Electronic Supplementary Material (ESI) for Chemical Communications.

Supplementary Information

Hydrogenation of Amides Catalyzed by Combined Catalytic System of Ru Complex with Zinc Salt

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Contents

General information

All manipulations involving air- and moisture-sensitive compounds were carried out under an argon atmosphere by using of standard vacuum line and Schlenk tube techniques. ^{i}PrOH and $^{i}Pr_2O$ were distilled under an argon atmosphere from the calcium hydride. Alternatively, toluene, THF, MeCN and hexane were dried and deoxygenated by using Grubbs column (Glass Counter Solvent Dispending System, Nikko Hansen & Co, Ltd.). 1,4-Dioxane was distilled over sodium benzophenone ketyl under an argon atmosphere. Amide substrates were synthesized by standard condensation reaction of acyl chlorides and amines. $Zn_4(OCOCF_3)_6O$ was prepared according to literature procedure.[1] All other reagents were purchased at the highest commercial quality and used without further purification. Flash column chromatography was performed using silica gel 60 (0.040–0.063 mm, 230–400 mesh ASTM). Hydrogenation was conducted with TAIATSU stainless autoclave.

Physical measurements

^{1}H NMR (300 MHz, 400 MHz), ^{13}C NMR (75MHz, 100 MHz), ^{19}F NMR (376 MHz) and ^{31}P NMR (160 MHz) spectra were measured on Varian Unity Inova-300 and Bruker Avance III-400 spectrometers in 5 mm NMR tubes. All ^{1}H NMR chemical shifts were reported in ppm relative to the residual solvent protons in chloroform-d_1 at δ 7.26, benzene-d_6 at δ 7.16, dichloromethane-d_2 at δ 5.32 and 1,4-dioxane-d_8 at δ 3.53. All ^{13}C NMR chemical shifts were reported in ppm relative to carbon resonance in chloroform-d_1 at δ 77.16 and dichloromethane-d_2 at δ 53.84. All ^{19}F NMR chemical shifts were reported in ppm relative to an external reference of α,α,α-trifluorotoluene at δ -63.9. ^{31}P NMR chemical shifts were recorded in ppm (δ) relative to 85% H_3PO_4 as an external standard at δ 0.00. GC analyses were recorded on a Shimadzu GC-2014 gas chromatograph with J&W Scientific DB-5 column. Mass spectra were obtained on Bruker Daltonics MicroTOF. IR spectra were recorded on a JASCO FT/IR-230 spectrometer. X-ray crystallographic studies were performed on Rigaku R-AXIS RAPID imaging plate area detector or Rigaku AFC7R/Mercury CCD detector with graphite-monochromated Mo Kα radiation (λ = 0.71075). The elemental analysis was recorded by Perkin-Elmer 2400 at the Faculty of Engineering Science, Osaka University. All melting point were recorded on BUCHI melting point M-565. Elemental analyses were recorded by using Perkin-Elmer 2400 at the Faculty of Engineering Science, Osaka University.

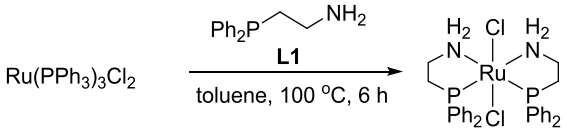
General procedure for the catalytic hydrogenation of amides

A glass tube was charged appropriate amide (1.0 mmol), $RuCl_2$(**L1**)$_2$ (0.020 mmol), KO^{t}Bu (0.20 mmol) and $Zn(OCOCF_3)_2$ (0.040 mmol). The glass tube was placed in an autoclave after three cycles of evacuation/argon backfilling, 1,4-dioxane (3.0 mL) was added to from the inlet, the mixture was charged with H_2, and then the hydrogen pressure was increased to 3.0 MPa. The

reaction mixture was stirred at 100 ºC for 18 h. The mixture was cooled to r.t. After release of H_2, dodecane was added to the mixture. The yield was determined by GC analysis.

Synthetic procedure of complexes

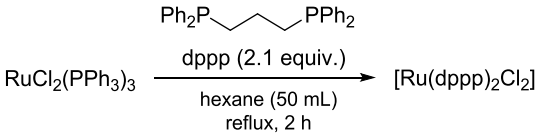
- **Synthesis of $[RuCl_2(L1)_2]$[2]**



84% yield

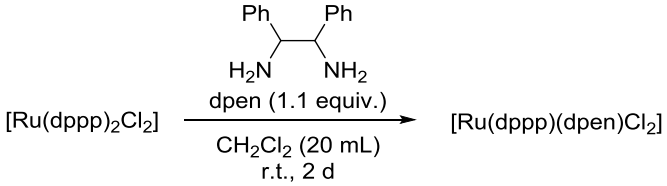
$Ph_2PCH_2CH_2NH_2$ (**L1**, 0.50 mmol), $[RuCl_2(PPh_3)_3]$ (0.25 mmol) and toluene (5.0 mL) were added to a schlenk tube equipped with a magnetic stir bar. The mixture was then heated at 100 ºC for 6 h. The yellow suspension that resulted was allowed to cool to r.t. before collecting the precipitate by filtration. The precipitate was then washed with 10.0 mL portions of toluene three times. The yellow solid was then dried *in vacuo*. Yield 133 mg (84%). NMR spectra were described in reference 2.

- **Synthesis of $[Ru(dppp)_2]Cl_2$**[3]



A suspension of $[RuCl_2(PPh_3)_3]$ (500 mg, 0.52 mmol, 1.0 equiv) and $PPh_2(CH_2)_3PPh_2$ (dppp, 442 mg, 1.07 mmol, 2.1 equiv) in hexane (50 mL) was refluxed for 2 h. The black suspension gradually became pale orange. The product was filtered off while hot, washed with hot hexane, and dried *in vacuo*. Yield 502 mg (97%). NMR spectra were described in reference 3.

- **Synthesis of $[Ru(dppp)(dpeda)]Cl_2$**[3]



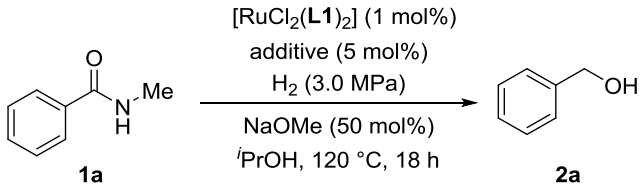
(±)-1,2-diphenylethylenediamine (dpen, 116 mg, 0.55 mmol, 1.1 equiv) was dissolved in 10 mL of CH_2Cl_2 and the solution was added dropwise to a stirred solution of $[Ru(dppp)_2]Cl_2$ (500 mg, 0.50 mmol, 1.0 equiv) in 10 mL of CH_2Cl_2 within 10 min. The mixture was stirred for 2 days at room temperature while the color changed from brown to reddish brown. After removal of any turbidity by filtration, the volume of solution was concentrated to about 5 mL under reduced pressure. Addition of 40 mL of Et_2O caused precipitation of a yellow solid, which was filtered and dried *in*

vacuo. Yield 122 mg (31%). NMR spectra were described in reference 3.

Optimization studies

We screened a variety of conditions such as additive (Table S1), base (Table S2), catalyst (Table S3), solvent (Table S4), hydrogen pressure, concentration, and temperature (Table S5).

Table S1 Screening of additive

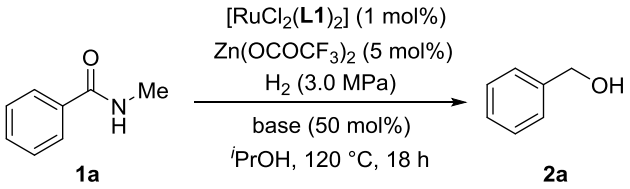


1a **2a**

entry	additive	yield[a] (%)	entry	additive	yield[a] (%)
1	LiCl	72	9	CuCl	68
2	NaCl	57	10	$CuCl_2$	35
3	$CrCl_2$	63	11	$ZnCl_2$	73
4	$CrCl_3(THF)_3$	68	12	$PdCl_2$	54
5	$MnCl_2$	67	13	AgCl	62
6	$FeCl_2$	72	14	$InCl_3$	70
7	$FeCl_3$	69	15	$CeCl_3$	71
8	$NiCl_2$	39	16	$PtCl_2$	45

[a] The yield was determined by GC analysis with dodecane as an internal standard.

Table S2 Screening of base

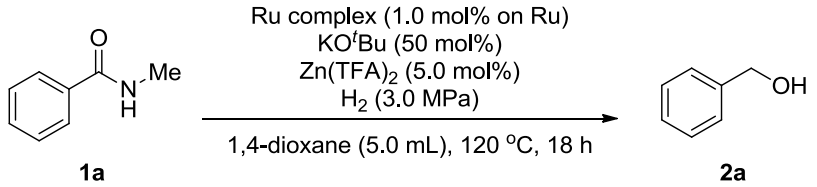


1a **2a**

entry	base	yield[a] (%)	entry	base	yield[a] (%)
1	NaOMe	74	4	NaOtBu	79
2	KOMe	77	5	KOtBu	80
3	K_2CO_3	n.d.	6	DBU	n.d.

[a] The yield was determined by GC analysis with dodecane as an internal standard.

Table S3 Screening of catalyst

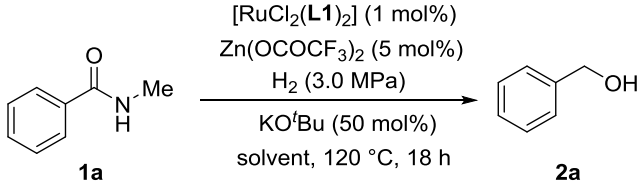


1a **2a**

entry	Ru complex	yield[a] (%)	entry	Ru complex	yield[a] (%)
1	$RuCl_2$(**L1**)$_2$	92	3	$RuCl_2$(dppp)(dpen)	n.d.
2	$RuCl_2$(**L2**)$_2$	n.d.	4	$Ru_3(CO)_{12}$	n.d.

[a] The yield was determined by GC analysis with dodecane as an internal standard. **L2** = ^{t}Bu$_2$PCH$_2$CH$_2$NH$_2$

Table S4 Screening of solvent

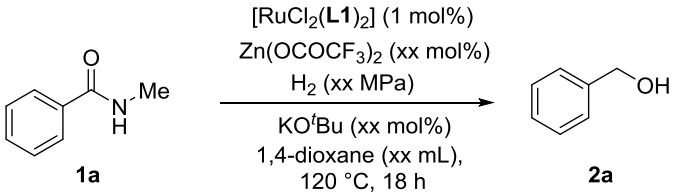


1a **2a**

entry	solvent	yield[a] (%)	entry	solvent	yield[a] (%)
1	^{i}PrOH	80	5	toluene	85
2	THF	87	6	hexane	33
3	^{i}Pr$_2$O	85	7	MeCN	n.d.
4	1,4-dioxane	92	8	DCE	n.d.

[a] The yield was determined by GC analysis with dodecane as an internal standard.

Table S5 Optimization study



1a **2a**

entry	KO^tBu (mol%)	$Zn(TFA)_2$ (mol%)	H_2 (MPa)	1,4-dioxane (mL)	temp. (^oC)	yield[a] (%)
1	50	5.0	3.0	5.0	120	92
2	50	5.0	3.0	5.0	100	83
3	50	5.0	3.0	5.0	80	37
4	50	5.0	3.0	3.0	100	90
5	50	5.0	3.0	3.0	80	55
6	50	5.0	3.0	2.0	100	84
7	50	5.0	3.0	1.0	100	83
8	20	5.0	3.0	3.0	100	87
9	10	5.0	3.0	3.0	100	n.d.
10	20	10.0	3.0	3.0	100	n.d.
11	20	2.0	3.0	3.0	100	95
12	20	2.0	2.0	3.0	100	80
13	20	2.0	1.0	3.0	100	56
14	20	0	3.0	3.0	100	74
15	20	2.0	3.0	3.0	100	n.d.

[a] The yield was determined by GC analysis with dodecane as an internal standard. b Without $[RuCl_2(\mathbf{L1})_2]$.

Mechanistic studies

We measured $^{31}P\{^1H\}$NMR of a mixture of $[RuCl_2(\mathbf{L1})_2]$ (0.010 mmol), KO^tBu (0.020 mmol) and $Zn(OCOCF_3)_2$ (0.020 mmol) in 1,4-dioxane-d_8 (0.50 mL). New singlet peaks were appeared at 62.3 and 62.6 ppm (Figure S1). Then, the mixture was heated at 100 °C for 3h. The intensity of the peak at 62.6 ppm was increased compared with that of 62.3 ppm. One of them could be assigned to $[Ru(OCOCF_3)_2(\mathbf{L1})_2]$ after the isolation by the extraction by toluene and subsequent filtration (see below).

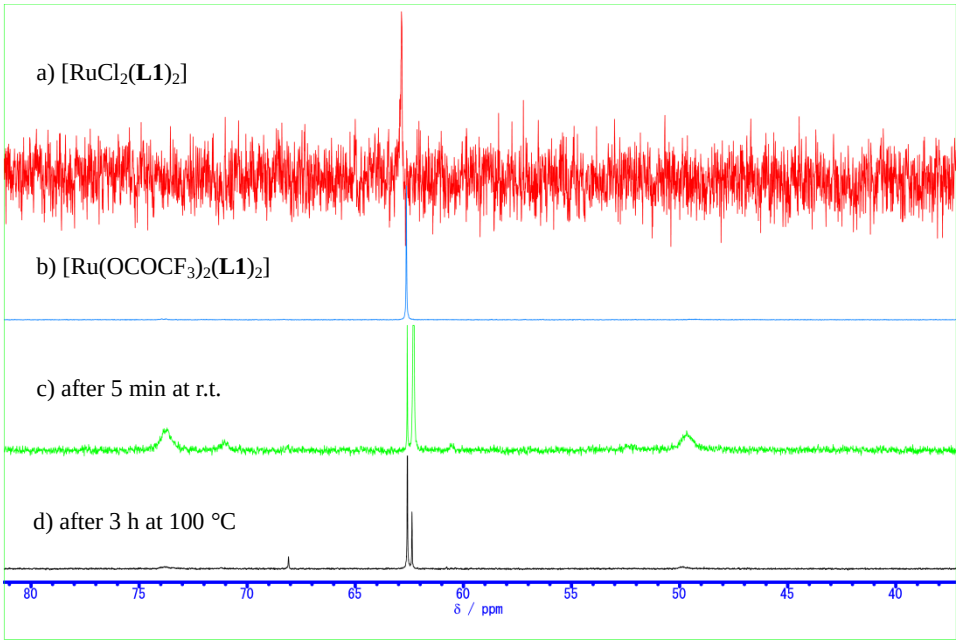


Figure S1 $^{31}P\{^{1}H\}$ NMR spectra of NMR experiments. a) Ruthenium catalyst precursor only, b) isolated $[Ru(OCOCF_3)_2(\mathbf{L1})_2]$, c) a solution of $[RuCl_2(\mathbf{L1})_2]$, KO^{t}Bu, and $Zn(OCOCF_3)_2$ after 5 min mixing at room temperature, d) a solution of $[RuCl_2(\mathbf{L1})_2]$, KO^{t}Bu, and $Zn(OCOCF_3)_2$ after heating at 100 °C, 3 h.

