCO) of the ion trap was set to 100 Th. Elemental analysis were carried out by the "Service Central d'Analyse", CNRS, Vernaison, France or by the ICSN, CNRS, Gif, France.

$TBA_5K[\alpha_1\text{-}Hf(H_2O)_4P_2W_{17}O_{61}]$ (1):

The lacunary $K_9[Li(\alpha_1\text{-}P_2W_{17}O_{61})]$ (5.0 g, 1.0 mmol) was dissolved in 125 mL of distilled water at 25°C. The suspension was stirred until a clear solution was obtained. $HfCl_4$ (321 mg, 1.0 mmol) was dissolved in 10 mL of water and added dropwise to the stirring solution. The pH of the solution decreased from 5.5 to 3.0 ± 0.1. After 2 minutes, a solution of TBABr (3.75 g, 11.5 mmol) in 50 mL water was added dropwise. After complete addition (pH = 4.0 ± 0.1), the solution was allowed to stir for an additional 2 minutes. The precipitate was then collected by filtration. The crude product was dissolved in CH_3CN (4 mL) and a solution of Et_2O/EtOH/Acetone (9/1/1) was added. The white precipitate was then collected by centrifugation. Yield : 4.81 g (83%). ^{31}P NMR (162 MHz, c= 0.04 $molL^{-1}$, CD_3CN + 10% D_2O): δ = – 10.7 (s, 1 P, PW_8Hf) and –11.5 ppm (s, 1 P, PW_9). IR ν = 2963(m), 2936 (m), 2875 (m), 1485 (m), 1459 (m), 1382 (w), 1153 (w), 1083 (s), 1015 (w), 954 (s), 904 (s), 777 (vs) cm^{-1}. ^{183}W NMR (12.5 MHz, c= 0.036 $molL^{-1}$, CD_3CN + 10% D_2O) : δ = -114.1, -119.9, -123.9, -126.2, -130.5, -140.5, -142.3, -147.8, -165.0, -167.6, -171.1, -174.0, -174.8, -175.0, -176.7, -177.2, -187.6 ppm.

Elemental analysis (%) for the product dried 12h. at $4x10^{-2}$ Torr. $C_{86}H_{197}N_8KHfO_{65}P_2W_{17}$ (5788.31) ; calcd: C 17.84, H 3.40, N 1.71, K 0.67, P 1.08, W 53.99, Hf 3.08; found: C 17.54, H 3.33, N 1.24, K 0.40, P 1.16, W 54.12, Hf 3.24.

The number of solvent molecules is difficult to determine with precision; Assuming eight coordination of Hf^{4+}, four solvent molecules should be included, most likely H_2O because Hf^{4+} is oxophilic. Elemental analysis and TGA are consistent with further 3 molecules MeCN from recristallization (see **figure S1**).

Figure S1 : Thermogravimetric Analysis (weight loss calcd: 24.32%; found: 24.95%; correspond to 5 TBA, 3 MeCN and $4H_2O$)

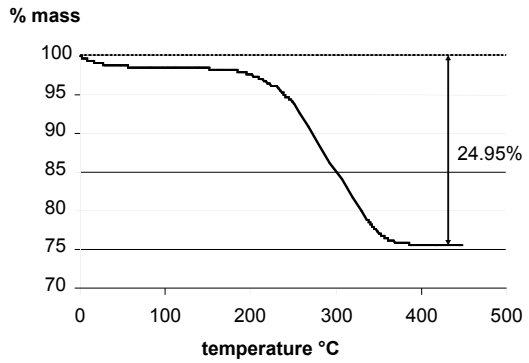


Figure S2 : ESI-MS of $(TBA)_5K[\alpha_1\text{-}HfP_2W_{17}O_{61}]$ in negative mode (50 µM). Key: (a) MeCN/MeOH; (b) MeCN/H_2O (90:10).

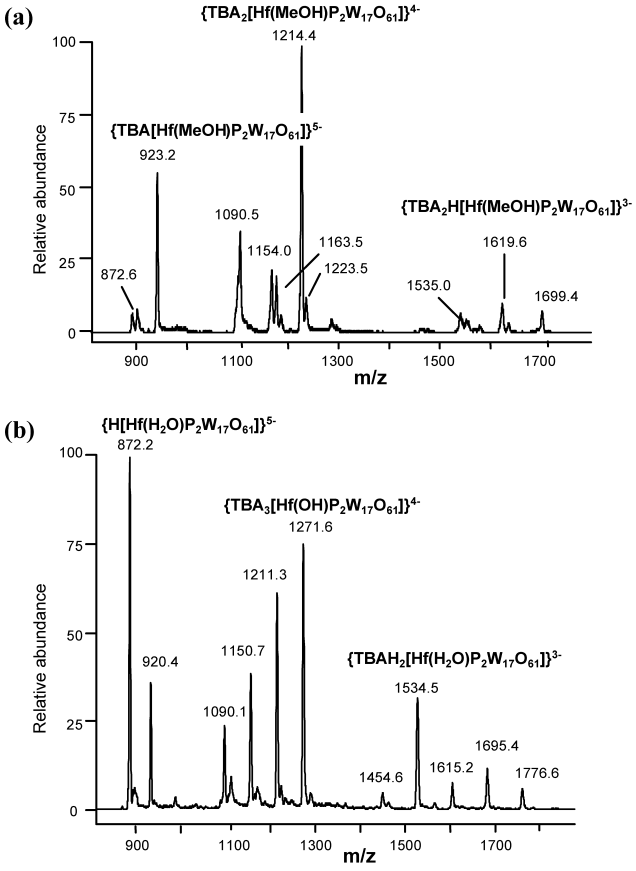


Table S1 : ESI-MS of $(TBA)_5K[\alpha_1\text{-}HfP_2W_{17}O_{61}]$ in negative mode (50 ⌈M), MeCN/MeOH.[a]

entry	charge	Simulated *m/z*[b]	Observed *m/z*[b]	Relative intensity	formula
1	3	1700.2	1699.4	8	$TBA_3[\alpha_1\text{-}\mathbf{Hf(MeOH)}P_2W_{17}O_{61}]$
2	3	1619.8	1619.6	10	$TBA_2H[\alpha_1\text{-}\mathbf{Hf(MeOH)}P_2W_{17}O_{61}]$
3	3	1534.7	1535.0	8	$TBAH_2[\alpha_1\text{-}\mathbf{Hf(H_2O)}P_2W_{17}O_{61}]$
4	4	1222.6	1223.5	13	$TBA_2[\alpha_1\text{-}\mathbf{Hf(MeOH)_2}P_2W_{17}O_{61}]$
5	4	1214.6	1214.6	**100**	$TBA_2[\alpha_1\text{-}\mathbf{Hf(MeOH)}P_2W_{17}O_{61}]$
6	4	1162.3	1163.5	20	$TBAH[\alpha_1\text{-}\mathbf{Hf(MeOH)_2}P_2W_{17}O_{61}]$
7	4	1154.3	1154.0	22	$TBAH[\alpha_1\text{-}\mathbf{Hf(MeOH)}P_2W_{17}O_{61}]$
8	4	1090.4	1090.5	35	$H_2[\alpha_1\text{-}\mathbf{Hf(H_2O)}P_2W_{17}O_{61}]$
9	5	923.2	923.2	**56**	$TBA[\alpha_1\text{-}\mathbf{Hf(MeOH)}P_2W_{17}O_{61}]$
10	5	881.4	881.9	8	$H[\alpha_1\text{-}\mathbf{Hf(MeOH)_2}P_2W_{17}O_{61}]$
11	5	872.2	872.6	7	$H[\alpha_1\text{-}\mathbf{Hf(H_2O)}P_2W_{17}O_{61}]$

[a] The formulas are written with the assumption of preferential protonation of the ligand on Hf. However, basicities in the gaz phase often do not parallel those observed in solution. The alternative formulation with an anionic ligand on Hf and a proton on the POM framework must be considered for the species.

