

Supplementary Material

Diastereoselective photochemical radical addition of a cyclic ether to olefins: addition of THF radicals to dialkyl maleates

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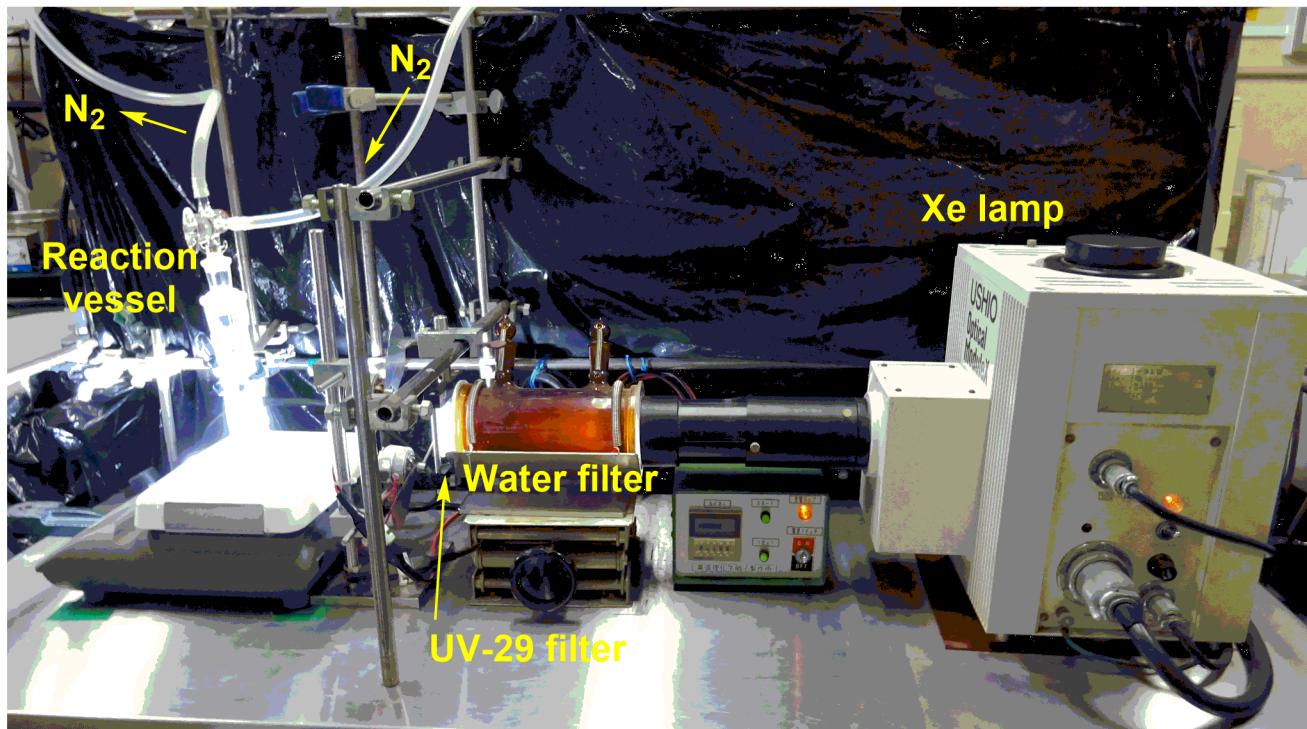
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Email: ouchi.akihiko@nihon-u.ac.jp*

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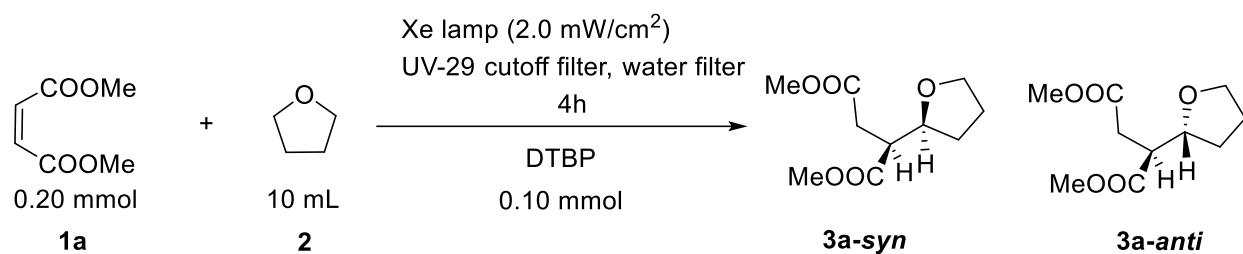
1. Experimental

1.1. Experimental setup



1.2. Experimental details of the reactions in Table 1

1.2.1. Entry 1: 2-(Tetrahydro-2-furanyl)butanedioic acid 1,4-dimethyl ester (**3a-syn/anti**)^{S1-S3}



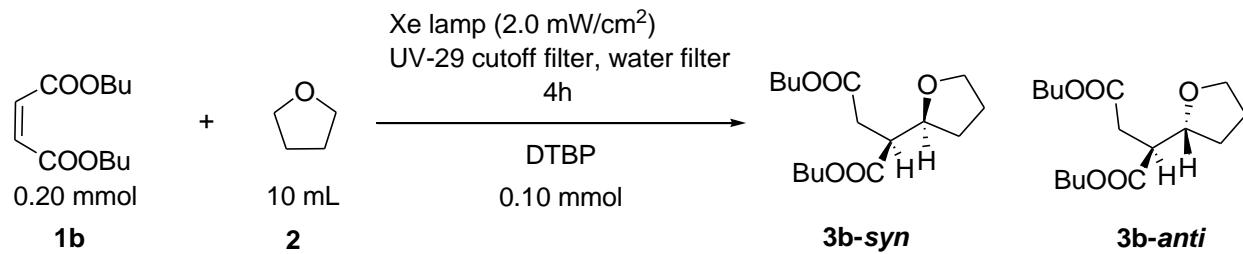
Run 1

Dimethyl maleate (**1a**, 28.87 mg, 0.20 mmol) and DTBP (14.76 mg, 0.10 mmol) in THF (**2**, 10 mL). Yield of **3a**: 100 % (*syn / anti* = 61 / 39) (conversion: 100 %) (NMR, CDCl₃).

Run 2

Dimethyl maleate (**1a**, 28.79 mg, 0.20 mmol) and DTBP (14.76 mg, 0.10 mmol) in THF (**2**, 10 mL). Yield of **3a**: 95 % (*syn / anti* = 60 / 35) (conversion: 100 %) (NMR, CDCl₃).