- **Synthesis of $[Ru(OCOCF_3)_2(L1)_2]$ (4)**

$$[RuCl_2(\mathbf{L1})_2] + Zn(OCOCF_3)_2 \xrightarrow[\text{1,4-dioxane (0.02 M)}\\ \text{100 °C, 18 h}]{KO^tBu} [Ru(OCOCF_3)_2(\mathbf{L1})_2]\ \mathbf{4}$$

A mixture of $RuCl_2(\mathbf{L1})_2$ (126.1 mg, 0.20 mmol), $Zn(OCOCF_3)_2$ (116.6 mg, 0.40 mmol) and KO^{t}Bu (44.9 mg, 0.40 mmol) in 1,4-dioxane (10 mL) was stirred at 100 °C for 18 h under an argon atmosphere. After 1,4-dioxane was removed *in vacuo*, the residue was extracted by toluene and filtrated by celite under an argon atmosphere. The filtrate was concentrated *in vacuo* and $Ru(OCOCF_3)_2(\mathbf{L1})_2$ (**4**) was obtained as yellow solid. Yield 97.0 mg (77%). Crystals suitable for X-ray diffraction were grown by vapor diffusion of *n*-hexane into a saturated 1,4-dioxane solution. Mp 140 °C (dec.); IR (KBr, ν/cm^{-1}) 3314 w, 3060 w, 1678 s, 1434 m, 1197 s, 1136 m, 1100 m, 693 m; ^{1}H NMR (400 MHz, CD_2Cl_2, 30 °C) δ 2.6-2.7 (m, 4H, *methylene*), 3.1-3.2 (m, 4H, *methylene*), 5.41 (br s, 4H, N*H*$_2$), 7.0-7.4 (m, 20H, *Ar*); ^{13}C NMR (100 MHz, CD_2Cl_2, 30 °C) δ 33.8 (d, $J_{C\text{-}P}$ = 14 Hz), 33.9 (d, $J_{C\text{-}P}$ = 12 Hz), 113.7 (q, $J_{C\text{-}F}$ = 291 Hz), 128.16 (d, $J_{C\text{-}P}$ = 5 Hz), 128.21 (d, $J_{C\text{-}P}$ = 4 Hz), 129.8, 133.40 (d, $J_{C\text{-}P}$ = 5 Hz), 133.45 (d, $J_{C\text{-}P}$ = 5 Hz), 135.3 (d, $J_{C\text{-}P}$ = 15 Hz), 135.5 (d, $J_{C\text{-}P}$ = 19 Hz), 135.7 (d, $J_{C\text{-}P}$ = 19 Hz), 135.9 (d, $J_{C\text{-}P}$ = 15 Hz), 166.5 (q, $J_{C\text{-}F}$ = 36 Hz); ^{19}F NMR (376 MHz, CD_2Cl_2, 30 °C) δ −75.6; ^{31}P NMR (162 MHz, CD_2Cl_2, 30 °C) δ 62.0; MS (ESI) m/z 673

([M-OCOCF$_3$]$^+$); HRMS (ESI) m/z calcd. for $C_{30}H_{32}F_3N_2O_2P_2Ru$ 673.0935 ([M-OCOCF$_3$]) found 673.0959. Anal. Calcd for $C_{32}H_{32}F_6N_2O_4P_2Ru$: C, 48.92; H, 4.11; N, 3.57. Found: C. 48.34; H, 3.89; N, 3.46.

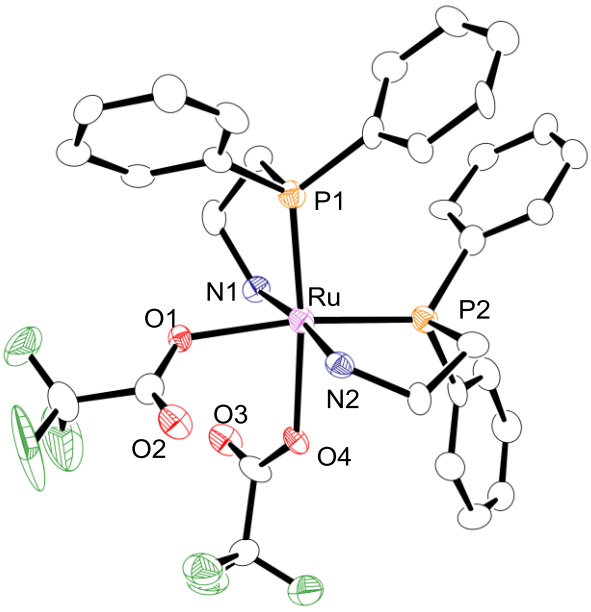


Figure S2 Molecular structure of **4**. All hydrogen atoms are omitted for clarity.

Table S5 Crystal data and data collection parameters.

	4
empirical formula	$C_{32}H_{32}F_6N_2O_4P_2Ru$
formula weight	785.61
crystal system	triclinic
space group	P-1 (#2)
a, Å	12.66(2)
b, Å	13.27(2)
c, Å	13.39(2)
α, deg.	119.5260(12)
β, deg.	92.52(2)
γ, deg.	115.846(8)
V, Å^3	1162(4)
Z	2

*D*calcd, g/cm-3	1.570
μ [Mo-*K*α], mm^{-1}	0.641
T, K	113(2)
crystal size, mm	0.14 x 0.11 x 0.06
θ range for data collection (deg.)	3.04 to 24.15
no. of reflections measured	15791
unique data (*R*int)	7288 (0.1124)
data / restraints / parameters	5059 / 0 / 352
*R*1 ($I > 2.0\sigma(I)$)	0.1234
*wR*2 ($I > 2.0\sigma(I)$)	0.3060
*R*1 (all data)	0.1648
*wR*2 (all data)	0.3475
GOF on F^2	1.131
Δρ, e Å-3	2.30, -1.18

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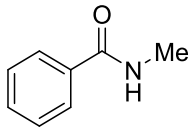
a) $R1 = (\Sigma||Fo| - |Fc||)/(\Sigma|Fo|)$ b) $wR2 = [\{\Sigma w(Fo^2\text{-}Fc^2)^2\}/\{\Sigma w(Fo^4)\}]^{1/2}$

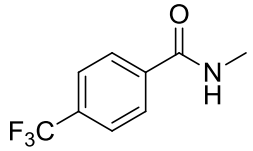
Spectral Data

1a: *N*-methylbenzamide CAS: 88070-48-8



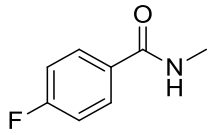
White solid; ^{1}H NMR (400 MHz, $CDCl_3$, 30 ºC) δ 3.01 (d, *J* = 4.9 Hz, 3H, C*H*$_3$), 6.20 (br s, 1H, N*H*), 7.4-7.5 (m, 3H, *Ar*), 7.7-7.8 (m, 2H, *Ar*); ^{13}C NMR (100 MHz, $CDCl_3$, 30 ºC) δ 26.9, 127.0, 128.6, 131.4, 134.7, 168.4.

1b: *N*-methyl-4-(trifluoromethyl)benzamide CAS: 65017-76-7



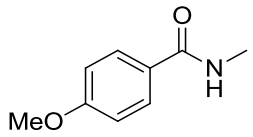
White solid; ^{1}H NMR (400 MHz, $CDCl_3$, 30 ºC) δ 3.04 (d, *J* = 4.8, 3H, C*H*$_3$), 6.17 (br s, 1H, N*H*), 7.70 (d, *J* = 8.0 Hz, 2H, *Ar*), 7.87 (d, *J* = 8.0, 2H, *Ar*); ^{13}C NMR (100 MHz, $CDCl_3$, 30 ºC) δ 27.1, 123.8 (q, $J_{C\text{-}F}$ = 273 Hz), 125.7 (q, $J_{C\text{-}F}$ = 4 Hz), 127.5, 133.3 (q, $J_{C\text{-}F}$ = 33 Hz), 138.0, 167.2; ^{19}F NMR (376 MHz, $CDCl_3$, 30 ºC) δ -63.0.

1c: 4-fluoro-*N*-methylbenzamide CAS: 701-49-5



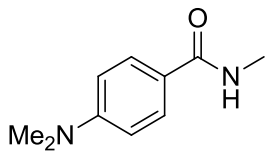
White solid; ^{1}H NMR (400 MHz, $CDCl_3$, 30 ºC) δ 3.00 (d, *J* = 4.8 Hz, 3H, C*H*$_3$), 6.20 (br s, 1H, N*H*), 7.09 (dd, *J* = 8.6, 8.0 Hz, 2H, *Ar*), 7.7-7.8 (m, 2H, *Ar*); ^{13}C NMR (100 MHz, $CDCl_3$, 30 ºC) δ 27.0, 115.7 (d, $J_{C\text{-}F}$ = 22 Hz), 129.3 (d, $J_{C\text{-}F}$ = 9 Hz), 131.0 (d, $J_{C\text{-}F}$ = 3 Hz), 164.8 (d, $J_{C\text{-}F}$ = 252 Hz), 167.3; ^{19}F NMR (376 MHz, $CDCl_3$, 30 ºC) δ -108.5.

1d: 4-methoxy-*N*-methylbenzamide CAS: 3400-22-4



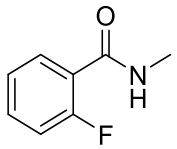
White solid; ^{1}H NMR (400 MHz, $CDCl_3$, 30 ºC) δ 2.99 (d, *J* = 4.9 Hz, 3H, C*H*$_3$), 3.84 (s, 3H, OC*H*$_3$), 6.07 (br s, 1H, N*H*), 6.91 (d, *J* = 8.8 Hz, 2H, *Ar*), 7.72 (d, *J* = 8.8 Hz, 2H, *Ar*); ^{13}C NMR (100 MHz, $CDCl_3$, 30 ºC) δ 26.9, 55.5, 113.8, 127.1, 128.8, 162.2, 167.9.

1e: 4-(dimethylamino)-*N*-methylbenzamide CAS: 21176-94-3



White solid; ^{1}H NMR (400 MHz, $CDCl_3$, 30 ºC) δ 2.99 (d, *J* = 4.8 Hz, 3H, C*H*$_3$), 3.01 (s, 6H, N(C*H*$_3$)$_2$), 5.96 (br s, 1H, N*H*), 6.67 (d, *J* = 8.8 Hz, 2H, *Ar*), 7.66 (d, *J* = 8.8 Hz, 2H, *Ar*); ^{13}C NMR (100 MHz, $CDCl_3$, 30 ºC) δ 26.7, 40.2, 111.2, 121.7, 121.7, 128.4, 152.4, 168.3.

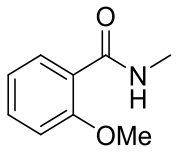
1f: 2-fluoro-*N*-methylbenzamide CAS: 52833-63-3



White solid; ^{1}H NMR (400 MHz, $CDCl_3$, 30 ºC) δ 3.04 (d, *J* = 4.8 Hz, 3H, C*H*$_3$), 6.75 (br s, 1H, N*H*), 7.11 (dd, *J* = 8.3, 8.3 Hz, 1H, *Ar*), 7.2-7.3 (m, 1H, Ar), 7.4-7.5 (m, 1H, Ar), 8.11 (ddd, *J* = 7.9, 7.9, 1.6 Hz, 1H, *Ar*); ^{13}C NMR (100 MHz, $CDCl_3$, 30 ºC) δ 26.9, 116.1 (d, $J_{C\text{-}F}$ = 25 Hz), 121.2 (d, $J_{C\text{-}F}$ = 12 Hz), 124.9 (d, $J_{C\text{-}F}$ = 3 Hz), 132.2 (d, $J_{C\text{-}F}$ = 2 Hz), 133.3 (d, $J_{C\text{-}F}$ = 9 Hz), 160.8 (d, $J_{C\text{-}F}$ = 247 Hz),

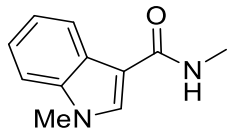
164.1; ^{19}F NMR (376MHz, $CDCl_3$, 30 ºC) δ -114.1.

1g: 2-methoxy-*N*-methylbenzamide CAS: 3400-35-9



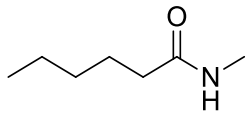
White solid; ^{1}H NMR (400 MHz, $CDCl_3$, 30 ºC) δ 3.00 (d, *J* = 4.8 Hz, 3H, C*H*$_3$), 3.94 (s, 3H, OC*H*$_3$), 5.96 (br s, 1H, N*H*), 6.67 (d, *J* = 8.8 Hz, 2H, *Ar*), 7.66 (d, *J* = 8.8 Hz, 2H, *Ar*); ^{13}C NMR (100 MHz, $CDCl_3$, 30 ºC) δ 26.7, 40.2, 111.2, 121.7, 121.7, 128.4, 152.4, 168.3.

1h: *N*,1-dimethyl-1*H*-indole-3-carboxamide CAS: 85729-23-3



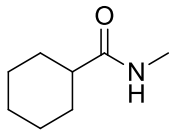
White solid; ^{1}H NMR (400 MHz, $CDCl_3$, 30 ºC) δ 3.07 (d, *J* = 4.8 Hz, 3H, C*H*$_3$), 3.81 (s, 3H, NC*H*$_3$), 5.99 (br s, 1H, N*H*), 7.2-7.4 (m, 3H, *Ar*), 7.66 (s, 1H, *Ar*), 7.97 (d, *J* = 7.6 Hz, 1H, *Ar*); ^{13}C NMR (100 MHz, $CDCl_3$, 30 ºC) δ 26.4, 33.2, 110.0, 111.0, 120.4, 121.4, 122.5, 125.6, 132.1, 137.3, 166.1.

