Supporting Information

Selective Reduction of Aldehydes and Ketones to Alcohols with Ammonia Borane in Neat Water

Lei Shi, Yingying Liu, Qingfeng Liu, Bin Wei, Guisheng Zhang*

Key Laboratory of Green Chemical Media and Reactions, Ministry of Education, College of Chemistry and Environmental Science, Henan Normal University, Xinxiang 453007, China

E-mail: zgs@htu.cn

Table of contents

I. General Remarks:

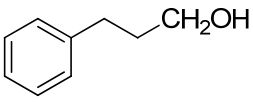
All reagents were purchased from commercial sources and used without further treatment, unless otherwise indicated. Ammonia borane was prepared according to the known methods.[1-2] The nucleoside **1e** was obtained from prof. Xueseng Fan lab in Henan Normal University. ^{1}H NMR spectra were recorded on a Bruker Avance/400 and TMS as internal standard. Data are represented as follows: chemical shift, integration, multiplicity (br = broad, s = singlet, d = doublet, dd = double doublet, t = triplet, q = quartet, m = multiplet), coupling constants in Hertz (Hz). Melting points were measured on a YuHua X-5 apparatus.. All reactions were monitored by TLC with GF254 silica gel coated plates. Flash column chromatography was carried out using 200-300 mesh silica gel at increased pressure.

Preparation of Ammonia Borane (AB) using Sodium Borohydride and Ammonium Sulfate in THF: A mixture of sodium borohydride (1.00 g, 26.3 mmol) and powdered dry ammonium sulfate (3.48 g, 26.3 mmol) in THF (156 mL) was vigorously stirred at 40 °C under nitrogen. The reaction was monitored by 11B NMR spectroscopy. Upon completion, the reaction mixture was cooled to room temperature and filtered. The filtrate was concentrated under vacuum to produce AB (690 mg, 85%) in >96% chemical purity, as determined by hydride analysis.[2] The solvent was recovered and reused for the preparation of subsequent batches of AB without further purification. The product AB was obtained as a white powder: mp. 108.9-110 ℃ (110 ℃ in literature[3]); ^{1}H NMR ($CDCl_3$, 400 MHz) δ: 3.40 (t, J_{N-H} = 48 Hz, 3H, NH_3), 1.62 (q, J_{B-H} = 96 Hz, 3H, BH_3); ^{1}H NMR (DMSO-*d6*, 400 MHz) δ: 4.42 (br., 3H, NH_3), 1.90-0.50 (m, 3H, BH_3).

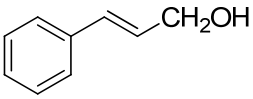
Caution: *A large amount of hydrogen is generated during the preparation of AB, which is a potential fire hazard. The reaction must be carried out in a well-ventilated hood and that the reaction vessel outlet be led directly into the hood exhaust.*

References:

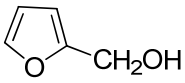
1. (S. G. Shore, X. Chen, "Methods for Synthesizing Ammonia Borane": WO 2007120511 A2 2007; US 20090104102 A1 2009).
2. P. V. Ramachandran and P. D. Gagare, *Inorg. Chem.*, **2007**, *46*, 7810-7817.
3. D. J. Heldebrant, A. Karkamkar, J. C. Linehan and T. Autrey, *Energy. Envir. Sci.*, **2008**, *1*, 156-160.



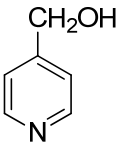
3-Phenyl propanol (2a): Colorless liquid, ^{1}H NMR ($CDCl_3$, 400 MHz) δ : 7.18-7.30 (m, 5H), 3.64-3.67 (t, J = 6.4 Hz, 2H), 2.68-2.72 (t, J = 7.6 Hz, 2H), 1.85-1.92 (m, 2H), 1.75 (s, 1H)



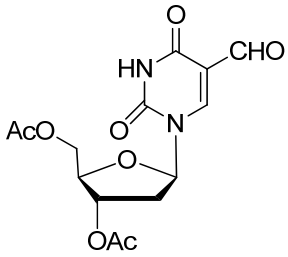
Cinnamyl alcohol (2b): Colorless liquid, ^{1}H NMR ($CDCl_3$, 400 MHz) δ : 7.40-7.42 (d, J = 8 Hz, 2H), 7.32-7.36 (m, 2H), 7.23-7.29 (m, 1H), 6.62-6.66 (d, J = 16 Hz, 1H), 6.36-6.42 (m, 1H), 4.34-4.35 (ds, J = 1.2 Hz, 4.4 Hz, 2H) 1.69 (br, 1H)



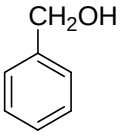
(Furan-2-yl)methanol (2c): Colorless liquid, ^{1}H NMR ($CDCl_3$, 400 MHz) δ : 7.39 (t, J = 0.8 Hz, 1H), 6.32-6.33 (m, 1H), 6.26-6.27 (d, J = 3.2 Hz, 1H), 4.56 (s, 2H), 2.61 (s, 1H).



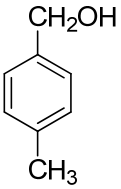
(Pyridine-4-yl)methanol (2d): White solid, ^{1}H NMR ($CDCl_3$, 400 MHz) δ :8.41-8.42 (d, J = 6.0Hz, 2H) 7.30-7.31 (d, J = 5.6 Hz, 2H), 4.72 (s, 2H), 2.48-2.51 (t, J = 6.4 Hz, 1H)



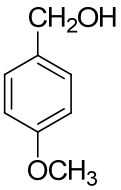
3',4'-*O*-Diacetyl-2'-deoxy-5-formyl-uridine (2e): White solid, ^{1}H NMR ($CDCl_3$, 400 MHz) δ : 9.69 (s,1H), 7.58(s,1H) 6.36-6.41(m, 1H), 5.31 (s, 1H), 4.27-4.40 (m, 4H), 2.48-2.53 (m,1H), 2.11-2.14 (m, 7H).



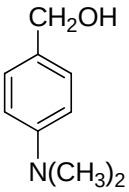
Benzyl alcohol (2f): Colorless liquid, ^{1}H NMR (DMSO-d6, 400 MHz) δ: 7.32-7.20 (m, 5H), 5.20-5.18 (t, J = 5.6 Hz, 1H), 4.51-4.49 (d, J = 8.0 Hz, 2H).



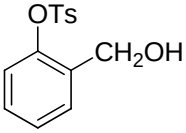
4-Methylbenzyl alcohol (2g): White solid, ^{1}H NMR (CDCl$_3$, 400 MHz) δ:7.22-7.24 (d, J = 8.0 Hz, 2H), 7.15-7.17 (d, J = 8.0 Hz, 2H), 4.61(s, 2H), 2.44-2.47 (t, J = 6.0 Hz, 1H), 2.34 (s, 3H).



4-Methoxybenzyl alcohol (2h): Colorless liquid, ^{1}H NMR (CDCl$_3$, 400 MHz) δ:7.26-7.28 (d, J = 8.4 Hz, 2H), 6.87-6.89 (d, J = 8.4 Hz, 2H), 4.59 (s, 2H), 3.80 (s, 3H), 1.96 (s, 1H).

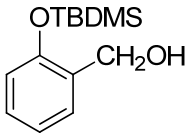


4-*N*,*N*-Dimethylbenzyl alcohol (2i): Colorless liquid, ^{1}H NMR (CDCl$_3$, 400 MHz) δ :7.07-7.04 (d, J = 8.4Hz, 2H) 6.70-6.67(d, J = 8.4Hz, 2H) 3.81(s, 1H) 2.90(s, 6H) 1.56(s, 2H).

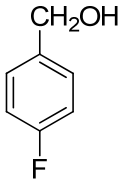


4-Tosyloxyl benzyl alcohol (2j): Colorless liquid, ^{1}H NMR (CDCl$_3$, 400 MHz) δ :7.77-7.79 (d, J = 8.0 Hz, 2H), 7.51-7.53 (d, J = 7.6 Hz, 1H), 7.19-7.38 (m, 4H), 6.84-6.86 (d, J = 8.0 Hz,

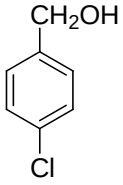
1H), 4.59-4.60 (d, J = 5.2 Hz, 2H),2.48 (s, 3H), 2.29-2.32 (m, 1H).



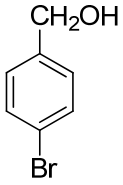
(2-((tert-Butyldimethylsilyl)oxy)benzyl alcohol (2k): Colorless liquid, ^{1}H NMR ($CDCl_3$, 400 MHz) δ : 6.80-7.31 (m, 4H), 4.66-4.68 (d, J = 6.4 Hz, 2H), 2.09-2.12 (m, 1H), 1.01 (s, 9H), 0.26 (s, 6H)



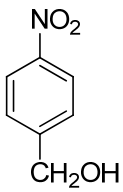
4-Fluorobenzyl alcohol (2l): Colorless liquid, ^{1}H NMR ($CDCl_3$, 400 MHz) δ: 7.30-7.33 (m, 2H), 7.01-7.05 (m, 2H), 4.63 (s, 2H), 2.07(s, 1H).



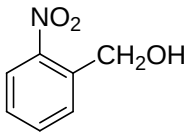
4-Chlorobenzyl alcohol (2m): White solid, ^{1}H NMR ($CDCl_3$, 400 MHz) δ: 7.30-7.36 (m, J = 8.8 HZ, 4H), 4.67 (S, 2H), 1.73-1.70 (t, J = 5.6 HZ 1H).



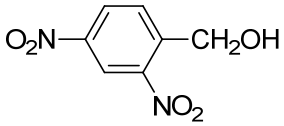
4-Bromobenzyl alcohol (2n): White solid, ^{1}H NMR ($CDCl_3$, 400 MHz) δ: 7.51-7.49 (d, J= 8.0 Hz, 2H), 7.27-7.26 (d, J= 8.8 Hz, 4H), 4.68 (s, 2H), 1.27 (s, 1H).



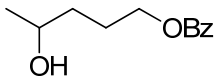
4-Nitrobenzyl alcohol (2o): Straw yellow solid, ^{1}H NMR (DMSO, 400 MHz) δ : 8.22-8.20(d, J=8.8Hz, 2H), 7.60-7.58(d, J=8.4Hz, 2H), 5.56-5.53(t, 1H), 4.65-4.63(d,, J=5.6Hz, 2H).



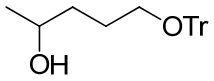
2-Nitrobenzyl alcohol (2p): White solid, ^{1}H NMR (DMSO, 400 MHz) δ : 8.05-8.03(d, J=8.4Hz, 1H), 7.84-7.74(m, 2H), 7.55-7.51(t, 1H), 5.56-5.53(t, 1H), 4.83-4.81(d, J=5.6Hz, 2H).



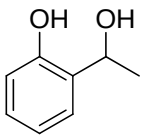
2, 4-Dinitrobenzyl alcohol (2q): White solid, ^{1}H NMR ($CDCl_3$, 400 MHz) δ: 8.97-8.98 (d, J = 1.2 Hz, 1H), 8.52-8.55 (dd, J = 1.6 Hz, 6.8 Hz, 1H), 8.14-8.17 (d, J = 8.8 Hz, 1H), 5.19 (s, 2H), 1.61-1.66 (br, 1H).



1-*O*-Benzoyl-1,4-pentanediol (2r): White solid, ^{1}H NMR (DMSO, 400 MHz) δ :8.01-8.03(m, 2H), 7.51-7.56(m,1H), 5.28(s, 1H), 7.40-7.44(m, 2H), 4.32-4.35(t, J = 6.8 Hz, 2H), 3.84-3.89(m, 1H), 1.78-1.87(m.2H), 1.56-1.65(m, 2H), 1.21-1.23(d,J = 6.0Hz, 2H).

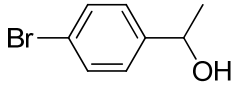


1-*O*-Trityl-1,4-pentanediol (2s): White solid, ^{1}H NMR (DMSO, 400 MHz) δ :7.20-7.45(m, 15H), 5.27-5.28(d, J = 2.0 Hz, 1H), 3.76-3.80(m, 1H), 3.09-3.12(m, 2H), 1.64-1.75(m, 2H), 1.52-1.54(m, 2H), 1.10-1.18(dd, J = 2.8 Hz, 6.0 Hz, 3H).

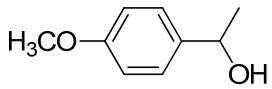


2-(1-Hydroxyethyl)phenol (2t): White solid, ^{1}H NMR ($CDCl_3$, 400 MHz) δ : 6.81-7.18 (m,

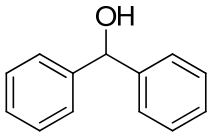
5H), 5.02-5.07 (dd, J = 6.4 Hz, 6.8 Hz, 1H), 2.04 (s, 1H), 1.56-1.58 (d, J = 6.8 Hz, 3H), 1.42-1.43 (br, 1H).



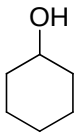
1-(4-Bromophenyl) ethanol (2u): Colorless liquid, ^{1}H NMR ($CDCl_3$, 400 MHz) δ : 7.44-7.47 (d, *J* = 8.4 Hz, 2H), 7.22-7.24 (d, *J* = 8.4 Hz, 2H), 4.81-4.86 (q, *J* = 6.4Hz, 1H), 2.13-2.18 (br, 1H), 1.44-1.46(d, *J* = 6.4 Hz, 3H).



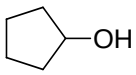
1-(4-Methoxyphenyl)ethanol (2v): Colorless liquid, ^{1}H NMR ($CDCl_3$, 400 MHz) δ : 7.29-7.31 (d, *J* = 8.8 Hz, 2H), 6.88-6.90 (d, *J* = 8.4 Hz, 2H), 4.85-4.88 (t, *J* = 6.4 Hz, 1H), 3.81 (s, 3H), 1.71 (s, 1H).



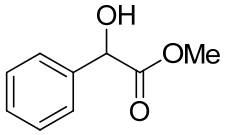
Diphenyl methanol (2W): Colorless liquid, 86% yield, ^{1}H NMR ($CDCl_3$, 400 MHz) δ : 7.25-7.39 (m, 10H), 5.84-5.85 (d, *J* = 3.2 Hz, 1H), 2.24-2.25 (d, *J* = 3.6 Hz, 1H).



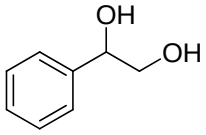
Cyclohexanol (2x): Colourless liquid, ^{1}H NMR (400 MHz, $CDCl_3$): 3.61-3.59 (m, 1H), 1.88-1.75 (m, 3H), 1.73-1.69 (m, 2H), 1.53-1.50 (m, 1H), 1.30-1.14(m, 5H).



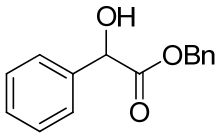
Cyclopentanol (2y): Colourless liquid, ^{1}H NMR (400 MHz, $CDCl_3$): δ 4.33-4.32 (m, 1H), 1.77 (s, 5H), 1.56 (s, 4H).