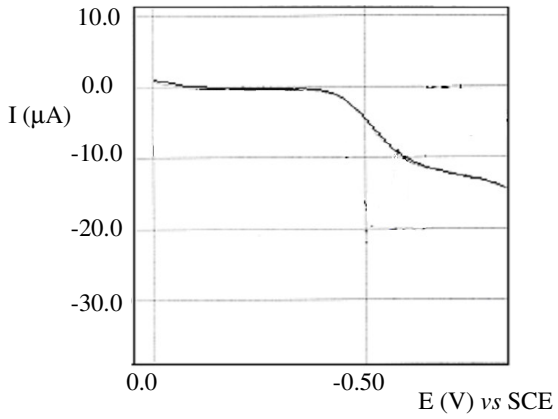
[b] *m/z* given for the most intense peak in the isotopic distribution**.**

Table S2 : ESI-MS of $(TBA)_5K[\alpha_1\text{-}HfP_2W_{17}O_{61}]$ in negative mode (50 ⌈M), MeCN/H_2O (90:10).[a]

entry	charge	Simulated *m/z*[b]	Observed *m/z*[b]	Relative intensity	formula
1	3	1776.3	1776.6	8	$TBA_4[\alpha_1\text{-}\mathbf{Hf(OH)}P_2W_{17}O_{61}]$
2	3	1695.5	1695.4	10	$TBA_3[\alpha_1\text{-}\mathbf{Hf(H_2O)}P_2W_{17}O_{61}]$
3	3	1615.2	1615.2	8	$TBA_2H[\alpha_1\text{-}\mathbf{Hf(H_2O)}P_2W_{17}O_{61}]$
4	3	1534.7	1534.5	30	$TBAH_2[\alpha_1\text{-}\mathbf{Hf(H_2O)}P_2W_{17}O_{61}]$
5	3	1454.3	1454.6	8	$H_3[\alpha_1\text{-}\mathbf{Hf(H_2O)}P_2W_{17}O_{61}]$
6	4	1271.4	1271.3	**74**	$TBA_3[\alpha_1\text{-}\mathbf{Hf(OH)}P_2W_{17}O_{61}]$
7	4	1211.1	1211.3	**60**	$TBA_2[\alpha_1\text{-}\mathbf{Hf(H_2O)}P_2W_{17}O_{61}]$
8	4	1150.8	1150.4	40	$TBAH[\alpha_1\text{-}\mathbf{Hf(H_2O)}P_2W_{17}O_{61}]$
9	4	1090.4	1090.1	25	$H_2[\alpha_1\text{-}\mathbf{Hf(H_2O)}P_2W_{17}O_{61}]$
10	5	920.4	920.3	37	$TBA[\alpha_1\text{-}\mathbf{Hf(H_2O)}P_2W_{17}O_{61}]$
11	5	872.2	872.2	**100**	$H[\alpha_1\text{-}\mathbf{Hf(H_2O)}P_2W_{17}O_{61}]$

[a] The formulas are written with the assumption of preferential protonation of the ligand on Hf. However, basicities in the gaz phase often do not parallel those observed in solution. The alternative formulation with an anionic ligand on Hf and a proton on the POM framework must be considered for the species.
[b] *m/z* given for the most intense peak in the isotopic distribution**.**

Figure S3 : polarogram of $(TBA)_5K[\alpha_1\text{-}HfP_2W_{17}O_{61}]$ in CH_3CN with $TBABF_4$ (10^{-1} M) as supporting electrolyte. Working electrode: glassy carbon rotating disk electrode (1000 rpm). Auxiliary electrode: Pt. Reference electrode: SCE connected with salt bridge.



$TBA_{3.7}K_{0.3}[\alpha\text{-}Hf(OH)PW_{11}O_{39}]$ (2):

The lacunary $K_7[\alpha\text{-}PW_{11}O_{39}]$ (2.0 g, 0.67 mmol) was dissolved in 8 mL of distilled water at 80-90°C. The suspension was stirred until a clear solution was obtained. $HfCl_4$ (235 mg, 0.73 mmol, 1.1 eq.) was dissolved in 1 mL of hot water and added dropwise to the stirring solution. After 5 minutes, a solution of TBABr (1.83 g, 5.7 mmol, 8.5 eq.) in 7 mL of hot water was added dropwise. After complete addition, the solution was allowed to stir for an additional 2 minutes. The precipitate was then collected by filtration and wash successively with H_2O, EtOH and Et_2O. The crude product was dissolved in CH_3CN (10 mL), the remaining solid was removed by centrifugation. 12 mL of Acetone/EtOH (1/1) were added to the filtrate and then 50 mL of Et_2O. The white precipitate was collected by centrifugation. Yield : 2.27 g (88%). ^{31}P NMR (162 MHz, c= 0.05 $molL^{-1}$, CD_3CN): δ = – 12.06 (s, 1 P). IR ν = 2963(m), 2936 (m), 2875 (m), 1485 (m), 1459 (m), 1382 (w), 1152 (w), 1091 (m), 1059 (s), 956 (s), 886 (s) cm^{-1}.

Elemental analysis (%) including 3 H_2O for $C_{59.2}H_{140.2}N_{3.7}K_{0.3}HfO_{43}PW_{11}$ (3835.7) ; calcd: C 18.53, H 3.68, N 1.35, K 0.31, P 0.81, W 52.72, Hf 4.67; found: C 18.33, H 3.56, N 1.30, K 0.29, P 0.85, W 51.68, Hf 4.67.

Figure S4 : ESI-MS of $TBA_{3.7}K_{0.3}[\alpha\text{-}Hf(OH)PW_{11}O_{39}]$ in negative mode (50 µM). Key: (a) MeCN/MeOH; (b) MeCN/H_2O (90:10).

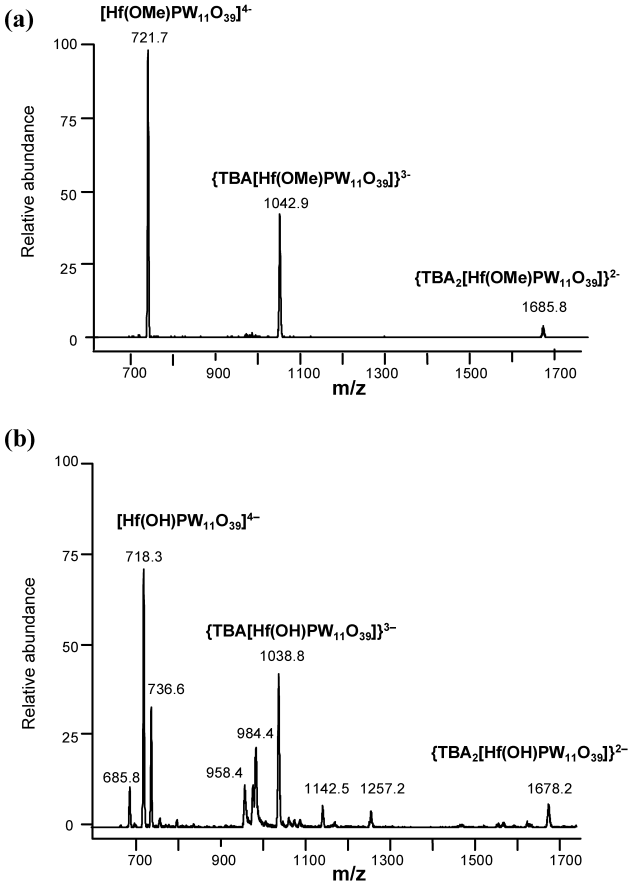


Table S3 : ESI-MS of $TBA_{3.7}K_{0.3}[\alpha\text{-}Hf(OH)PW_{11}O_{39}]$ in negative mode (50 ⌈M), MeCN/MeOH (90:10).[a]

entry	charge	Simulated *m/z*[a]	Observed *m/z*[a]	Relative intensity	formula
1	2	1685.9	1685.7	5	$TBA_2[\alpha\text{-}\mathbf{Hf(OMe)}PW_{11}O_{39}]$
2	3	1042.9	1042.9	40	$TBA[\alpha\text{-}\mathbf{Hf(OMe)}PW_{11}O_{39}]$
3	3	721.8	721.9	100	$[\alpha\text{-}\mathbf{Hf(OMe)}PW_{11}O_{39}]$

[a] *m/z* given for the most intense peak in the isotopic distribution**.**

Table S3 : ESI-MS of $(TBA)_5K[\alpha_1\text{-}HfP_2W_{17}O_{61}]$ in negative mode (50 ⌈M), MeCN/H_2O (90:10).

entry	charge	Simulated m/z[a]	Observed m/z[a]	Relative intensity	formula
1	2	1678.4	1678.2	9	$TBA_2[\alpha\text{-}\mathbf{Hf(OH)}PW_{11}O_{39}]$
2	5	1143.2	1142.5	8	$H\{[\alpha\text{-}\mathbf{Hf}PW_{11}O_{39}]\}_2$
3	3	1038.5	1038.8	60	$TBA[\alpha\text{-}\mathbf{Hf(OH)}PW_{11}O_{39}]$
4	3	958.1	958.4	16	$H[\alpha\text{-}\mathbf{Hf(OH)}PW_{11}O_{39}]$
5	4	718.3	718.3	100	$[\alpha\text{-}\mathbf{Hf(OH)}PW_{11}O_{39}]$

[a] *m/z* given for the most intense peak in the isotopic distribution**.**

$TBA_7[\alpha_1\text{-}Hf(OH)P_2W_{17}O_{61}]$ (3):

$TBA_5K[\alpha_1\text{-}Hf(H_2O)_4P_2W_{17}O_{61}]$ (600 mg, 0.104 mmol) was dissolved in 25 mL of CH_3CN. The suspension was stirred until a clear solution was obtained. Then 15 g of a TBA^+-loaded cationic resin (Amberlyst A23) was added. After 2 h, the cationic resin was filtered off and the organic layer was concentrated under reduced pressure. The white solid was dissolved in CH_2Cl_2 (5 mL) and 50 mL of Et_2O were added. The white precipitate was collected by centrifugation. Yield : 575 mg (90%). ^{31}P NMR (162 MHz, c= 0.04 $molL^{-1}$, CD_3CN + 10% D_2O): δ = – 10.2 (s, 1 P, PW_8Hf) and –11.9 ppm (s, 1 P, PW_9). IR ν = 2963(m), 2936 (m), 2875 (m), 1485 (m), 1459 (m), 1382 (w), 1153 (w), 1080 (s), 1010 (w), 946 (s), 903 (s) cm^{-1}. Elemental analysis (%) for $C_{112}H_{253}N_7HfO_{62}P_2W_{17}$ (6056.13) ; calcd: C 22.21, H 4.21, N 1.71; found: C 21.91, H 4.24, N 1.71.