1i: *N*-methylhexanamide CAS: 3418-05-1



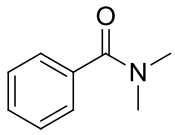
Colorless liquid; ^{1}H NMR (400 MHz, $CDCl_3$, 30 ºC) δ 0.85 (t, *J* = 7.0 Hz, 3H, C*H*$_3$), 1.2-1.3 (m, 4H, *methylene*), 1.5-1.6 (m, 2H, *methylene*), 2.13 (t, *J* = 7.8 Hz, 2H, C*H*$_3$CO), 2.76 (d, *J* = 4.8 Hz, 3H, NHC*H*$_3$), 5.90 (br s, 1H, N*H*); ^{13}C NMR (100 MHz, $CDCl_3$, 30 ºC) δ 13.9, 22.4, 25.5, 26.1, 31.5, 36.5, 174.3.

1j: *N*-methylcyclohexanecarboxamide CAS: 6830-84-8



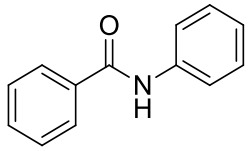
White solid; ^{1}H NMR (400 MHz, $CDCl_3$, 30 ºC) δ 1.2-2.1 (m, 11H, *methylene*, *methine*), 2.79 (d, *J* = 4.6 Hz, 3H, C*H*$_3$), 5.53 (br s, 1H, N*H*); ^{13}C NMR (100 MHz, $CDCl_3$, 30 ºC) δ 25.9, 26.2, 45.6, 176.9.

1k: *N*,*N*-dimethylbenzamide CAS: 611-74-5



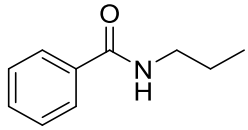
White solid; ^{1}H NMR (400 MHz, $CDCl_3$, 30 ºC) δ 2.97 (s, 3H, C*H*$_3$), 3.08 (s, 3H, C*H*$_3$), 7.3-7.4 (m, 5H, *Ar*); ^{13}C NMR (100 MHz, $CDCl_3$, 30 ºC) δ 35.3, 39.6, 127.1, 128.4, 129.5, 136.5, 171.6.

1l: *N*-phenylbenzamide CAS: 93-98-1



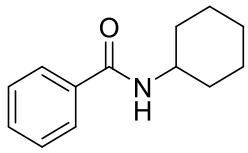
White solid; ^{1}H NMR (400 MHz, $CDCl_3$, 30 ºC) δ 7.1-7.2 (m, 1H, *Ar*), 7.1-7.2 (m, 1H, *Ar*), 7.3-7.4 (m, 2H, *Ar*), 7.4-7.6 (m, 3H, *Ar*), 7.6-7.7 (m, 1H, *Ar*), 7.8-7.9 (m, 2H, *Ar*), 7.92 (br s, 1H, N*H*); ^{13}C NMR (100 MHz, $CDCl_3$, 30 ºC) δ 120.4, 124.7, 127.2, 128.9, 129.2, 131.9, 135.2, 138.1, 165.9.

1m: *N*-propylbenzamide CAS: 10546-70-0



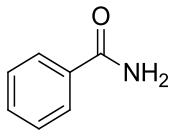
White solid; ^{1}H NMR (400 MHz, $CDCl_3$, 30 ºC) δ 0.99 (t, *J* = 7.5 Hz, 3H, CH_2CH_3), 1.6-1.7 (m, 2H, CH_2CH_3), 3.4-3.5 (m, 2H, NHC*H*$_2$), 6.17 (br s, 1H, N*H*), 7.4-7.5 (m, 3H, *Ar*), 7.7-7.8 (m, 2H, *Ar*),; ^{13}C NMR (100 MHz, $CDCl_3$, 30 ºC) δ 11.4, 22.9, 41.8, 126.8, 128.5, 131.3, 134.9, 167.5.

1n: *N*-cyclohexylbenzamide CAS: 1759-68-8



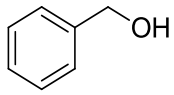
White solid; ^{1}H NMR (400 MHz, $CDCl_3$, 30 ºC) δ 1.1-1.2 (m, 3H, *methylene*), 1.4-1.5 (m, 2H, *methylene*), 1.6-1.8 (m, 3H, *methylene*), 2.0-2.1 (m, 2H, *methylene*), 3.9-4.0 (m, 1H, NHC*H*), 5.96 (br s, 1H, N*H*), 7.4-7.5 (m, 3H, *Ar*), 7.7-7.8 (m, 2H, *Ar*); ^{13}C NMR (100 MHz, $CDCl_3$, 30 ºC) δ 24.9, 25.6, 33.2, 48.7, 126.8, 128.5, 131.2, 135.2, 166.6.

1o: Benzamide CAS: 55-21-0



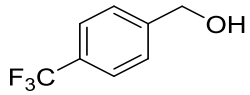
White solid; ^{1}H NMR (400 MHz, $CDCl_3$, 30 ºC) δ 6.21 (br s, 2H, N*H*$_2$), 7.4-7.5 (m, 2H, *Ar*), 7.5-7.6 (m, 1H, *Ar*), 7.8-7.9 (m, 2H, *Ar*); ^{13}C NMR (100 MHz, $CDCl_3$, 30 ºC) δ 127.5, 128.7, 132.1, 133.5, 169.8.

2a: Benzyl alcohol CAS:100-51-6



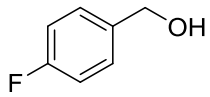
Colorless liquid; ^{1}H NMR (400 MHz, $CDCl_3$, 30 ºC) δ 1.79 (br s, O*H*), 4.69 (s, 1H, PhC*H*$_2$), 7.3-7.4 (m, 5H, *Ar*); ^{13}C NMR (100 MHz, $CDCl_3$, 30 ºC) δ 65.1, 127.0, 127.6, 128.5, 141.0.

2b: (4-(trifluoromethyl)phenyl)methanol CAS: 349-95-1 air sensitive



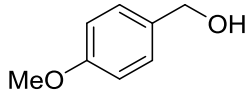
Colorless liquid; ^{1}H NMR (400 MHz, $CDCl_3$, 30 ºC) δ 3.01 (br s, 1H, O*H*), 4.67 (s, 2H, ArC*H*$_2$), 7.40 (d, *J* = 8.1 Hz, 2H, *Ar*), 7.58 (d, *J* = 8.1 Hz, 2H, *Ar*); ^{13}C NMR (100 MHz, $CDCl_3$, 30 ºC) δ 64.3, 124.3 (q, $J_{C\text{-}F}$ = 272 Hz), 125.5 (q, $J_{C\text{-}F}$ = 4 Hz), 126.9, 129.9 (q, $J_{C\text{-}F}$ = 32 Hz), 144.8; ^{19}F NMR (376 MHz, $CDCl_3$, 30 ºC) δ -62.6.

2c: (4-fluorophenyl)methanol CAS: 459-56-3



Colorless liquid; ^{1}H NMR (400 MHz, CD_2Cl_2, 30 ºC) δ 1.95 (br s, 1H, O*H*), 4.63 (s, 2H, ArC*H*$_2$), 7.05 (dd, *J* = 8.8, 8.5 Hz, 2H, *Ar*), 7.3-7.4 (m, 2H, *Ar*); ^{13}C NMR (100 MHz, CD_2Cl_2, 30 ºC) δ 64.8, 115.6 (d, $J_{C\text{-}F}$ = 21 Hz), 129.1 (d, $J_{C\text{-}F}$ = 8 Hz), 137.6 (d, $J_{C\text{-}F}$ = 3 Hz), 162.7 (d, $J_{C\text{-}F}$ = 244 Hz); ^{19}F NMR (376 MHz, $CDCl_3$, 30 ºC) δ -116.1.

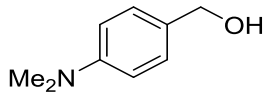
2d: 4-methoxybenzylalcohol CAS: 105-13-5



Colorless liquid; ^{1}H NMR (400 MHz, $CDCl_3$, 30 ºC) δ 1.67 (br s, 1H, O*H*), 3.81 (s, 3H, OC*H*$_3$), 4.61

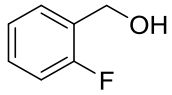
(s, 2H, ArCH_2), 6.89 (d, J = 8.6 Hz, 2H, *Ar*), 7.29 (d, J = 8.6 Hz, 2H, *Ar*); ^{13}C NMR (100 MHz, $CDCl_3$, 30 ºC) δ 55.4, 65.2, 114.1, 128.8, 133.3, 159.4.

1e: (4-(dimethylamino)phenyl)methanol CAS: 1703-46-4



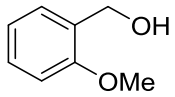
Colorless liquid; ^{1}H NMR (400 MHz, $CDCl_3$, 30 ºC) δ 2.93 (s, 6H, N(CH_3)$_2$), 4.52 (s, 2H, ArCH_2), 6.6-6.7 (m, 2H, *Ar*), 7.1-7.2 (m, 2H, *Ar*); ^{13}C NMR (100 MHz, $CDCl_3$, 30 ºC) δ 40.8, 65.4, 112.9, 128.7, 129.5, 150.9.

2f: (2-fluorophenyl)methanol CAS: 446-51-5



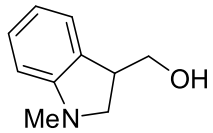
Colorless liquid; ^{1}H NMR (400 MHz, $CDCl_3$, 30 ºC) δ 1.78 (br s, 1H, O*H*), 4.77 (s, 2H, ArCH_2OH), 7.0-7.1 (m, 1H, *Ar*), 7.1-7.2 (m, 1H, *Ar*), 7.2-7.3 (m, 1H, *Ar*), 7.4-7.5 (m, 1.6 Hz, 1H, *Ar*); ^{13}C NMR (100 MHz, $CDCl_3$, 30 ºC) δ 59.3, 115.3 (d, $J_{C\text{-}F}$ = 21 Hz), 124.3 (d, $J_{C\text{-}F}$ = 3 Hz), 127.9 (d, $J_{C\text{-}F}$ = 15 Hz), 129.4 (d, $J_{C\text{-}F}$ = 4 Hz), 129.4 (d, $J_{C\text{-}F}$ = 9 Hz), 160.7 (d, $J_{C\text{-}F}$ = 246 Hz); ^{19}F NMR (376MHz, $CDCl_3$, 30 ºC) δ -119.8.

2g: (2-methoxyphenyl)methanol CAS: 612-16-8



Colorless liquid; ^{1}H NMR (400 MHz, CD_2Cl_2, 30 ºC) δ 2.52 (t, J = 6.0 Hz, 1H, O*H*), 3.86 (s, 3H, OCH_3), 4.65 (d, J = 6.0 Hz, 2H, ArCH_2), 6.9-7.0 (m, 2H, *Ar*), 7.2-7.3 (m, 2H, *Ar*); ^{13}C NMR (100 MHz, CD_2Cl_2, 30 ºC) δ 55.6, 61.9, 110.6, 120.9, 128.8, 129.1, 129.9, 157.9.

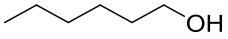
2h: (1-methylindolin-3-yl)methanol CAS: 795275-62-6



yellow oil; ^{1}H NMR (400 MHz, $CDCl_3$, 30 ºC) δ 2.76 (s, 3H, NCH_3), 3.2-3.3 (m, 1H, ArC*H*CH_2), 3.4-3.5 (m, 2H, N(CH_3)CH_2), 3.7-3.8 (m, 2H, OHCH_2CH), 6.49 (d, 2H, J = 7.6 Hz, *Ar*), 6.69 (ddd, J = 7.4, 7.4, 0.9 Hz, 1H, *Ar*), 7.1-7.2 (m, 2H, *Ar*); ^{13}C NMR (100 MHz, $CDCl_3$, 30 ºC) δ 36.0, 43.6,

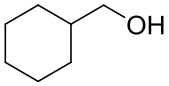
58.9, 64.8, 107.5, 117.9, 124.2, 128.4, 130.1, 153.7.

2i: 1-hexanol CAS: 111-27-3



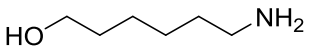
Colorless liquid; ^{1}H NMR (400 MHz, $CDCl_3$, 30 ºC) δ 0.89 (t, *J* = 6.2 Hz, 1H, C*H*$_3$), 1.2-1.4 (m, 7H, methylene, O*H*), 1.5-1.6 (m, 2H, C*H*$_2$CH$_2$OH), 3.63 (t, *J* = 6.6 Hz, 2H, C*H*$_2$OH); ^{13}C NMR (100 MHz, $CDCl_3$, 30 ºC) δ 14.1, 22.8, 25.6, 31.8, 32.9, 63.2.

2j: cyclohexylmethanol CAS: 100-49-2



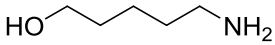
Colorless liquid; ^{1}H NMR (400 MHz, $CDCl_3$, 30 ºC) δ 0.9-1.8 (m, 12H, *methylene*, *methane*, O*H*), 3.43 (d, *J* = 6.3 Hz, 2H, C*H*$_2$OH); ^{13}C NMR (100 MHz, $CDCl_3$, 30 ºC) δ 26.0, 26.7, 29.7, 40.7, 68.9.

2p: 6-aminohexan-1-ol CAS: 4048-33-3



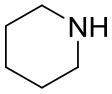
Colorless liquid; ^{1}H NMR (400 MHz, $CDCl_3$, 30 ºC) δ 1.3-1.6 (m, 11H, *methylene*, O*H*, N*H*$_2$), 2.69 (t, *J* = 6.8 Hz, 2H, C*H*$_2$NH$_2$), 3.63 (t, *J* = 6.6 Hz, 2H, C*H*$_2$OH); ^{13}C NMR (100 MHz, $CDCl_3$, 30 ºC) δ 25.7, 26.7, 32.8, 33.6, 42.0, 62.2.