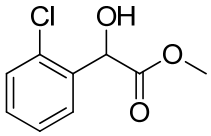
Methyl mandelate (2A): Colorless liquid, ^{1}H NMR ($CDCl_3$, 400 MHz) δ :7.31-7.43 (m, 5H), 5.17-5.19 (d, *J* = 5.2 Hz, 1H), 3.76 (s, 3H), 3.40-3.42 (d, *J* = 5.2 Hz, 1H)



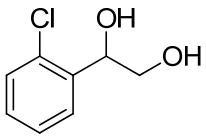
1-Phenyl glycol (3A) ^{1}H NMR (DMSO-d_6, 400 MHz): 7.34-7.20 (m, 5H), 5.17 (d, *J* = 3.6 Hz, 1H), 4.67 (t, *J* = 5.6 Hz, 1H), 4.53 (q, *J* = 5.6 Hz, 1H), 3.43 (t, *J* = 6.0 Hz, 2H).



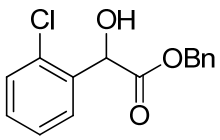
Benzyl mandelate (2B):. ^{1}H NMR ($CDCl_3$, 400 MHz): 7.37-7.30 (m, 10H), 5.03-6.01 (m, 2H), 4.92-4.89 (m, 1H), 5.15 (s, 2H).



Methyl 2-chloromandelate (2C): ^{1}H NMR (DMSO-d_6, 400 MHz): 7.51-7.36 (m, 4H), 6.38-6.36 (d, *J* = 8.0 Hz, 1H), 5.43-5.41 (d, *J* = 8.0 Hz, 1H), 3.62 (s, 3H).

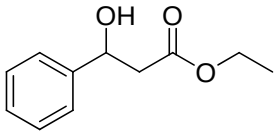


2-Chlorophenyl glycol (3C): ^{1}H NMR (DMSO-d_6, 400 MHz): 7.57-7.56 (d, *J* = 7.2 Hz 1H), 7.38-7.24 (m,3H), 5.48 (s, 1H), 4.93-4.88 (m, 2H), 3.53-3.47 (m, 1H), 3.34-3.28 (m, 1H).

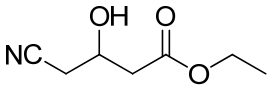


Phenyl 2-chloromandelate (2D): ^{1}H NMR (DMSO-d_6, 400 MHz): 7.56-7.25 (m, 9H),

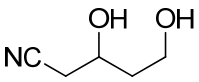
6.47-6.46 (d, *J* = 5.6 Hz, 1H), 5.51-5.23 (d, *J* = 6.0 Hz, 1H), 5.15 (s, 2H).



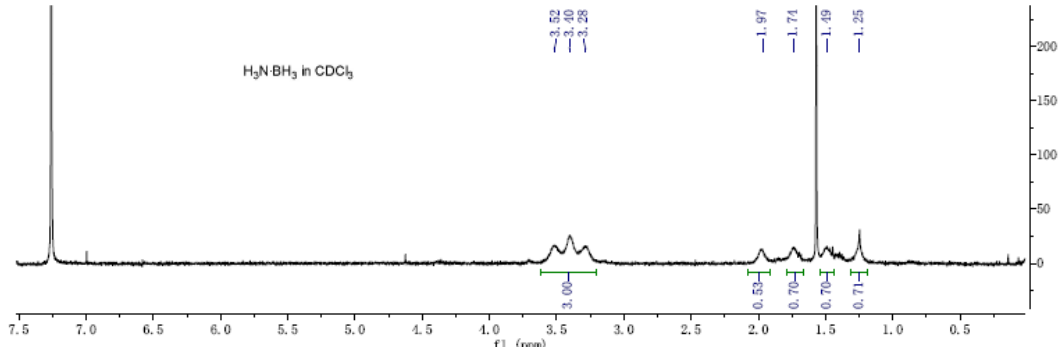
Ethyl 3-hydroxy-3-phenylpropionate (2E): Colorless liquid, ^{1}H NMR ($CDCl_3$, 400 MHz) δ :7.27-7.39 (m, 5H), 5.12-5.15 (m, 1H), 4.15-4.21 (q, *J* = 7.2 Hz, 2H), 3.32 (s, 1H), 2.67-2.79 (m, 2H), 1.24-1.28 (t, *J* = 7.2 Hz, 3H).

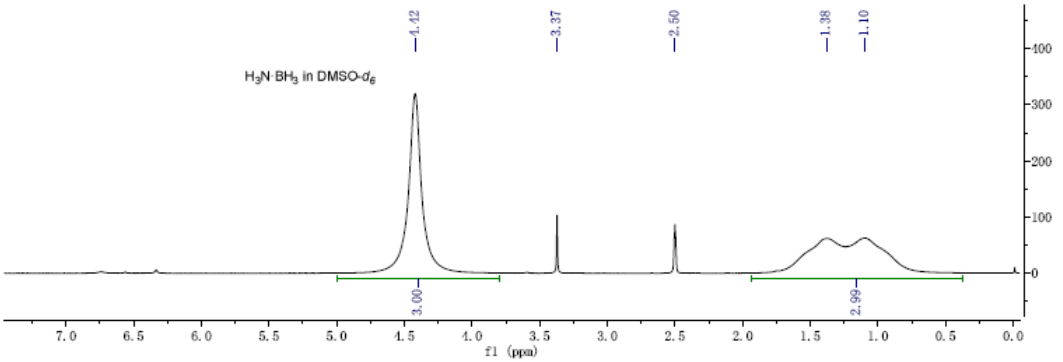


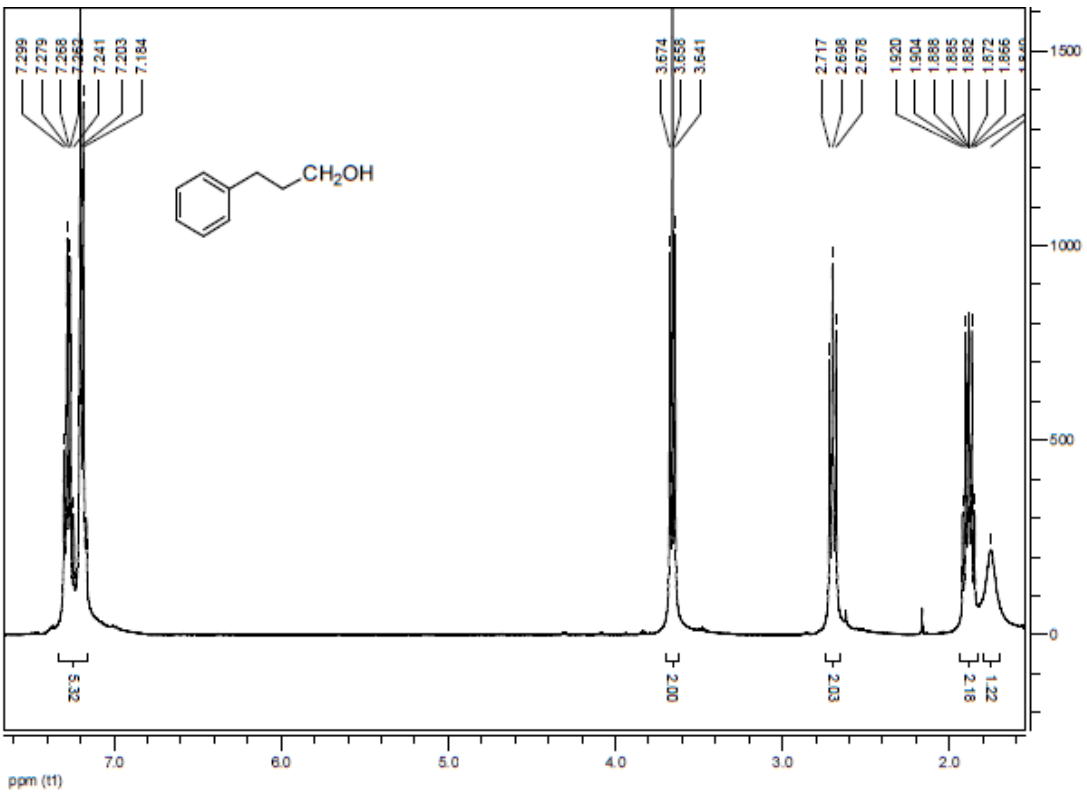
Ethyl 3-cyano-3-hydroxylpropionate (2F): ^{1}H NMR ($CDCl_3$, 400 MHz): 4.39-4.31 (m, 1H), 4.22-4.17 (q, *J* = 7.2 Hz, 2H), 3.64-3.63 (d, *J* = 4.0 Hz, 1H), 2.69-2.58 (m, 4H), 1.30-1.26 (t, *J* = 7.2 Hz, 3H).

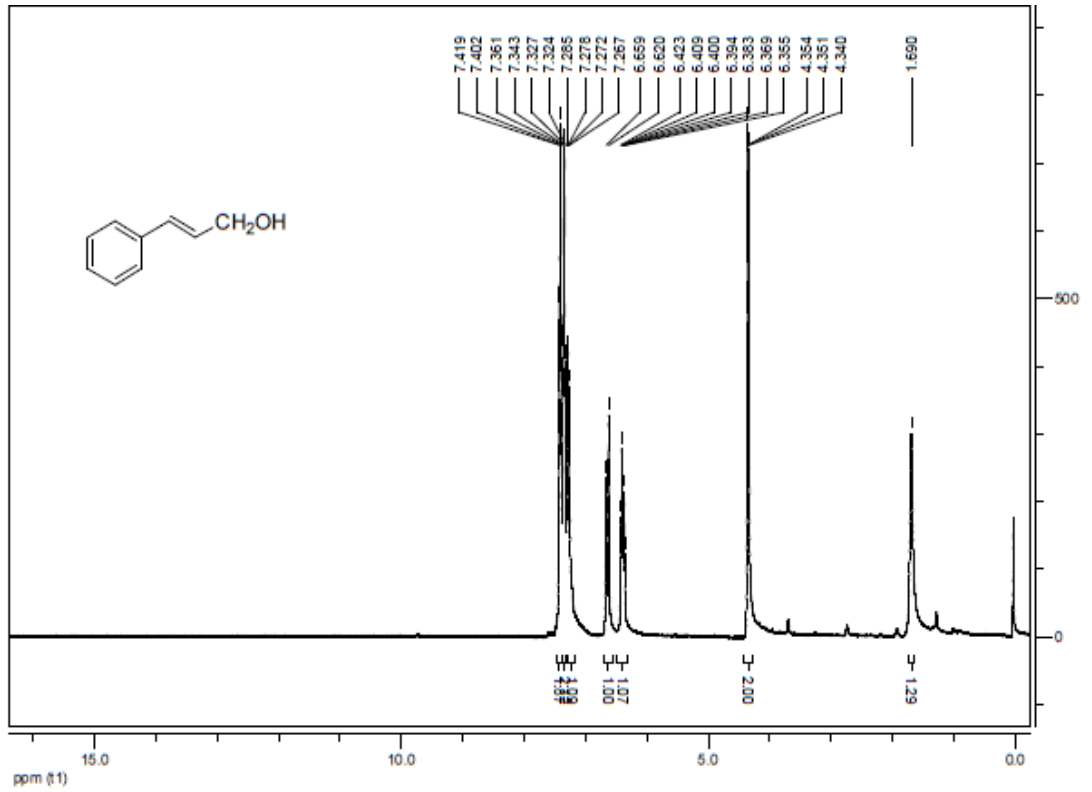


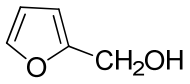
4-Cyano-butane-1,3-diol (3F): ^{1}H NMR ($CDCl_3$, 400 MHz): 4.27-4.21 (m, 1H), 4.02-3.89 (m, 2H), 3.51 (br, 1H), 2.61-2.60 (d, *J* = 5.6 Hz, 2H), 1.94-1.84 (m, 2H), 0.89 (m, 1H).