1.2.2. Entry 2: 2-(Tetrahydro-2-furanyl)butanedioic acid 1,4-dibutyl ester (**3b-syn/anti**)

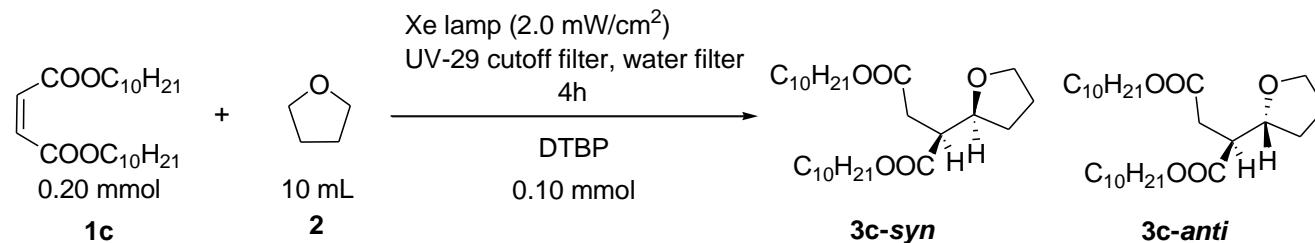


Run 1

Dibutyl maleate (**1b**, 45.52 mg, 0.20 mmol) and DTBP (15.14 mg, 0.10 mmol) in THF (**2**, 10 mL). Yield of **3b**: 100 % (*syn / anti* = 64 / 36) (conversion: 100 %) (NMR, CDCl₃).

Run 2

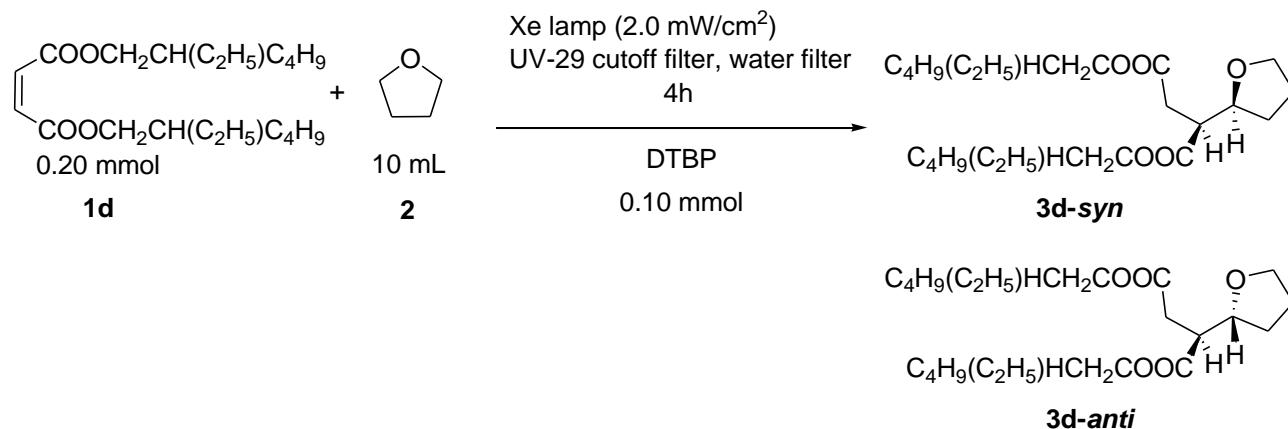
Dibutyl maleate (**1b**, 45.61 mg, 0.20 mmol) and DTBP (14.68 mg, 0.10 mmol) in THF (**2**, 10 mL). Yield of **3b**: 100 % (*syn / anti* = 65 / 35) (conversion: 100 %) (NMR, CDCl₃).

1.2.3. Entry 3: 2-(Tetrahydro-2-furanyl)butanedioic acid 1,4-didecyl ester (**3c-syn/anti**)**Run 1**

Didecyl maleate (**1c**, 79.08 mg, 0.20 mmol) and DTBP (14.86 mg, 0.10 mmol) in THF (**2**, 10 mL). Yield of **3c**: 86 % (*syn / anti* = 60 / 26) (conversion: 100 %) (NMR, CDCl₃).

Run 2

Didecyl maleate (**1c**, 79.56 mg, 0.20 mmol) and DTBP (14.85 mg, 0.10 mmol) in THF (**2**, 10 mL). Yield of **3c**: 89 % (*syn / anti* = 60 / 29) (conversion: 100 %) (NMR, CDCl₃).

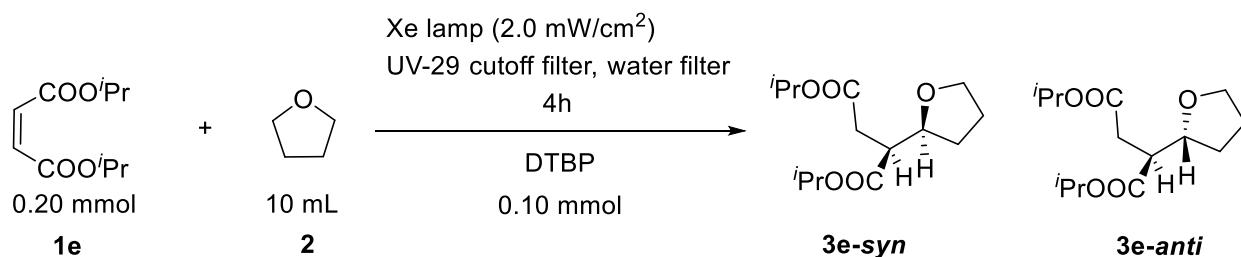
1.2.4. Entry 4: 2-(Tetrahydro-2-furanyl)butanedioic acid 1,4-bis(2-ethylhexyl) ester (**3d-syn/anti**)**Run 1**

Bis (2-ethylhexyl) maleate (**1d**, 68.07 mg, 0.20 mmol) and DTBP (14.79 mg, 0.10 mmol) in THF (**2**, 10 mL). Yield of **3d**: 99 % (*syn / anti* = 67 / 32) (conversion: 100 %) (NMR, CDCl₃).

Run 2

Bis (2-ethylhexyl) maleate (**1d**, 68.18 mg, 0.20 mmol) and DTBP (14.63 mg, 0.10 mmol) in THF (**2**, 10 mL). Yield of **3d**: 96 % (*syn / anti* = 62 / 34) (conversion: 100 %) (NMR, CDCl₃).