2q: 5-aminohexan-1-ol CAS: 2508-29-4



Colorless liquid; ^{1}H NMR (400 MHz, $CDCl_3$, 30 ºC) δ 1.3-1.6 (m, 9H, *methylene*, O*H*, N*H*$_2$), 2.71 (t, *J* = 6.6 Hz, 2H, C*H*$_2$NH$_2$), 3.65 (t, *J* = 6.5 Hz, 2H, C*H*$_2$OH); ^{13}C NMR (100 MHz, $CDCl_3$, 30 ºC) δ 23.1, 32.5, 33.2, 41.9, 61.8.

3q: piperidine CAS: 110-89-4



Colorless liquid; ^{1}H NMR (400 MHz, $CDCl_3$, 30 ºC) δ 1.4-1.5 (m, 7H, *methylene*, N*H*), 2.7-2.8 (m, 4H, C*H*$_2$NHC*H*$_2$); ^{13}C NMR (100 MHz, $CDCl_3$, 30 ºC) δ 25.0, 27.1, 47.3.

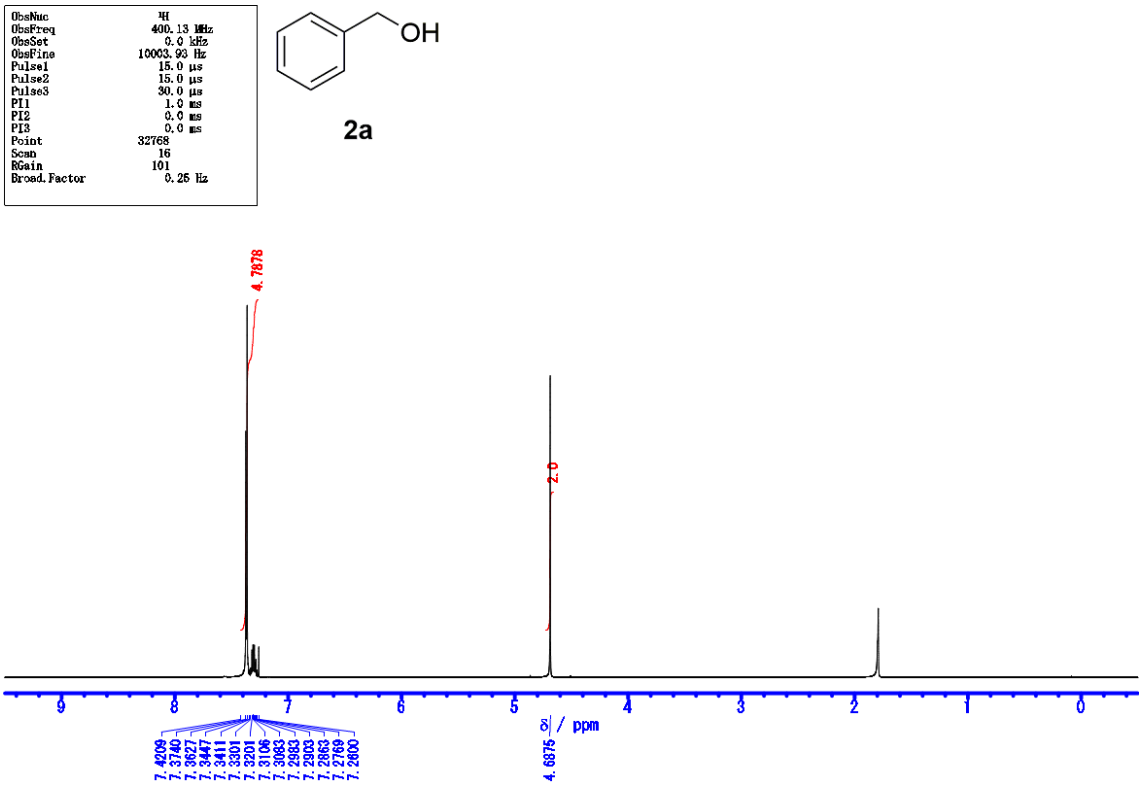
References

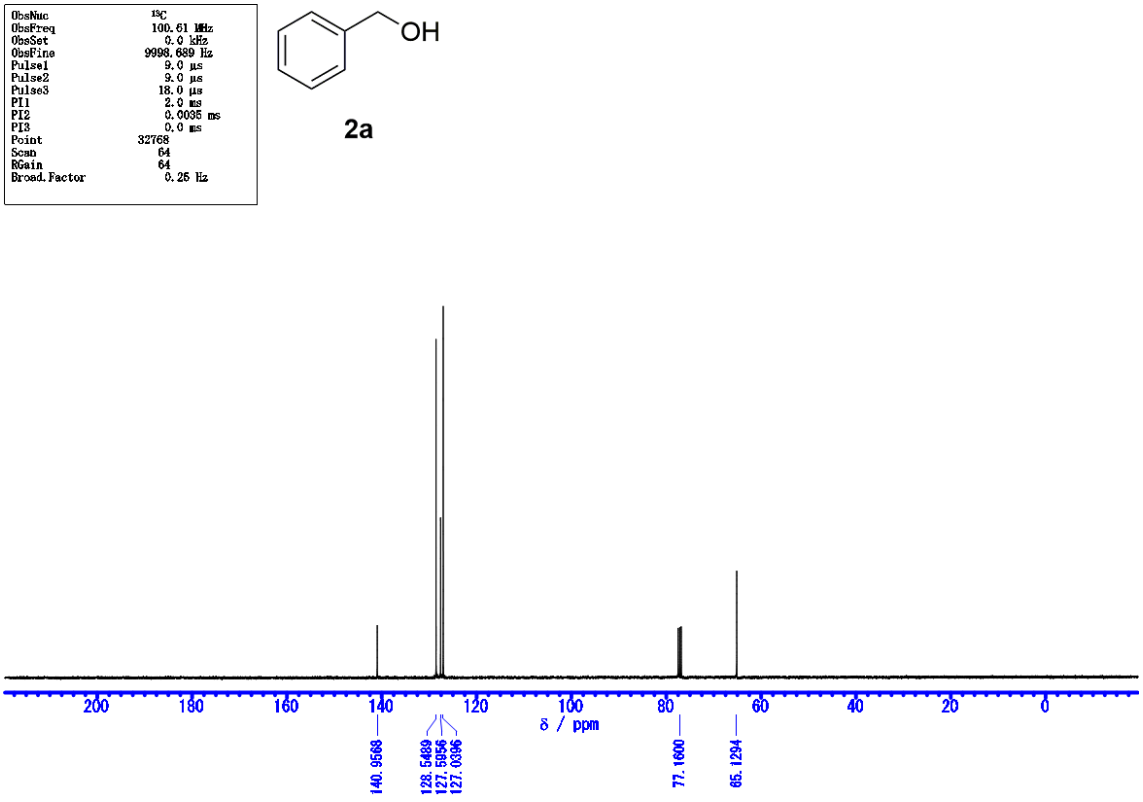
(1) McKennon, M. J.; Meyers, A. I.; Drauz, K.; Schwarm, M. *J. Org. Chem*. **1993,** *58*, 3568.

(2) John, J. M.; Bergens, S. H. *Angew. Chem., Int. Ed.* **2011,** *50,* 10377.

(3) Lindner, E.; Mayer, A. H.; Warad, I.; Eichele, K. *J. Organomet. Chem.* **2003,** *665,* 176.

^{1}H and ^{13}C NMR spectra of products





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Pulse3	30.0 μs
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PI3	0.0 ms
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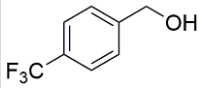
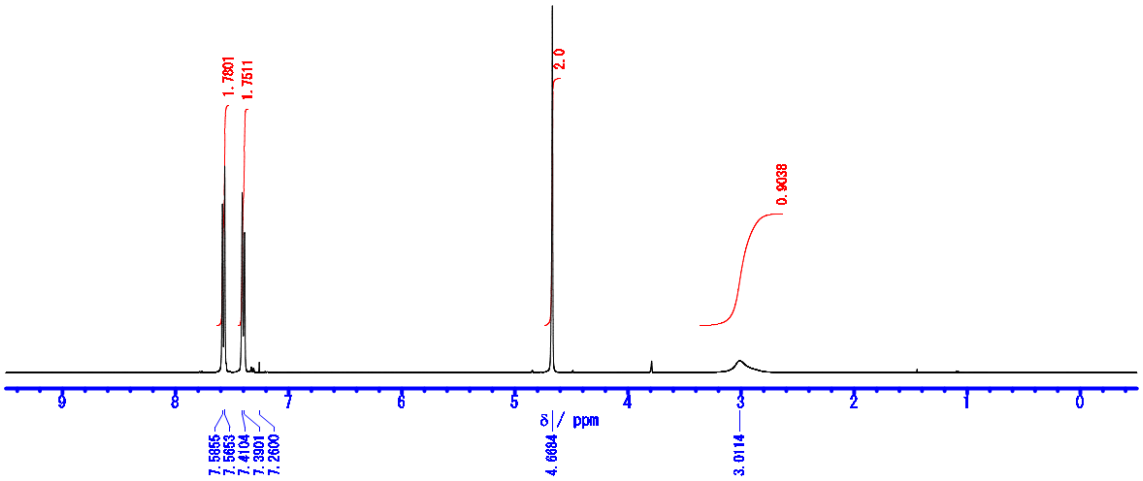
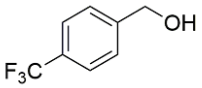
Broad.Factor	0.25 Hz



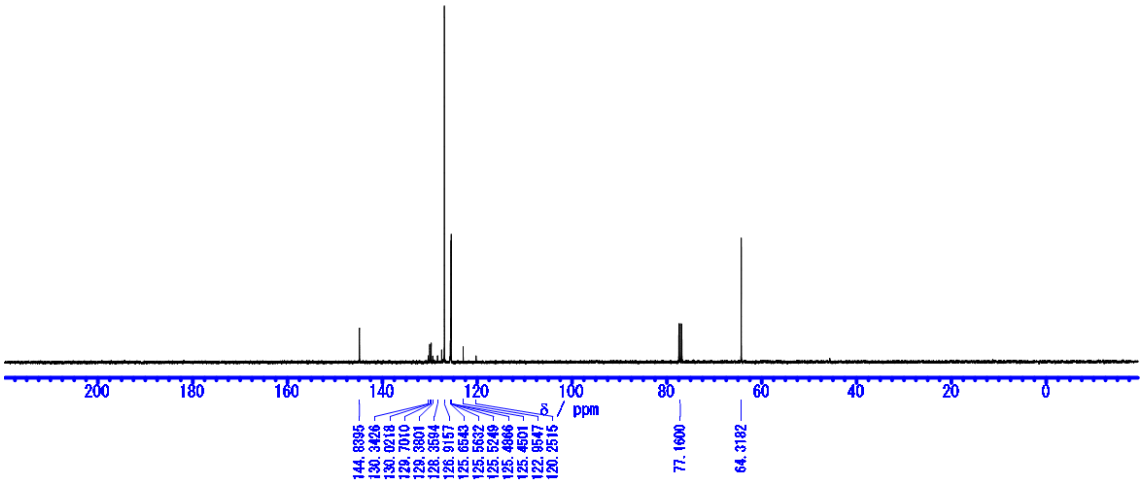
2b



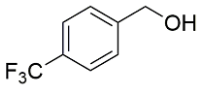
ObsNuc	^{13}C
ObsFreq	100.61 MHz
ObsSet	0.0 kHz
ObsFine	9998.689 Hz
Pulse1	9.0 μs
Pulse2	9.0 μs
Pulse3	18.0 μs
PI1	2.0 ms
PI2	0.0035 ms
PI3	0.0 ms
Point	32768
Scan	35
RGain	144
Broad.Factor	0.25 Hz



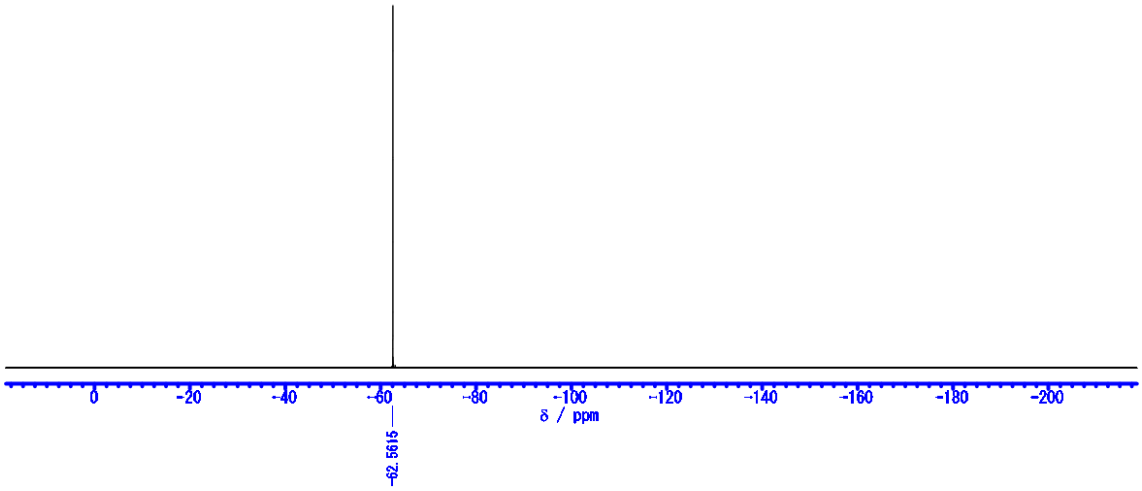
2b



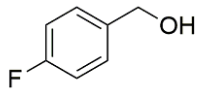
ObsNuc	^{19}F
ObsFreq	376.5 MHz
ObsSet	0.0 kHz
ObsFine	10002.27 Hz
Pulse1	14.0 μs
Pulse2	14.0 μs
Pulse3	28.0 μs
PI1	1.0 ms
PI2	0.0 ms
PI3	0.0 ms
Point	65536
Scan	16
RGain	203
Broad.Factor	0.25 Hz