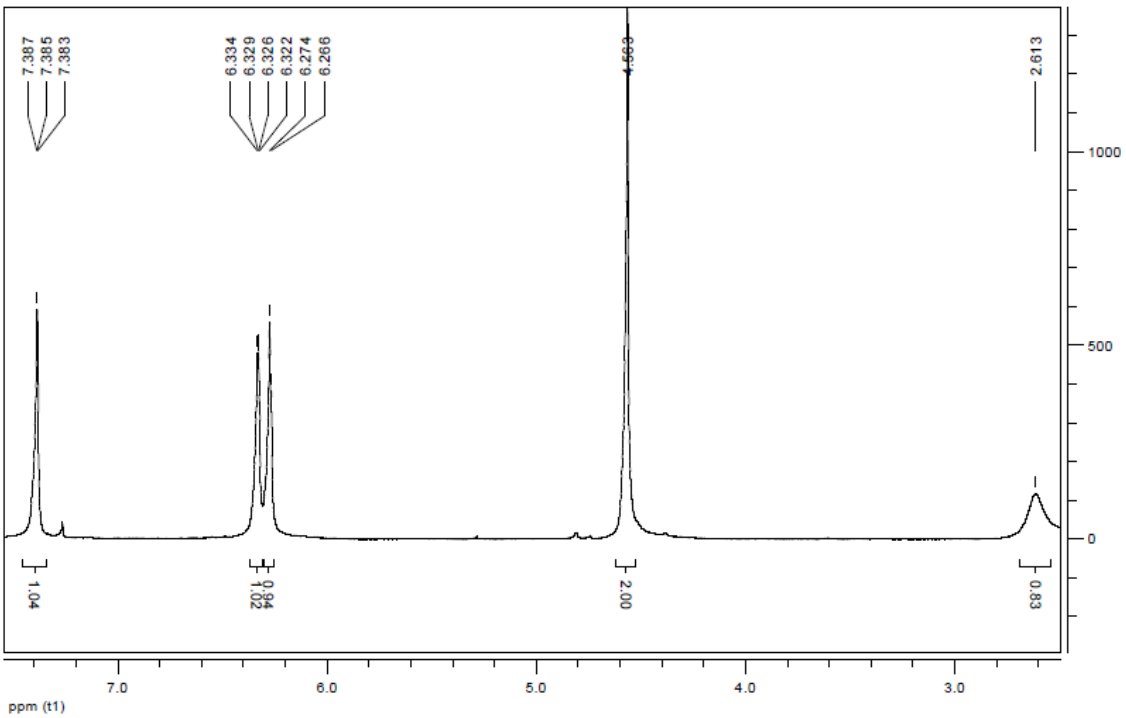

H3N·BH3 in CDCl3
3.52
3.40
3.28
1.97
1.71
1.49
1.25
3.00
0.53
0.70
0.70
0.71

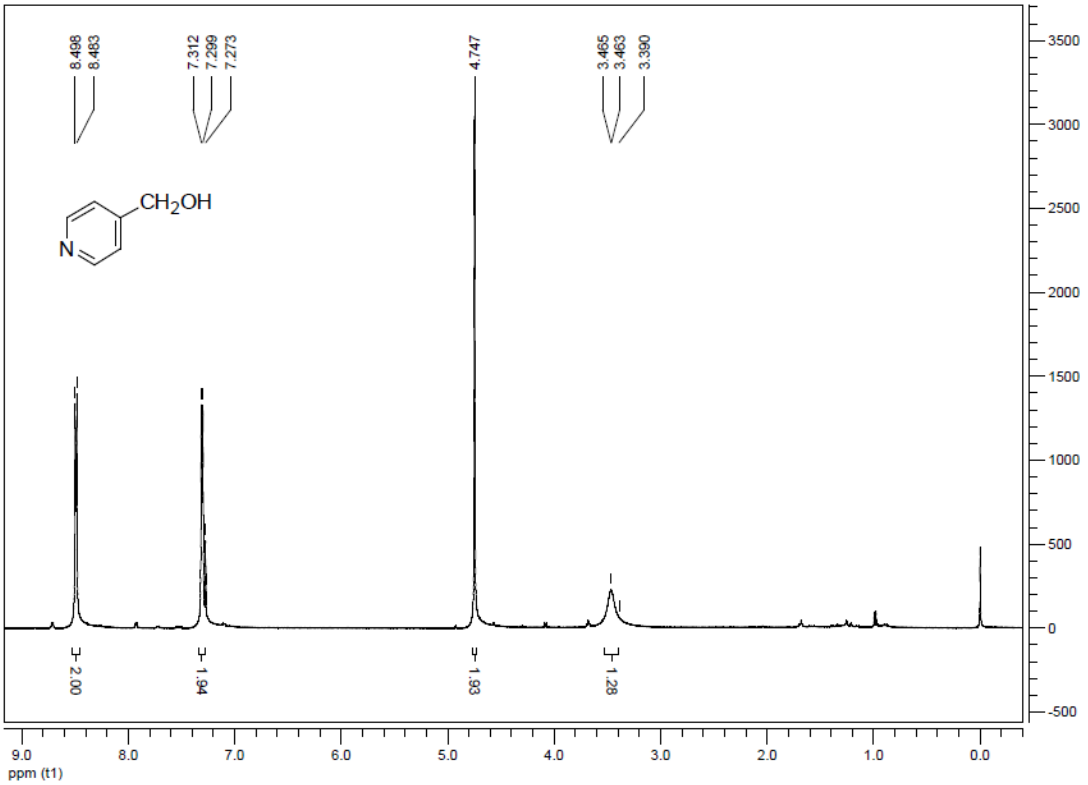

H3N·BH3 in DMSO-d6
4.42
3.37
2.50
1.38
1.10
3.00
2.99
f1 (ppm)

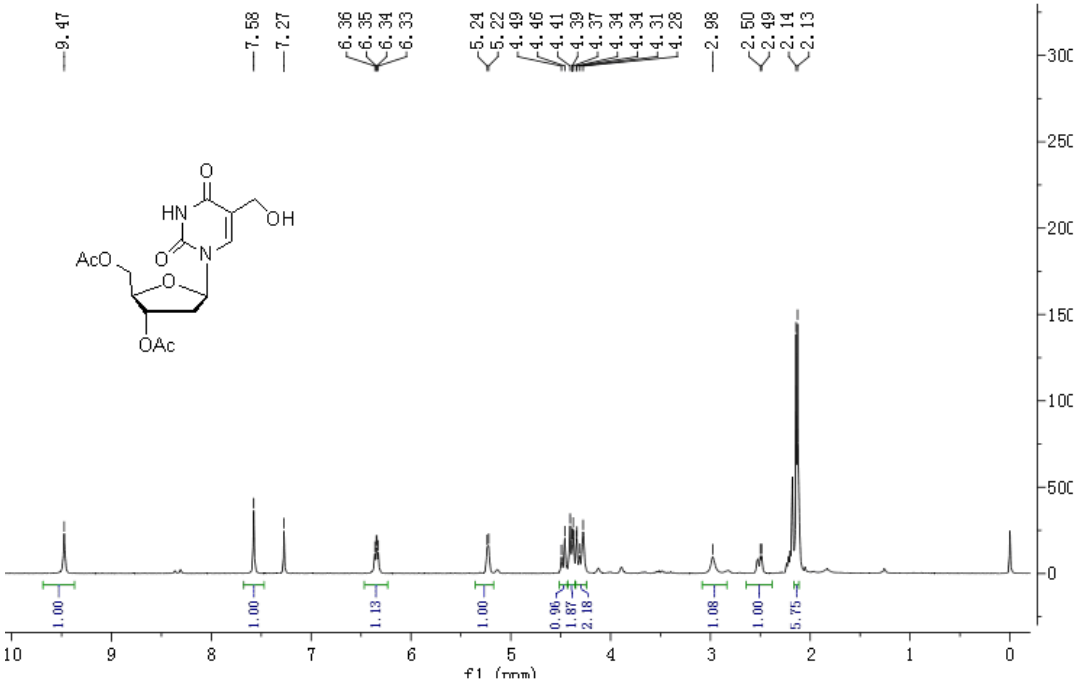

7.299
7.279
7.268
7.263
7.241
7.203
7.184
3.674
3.658
3.641
2.717
2.698
2.678
1.920
1.904
1.886
1.885
1.882
1.872
1.866
CH2OH
5.32
2.00
2.03
2.18
1.22
ppm (t1)