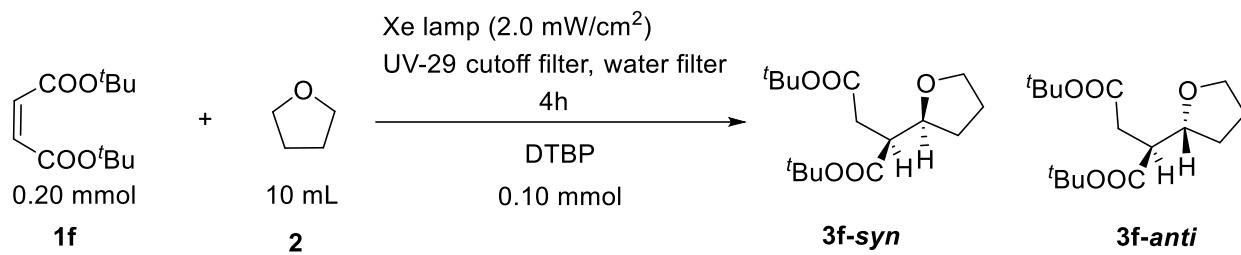
1.2.5. Entry 5: 2-(Tetrahydro-2-furanyl)butanedioic acid 1,4-diisopropyl ester (**3e-syn/anti**)^{S3}

**Run 1**

Diisopropyl maleate (**1e**, 40.32 mg, 0.20 mmol) and DTBP (14.60 mg, 0.10 mmol) in THF (**2**, 10 mL). Yield of **3e**: 91 % (*syn* / *anti* = 61 / 30) (conversion: 100 %) (NMR, CDCl_3).

Run 2

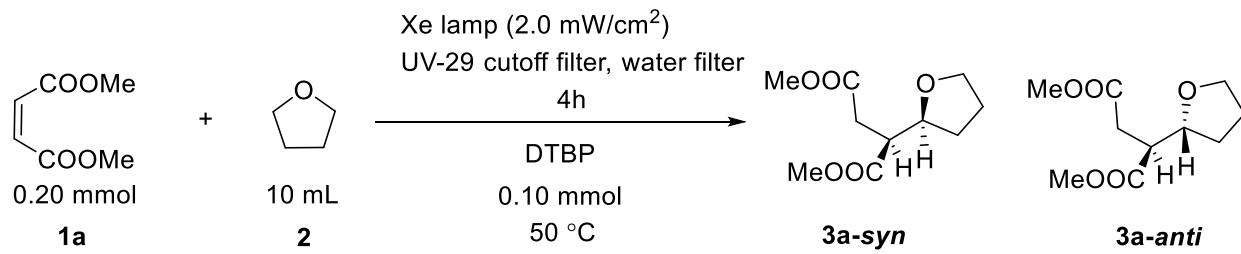
Diisopropyl maleate (**1e**, 68.07 mg, 0.20 mmol) and DTBP (14.79 mg, 0.10 mmol) in THF (**2**, 10 mL). Yield of **3e**: 96 % (*syn* / *anti* = 64 / 32) (conversion: 100 %) (NMR, CDCl_3).

1.2.6. Entry 6: 2-(Tetrahydro-2-furanyl)butanedioic acid 1,4- di-*tert*-butyl ester (3f-syn/anti**)****Run 1**

Di-*tert*-butyl maleate (**1f**, 45.50 mg, 0.20 mmol) and DTBP (14.51 mg, 0.10 mmol) in THF (**2**, 10 mL). Yield of **3f**: 96 % (*syn* / *anti* = 67 / 29) (conversion: 100 %) (NMR, CDCl_3).

Run 2

Di-*tert*-butyl maleate (**1f**, 45.59 mg, 0.20 mmol) and DTBP (14.75 mg, 0.10 mmol) in THF (**2**, 10 mL). Yield of **3f**: 96 % (*syn* / *anti* = 67 / 29) (conversion: 100 %) (NMR, CDCl_3).

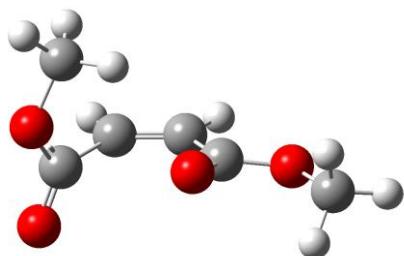
1.3. Reaction of **1a and **2** at 50 °C (**3a-cis-syn/anti**)^{S1-S3}**

Dimethyl maleate (**1a**, 28.84 mg, 0.20 mmol) and DTBP (14.56 mg, 0.10 mmol) in THF (**2**, 10 mL).

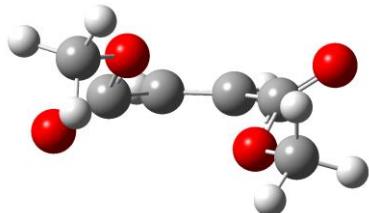
Irradiation time: 4h. Irradiation temperature: 50 °C. Yield of **3a**: 100 % (*syn* / *anti* = 61 / 38) (conversion: 100 %) (NMR, CDCl_3).

References

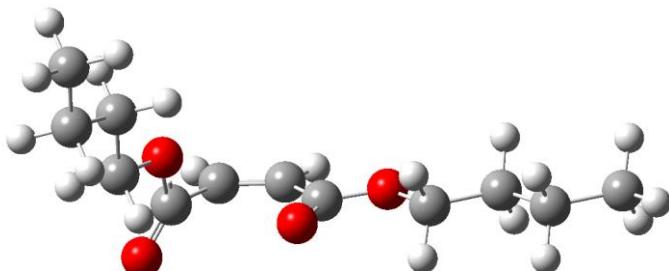
- S1. Hayakawa, M.; Shimizu, R.; Omori, H.; Shirota, H.; Uchida, K.; Mashimo, H.; Xu, H.; Yamada, R.; Niino, S.; Wakame, Y.; Liu, C.; Aoyama, T.; Ouchi, A., *Tetrahedron*, **2020**, 76, 131557.
- S2. Rohe, S.; Morris, A. O.; McCallum, T.; Barriault, L., *Angew. Chem. Int. Ed.*, **2018**, 57, 15664–15669.
- S3. Papadopoulos, G. N.; Kokotou, M. G.; Spiliopoulou, N.; Nikitas, N. F.; Voutyritsa, E.; Tzaras, D. I.; Kaplaneris, N.; Kokotos, C. G., *ChemSusChem*, **2020**, 13, 5934–5944.