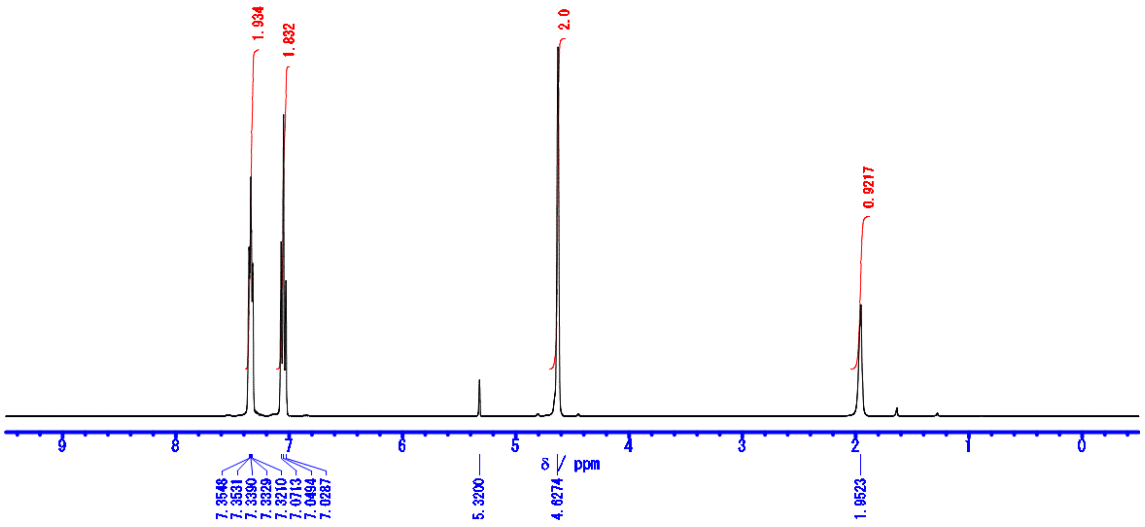
2b



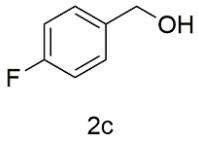
ObsNuc	^{1}H
ObsFreq	400.13 MHz
ObsSet	0.0 kHz
ObsFine	10003.93 Hz
Pulse1	15.0 μs
Pulse2	15.0 μs
Pulse3	30.0 μs
PI1	1.0 ms
PI2	0.0 ms
PI3	0.0 ms
Point	32768
Scan	4
RGain	128
Broad.Factor	0.25 Hz



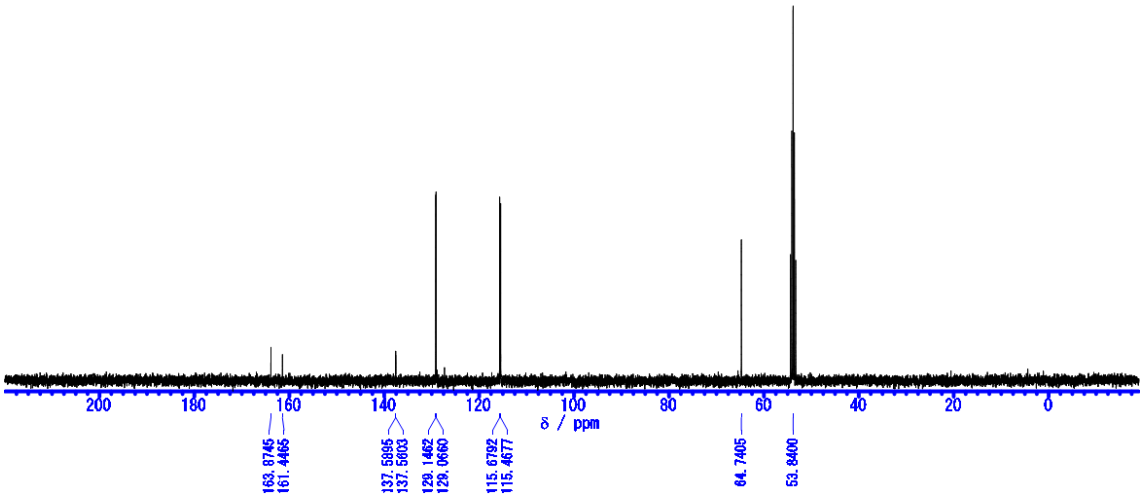
2c



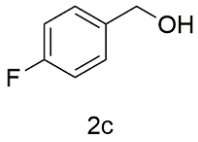
ObsNuc	^{13}C
ObsFreq	100.61 MHz
ObsSet	0.0 kHz
ObsFine	9998.689 Hz
Pulse1	9.0 μs
Pulse2	9.0 μs
Pulse3	18.0 μs
PI1	2.0 ms
PI2	0.0035 ms
PI3	0.0 ms
Point	32768
Scan	50
RGain	144
Broad.Factor	0.25 Hz



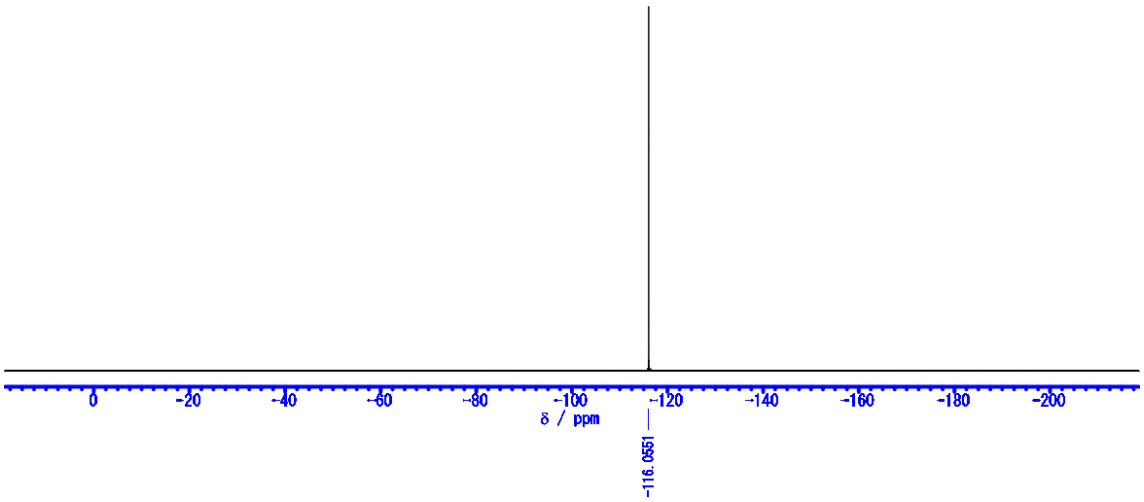
2c

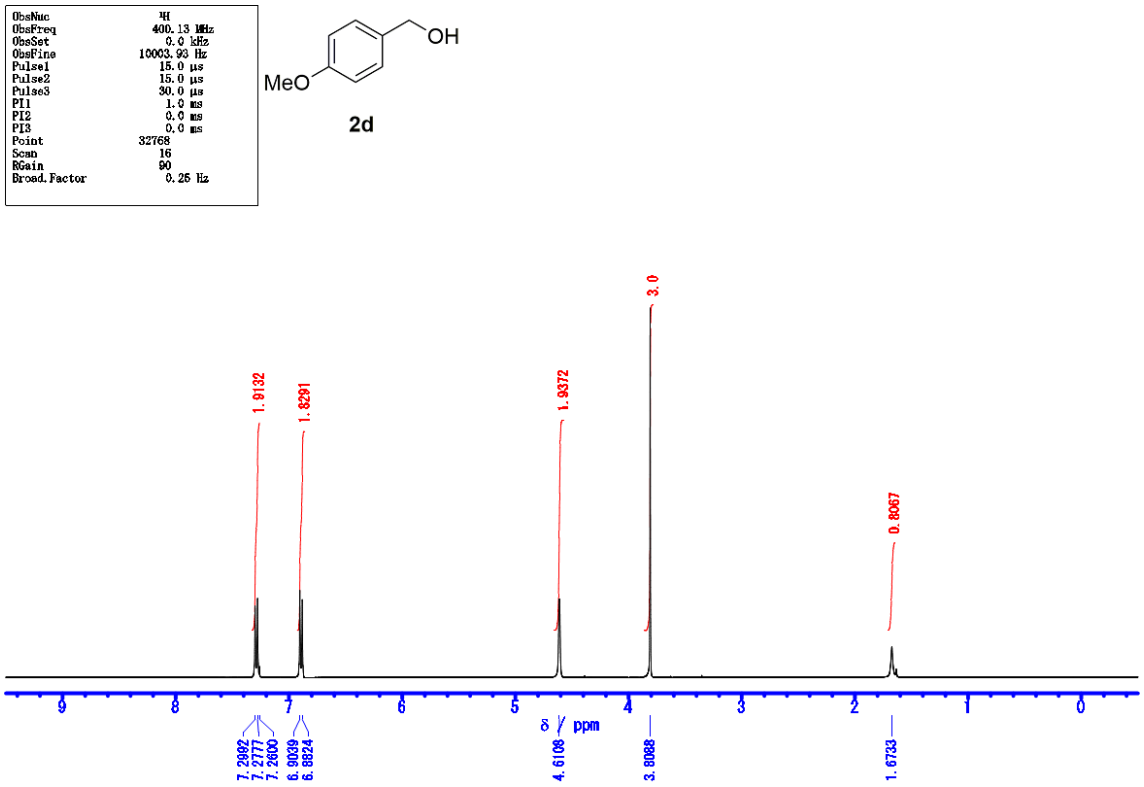


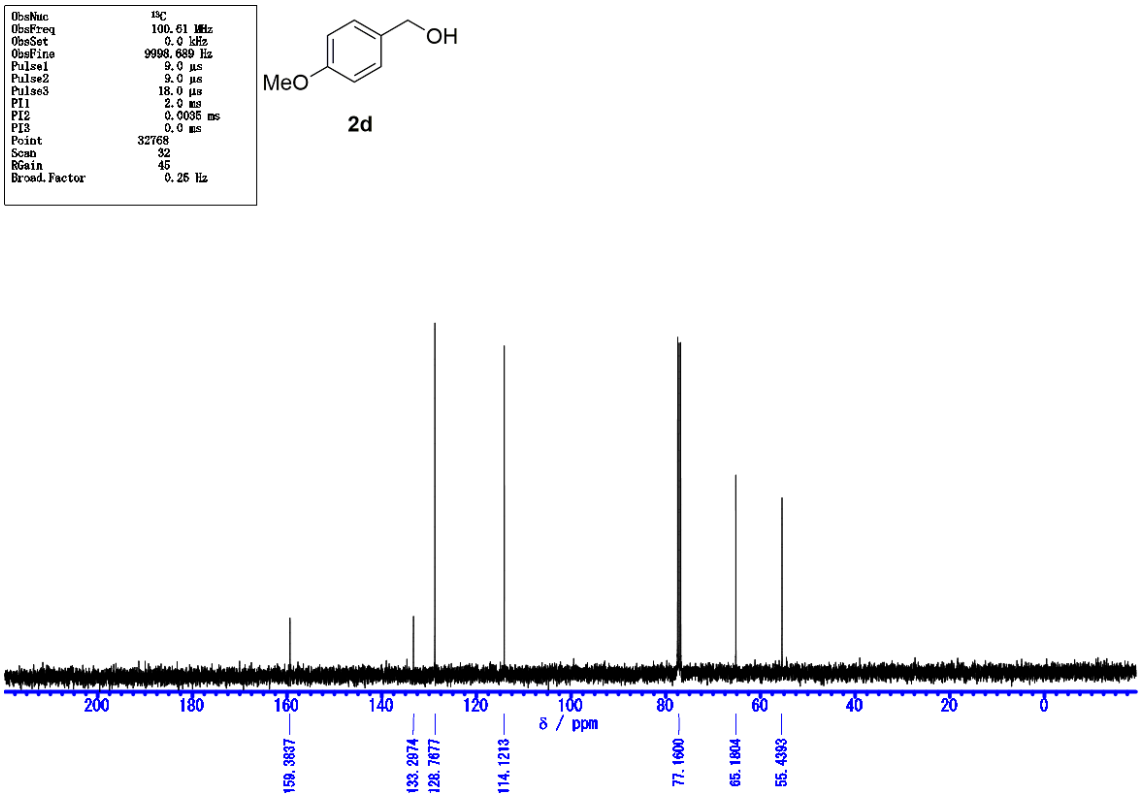
ObsNuc	^{19}F
ObsFreq	376.5 MHz
ObsSet	0.0 kHz
ObsFine	10002.27 Hz
Pulse1	14.0 μs
Pulse2	14.0 μs
Pulse3	28.0 μs
PI1	1.0 ms
PI2	0.0 ms
PI3	0.0 ms
Point	65536
Scan	5
RGain	203
Broad.Factor	0.25 Hz



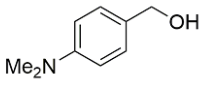
2c



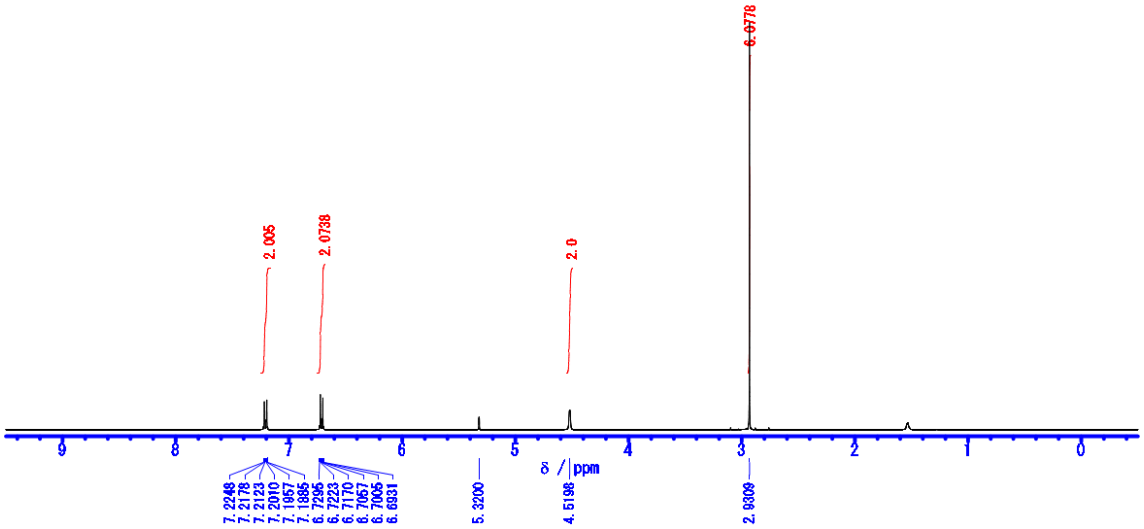

ObsNuc 1H
ObsFreq 400.13 MHz
ObsSet 0.0 kHz
ObsFine 10003.93 Hz
Pulse1 15.0 µs
Pulse2 15.0 µs
Pulse3 30.0 µs
PI1 1.0 ms
PI2 0.0 ms
PI3 0.0 ms
Point 32768
Scan 16
RGain 90
Broad.Factor 0.25 Hz
MeO
OH
2d
1.9132
1.8291
1.9372
3.0
0.8067
δ / ppm
7.2982
7.2777
7.2600
6.9039
6.8824
4.6108
3.8088
1.6733