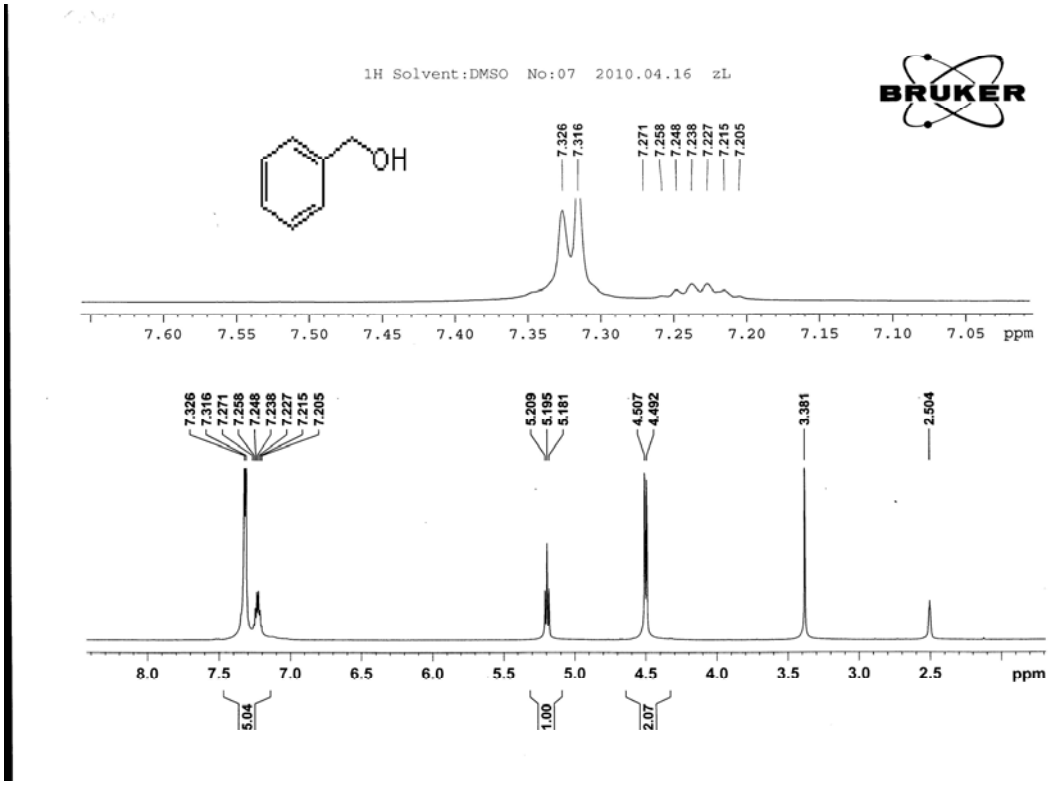


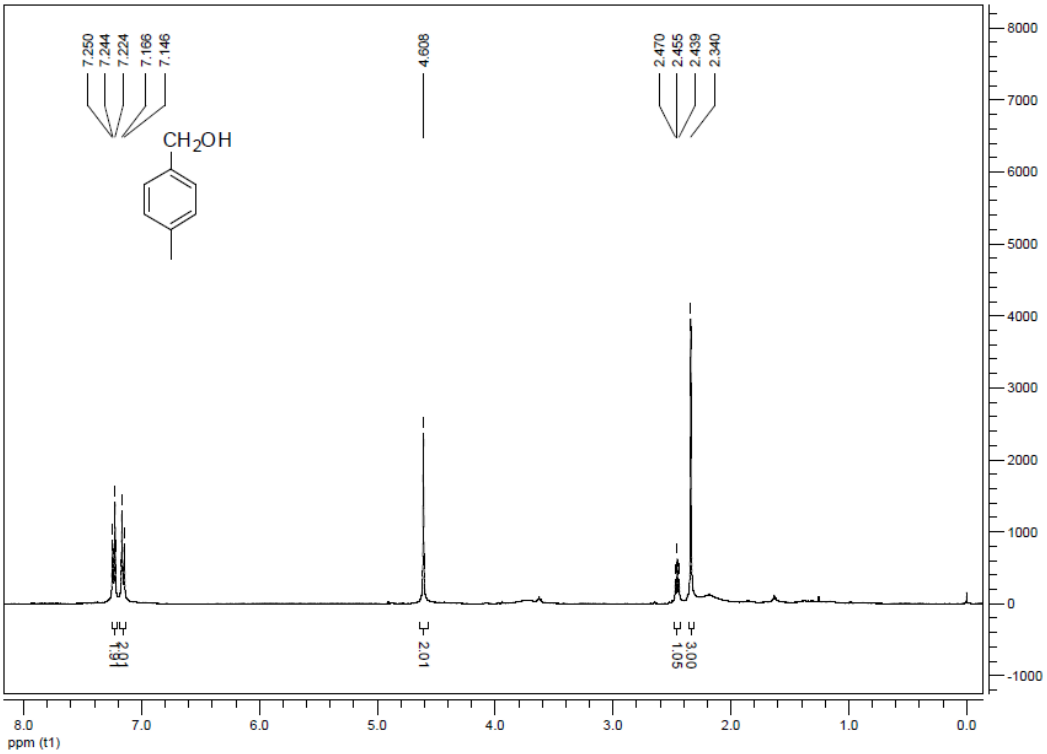


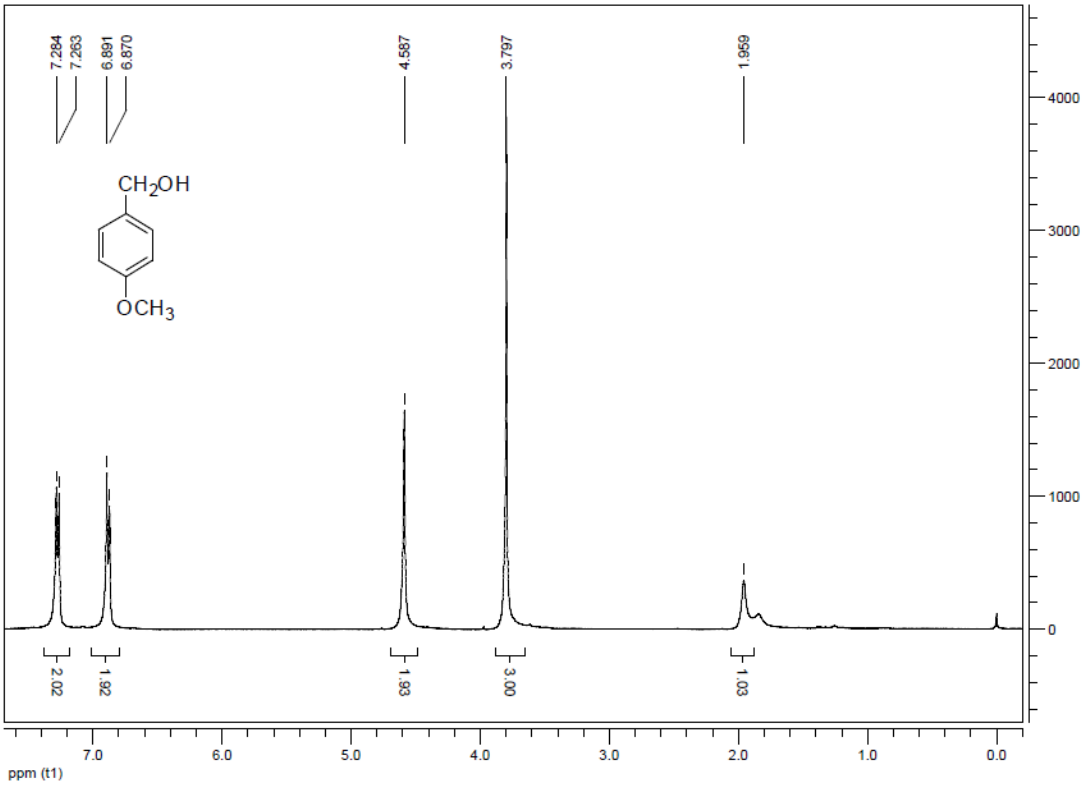


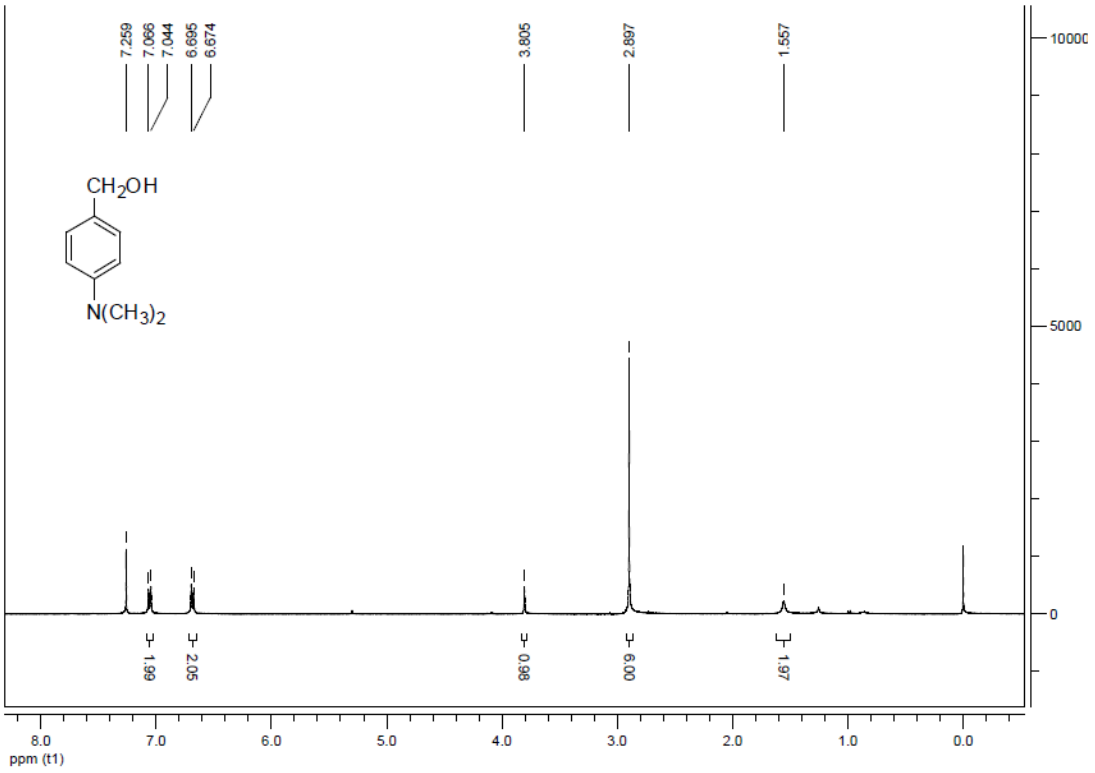


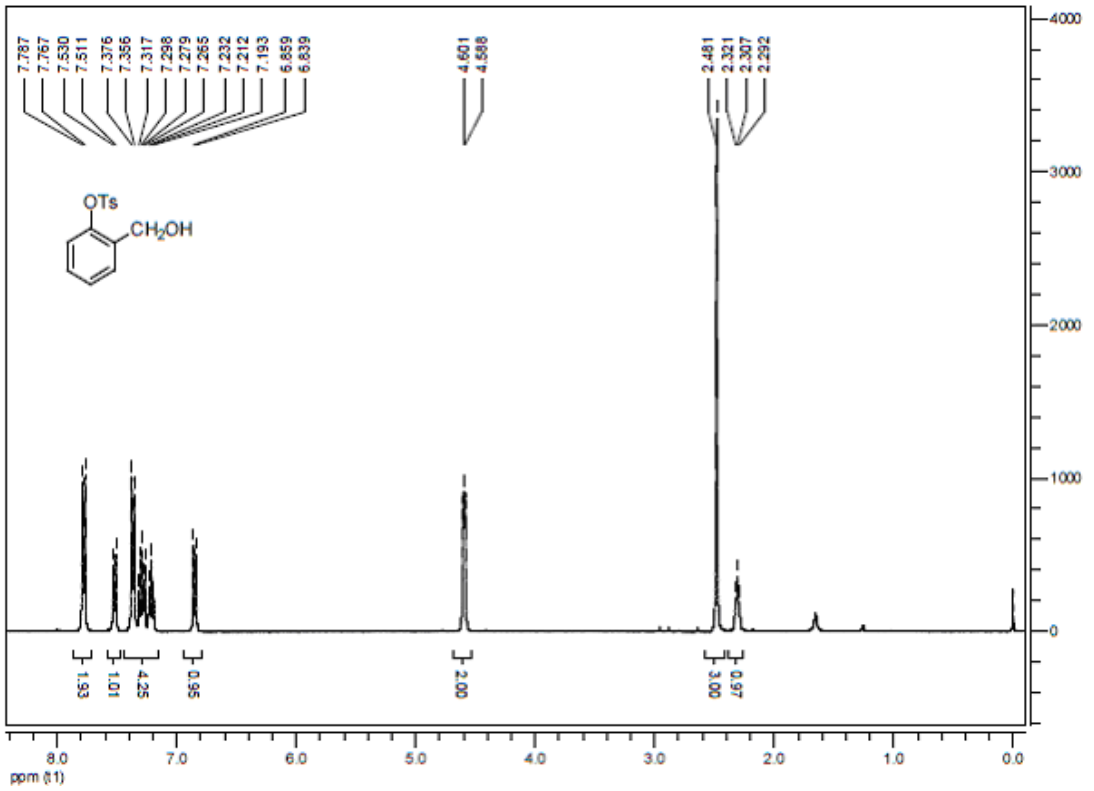


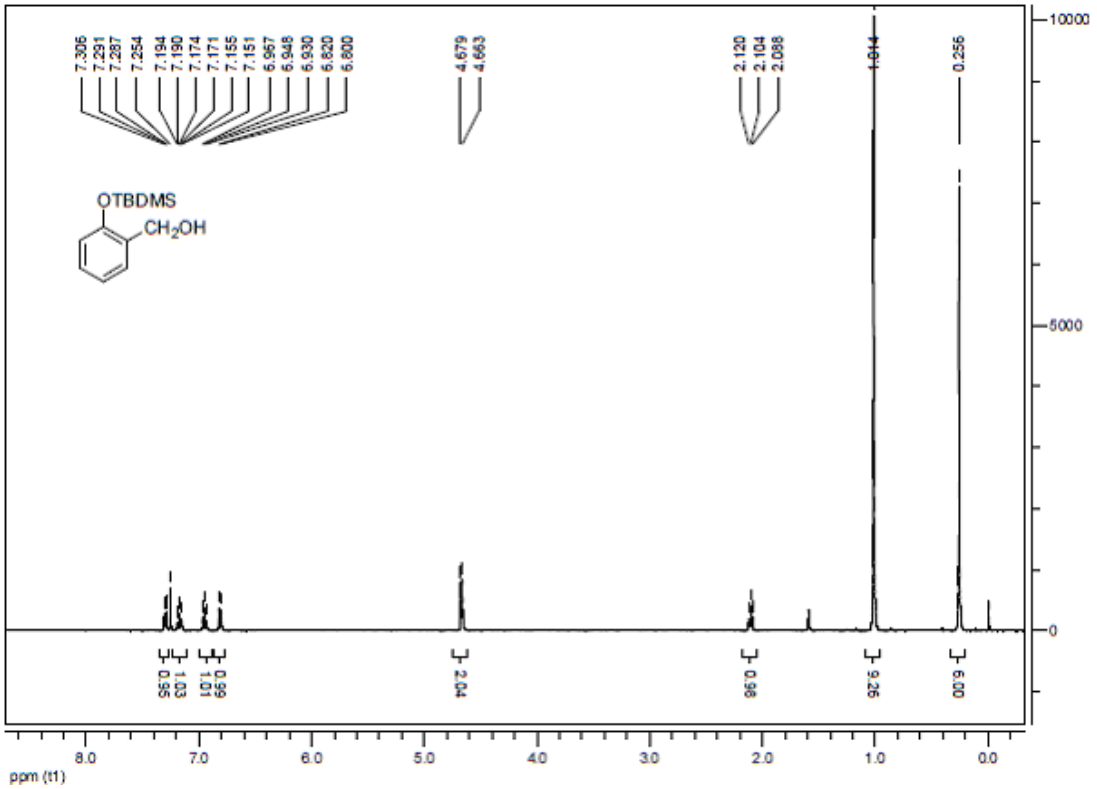

1H Solvent:DMSO No:07 2010.04.16 zL
BRUKER
OH
7.326
7.316
7.271
7.258
7.248
7.238
7.227
7.215
7.205
7.60 7.55 7.50 7.45 7.40 7.35 7.30 7.25 7.20 7.15 7.10 7.05 ppm
5.209
5.195
5.181
4.507
4.492
3.381
2.504
8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 ppm
5.04
1.00
2.07

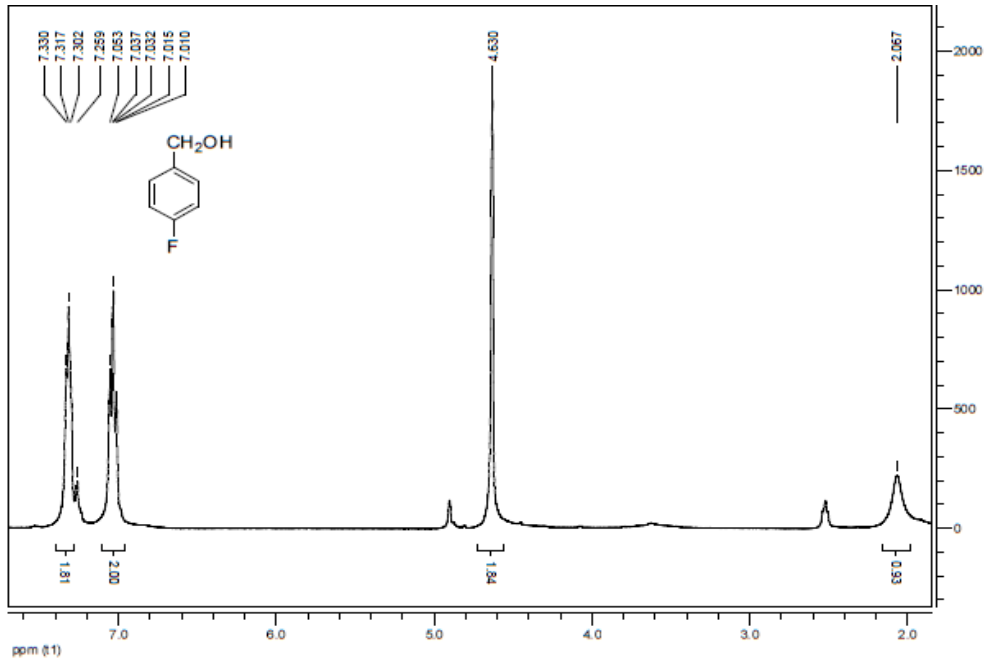

7.250
7.244
7.224
7.166
7.146
4.608
2.470
2.455
2.439
2.340
CH2OH
8000
7000
6000
5000
4000
3000
2000
1000
0
-1000
2.91
2.01
3.00
1.05
8.0 7.0 6.0 5.0 4.0 3.0 2.0 1.0 0.0
ppm (t1)

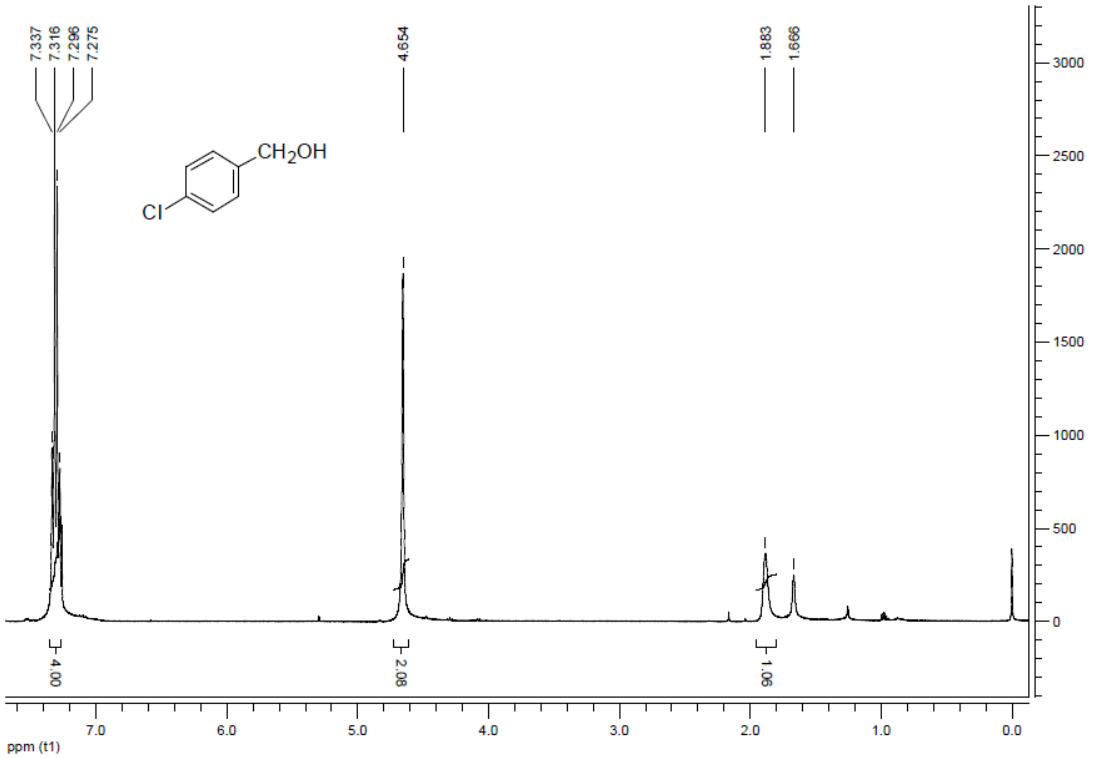

7.284
7.263
6.891
6.870
4.587
3.797
1.959
CH2OH
OCH3
2.02
1.92
1.93
3.00
1.03
ppm (t1)

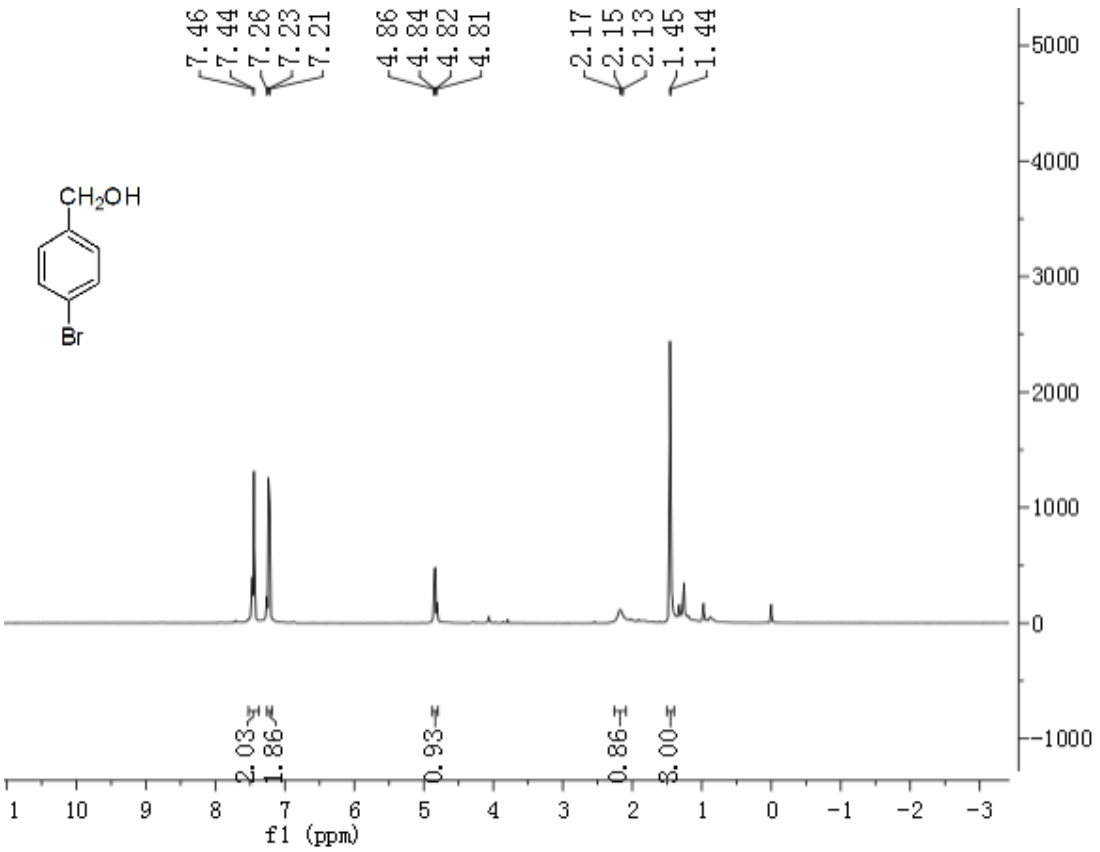

7.259
7.066
7.044
6.695
6.674
3.805
2.897
1.557
CH2OH
N(CH3)2
1.99
2.05
0.98
6.00
1.97
ppm (t1)