General procedure 1 (GP1): *Mannich type reaction* :

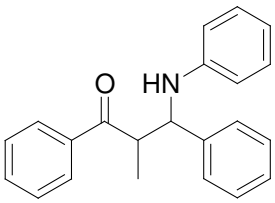
To a solution of $TBA_5K[\alpha_1\text{-}Hf(H_2O)nP_2W_{17}O_{61}]$ or $TBA_{3.7}K_{0.3}[\alpha\text{-}Hf(OH)PW_{11}O_{39}]$ (20 mol%, 0.1 mmol) in CH_3CN (3 mL) were added the imine (0.5 mmol, 1 equiv.) and the silyl enol ether (0.5 mmol, 1 equiv.). After completion (unless otherwise noted), 6 mL of a solution of acetone/ethanol (1/1) were added, followed by 60 mL of diethyl ether. The white precipitate (catalyst) was centrifuged and separated from the reaction products. The remaining organics were concentrated under reduced pressure. The residue was purified by flash column chromatography (pentane/ethyl acetate: 95/5) to afford the desired β-amino ketones as mixtures of the 2 diastereomers.

General procedure 2 (GP2): *Aldol type reaction*:

To a solution of $TBA_5K[\alpha_1\text{-}Hf(H_2O)nP_2W_{17}O_{61}]$ or $TBA_{3.7}K_{0.3}[\alpha\text{-}Hf(OH)PW_{11}O_{39}]$ (20 mol%, 0.1 mmol, 560 mg) in CH_3CN (3 mL) were added the aldehyde (0.5 mmol, 1 equiv.) and the silyl enol ether (0.75 mmol, 1.5 equiv.). After completion, 6 mL of a solution of acetone/ethanol (1/1) were added followed by 60 mL of diethyl ether. The white precipitate (catalyst) was centrifuged and separated from the reaction products. The organics were concentrated *in vacuo*. The crude mixture was dissolved in dichloromethane (2 mL) and 0.2 mL of a solution of HCl in diethylether were added. After 10 minutes, the solvent was evaporated under reduced pressure. The crude mixture was dissolved in dichloromethane and washed with aq. sat. sodium hydrogenocarbonate, then with brine, dried over $MgSO_4$, filtered and concentrated. The residue was purified by flash column chromatography to afford the desired products.

General procedure 3 (GP3): *Imino Diels-Alder reaction*:

To a solution of the catalyst $TBA_5K[\alpha_1\text{-}Hf(H_2O)nP_2W_{17}O_{61}]$ (10 mol%, 0.05 mmol, 280 mg) in CH_3CN (3 mL) was added the imine (0.5 mmol, 1 equiv.) and diene or enol ether (0.75 mmol, 1.5 equiv.). After completion, 6 mL of a solution of acetone/ethanol (1/1) was added followed by 60 mL of diethyl ether. The white precipitate (catalyst) was centrifuged and separated from the reaction products. The organics were concentrated under reduced pressure. The residue was purified by flash column chromatography to afford the desired cyclic adducts.

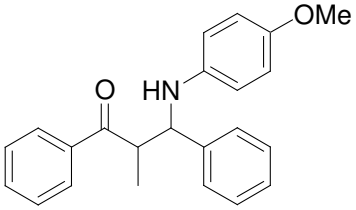


$C_{22}H_{21}NO$

M = 315.41 g.mol^{-1}

*2-Methyl-1,3-diphenyl-3-phenylamino-propan-1-one **(4a)***:

Following GP1 (reaction time: 6 hours), product **4a** was isolated (pentane/ethyl acetate: 80/20) as an inseparable mixture of the 2 diastereomers (ratio 62/38, pale yellow solid, 0.425 mmol, 134 mg, 85 %). Spectral data corresponded to those described in the literature.[3] HRMS calcd. for $C_{22}H_{21}NONa$ ($[M + Na]^+$) 338.1521, found 338.1500. Elemental analysis (%) for $C_{22}H_{21}NO$ (315.41); calcd: C 83.78, H 6.71, N 4.44; found: C 83.62, H 6.68, N 4.34.

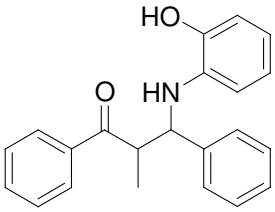


$C_{32}H_2NO_2$

M = 345.43 g.mol^{-1}

*3-(4-Methoxy-phenylamino)-2-methyl-1,3-diphenyl-propan-1-one **(4b)**:*

Following GP1 (reaction time: 6 days), product **4b** was isolated (pentane/ethyl acetate 90/10) as an inseparable mixture of the 2 diastereomers (ratio 50/50, pale yellow solid, 0.2 mmol, 70 mg, 40 %). Spectral data corresponded to those described in the literature.[3] HRMS calcd. for $C_{22}H_{21}NONa$ ($[M + Na]^+$) 368.1626, found 368.1612. Elemental analysis (%) for $C_{23}H_{23}NO_2$ (345.43); calcd: C 79.97, H 6.71, N 4.05; found: C 79.61, H 6.71, N 3.86.

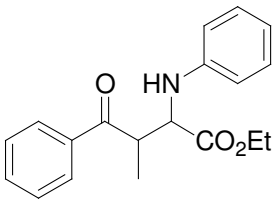


$C_{22}H_{21}NO_2$

M = 331.41 g.mol^{-1}

*3-(2-Hydroxy-phenylamino)-2-methyl-1,3-diphenyl-propan-1-one **(4c)**:*

Following GP1 (reaction time: 7 hours), product **4c** was isolated (pentane/ethyl acetate 80/20) as an inseparable mixture of the 2 diastereomers (ratio 50/50, brown gum, 0.25 mmol, 86 mg, 52 %). Spectral data corresponded to those described in the literature.[3b] HRMS calcd. for $C_{22}H_{21}NO_2Na$ ($[M + Na]^+$) 354.1470, found 354.1463.

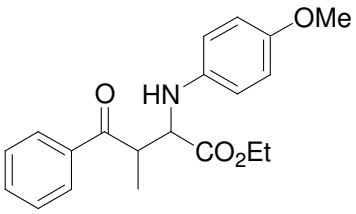


$C_{19}H_{21}NO_3$

M = 311.37 g.mol^{-1}

*3-Methyl-4-oxo-4-phenyl-2-phenylamino-butyric acid ethyl ester **(4d)**:*

Following a modified GP1 with 3 equivalents of imine (reaction time: 45 min.), product **4d** was isolated (pentane/ethyl acetate 80/20) as an inseparable mixture of the 2 diastereomers (ratio 60/40, white solid, 0.48 mmol, 149 mg, 96 %). Spectral data corresponded to those described in the literature.[3b] Elemental analysis (%) for $C_{19}H_{21}NO_3$ (311.37); calcd: C 73.29, H 6.80, N 4.50; found: C 73.07, H 6.77, N 4.63.

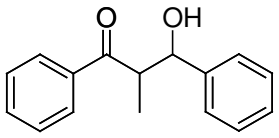


$C_{20}H_{23}NO_4$

M = 341.40 g.mol^{-1}

*2-(4-Methoxy-phenylamino)-3-methyl-4-oxo-4-phenyl-butyric acid ethyl ester (**4e**):*

Following GP1 (reaction time: 30 min.), product **4e** was isolated (pentane/ethyl acetate 80/20) as an inseparable mixture of the 2 diastereomers (ratio 60/40, brown solid, 0.50 mmol, 169 mg, 99%). Spectral data corresponded to those described in the literature.[3b] Elemental analysis (%) for $C_{20}H_{23}NO_4$ (341.40); calcd: C 70.36, H 6.79, N 4.10; found: C 70.62, H 6.81, N 3.92.

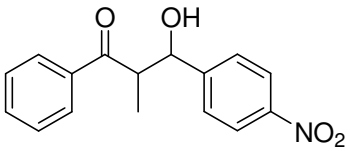


$C_{16}H_{16}O_2$

M = 240.3 g.mol^{-1}

*3-hydroxy-2-methyl-1,3-diphenylpropan-1-one **(4f)***

Following GP2 (reaction time: 24 hours), product **4f** was isolated (pentane/ethyl acetate: 80/20) as an inseparable mixture of the 2 diastereomers (ratio syn/anti 48/52, uncolored oil, 0.425 mmol, 102 mg, 85 %). Spectral data corresponded to those described in the literature.[5] See ^{1}H NMR spectra.