2. Calculated stable conformers and energies of maleic acid and its dialkyl esters.^{S4, S5}

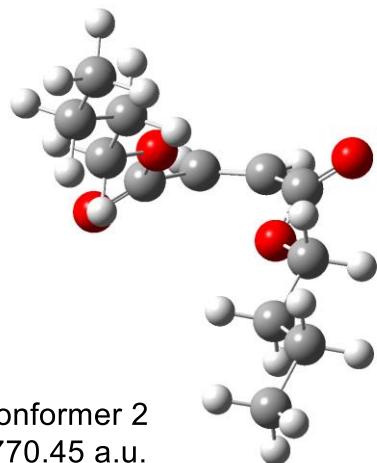
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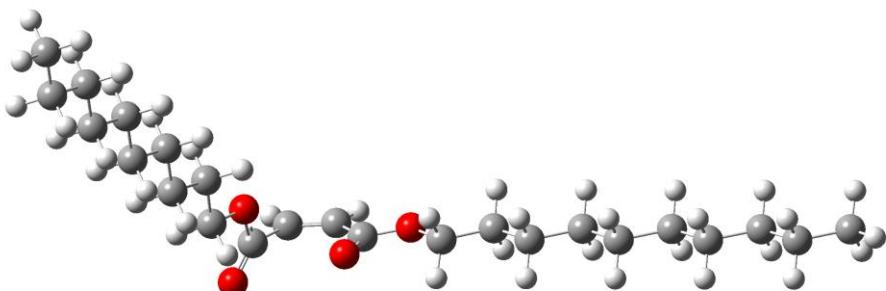
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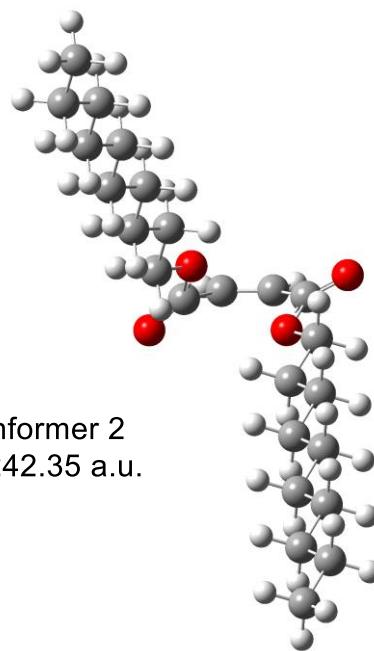
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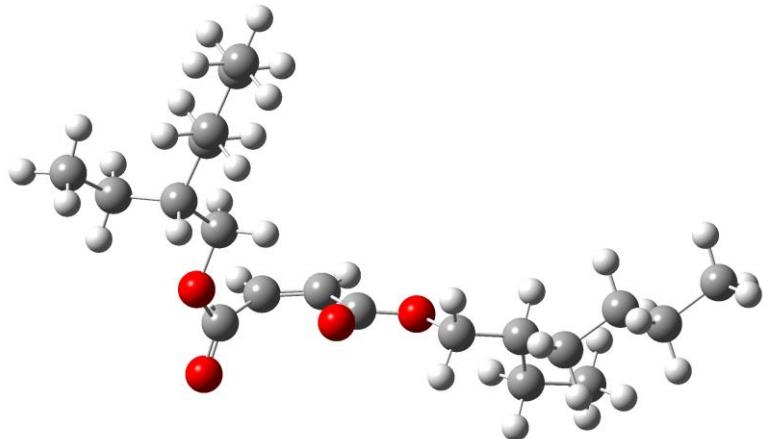
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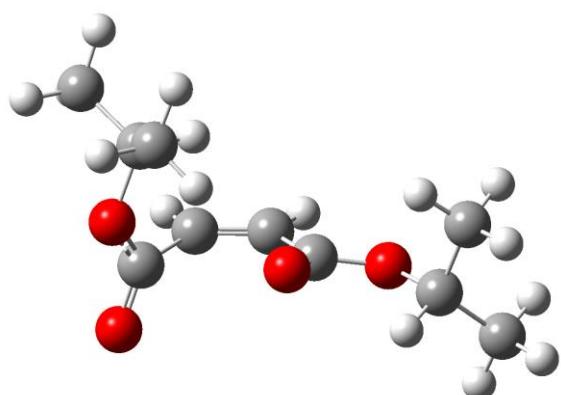
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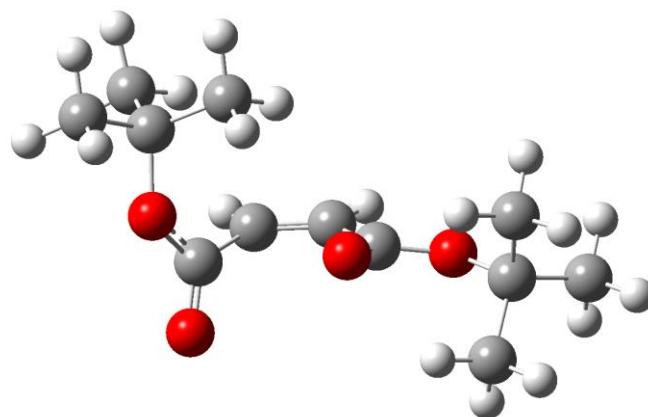