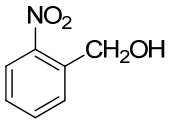


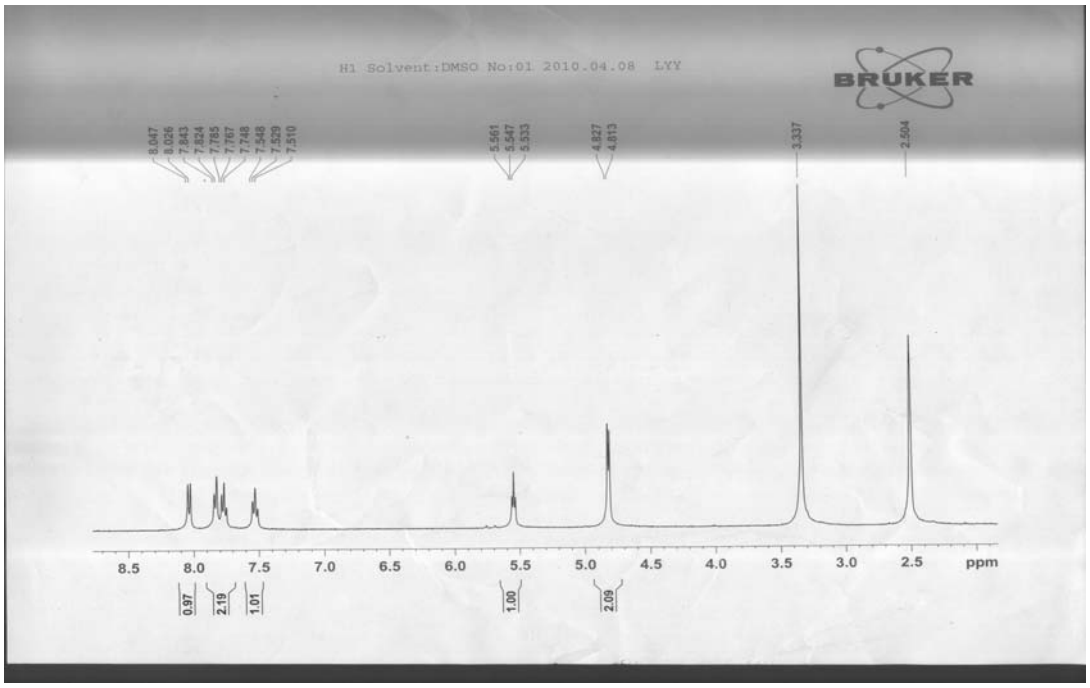


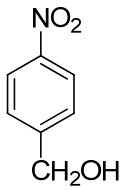


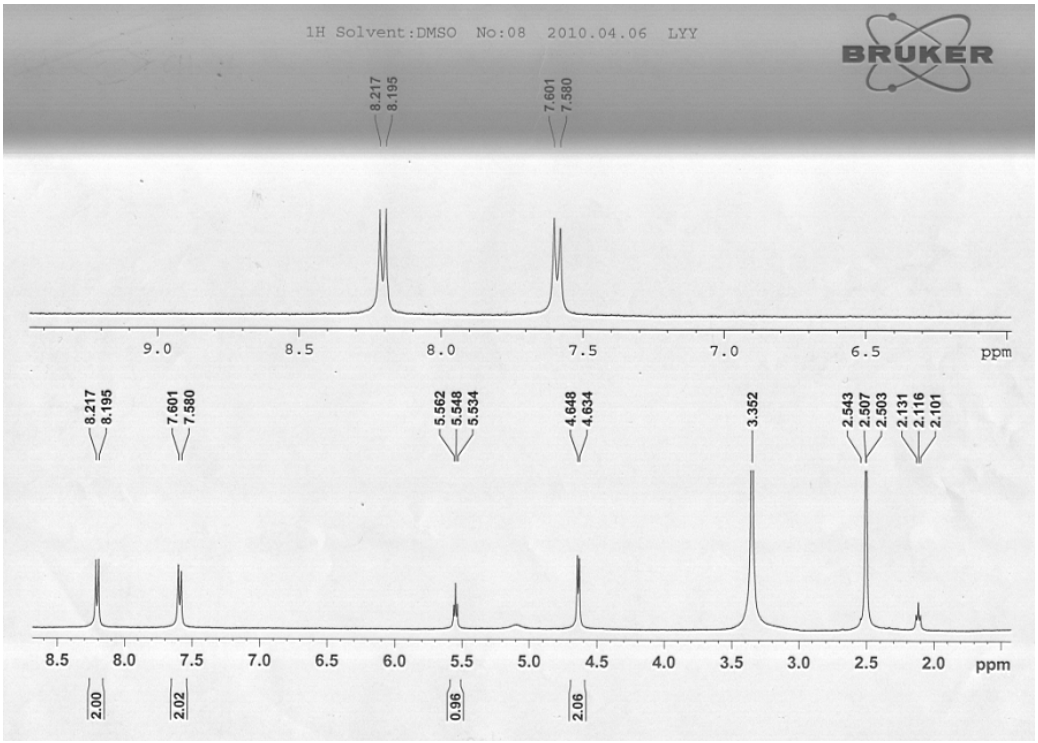


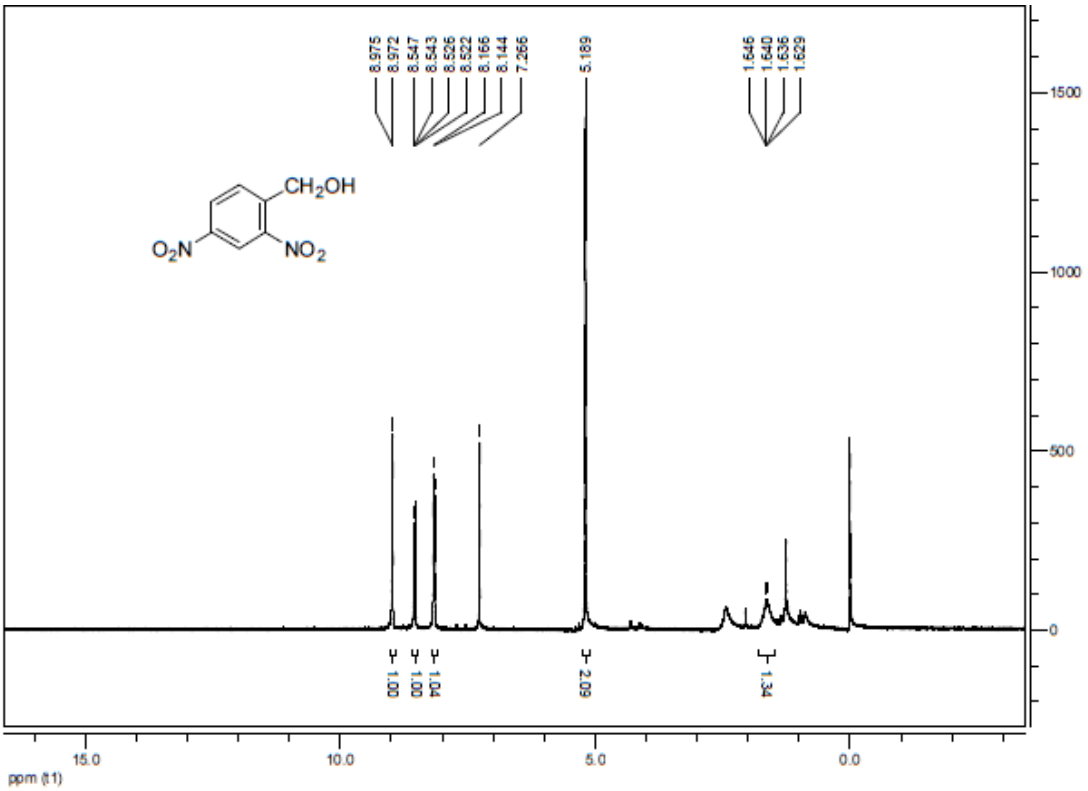


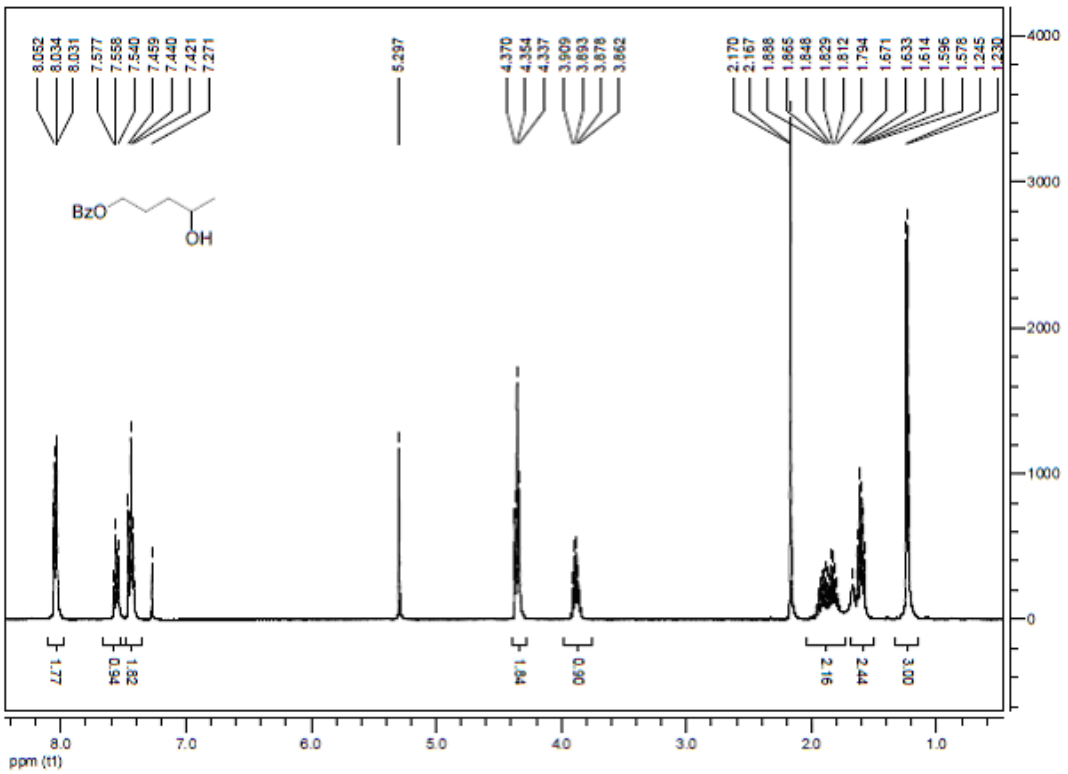


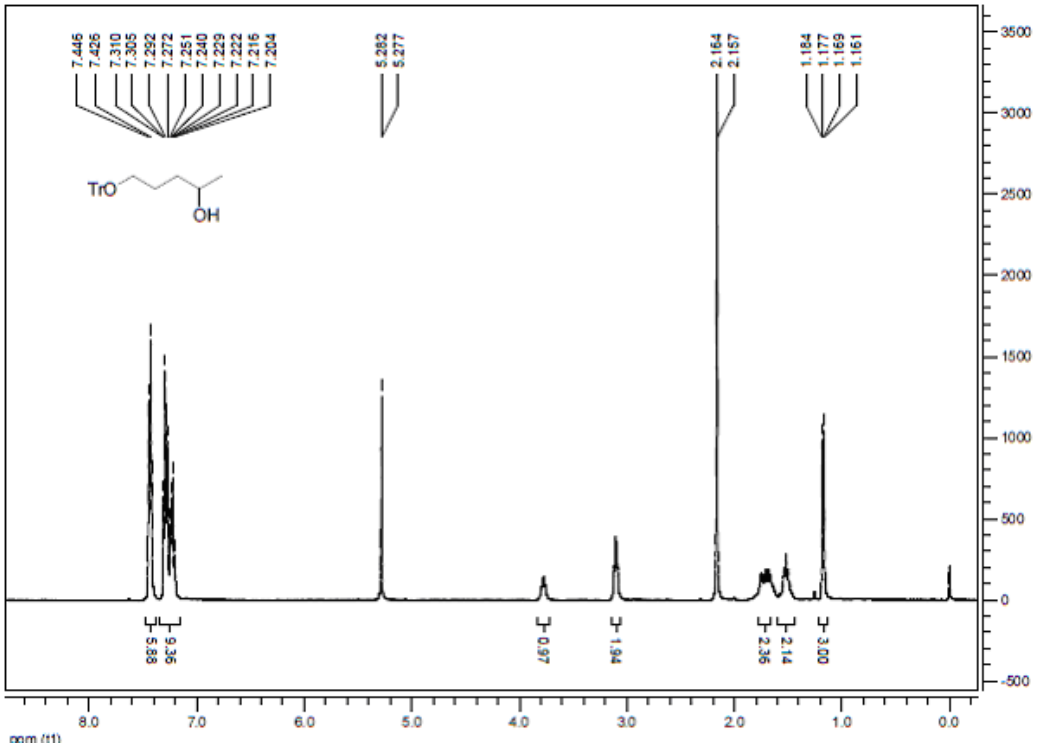


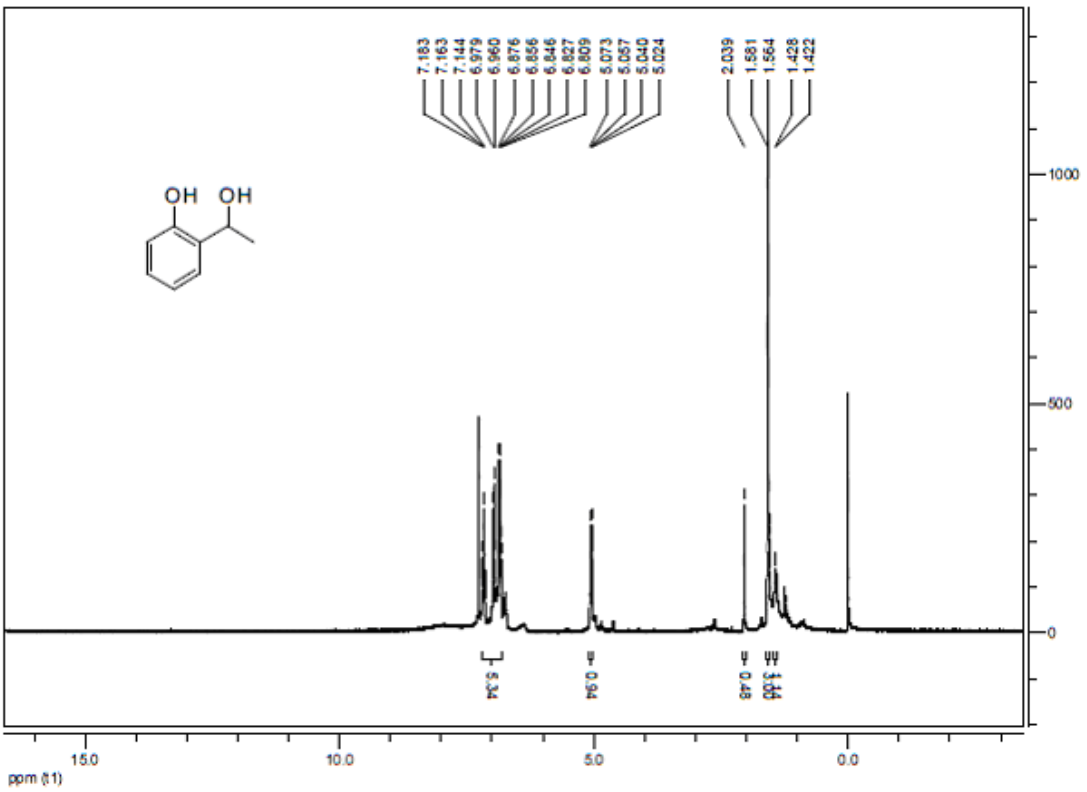