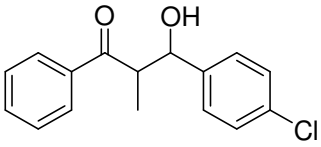


$C_{16}H_{15}NO_4$

M = 285.3 g.mol^{-1}

*3-hydroxy-2-methyl-3-(4-nitrophenyl)-1-phenylpropan-1-one **(4g)**:*

Following GP2 (reaction time: 24 hours), product **4g** was isolated (pentane/ethyl acetate: 80/20) as an inseparable mixture of the 2 diastereomers (ratio syn/anti 56/44, yellow solid, 0.37 mmol, 105 mg, 74 %). Spectral data corresponded to those described in the literature.[7] See ^{1}H and ^{13}C NMR spectra. Elemental analysis (%) for $C_{16}H_{15}NO_4$ (285.29); calcd: C 67.36, H 5.30, N 4.91; found: C 67.56, H 5.09, N 4.92.

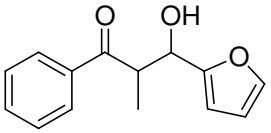


$C_{16}H_{15}ClO_2$

M = 274.7 g.mol^{-1}

*3-hydroxy-2-methyl-3-(4-chlorophenyl)-1-phenylpropan-1-one **(4h)***:

Following GP2 (reaction time: 36 h), product **4h** was isolated (pentane/ethyl acetate: 80/20) as an inseparable mixture of the 2 diastereomers (ratio syn/anti 60/40, white solid, 0.32 mmol, 89 mg, 65 %). Spectral data corresponded to those described in the literature.[4] See ^{1}H and ^{13}C NMR spectra.

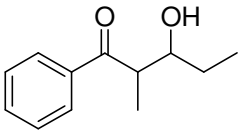


$C_{14}H_{14}O_3$

M = 230.3 g.mol^{-1}

*3-(furan-2-yl)-3-hydroxy-2-methyl-1-phenylpropan-1-one **(4i)***:

Following GP2 (reaction time: 7 days), product **4i** was isolated (pentane/ethyl acetate: 80/20) as an inseparable mixture of the 2 diastereomers (ratio syn/anti 55/45, uncolored oil, 0.2 mmol, 46 mg, 40 %). Spectral data corresponded to those described in the literature.[7] See ^{1}H and ^{13}C NMR spectra. Elemental analysis (%) for $C_{14}H_{14}O_3$ (230.26); calcd: C 73.03, H 6.13; found: C 72.85, H 6.15.



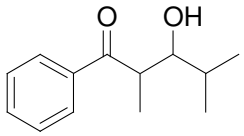
$C_{12}H_{16}O_2$

M = 192.3 g.mol^{-1}

*3-hydroxy-2-methyl-1-phenylpentan-1-one **(4j)***:

Following GP2 (reaction time: 3 days), product **4j** was isolated (pentane/ethyl acetate: 80/20) as an inseparable mixture of the 2 diastereomers (ratio syn/anti 66/34, uncolored oil, 0.21

mmol, 43 mg, 45 %). Spectral data corresponded to those described in the literature.[9] See ^{1}H and ^{13}C NMR spectra. Elemental analysis (%) for $C_{12}H_{16}O_2$ (192.25); calcd: C 74.97, H 8.39; found: C 74.58, H 8.67.

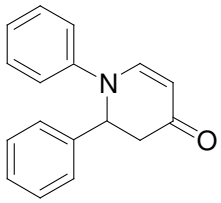


$C_{13}H_{18}O_2$

M = 206.3 g.mol^{-1}

*3-hydroxy-2,4-methyl-l-phenylpentan-l-one **(4k)***:

Following GP2 (reaction time: 2 days), product **4k** was isolated (pentane/ethyl acetate: 80/20) as an inseparable mixture of the 2 diastereomers (0.05 mmol, 11 mg, 11 %). Spectral data corresponded to those described in the literature.[5] See ^{1}H spectrum.

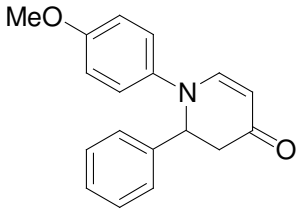


$C_{17}H_{15}NO$

M = 248.31 g.mol^{-1}

*1,2-Diphenyl-2,3-dihydro-1H-pyridin-4-one **(5a)**:*

Following GP3 with 0.5 mmol of starting imine (0.5 mmol, 1 equiv., 90.6 mg), after 7 hours, pyridinone **5a** was isolated (pentane/ethyl acetate 7:3; 0.42 mmol, 105 mg; 84 %) as a pale yellow oil. Spectral data corresponded to those described in the literature.[10, 3b]

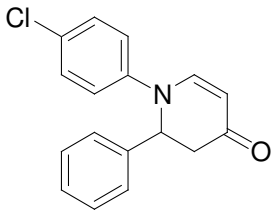


$C_{18}H_{17}NO_2$

M = 279.33 g.mol^{-1}

*1-(4-Methoxy-phenyl)-2-phenyl-2,3-dihydro-1H-pyridin-4-one **(5b)**:*

Following GP3 with 0.5 mmol of starting imine (0.5 mmol, 1 equiv., 105.5 mg), after 5 hours, pyridinone **5b** was isolated (pentane/ethyl acetate: 5/5; 0.45 mmol, 125 mg; 90 %) as orange cristals, mp = 111°C. Spectral data corresponded to those described in the literature.[10, 3b]



$C_{17}H_{14}ClNO_2$

M = 283.75 g.mol^{-1}

1-(4-Chloro-phenyl)-2-phenyl-2,3-dihydro-1H-pyridin-4-one ***(5c)****:*

Following GP3 with 0.5 mmol of starting imine (0.5 mmol, 1 equiv., 107.9 mg), after 20 hours, pyridinone **5c** was isolated (pentane/ethyl acetate: 5/5; 0.35 mmol, 98 mg, 69 %) as a white solid, mp 149°C.[10, 3b] Spectral data corresponded to those described in the literature.[3]

[1] Contant, R. *Inorg. Synth.* **1990**, *27*, 104–111.

[2] Contant, R. *Can. J. Chem.* **1987**, *65*, 568–573.

[3] a) Kobayashi, S.; Nagayama, S. *J. Org. Chem.* **1997**, *62*, 232–233. b) Boglio, C.; Lemiere, G.; Hasenknopf, B.; Thorimbert, S.; Lacote, E.; Malacria, M. *Angew. Chem.* **2006**, 118, 3402-3405; *Angew. Chem., Int. Ed.* **2006**, *45*, 3324–3327.

[4] Kobayashi, S., Nagayama, S. *J. Am. Chem. Soc.* **1997**, *119*, 10049–10053.

[5] Jankowska, J. Mlynarski, J. *J. Org. Chem.* **2006**, *71*, 1317–1321.

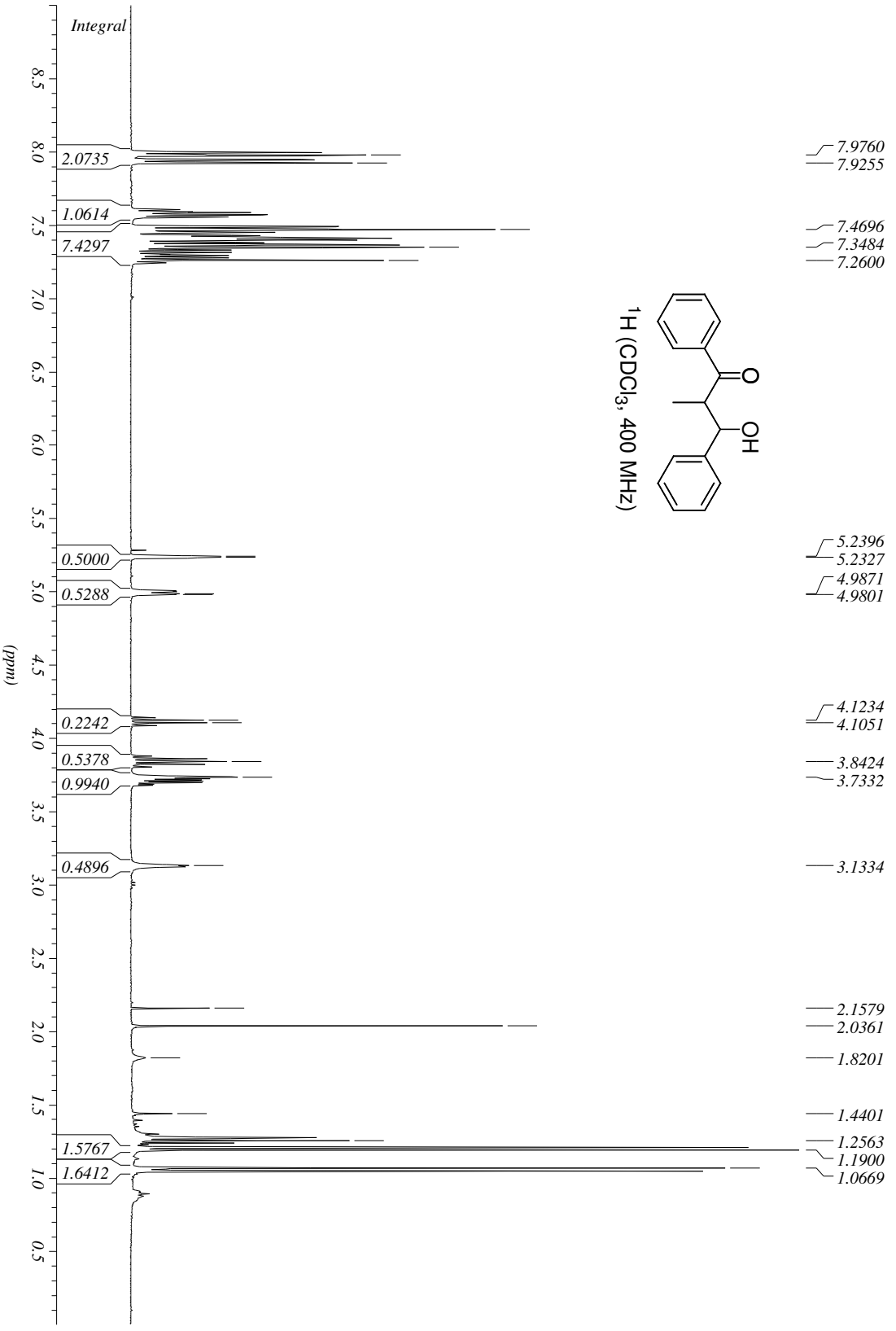
[6] Denmark, S.; Wong, K.-T.; Stavenger, R. A. *J. Am. Chem. Soc.* **1997**, *119*, 2333–2334.