ObsNuc 13C
ObsFreq 100.61 MHz
ObsSet 0.0 kHz
ObsFine 9998.689 Hz
Pulse1 9.0 µs
Pulse2 2.0 µs
Pulse3 18.0 µs
PI1 2.0 ms
PI2 0.0035 ms
PI3 0.0 ms
Point 32768
Scan 32
RGain 45
Broad.Factor 0.25 Hz
MeO
OH
2d
δ / ppm
159.3837
133.2874
128.7677
114.1213
77.1600
65.1804
55.4393

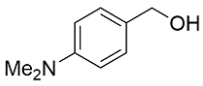
ObsNuc	^{1}H
ObsFreq	400.13 MHz
ObsSet	0.0 kHz
ObsFine	10003.93 Hz
Pulse1	15.0 μs
Pulse2	15.0 μs
Pulse3	30.0 μs
PI1	1.0 ms
PI2	0.0 ms
PI3	0.0 ms
Point	32768
Scan	8
RGain	203
Broad.Factor	0.25 Hz



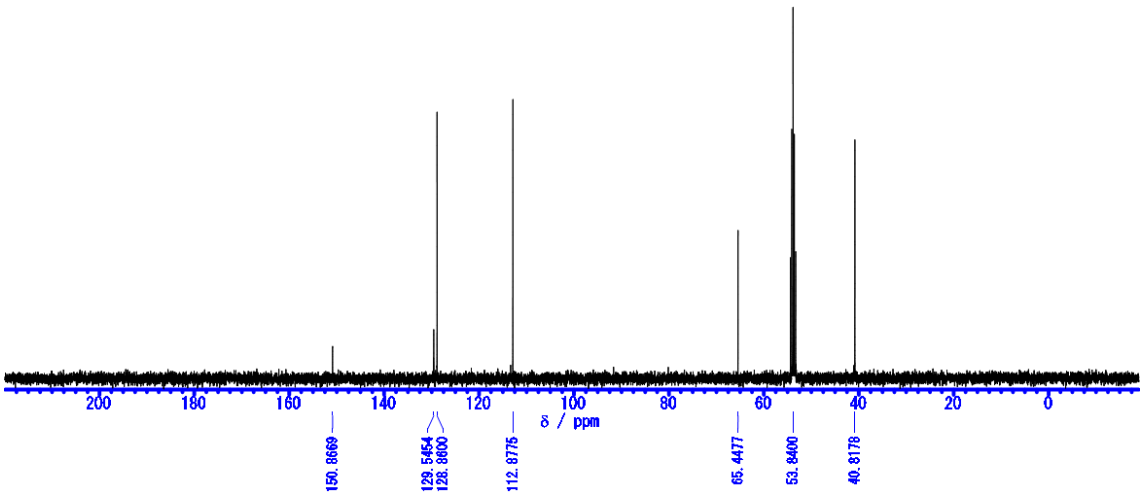
2e



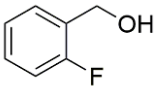
ObsNuc	^{13}C
ObsFreq	100.61 MHz
ObsSet	0.0 kHz
ObsFine	9998.689 Hz
Pulse1	9.0 μs
Pulse2	9.0 μs
Pulse3	18.0 μs
PI1	2.0 ms
PI2	0.0035 ms
PI3	0.0 ms
Point	32768
Scan	32
RGain	161
Broad.Factor	0.25 Hz



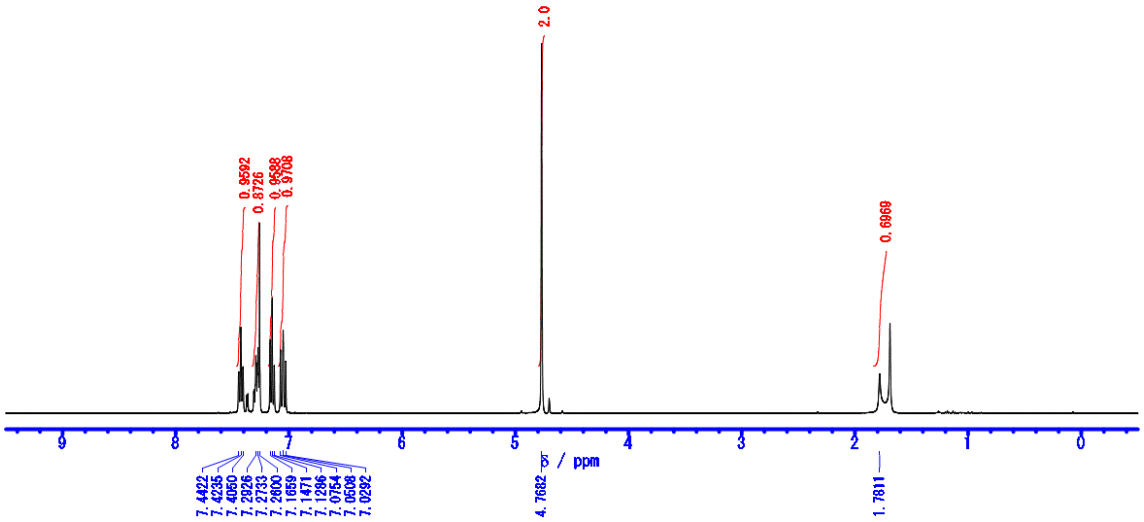
2e



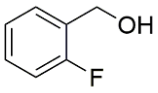
ObsNuc	^{1}H
ObsFreq	400.13 MHz
ObsSet	0.0 kHz
ObsFine	10003.93 Hz
Pulse1	15.0 μs
Pulse2	15.0 μs
Pulse3	30.0 μs
PI1	1.0 ms
PI2	0.0 ms
PI3	0.0 ms
Point	32768
Scan	5
RGain	203
Broad.Factor	0.25 Hz



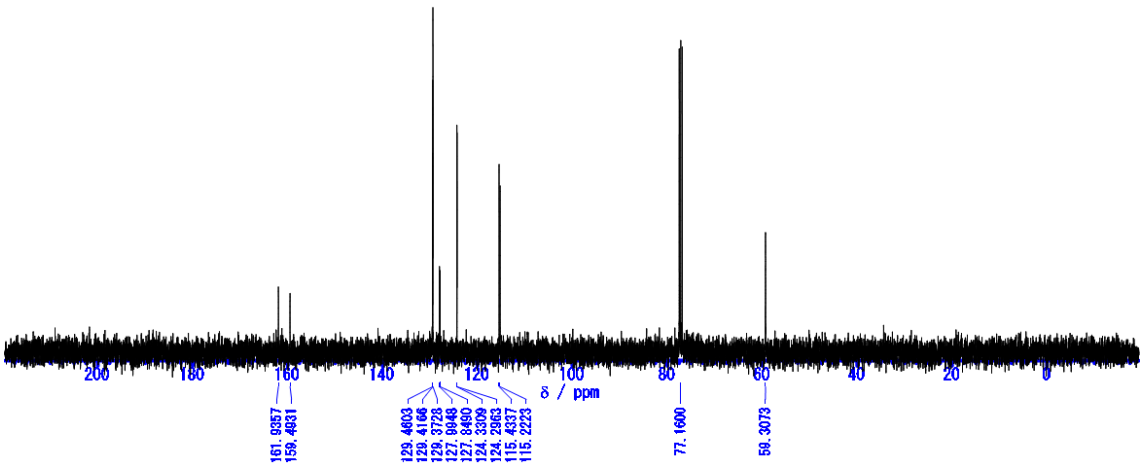
2f



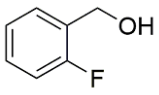
ObsNuc	^{13}C
ObsFreq	100.61 MHz
ObsSet	0.0 kHz
ObsFine	9998.689 Hz
Pulse1	9.0 μs
Pulse2	9.0 μs
Pulse3	18.0 μs
PI1	2.0 ms
PI2	0.0035 ms
PI3	0.0 ms
Point	32768
Scan	10
RGain	203
Broad.Factor	0.25 Hz



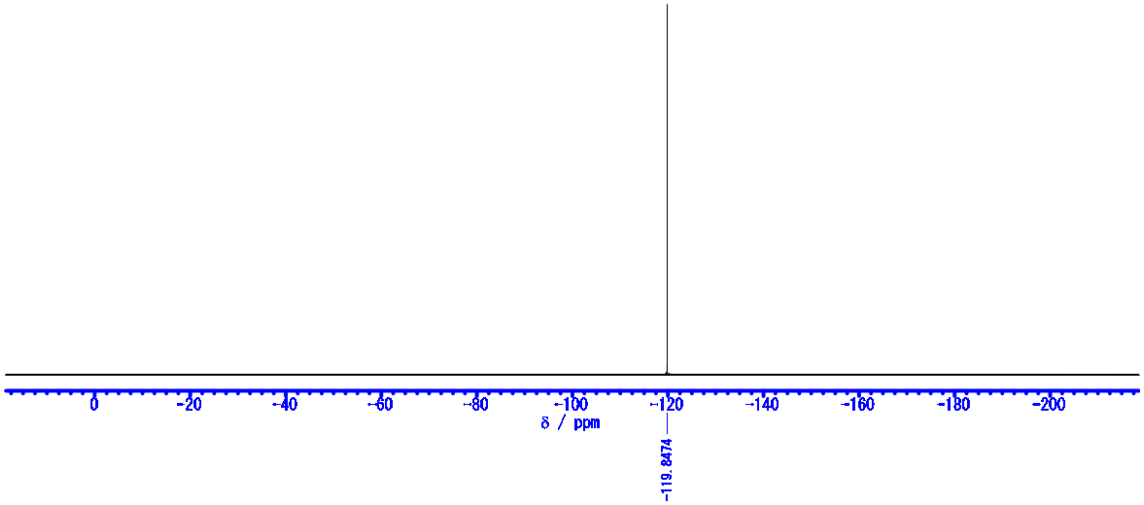
2f



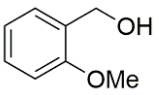
ObsNuc	^{19}F
ObsFreq	376.5 MHz
ObsSet	0.0 kHz
ObsFine	10002.27 Hz
Pulse1	14.0 μs
Pulse2	14.0 μs
Pulse3	28.0 μs
PI1	1.0 ms
PI2	0.0 ms
PI3	0.0 ms
Point	65536
Scan	16
RGain	203
Broad.Factor	0.25 Hz



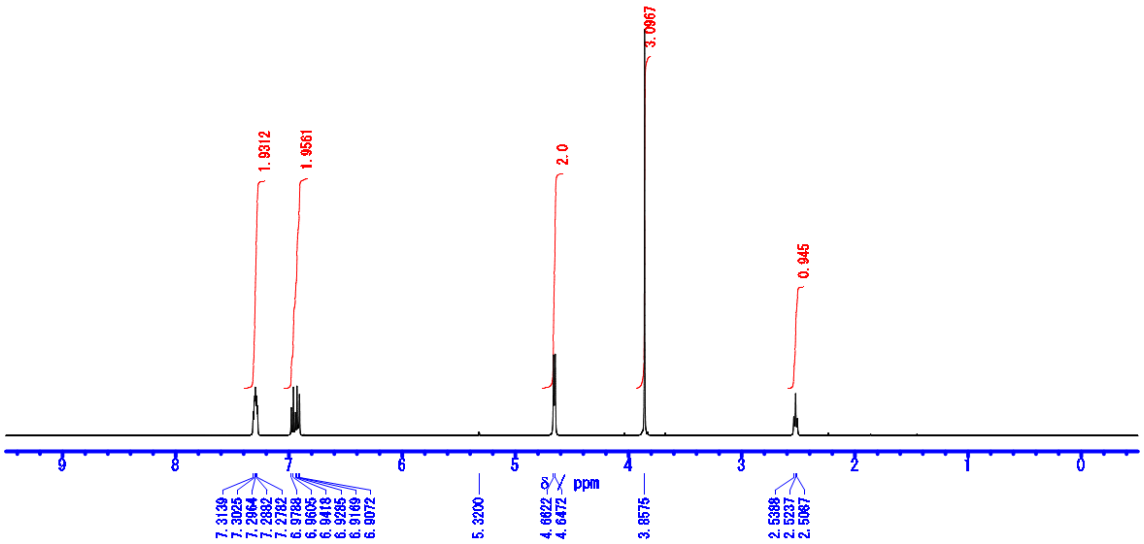
2f



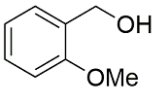
ObsNuc	^{1}H
ObsFreq	400.13 MHz
ObsSet	0.0 kHz
ObsFine	10003.93 Hz
Pulse1	15.0 μs
Pulse2	15.0 μs
Pulse3	30.0 μs
PI1	1.0 ms
PI2	0.0 ms
PI3	0.0 ms
Point	32768
Scan	14
RGain	36
Broad.Factor	0.25 Hz