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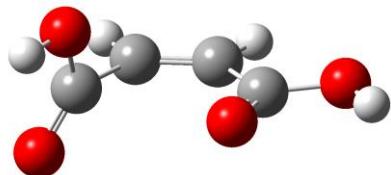
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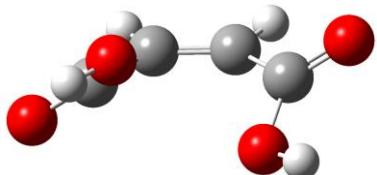
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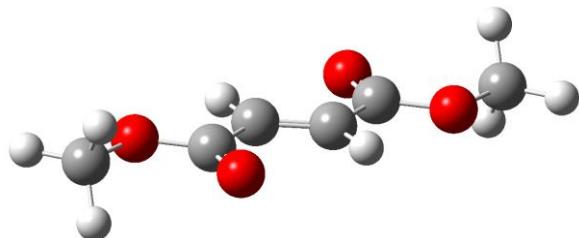
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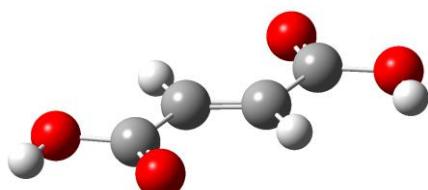
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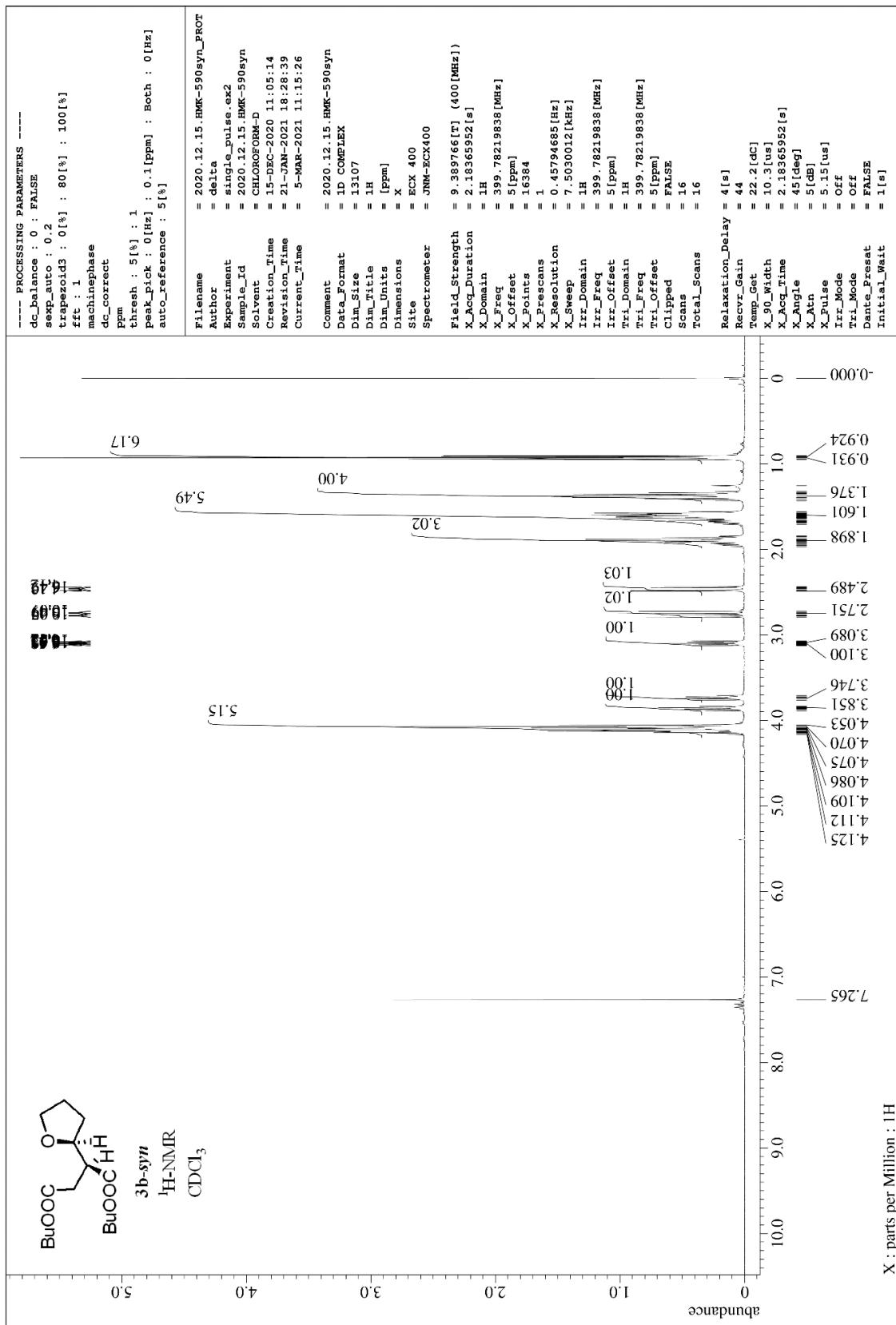
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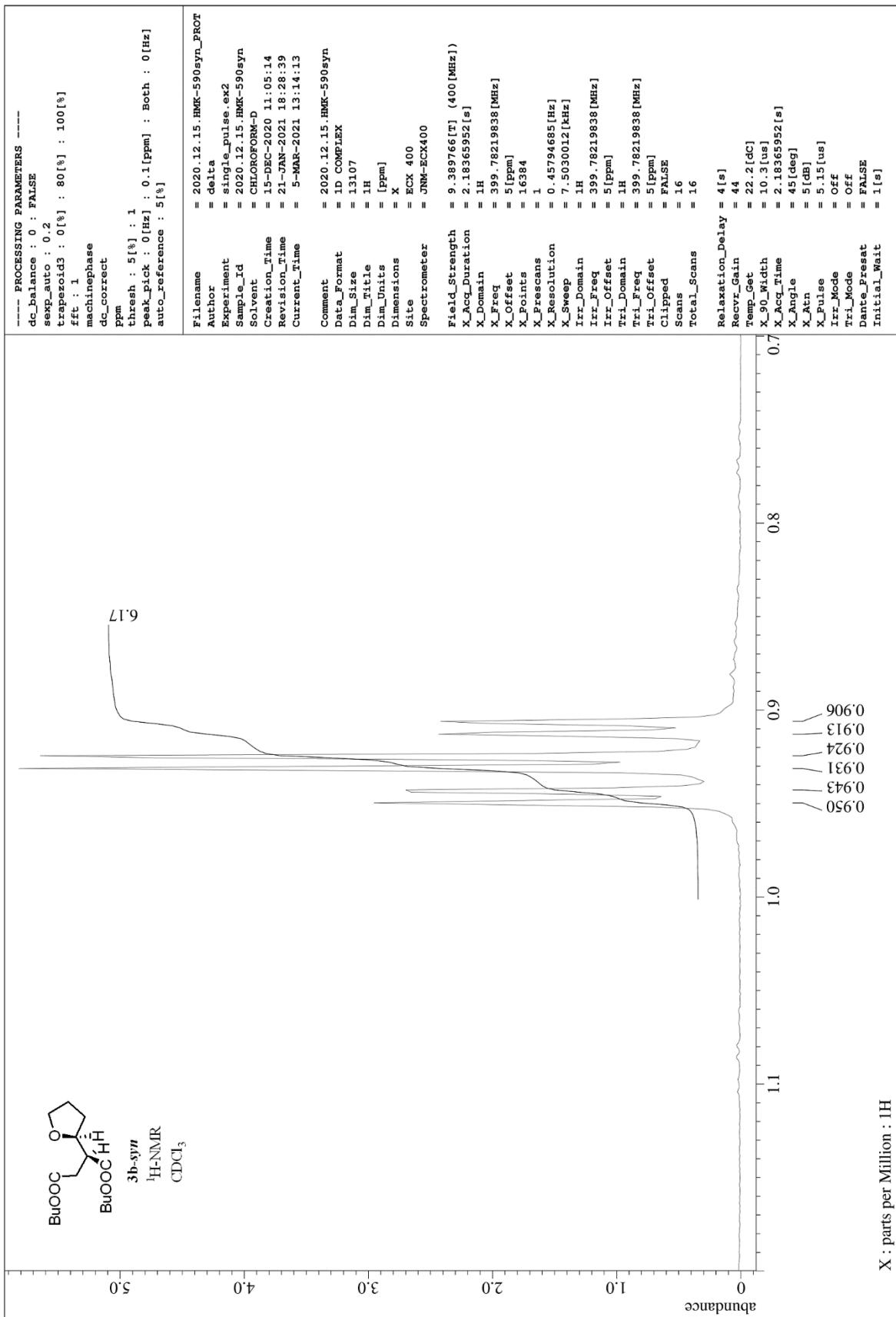