[7] Jang, H. Y.; Huddleston, R. R.; Krische, M. J. *J. Am. Chem. Soc.* **2002**, *124*, 15156–15157.

[8] Nagayama, S.; Kobayashi, S. *J. Am. Chem. Soc.* **2000**, *122*, 11531–11532.

[9] Singhal, N.; Koner, A.L.; Mal, P.; Venugopalan, P.; Nau, W.M.; Moorthy, J. N. *J. Am. Chem. Soc.* **2005**, *127*, 14375–14382.

[10] Kobayashi, S.; Ishitani, H.; Nagayama, S. *Synthesis* **1995**, 1195–1202.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0.5288
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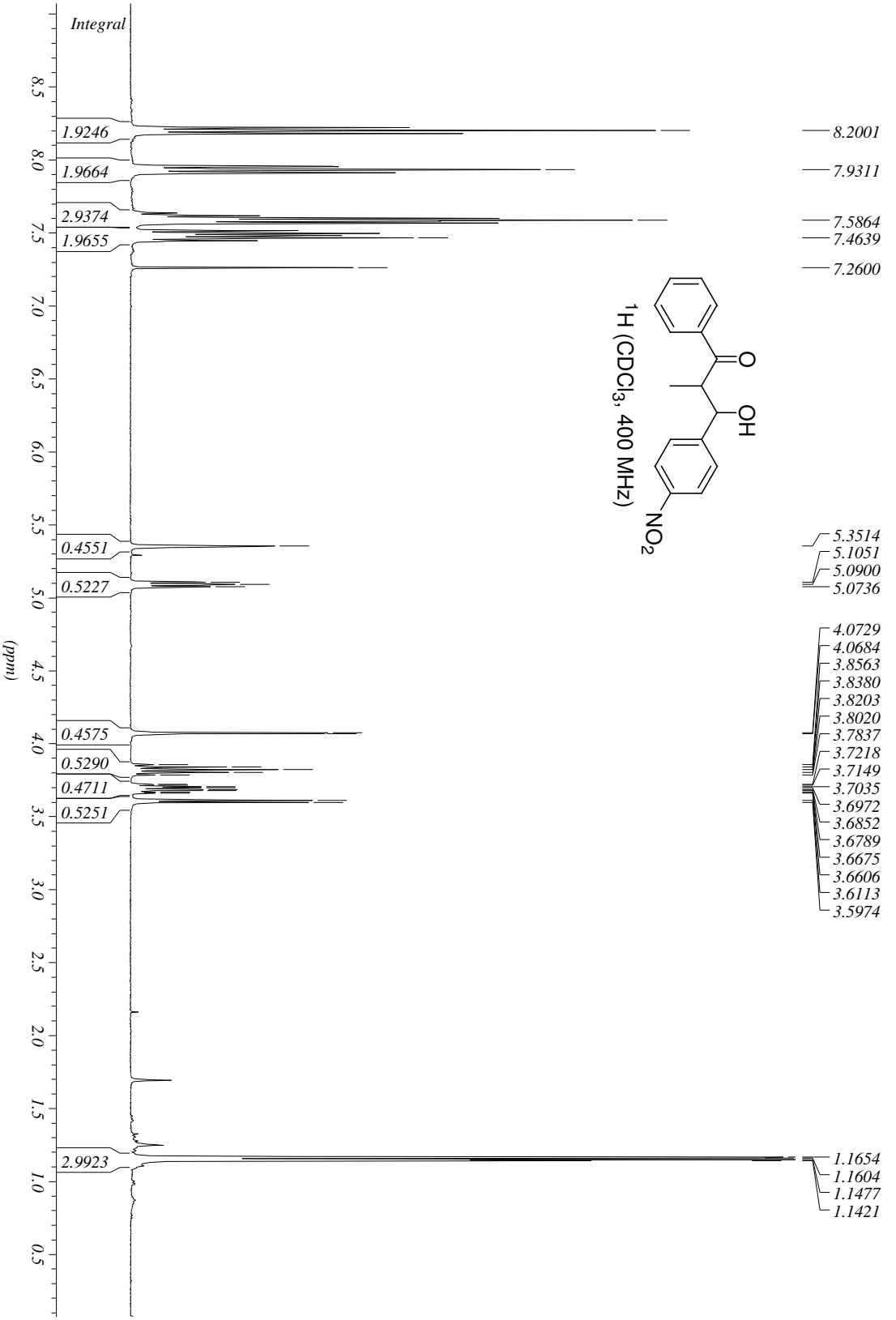
0.5378
0.9940
0.4896
1.5767
1.6412
(ppm)
7.9760
7.9255
7.4696
7.3484
7.2600
5.2396
5.2327
4.9871
4.9801
4.1234
4.1051
3.8424
3.7332
3.1334
2.1579
2.0361
1.8201
1.4401
1.2563
1.1900
1.0669
O
OH
1H (CDCl3, 400 MHz)