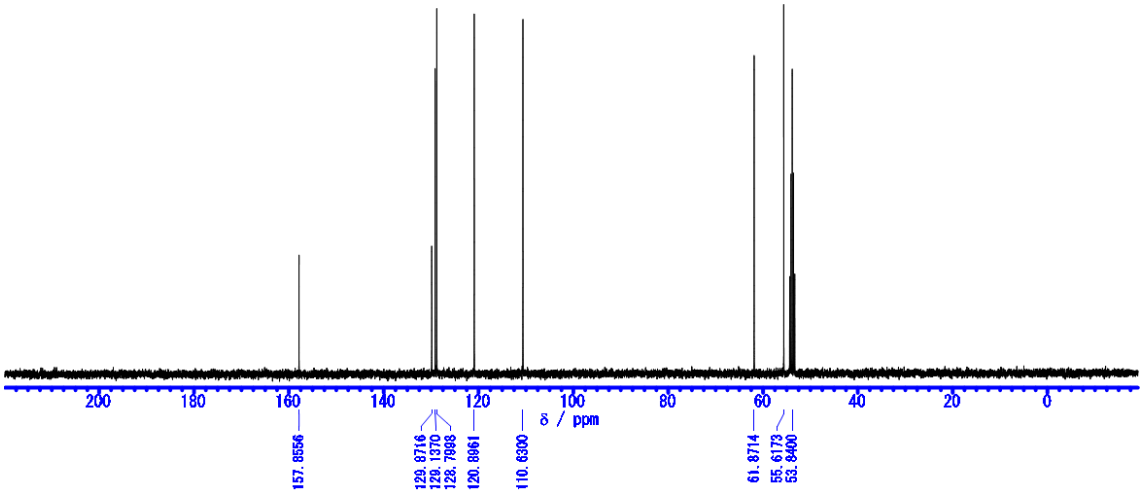
2g



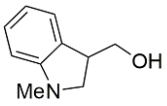
ObsNuc	^{13}C
ObsFreq	100.61 MHz
ObsSet	0.0 kHz
ObsFine	9998.689 Hz
Pulse1	9.0 μs
Pulse2	9.0 μs
Pulse3	18.0 μs
PI1	2.0 ms
PI2	0.0035 ms
PI3	0.0 ms
Point	32768
Scan	27
RGain	45
Broad.Factor	0.25 Hz



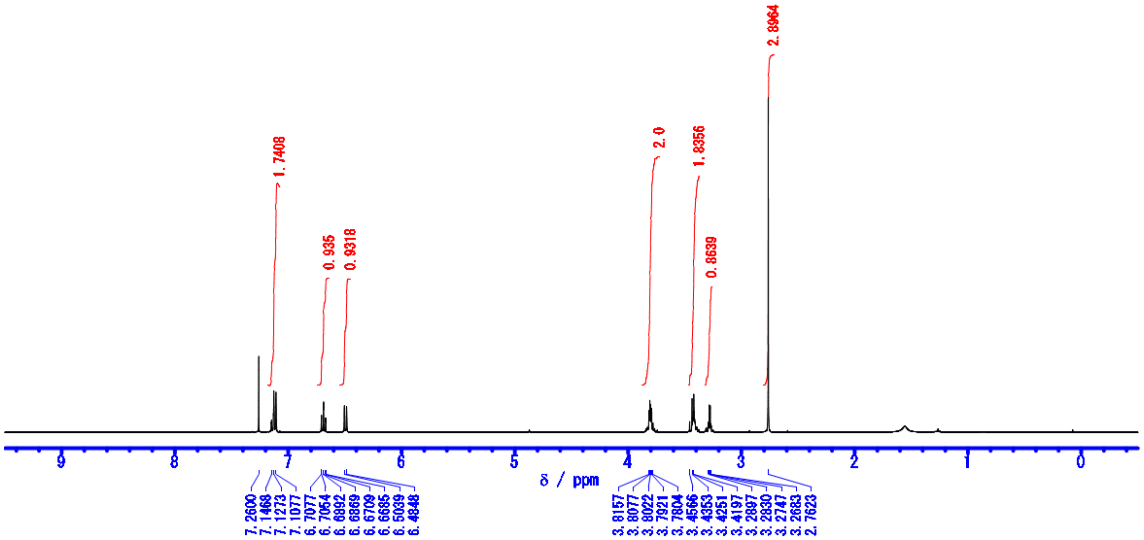
2g



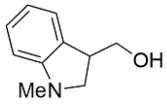
ObsNuc	^{1}H
ObsFreq	400.13 MHz
ObsSet	0.0 kHz
ObsFine	10003.93 Hz
Pulse1	15.0 μs
Pulse2	15.0 μs
Pulse3	30.0 μs
PI1	1.0 ms
PI2	0.0 ms
PI3	0.0 ms
Point	32768
Scan	8
RGain	203
Broad.Factor	0.25 Hz



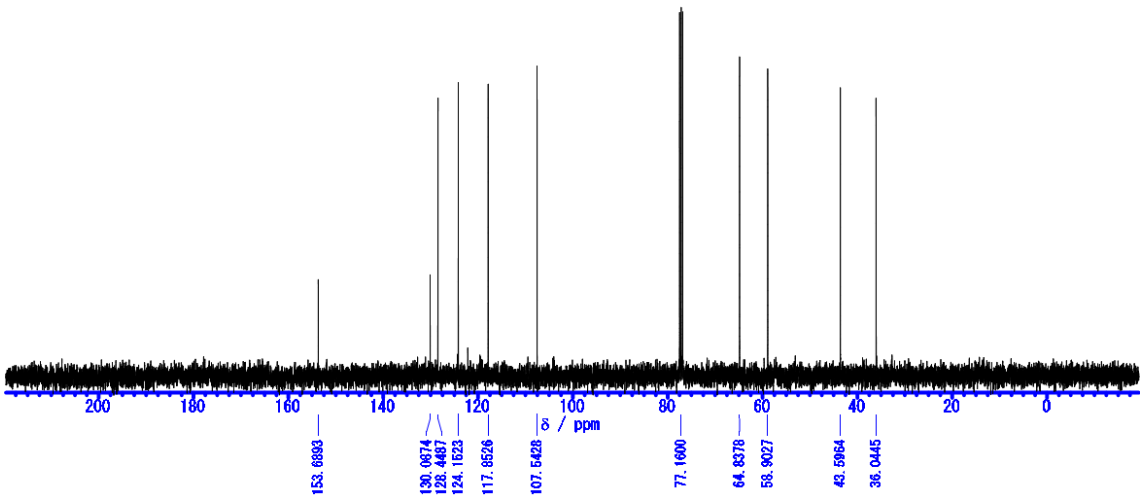
2h



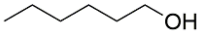
ObsNuc	^{13}C
ObsFreq	100.61 MHz
ObsSet	0.0 kHz
ObsFine	9998.689 Hz
Pulse1	9.0 μs
Pulse2	9.0 μs
Pulse3	18.0 μs
PI1	2.0 ms
PI2	0.0035 ms
PI3	0.0 ms
Point	32768
Scan	16
RGain	144
Broad.Factor	0.25 Hz



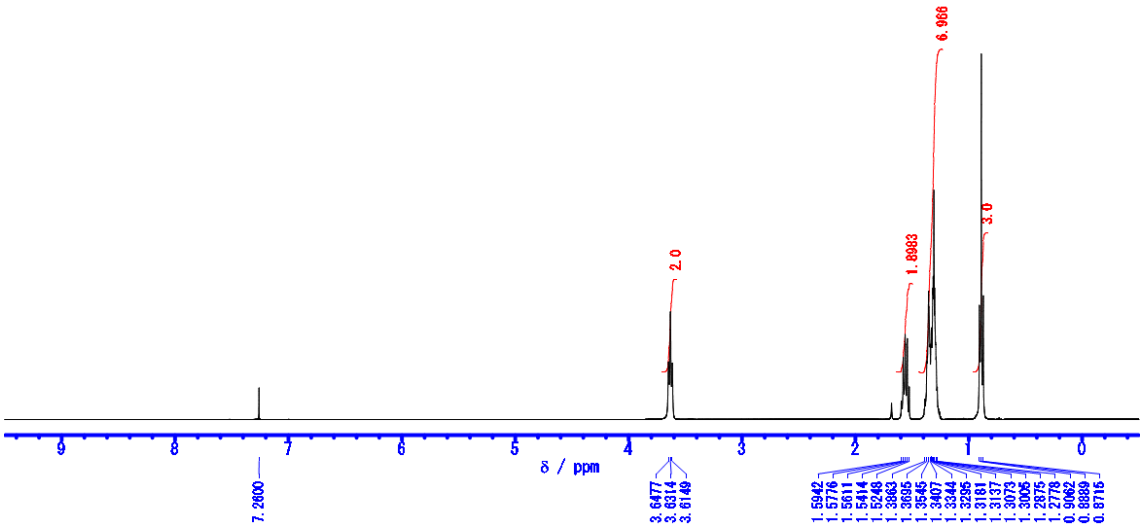
2h



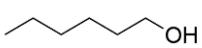
ObsNuc	^{1}H
ObsFreq	400.13 MHz
ObsSet	0.0 kHz
ObsFine	10003.93 Hz
Pulse1	15.0 μs
Pulse2	15.0 μs
Pulse3	30.0 μs
PI1	1.0 ms
PI2	0.0 ms
PI3	0.0 ms
Point	32768
Scan	16
RGain	72
Broad.Factor	0.25 Hz



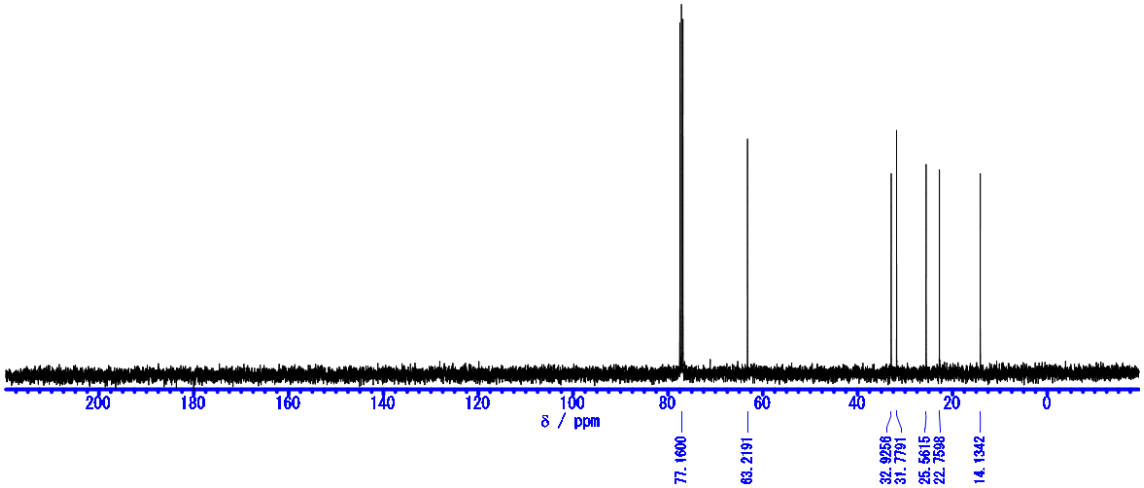
2i



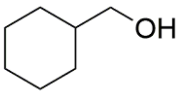
ObsNuc	^{13}C
ObsFreq	100.61 MHz
ObsSet	0.0 kHz
ObsFine	9998.689 Hz
Pulse1	9.0 μs
Pulse2	9.0 μs
Pulse3	18.0 μs
PI1	2.0 ms
PI2	0.0035 ms
PI3	0.0 ms
Point	32768
Scan	32
RGain	203
Broad.Factor	0.25 Hz



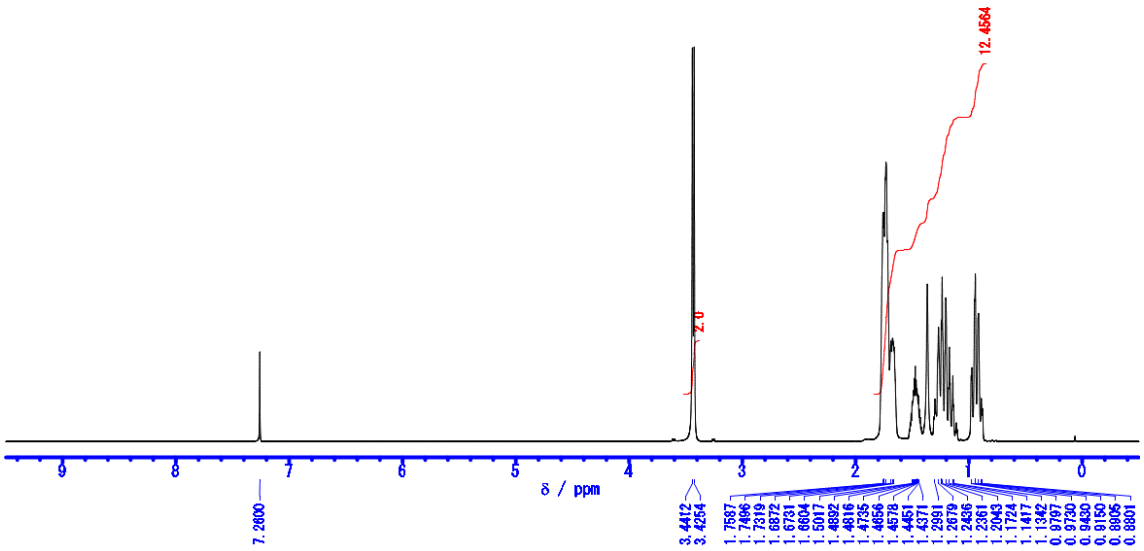
2i



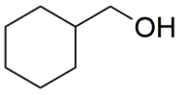
ObsNuc	^{1}H
ObsFreq	400.13 MHz
ObsSet	0.0 kHz
ObsFine	10003.93 Hz
Pulse1	15.0 μs
Pulse2	15.0 μs
Pulse3	30.0 μs
PI1	1.0 ms
PI2	0.0 ms
PI3	0.0 ms
Point	32768
Scan	4
RGain	81
Broad.Factor	0.25 Hz