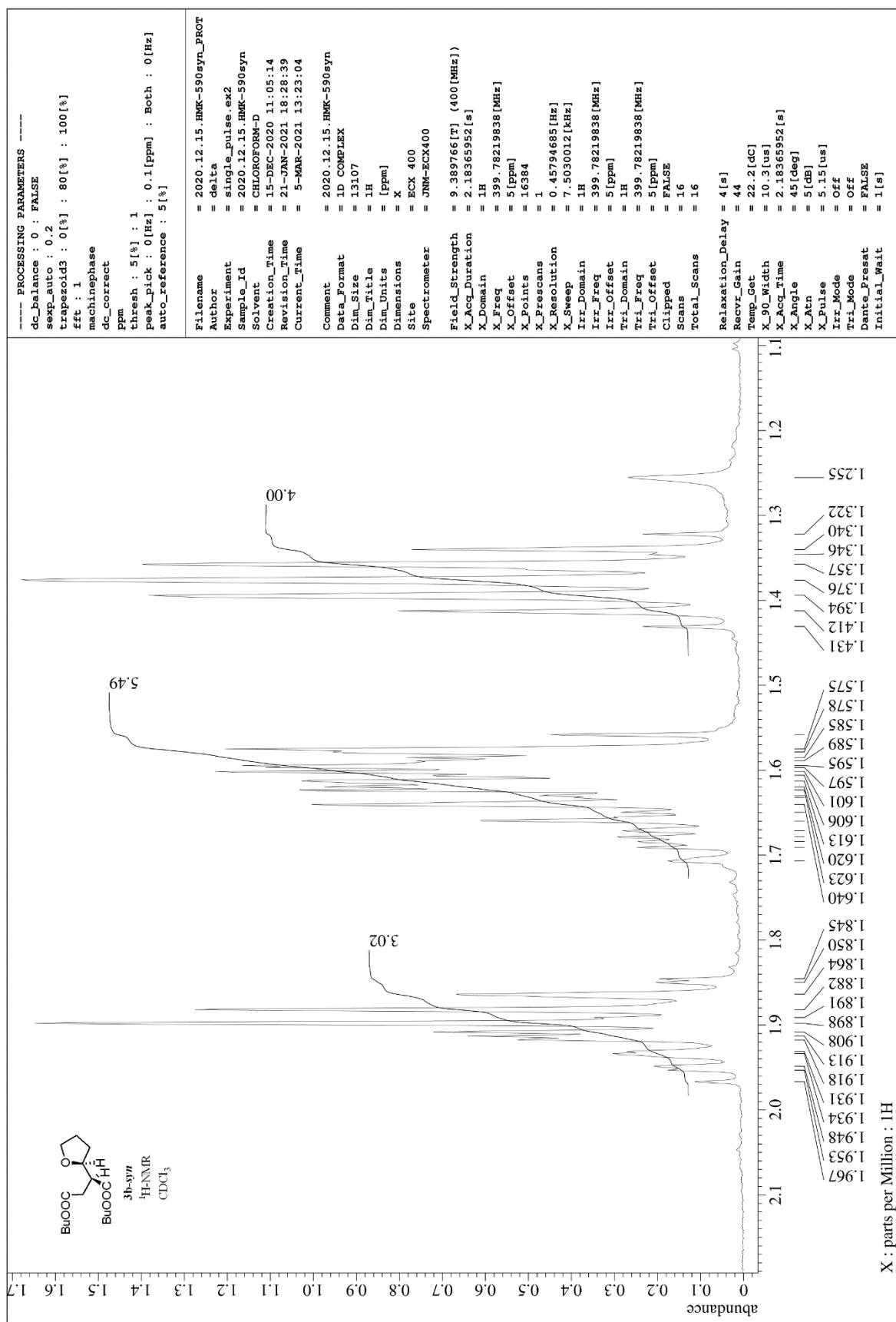
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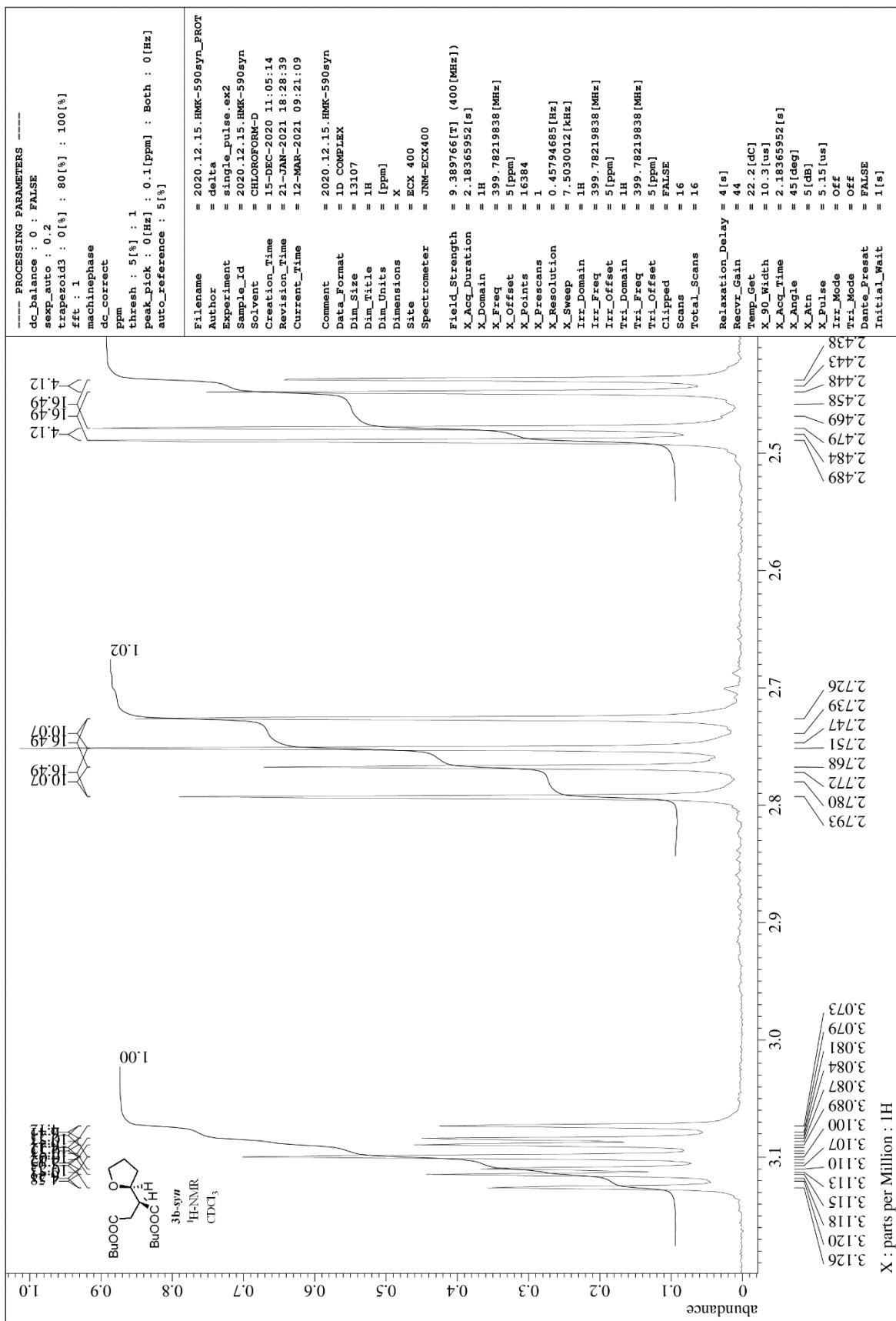
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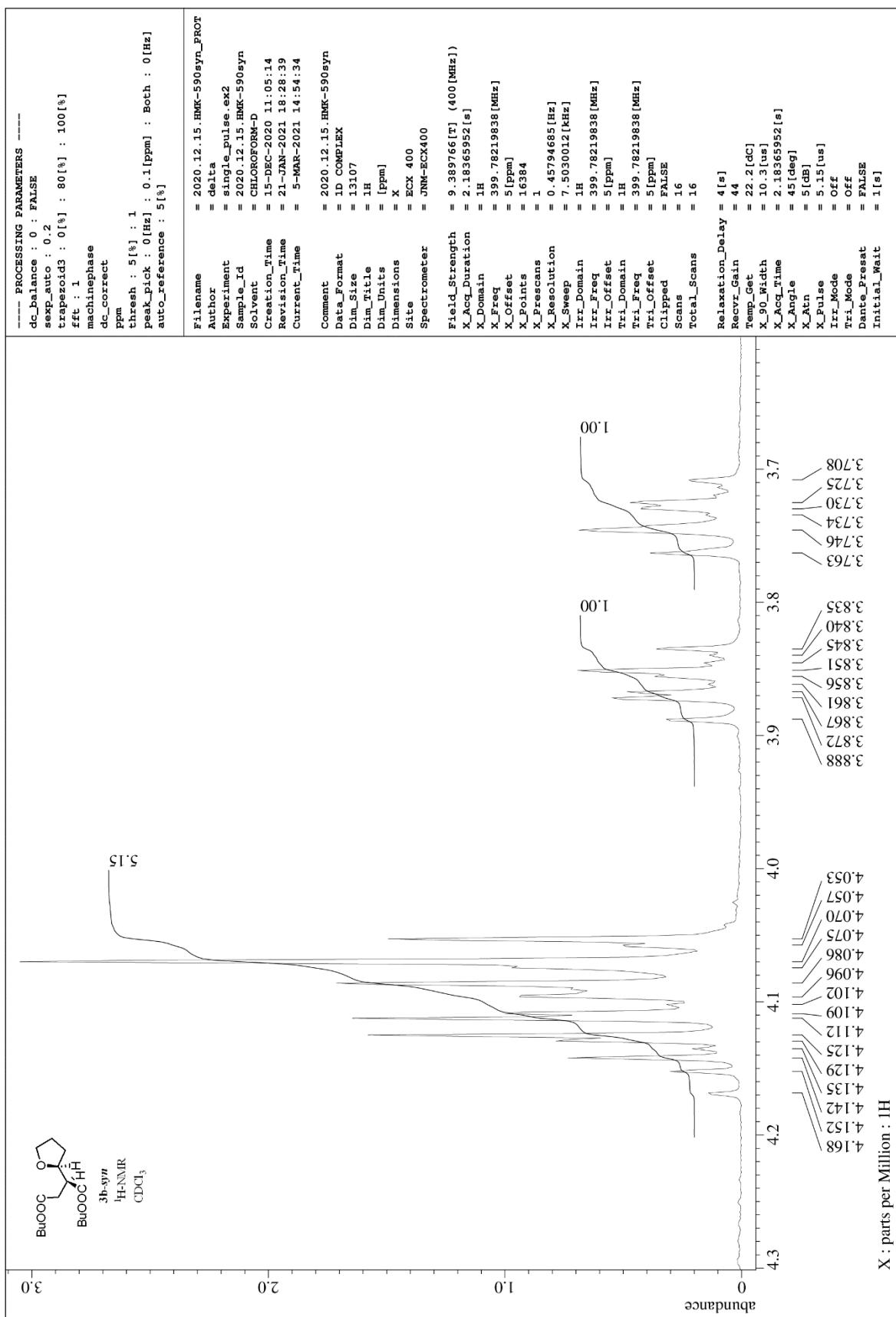
- S4. Stable conformations were calculated by B3LYP/6-31++G(d,p) using Gaussian 16; Gaussian 16, Revision A.03, Frisch, M. J.; Trucks, G. W.; Schlegel, H. B.; Scuseria, G. E.; Robb, M. A.; Cheeseman, J. R.; Scalmani, G.; Barone, V.; Petersson, G. A.; Nakatsuji, H.; Li, X.; Caricato, M.; Marenich, A. V.; Bloino, J.; Janesko, B. G.; Gomperts, R.; Mennucci, B.; Hratchian, H. P.; Ortiz, J. V.; Izmaylov, A. F.; Sonnenberg, J. L.; Williams-Young, D.; Ding, F.; Lipparini, F.; Egidi, F.; Goings, J.; Peng, B.; Petrone, A.; Henderson, T.; Ranasinghe, D.; Zakrzewski, V. G.; Gao, J.; Rega, N.; Zheng, G.; Liang, W.; Hada, M.; Ehara, M.; Toyota, K.; Fukuda, R.; Hasegawa, J.; Ishida, M.; Nakajima, T.; Honda, Y.; Kitao, O.; Nakai, H.; Vreven, T.; Throssell, K.; Montgomery, J. A., Jr.; Peralta, J. E.; Ogliaro, F.; Bearpark, M. J.; Heyd, J. J.; Brothers, E. N.; Kudin, K. N.; Staroverov, V. N.; Keith, T. A.; Kobayashi, R.; Normand, J.; Raghavachari, K.; Rendell, A. P.; Burant, J. C.; Iyengar, S. S.; Tomasi, J.; Cossi, M.; Millam, J. M.; Klene, M.; Adamo, C.; Cammi, R.; Ochterski, J. W.; Martin, R. L.; Morokuma, K.; Farkas, O.; Foresman, J. B.; Fox, D. J. Gaussian, Inc., Wallingford CT, 2016.
- S5. Graphics were prepared using GausView 6; GaussView, Version 6, Dennington, Roy; Keith, Todd A.; Millam, John M. Semichem Inc., Shawnee Mission, KS, 2016.