Integral
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1.9655
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0.5227
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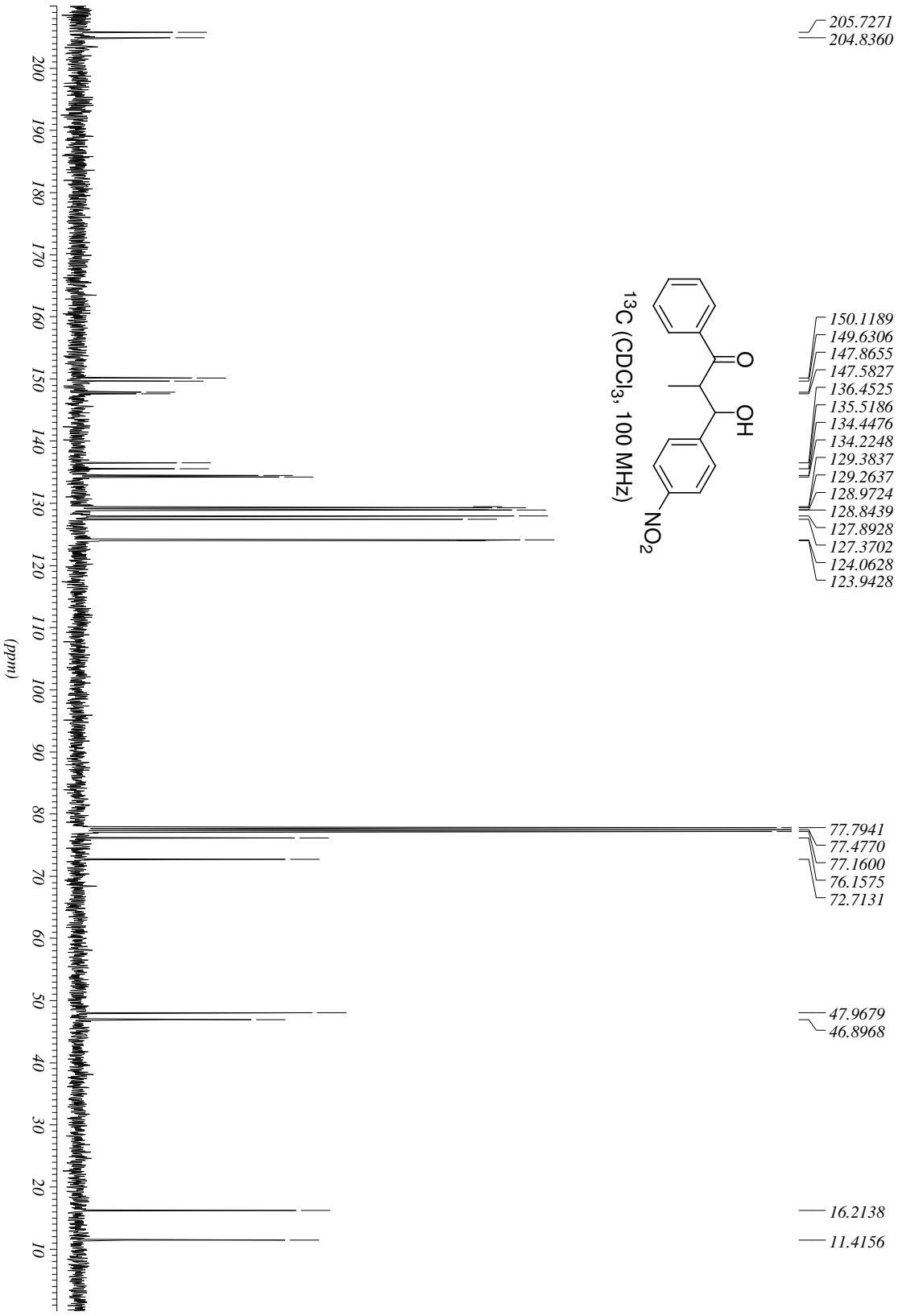
0.5290
0.4711
0.5251
2.9923
8.2001
7.9311
7.5864
7.4639
7.2600
5.3514
5.1051
5.0900
5.0736
4.0729
4.0684
3.8563
3.8380
3.8203
3.8020
3.7837
3.7218
3.7149
3.7035
3.6972
3.6852
3.6789
3.6675
3.6606
3.6113
3.5974
1.1654
1.1604
1.1477
1.1421
(ppm)
^{1}H (CDCl$_3$, 400 MHz)
O
OH
NO$_2$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150.1189
149.6306
147.8655
147.5827
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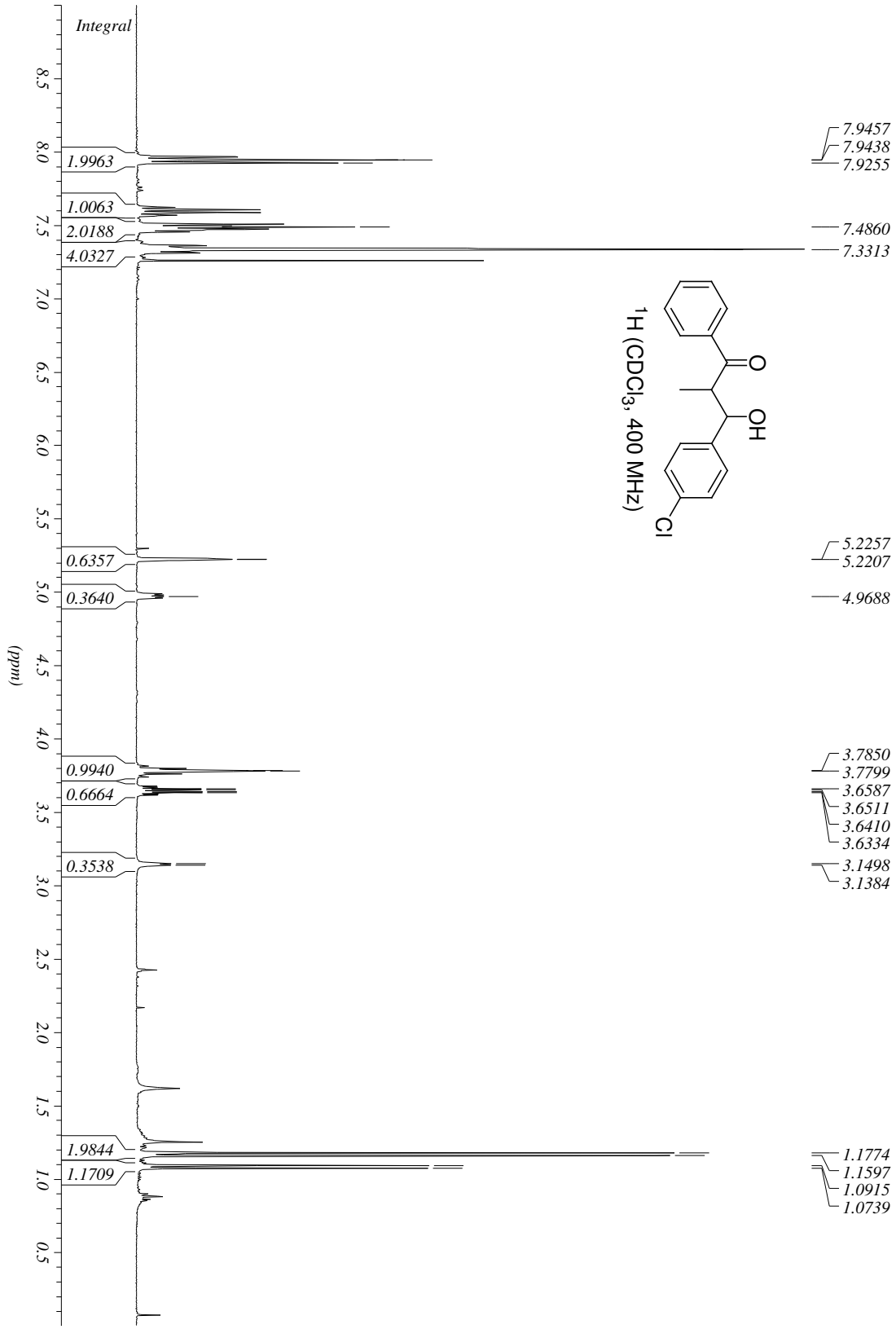
134.4476
134.2248
129.3837
129.2637
128.9724
128.8439
127.8928
127.3702
124.0628
123.9428
77.7941
77.4770
77.1600
76.1575
72.7131
47.9679
46.8968
16.2138
11.4156
^{13}C (CDCl$_3$, 100 MHz)
O
OH
NO$_2$
(ppm)
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10


Integral
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1.0063
2.0188
4.0327
0.6357
0.3640
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0.6664
0.3538
1.9844
1.1709
(ppm)
7.9457
7.9438
7.9255
7.4860
7.3313
5.2257
5.2207
4.9688
3.7850
3.7799
3.6587
3.6511
3.6410
3.6334
3.1498
3.1384
1.1774
1.1597
1.0915
1.0739
^{1}H (CDCl$_3$, 400 MHz)
O
OH
Cl