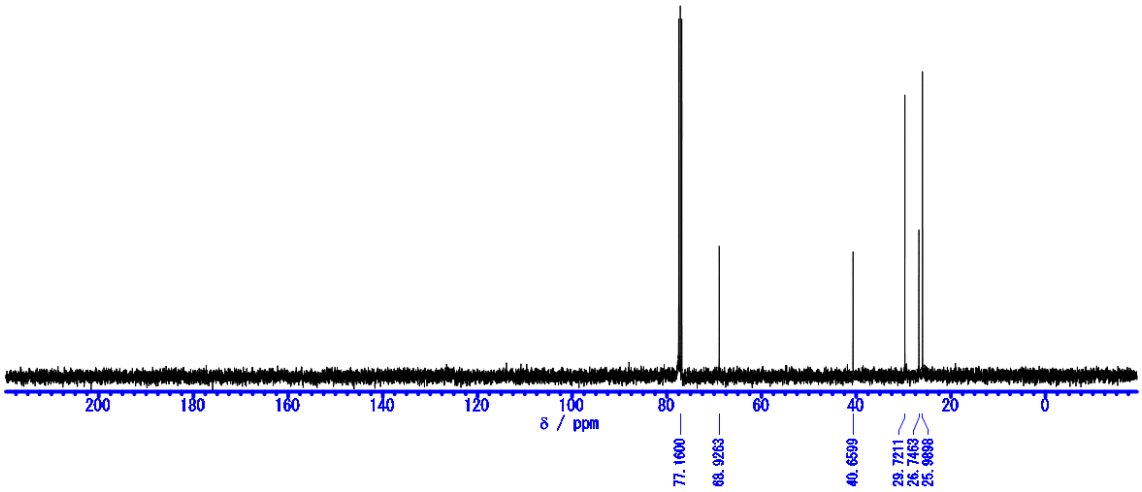
2j



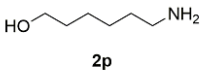
ObsNuc	^{13}C
ObsFreq	100.61 MHz
ObsSet	0.0 kHz
ObsFine	9998.689 Hz
Pulse1	9.0 μs
Pulse2	9.0 μs
Pulse3	18.0 μs
PI1	2.0 ms
PI2	0.0035 ms
PI3	0.0 ms
Point	32768
Scan	32
RGain	161
Broad.Factor	0.25 Hz



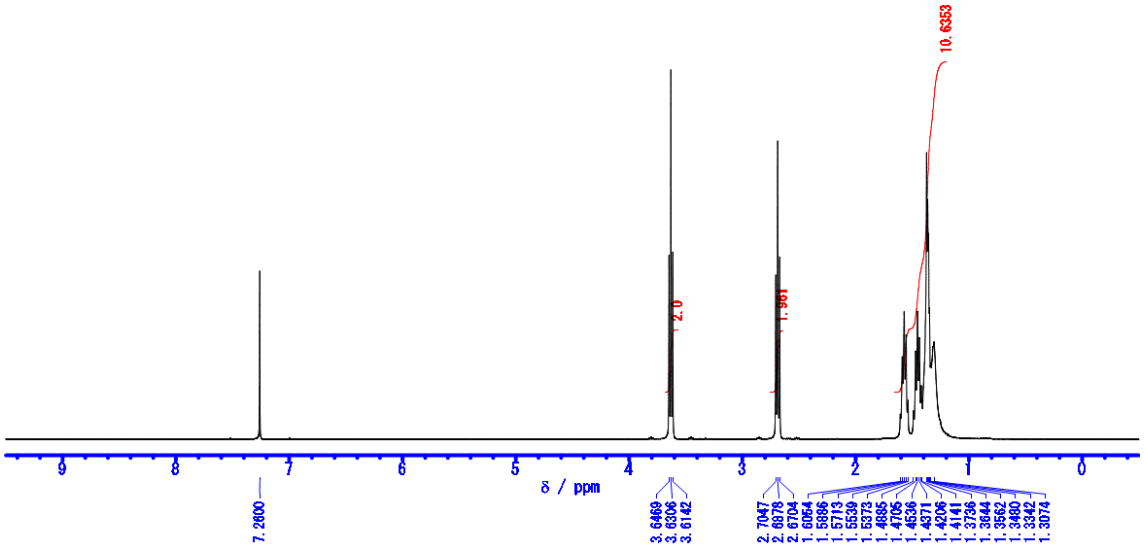
2j



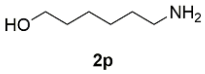
ObsNuc	^{1}H
ObsFreq	400.13 MHz
ObsSet	0.0 kHz
ObsFine	10003.93 Hz
Pulse1	15.0 μs
Pulse2	15.0 μs
Pulse3	30.0 μs
PI1	1.0 ms
PI2	0.0 ms
PI3	0.0 ms
Point	32768
Scan	4
RGain	181
Broad.Factor	0.25 Hz



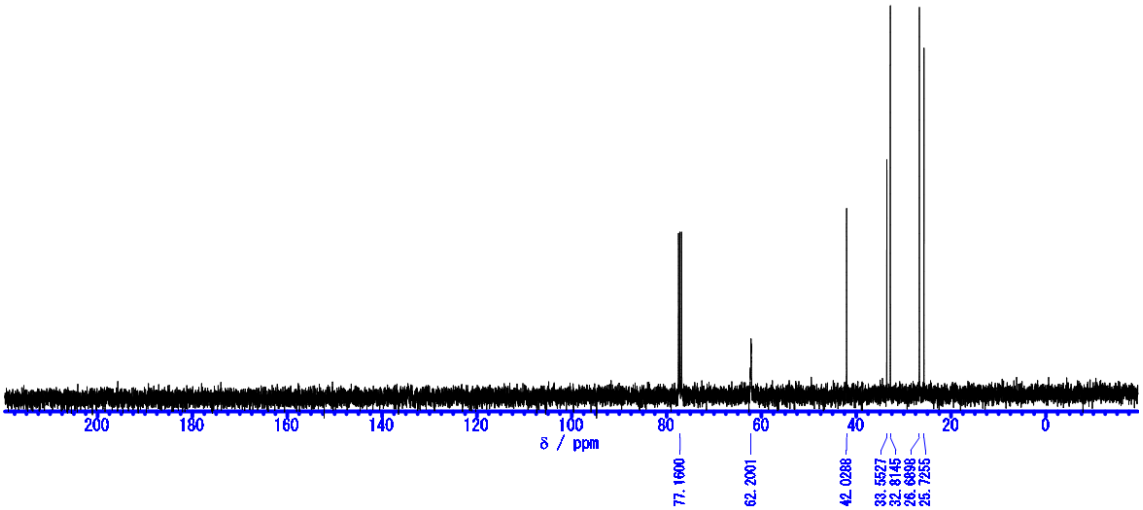
2p



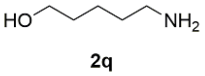
ObsNuc	^{13}C
ObsFreq	100.61 MHz
ObsSet	0.0 kHz
ObsFine	9998.689 Hz
Pulse1	9.0 μs
Pulse2	9.0 μs
Pulse3	18.0 μs
PI1	2.0 ms
PI2	0.0035 ms
PI3	0.0 ms
Point	32768
Scan	11
RGain	161
Broad.Factor	0.25 Hz



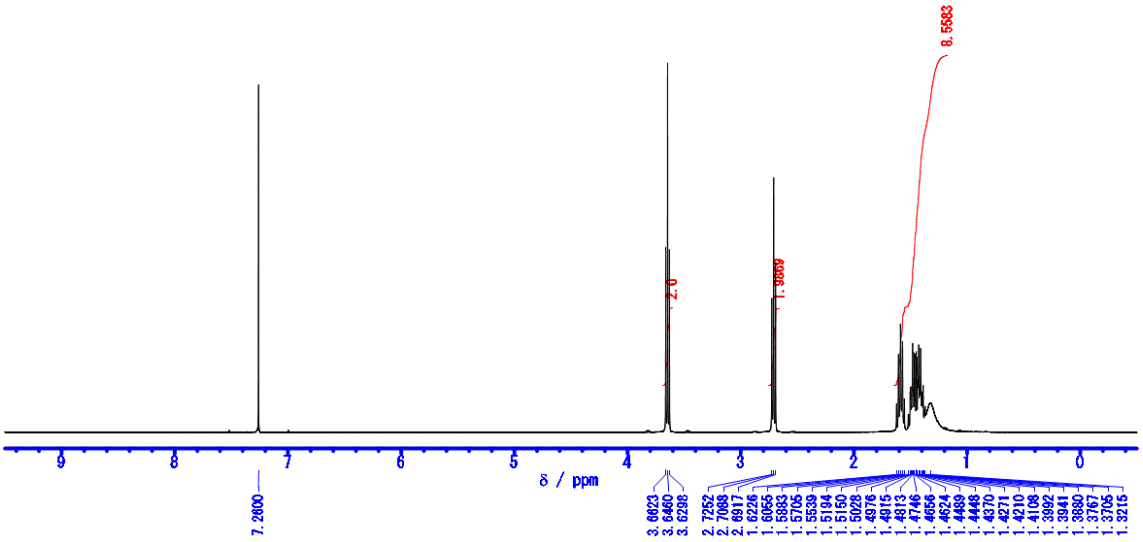
2p



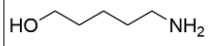
ObsNuc	^{1}H
ObsFreq	400.13 MHz
ObsSet	0.0 kHz
ObsFine	10003.93 Hz
Pulse1	15.0 μs
Pulse2	15.0 μs
Pulse3	30.0 μs
PI1	1.0 ms
PI2	0.0 ms
PI3	0.0 ms
Point	32768
Scan	8
RGain	203
Broad.Factor	0.25 Hz



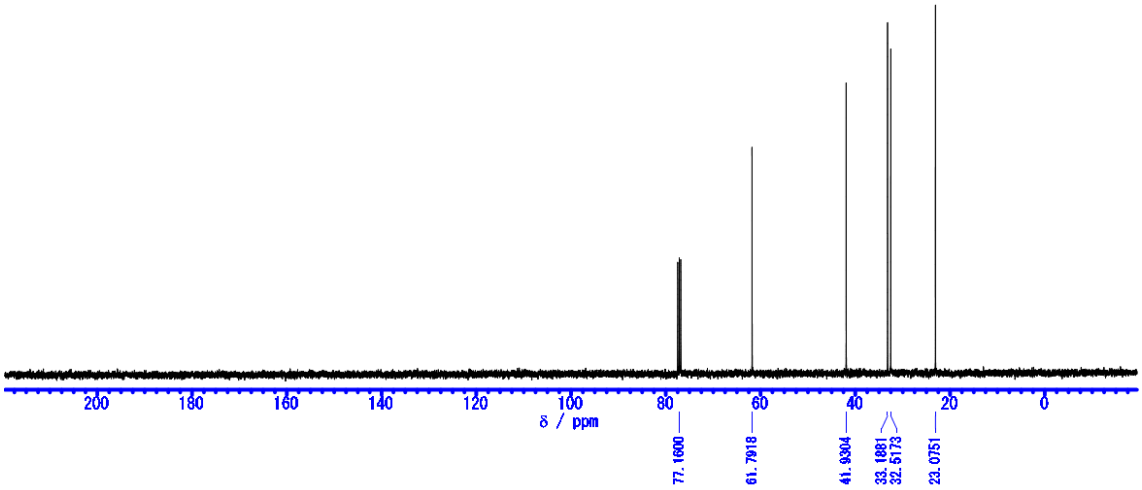
2q



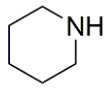
ObsNuc	^{13}C
ObsFreq	100.61 MHz
ObsSet	0.0 kHz
ObsFine	9998.689 Hz
Pulse1	9.0 μs
Pulse2	9.0 μs
Pulse3	18.0 μs
PI1	2.0 ms
PI2	0.0035 ms
PI3	0.0 ms
Point	32768
Scan	16
RGain	161
Broad.Factor	0.25 Hz



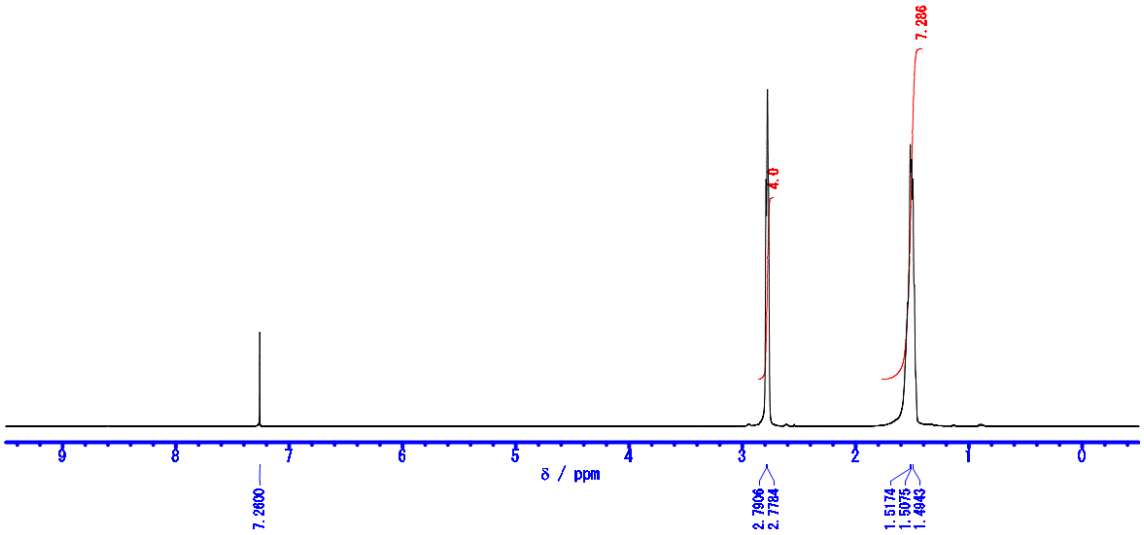
2q



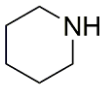
ObsNuc	^{1}H
ObsFreq	400.13 MHz
ObsSet	0.0 kHz
ObsFine	10003.93 Hz
Pulse1	15.0 μs
Pulse2	15.0 μs
Pulse3	30.0 μs
PI1	1.0 ms
PI2	0.0 ms
PI3	0.0 ms
Point	32768
Scan	4
RGain	72
Broad.Factor	0.25 Hz



3q



ObsNuc	^{13}C
ObsFreq	100.61 MHz
ObsSet	0.0 kHz
ObsFine	9998.689 Hz
Pulse1	9.0 μs
Pulse2	9.0 μs
Pulse3	18.0 μs
PI1	2.0 ms
PI2	0.0035 ms
PI3	0.0 ms
Point	32768
Scan	4
RGain	144
Broad.Factor	0.25 Hz



3q