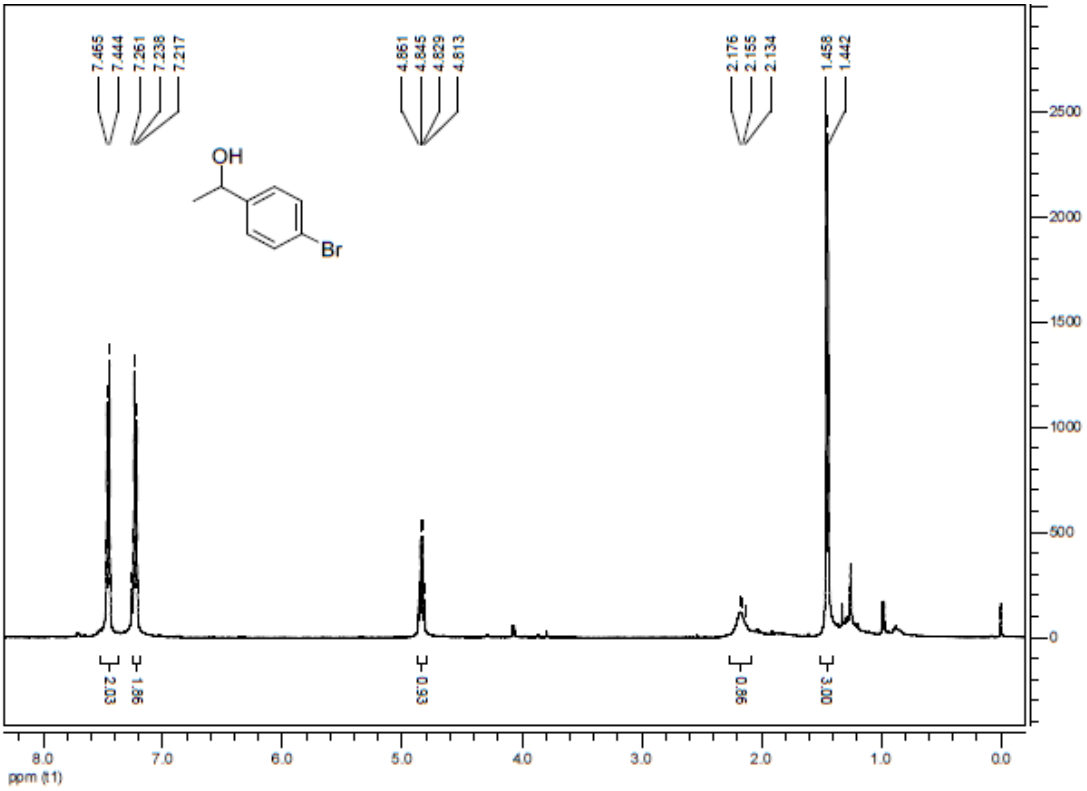


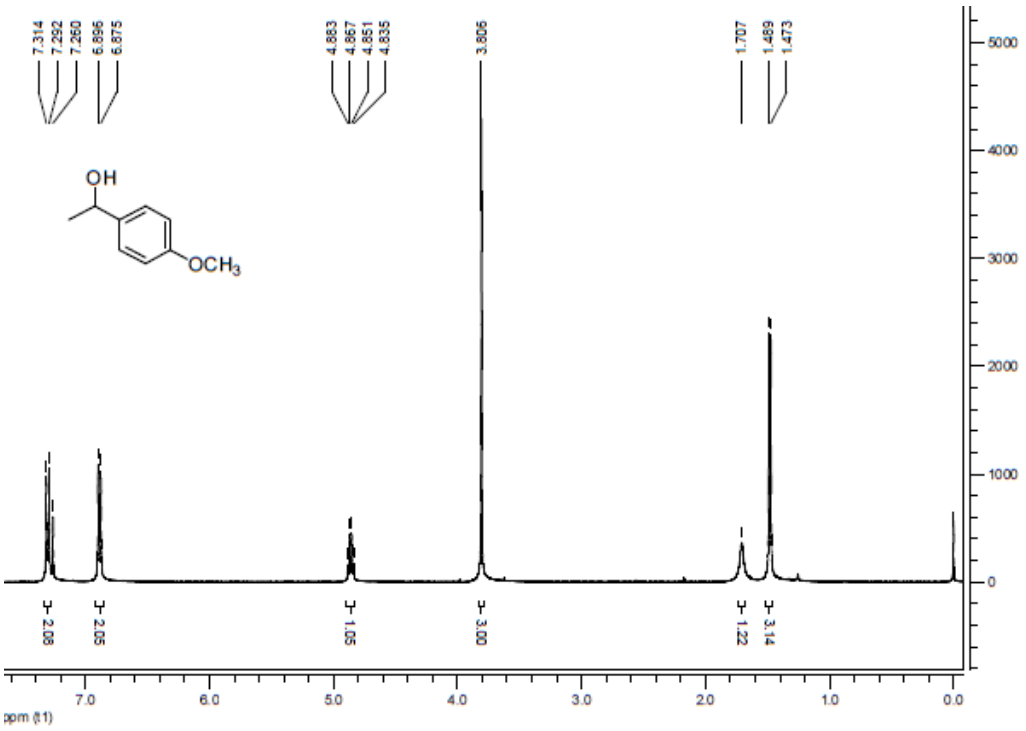


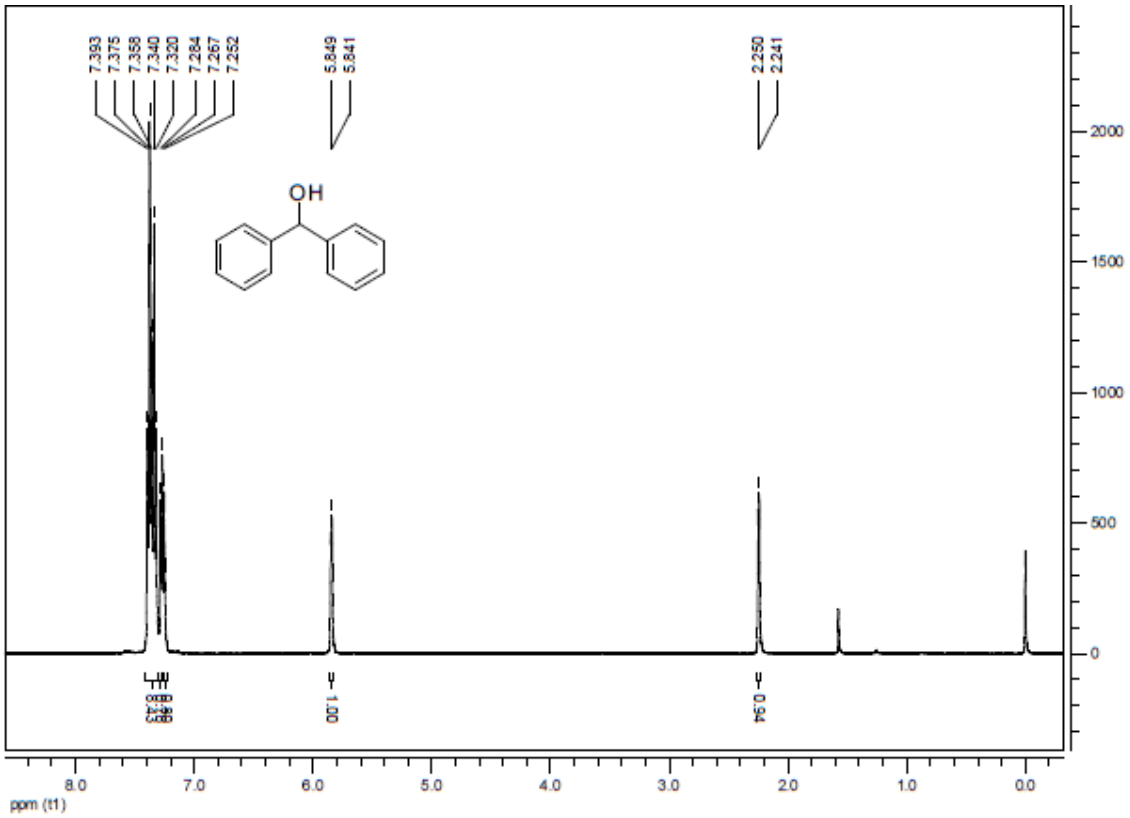




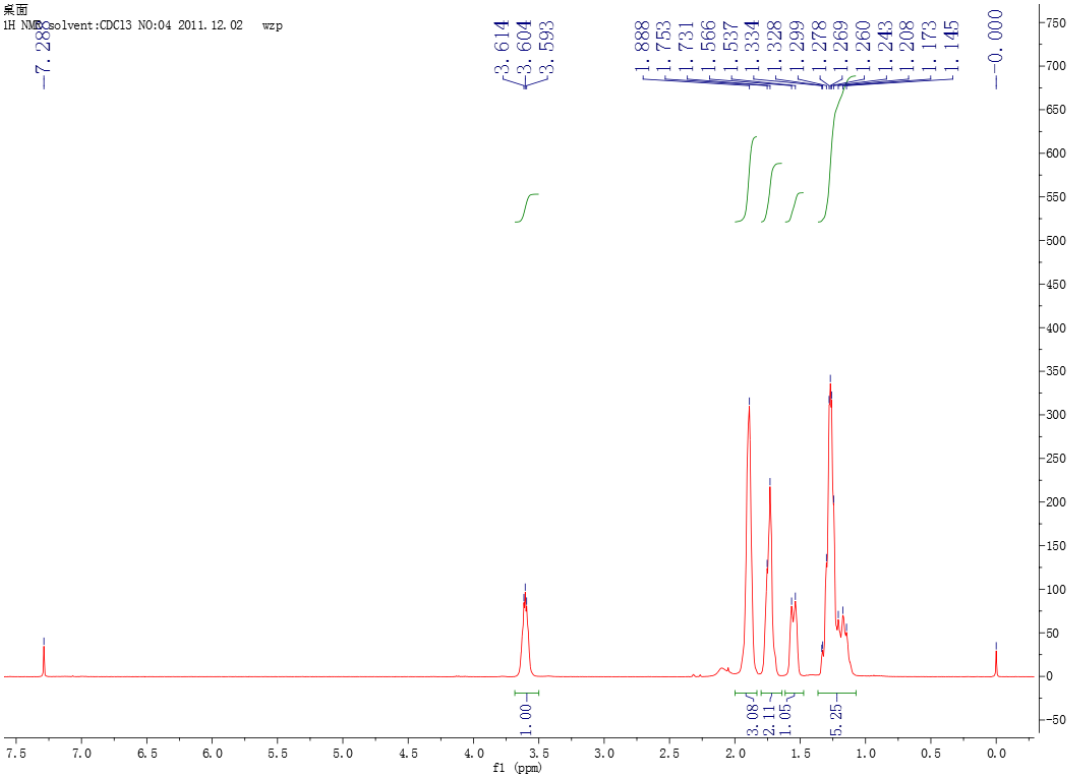




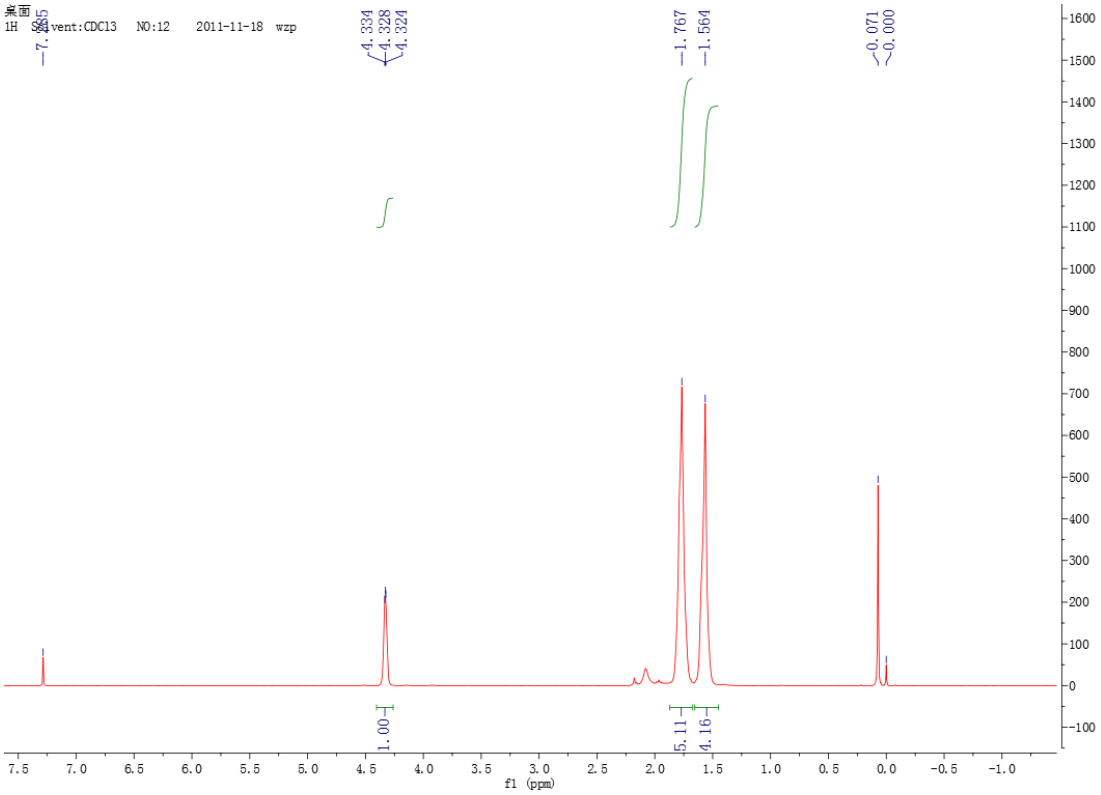


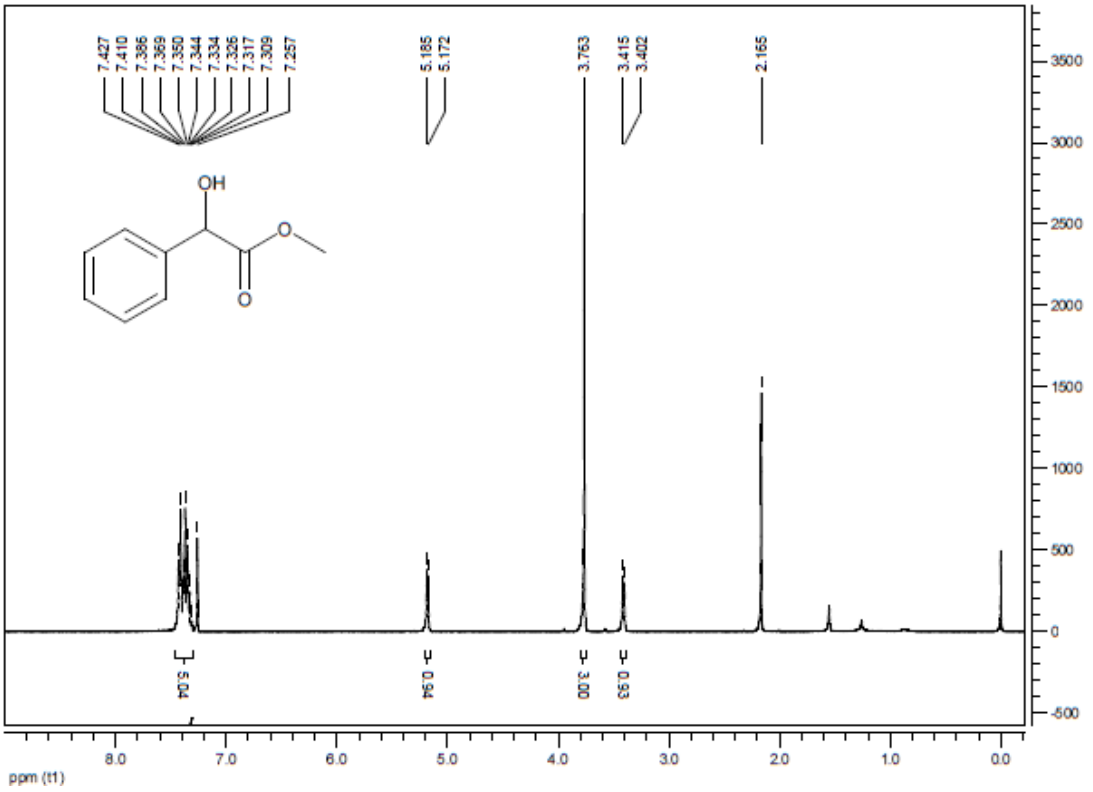


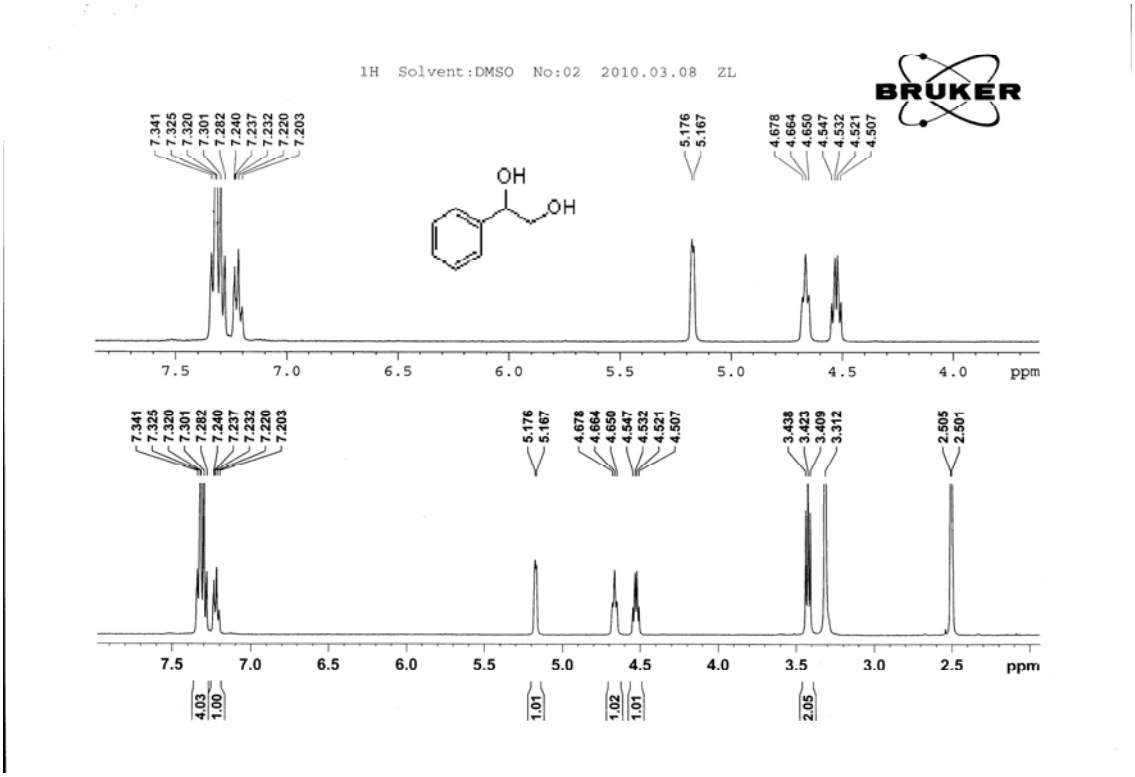
Cyclohexanol