206.0955
205.1873
141.1565
140.7452
136.8981
135.8785
134.2162
134.0363
133.9592
133.4365
129.3151
129.1952
129.0752
128.9467
128.8610
128.5183
127.9014
77.7941
77.4770
77.1600
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16.1881
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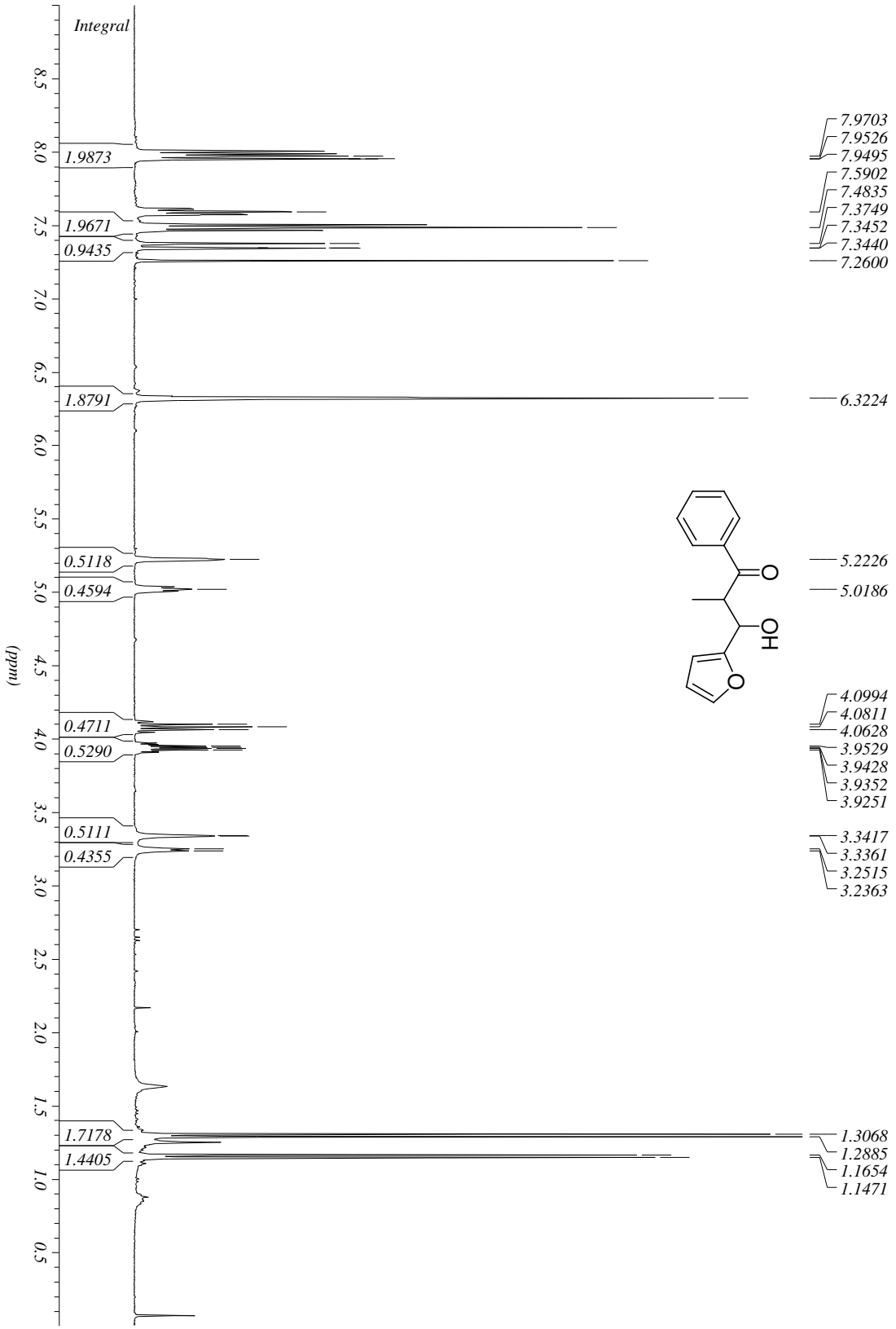
OH
Cl
13C (CDCl3, 100 MHz)
(ppm)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0.5290
0.5111
0.4355
1.7178
1.4405
(ppm)
7.9703
7.9526
7.9495
7.5902
7.4835
7.3749
7.3452
7.3440
7.2600
6.3224
5.2226
5.0186
4.0994
4.0811
4.0628
3.9529
3.9428
3.9352
3.9251
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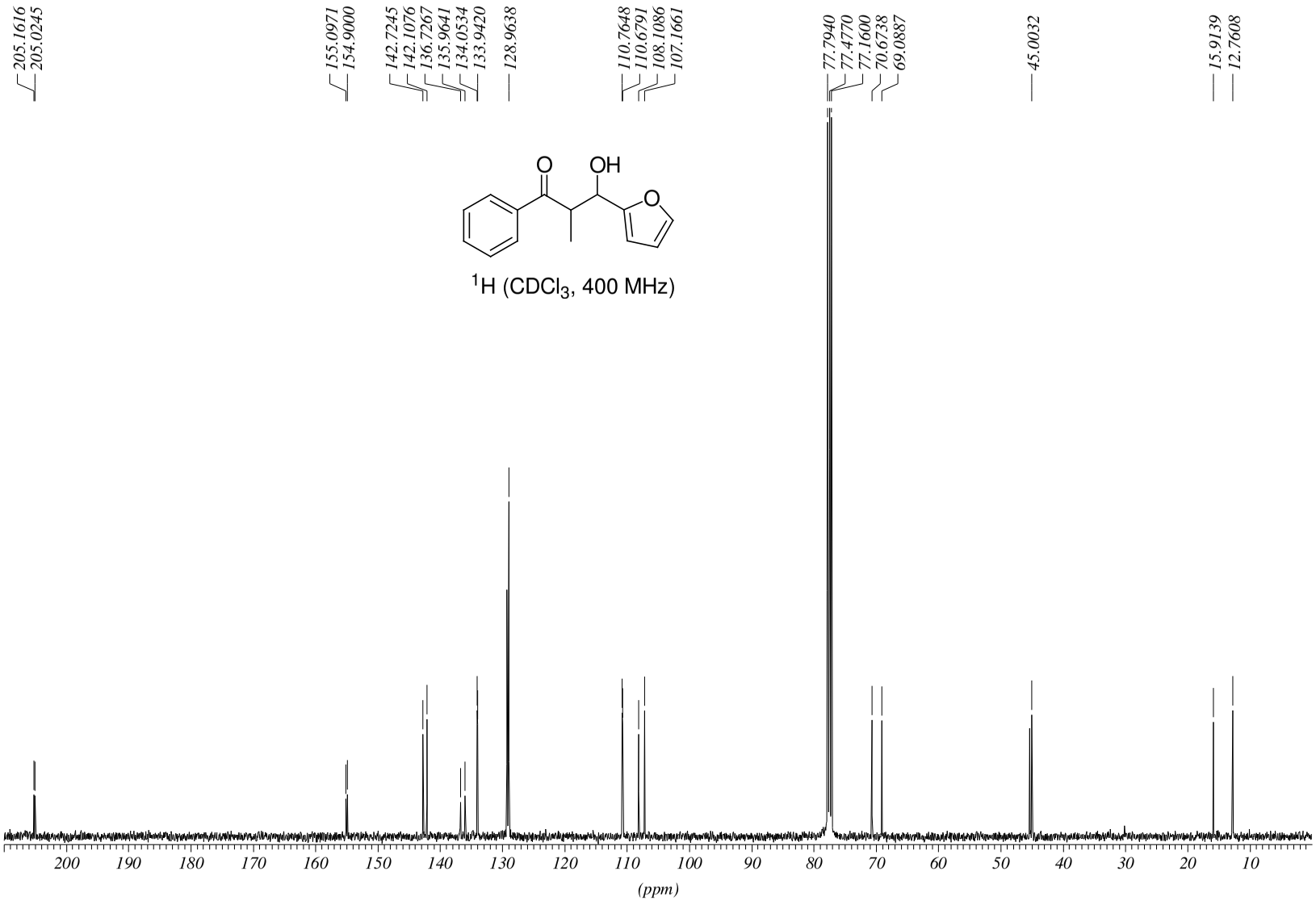
O
HO
O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205.0245
155.0971
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142.7245
142.1076
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135.9641
134.0534
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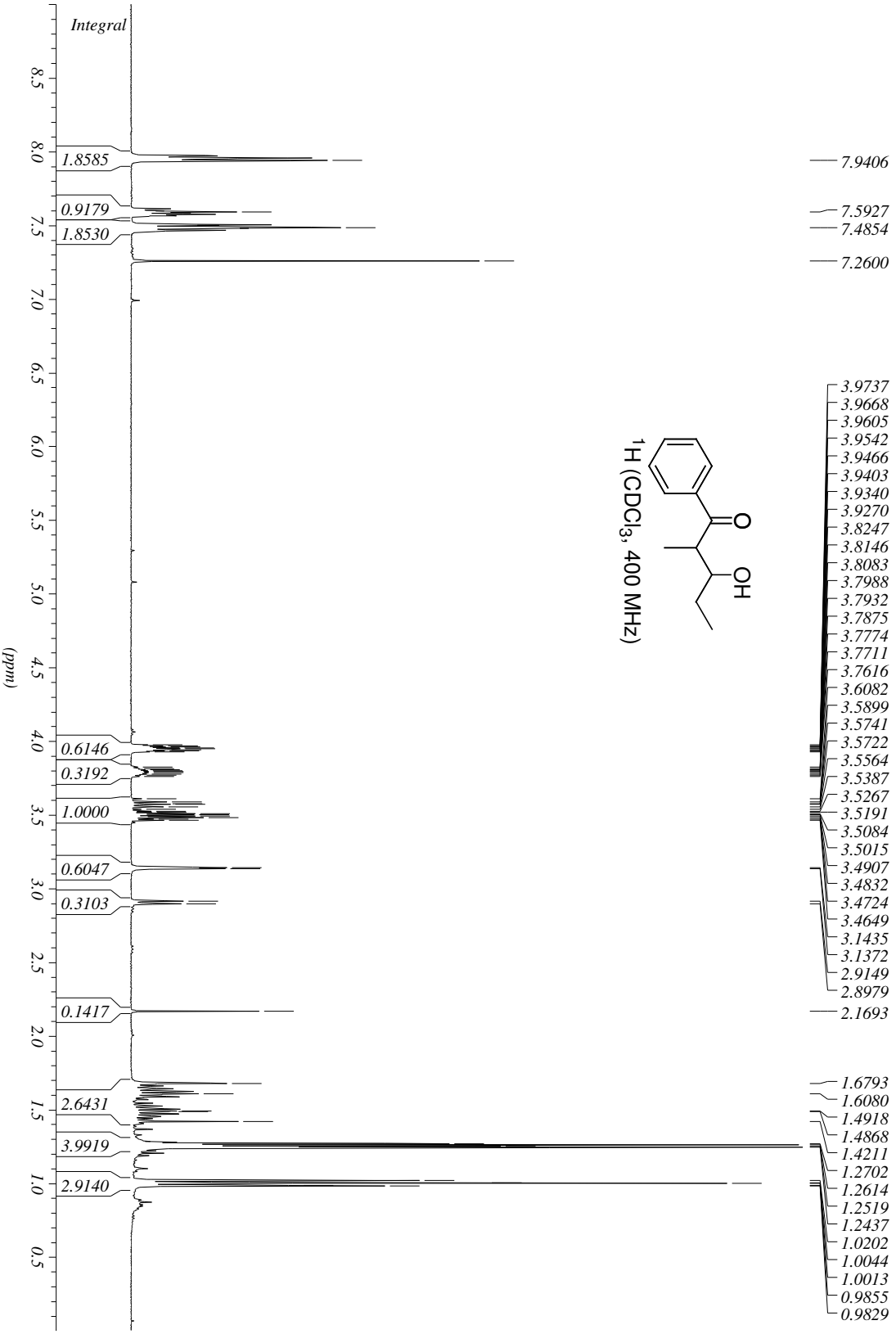
128.9638
110.7648
110.6791
108.1086
107.1661
77.7940
77.4770
77.1600
70.6738
69.0887
45.0032
15.9139
12.7608
O
OH
O
1H (CDCl3, 400 MHz)
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
(ppm)