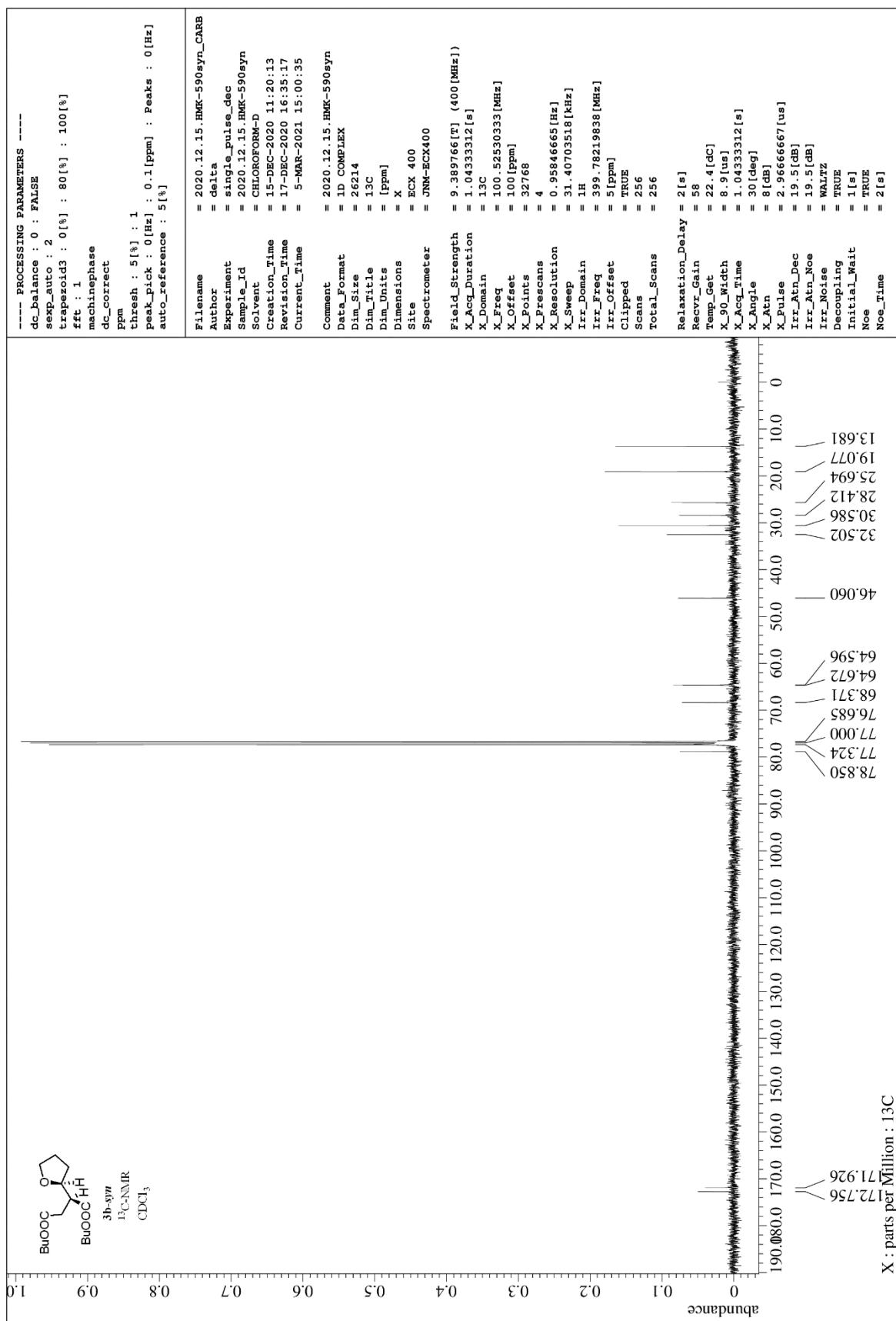
3. ^1H -NMR and ^{13}C -NMR spectra.