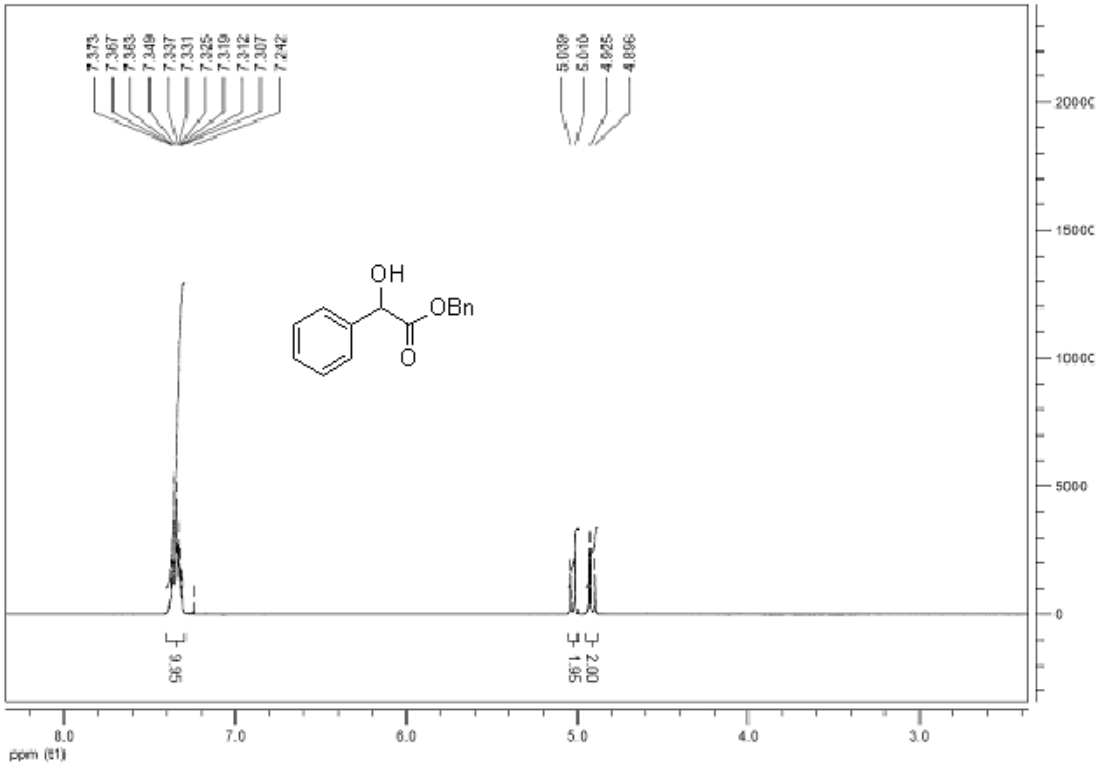


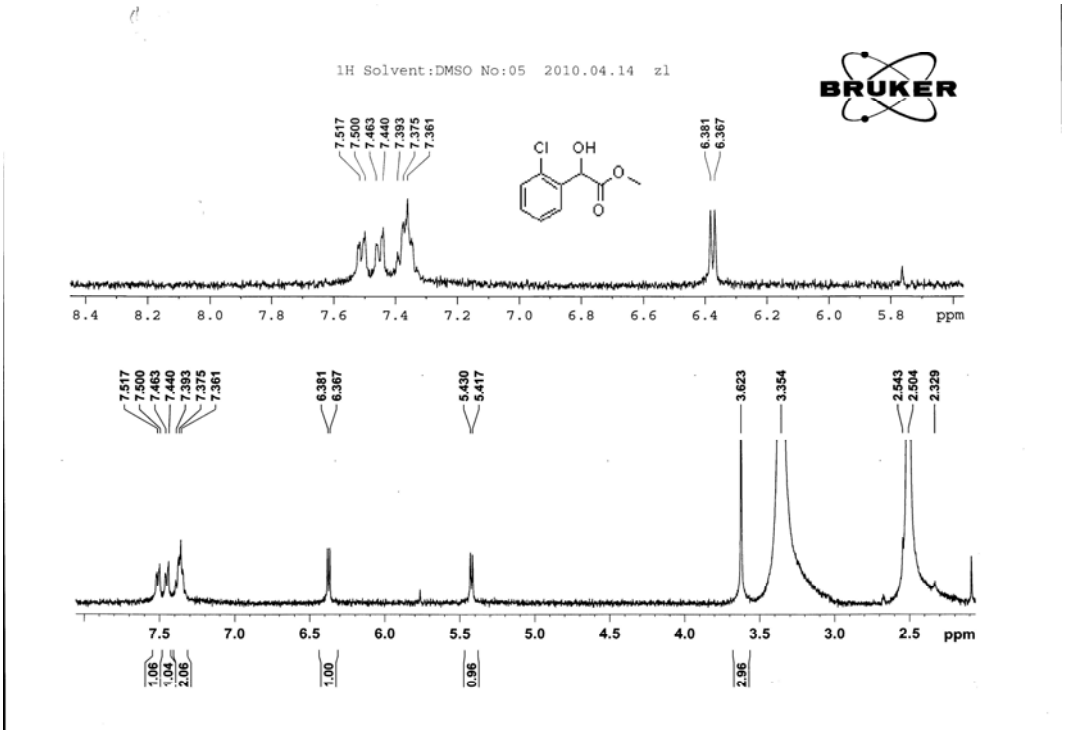
Cyclopentanol

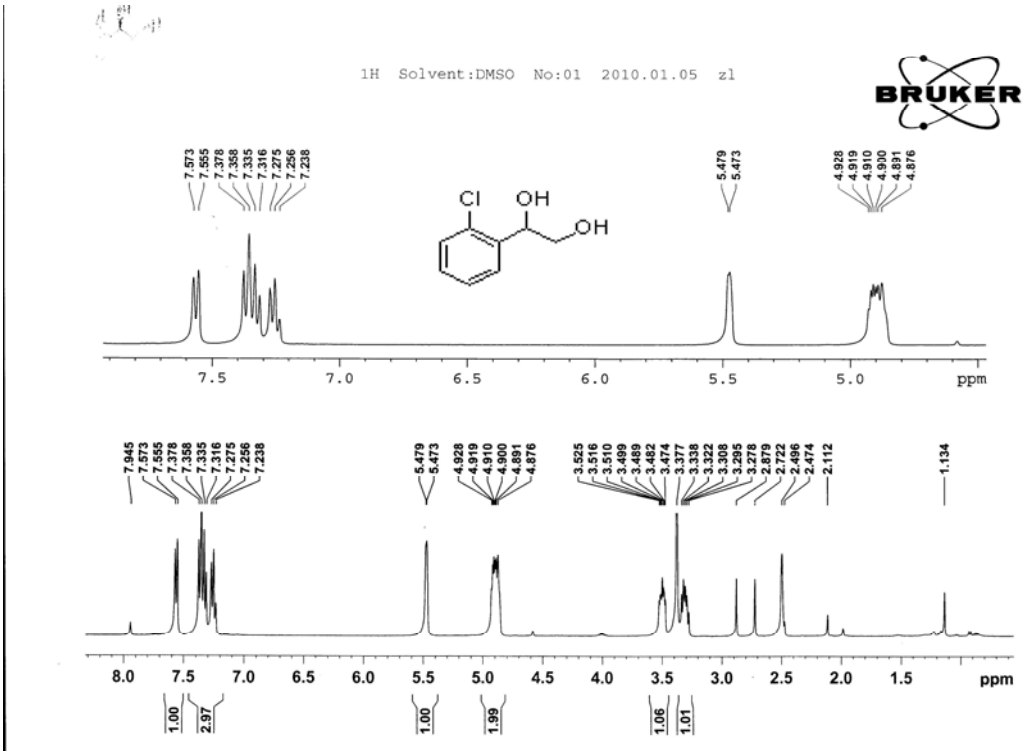


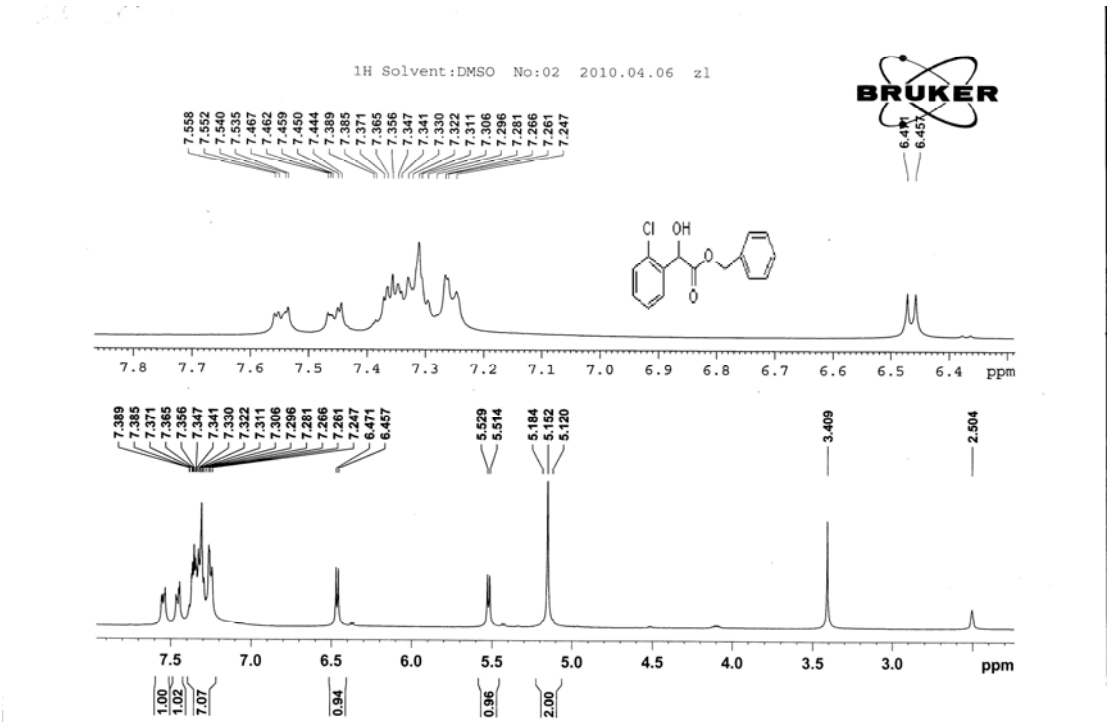

7.427
7.410
7.386
7.369
7.350
7.344
7.334
7.326
7.317
7.309
7.257
5.185
5.172
3.763
3.415
3.402
2.165
OH
O
O
5.04
0.94
3.00
0.93
ppm (t1)