Integral
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1.8530
0.6146
0.3192
1.0000
0.6047
0.3103
0.1417
2.6431
3.9919
2.9140
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
(ppm)
^{1}H (CDCl$_3$, 400 MHz)
O
OH
7.9406
7.5927
7.4854
7.2600
3.9737
3.9668
3.9605
3.9542
3.9466
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3.9270
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3.7988
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1.4868
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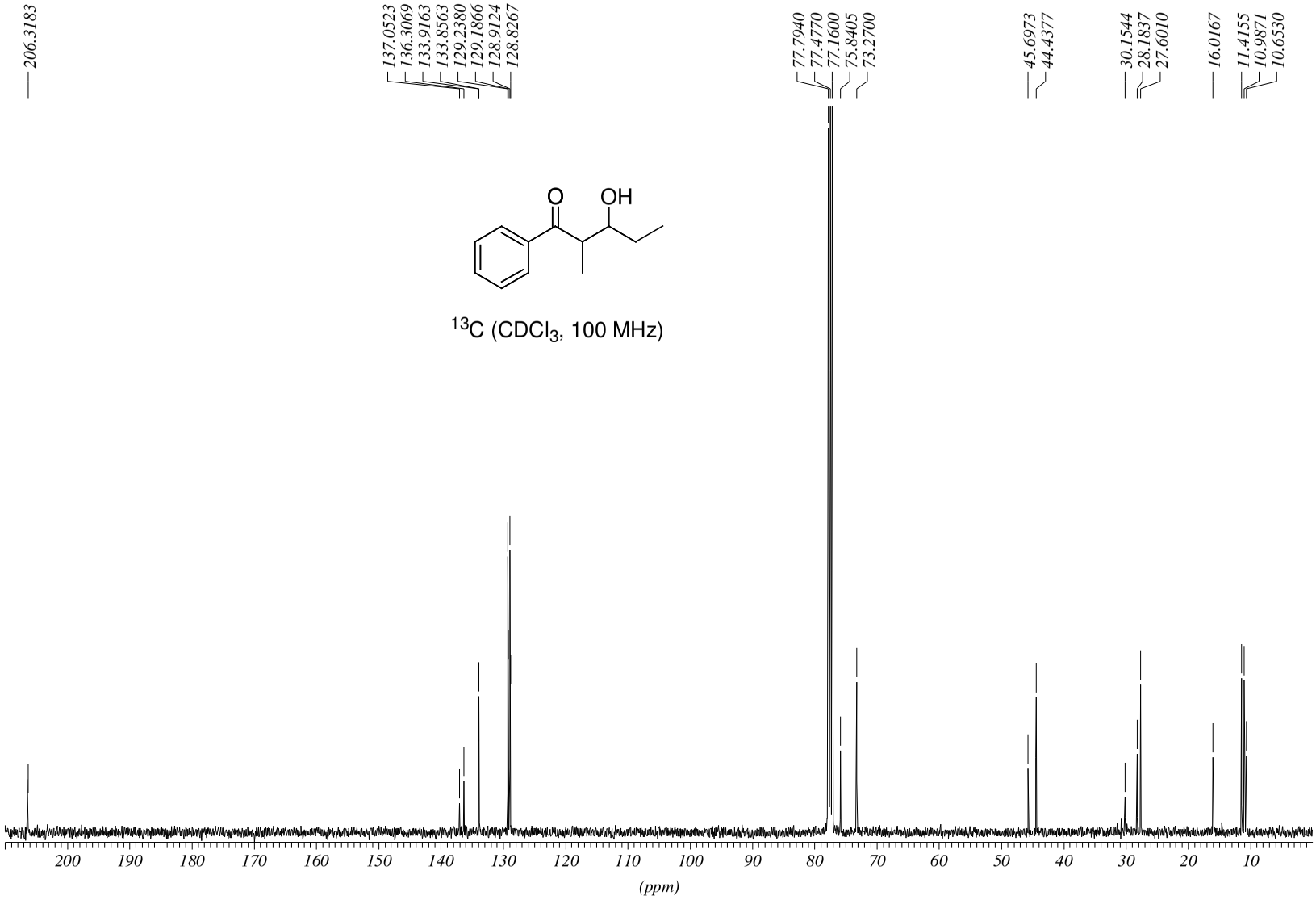
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77.1600
75.8405
73.2700
45.6973
44.4377
30.1544
28.1837
27.6010
16.0167
11.4155
10.9871
10.6530
O
OH
13C (CDCl3, 100 MHz)
200
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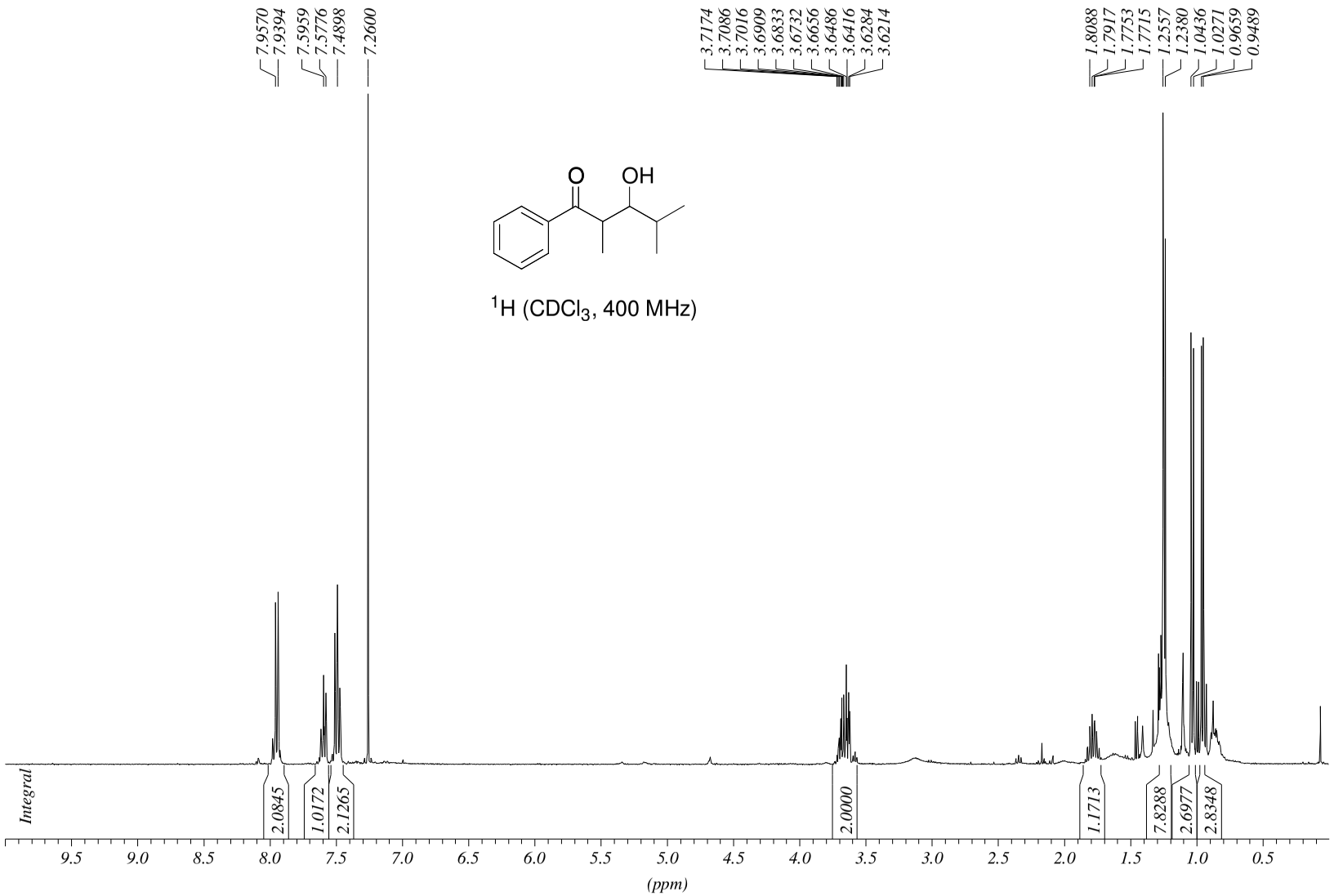
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
(ppm)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3.6732
3.6656
3.6486
3.6416
3.6284
3.6214
1.8088
1.7917
1.7753
1.7715
1.2557
1.2380
1.0436
1.0271
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O
OH
1H (CDCl3, 400 MHz)
Integral
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2.1265
2.0000
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2.8348
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
(ppm)