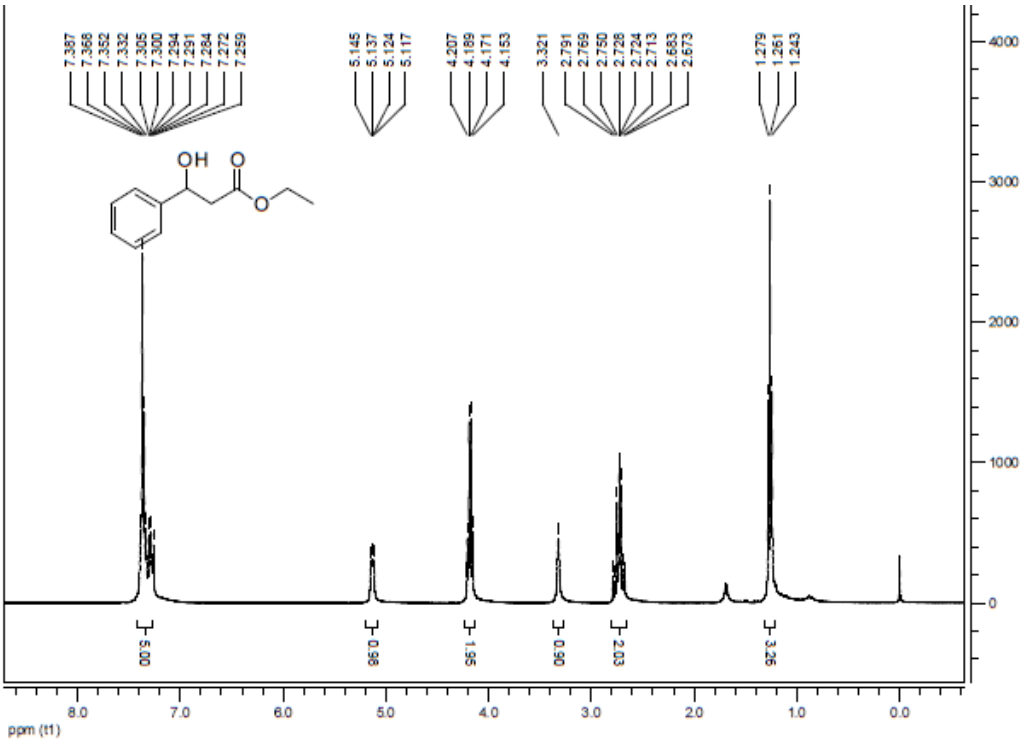

1H Solvent:DMSO No:02 2010.03.08 ZL
BRUKER
7.341
7.325
7.320
7.301
7.282
7.240
7.237
7.232
7.220
7.203
5.176
5.167
4.678
4.664
4.650
4.547
4.532
4.521
4.507
OH
OH
ppm
3.438
3.423
3.409
3.312
2.505
2.501
4.03
1.00
1.01
1.02
1.01
2.05

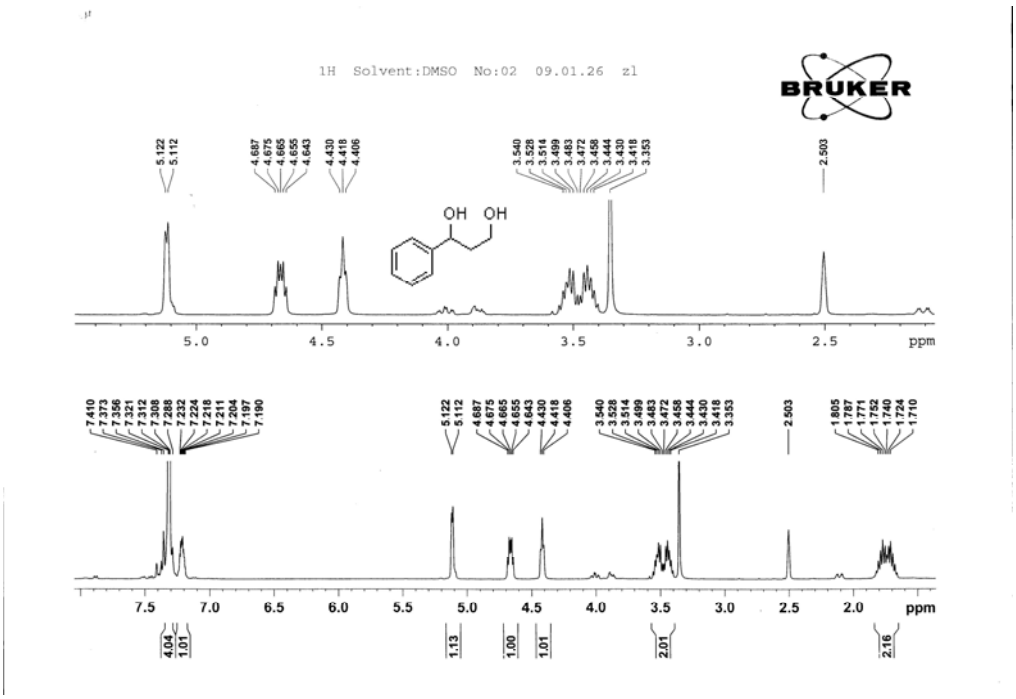

OH
OBn
O
9.95
2.00
1.95
ppm (f1)

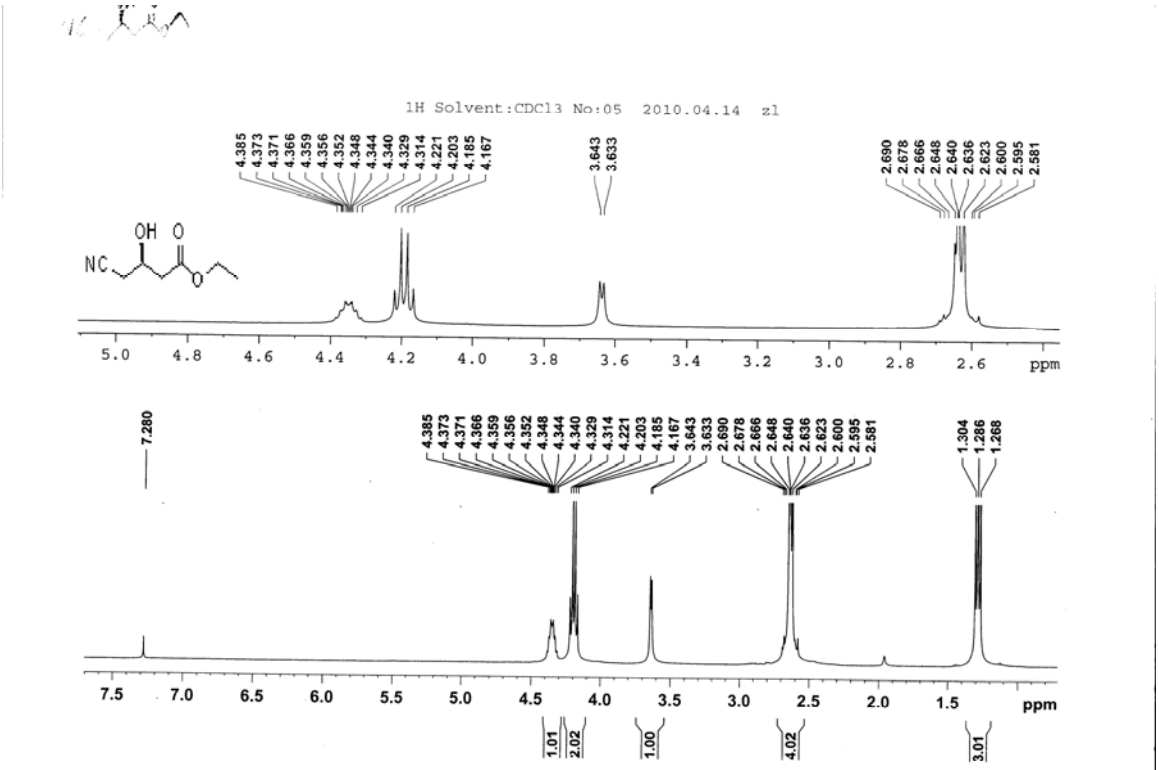

1H Solvent:DMSO No:05 2010.04.14 z1
BRUKER
Cl
OH
O
ppm
1.06
1.04
2.06
1.00
0.96
2.96

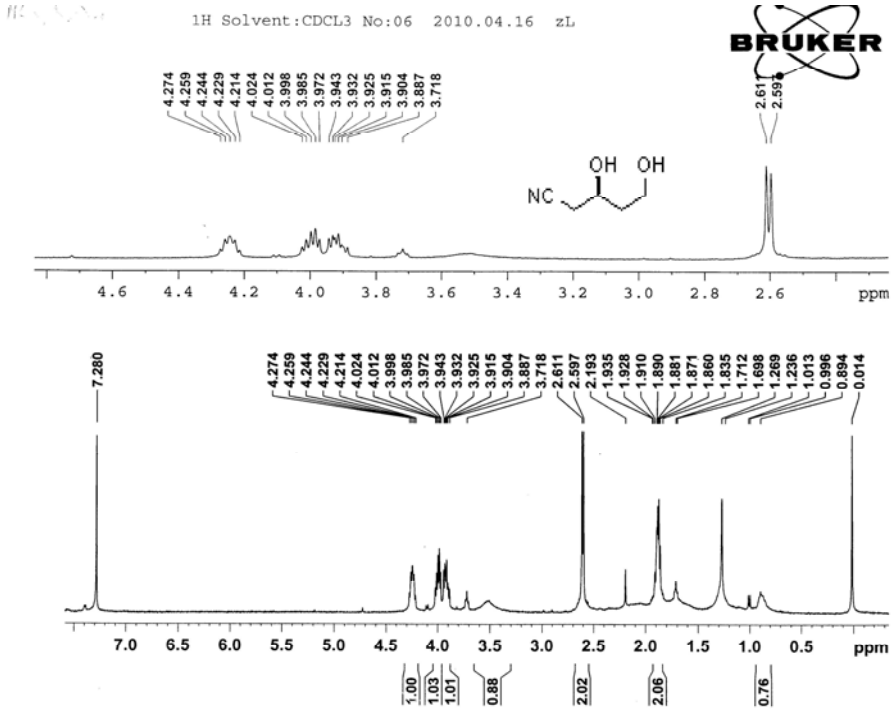

1H Solvent:DMSO No:01 2010.01.05 zl
BRUKER
Cl OH
OH
ppm


1H Solvent:DMSO No:02 2010.04.06 zl
BRUKER
Cl OH
O
O
ppm


7.387
7.368
7.352
7.332
7.305
7.300
7.284
7.291
7.284
7.272
7.259
5.145
5.137
5.124
5.117
4.207
4.189
4.171
4.153
3.321
2.791
2.769
2.750
2.728
2.724
2.713
2.683
2.673
1.279
1.261
1.243
OH
O
O
5.00
0.98
1.95
0.90
2.03
3.26
4000
3000
2000
1000
0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
ppm (t1)


1H Solvent:DMSO No:02 09.01.26 zl
BRUKER
5.122
5.112
4.687
4.675
4.665
4.655
4.643
4.430
4.418
4.406
3.540
3.528
3.514
3.499
3.483
3.472
3.458
3.444
3.430
3.418
3.353
2.503
OH
OH
5.0
4.5
4.0
3.5
3.0
2.5
ppm
7.410
7.373
7.356
7.321
7.312
7.308
7.288
7.232
7.224
7.218
7.211
7.204
7.197
7.190
1.805
1.787
1.771
1.752
1.740
1.724
1.710
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
ppm
4.04
1.01
1.13
1.00
1.01
2.01
2.16


1H Solvent:CDCl3 No:05 2010.04.14 zl
4.385 4.373 4.371 4.366 4.359 4.356 4.352 4.348 4.344 4.340 4.329 4.314 4.221 4.203 4.185 4.167
3.643 3.633
2.690 2.678 2.666 2.648 2.640 2.636 2.623 2.600 2.595 2.581
OH O
NC
O
5.0 4.8 4.6 4.4 4.2 4.0 3.8 3.6 3.4 3.2 3.0 2.8 2.6 ppm
7.280
4.385 4.373 4.371 4.366 4.359 4.356 4.352 4.348 4.344 4.340 4.329 4.314 4.221 4.203 4.185 4.167 3.643 3.633 2.690 2.678 2.666 2.648 2.640 2.636 2.623 2.600 2.595 2.581
1.304 1.286 1.268
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 ppm
1.01 2.02 1.00 4.02 3.01


1H Solvent:CDCL3 No:06 2010.04.16 zL
BRUKER
4.274 4.259 4.244 4.229 4.214 4.024 4.012 3.998 3.985 3.972 3.943 3.932 3.925 3.915 3.904 3.887 3.718
2.611 2.597
OH OH
NC
4.6 4.4 4.2 4.0 3.8 3.6 3.4 3.2 3.0 2.8 2.6 ppm
7.280
4.274 4.259 4.244 4.229 4.214 4.024 4.012 3.998 3.985 3.972 3.943 3.932 3.925 3.915 3.904 3.887 3.718 2.611 2.597 2.193 1.935 1.928 1.910 1.890 1.881 1.871 1.860 1.835 1.712 1.698 1.269 1.236 1.013 0.996 0.894 0.014
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
1.00 1.03 1.01 0.88 2.02 2.06 0.76