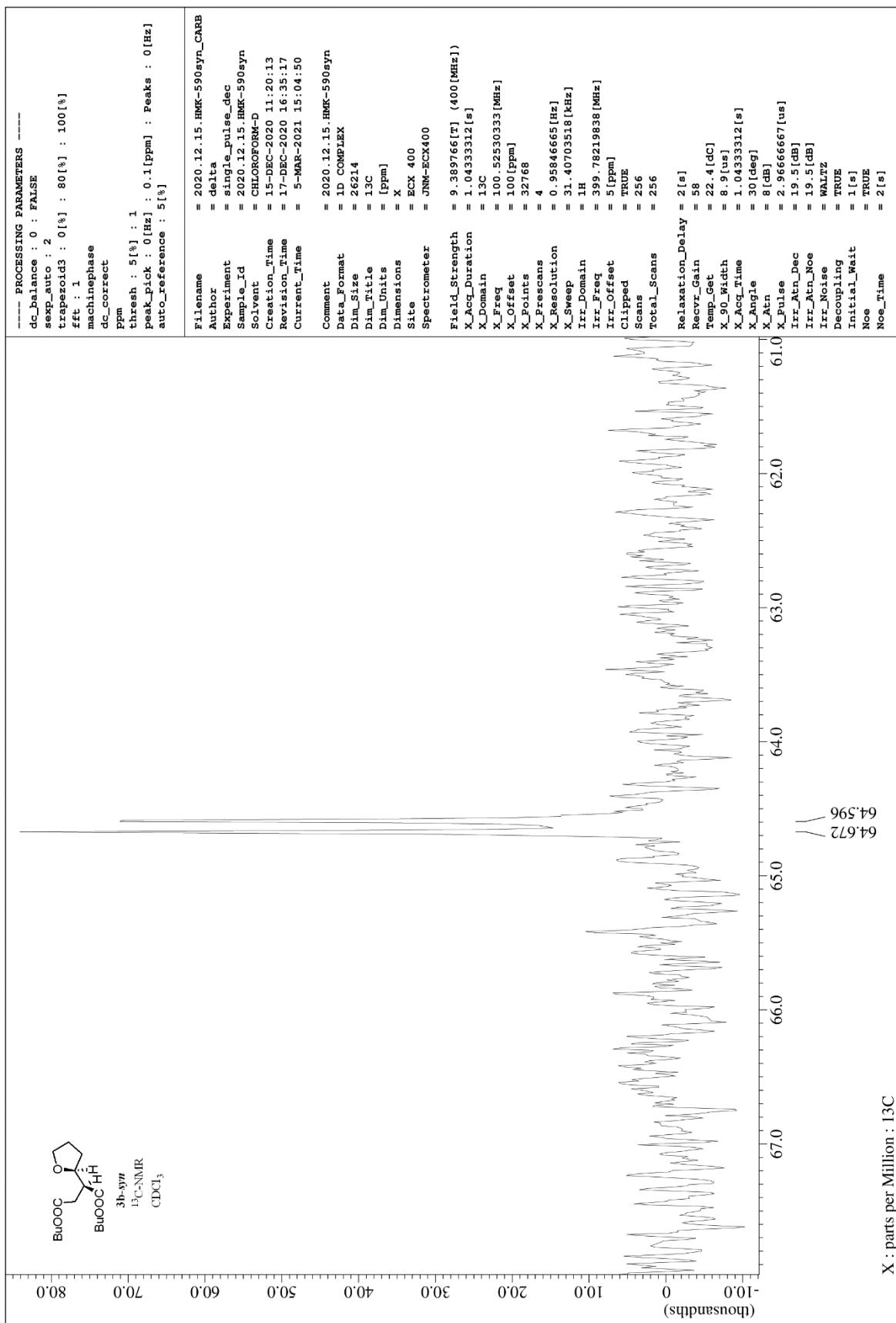


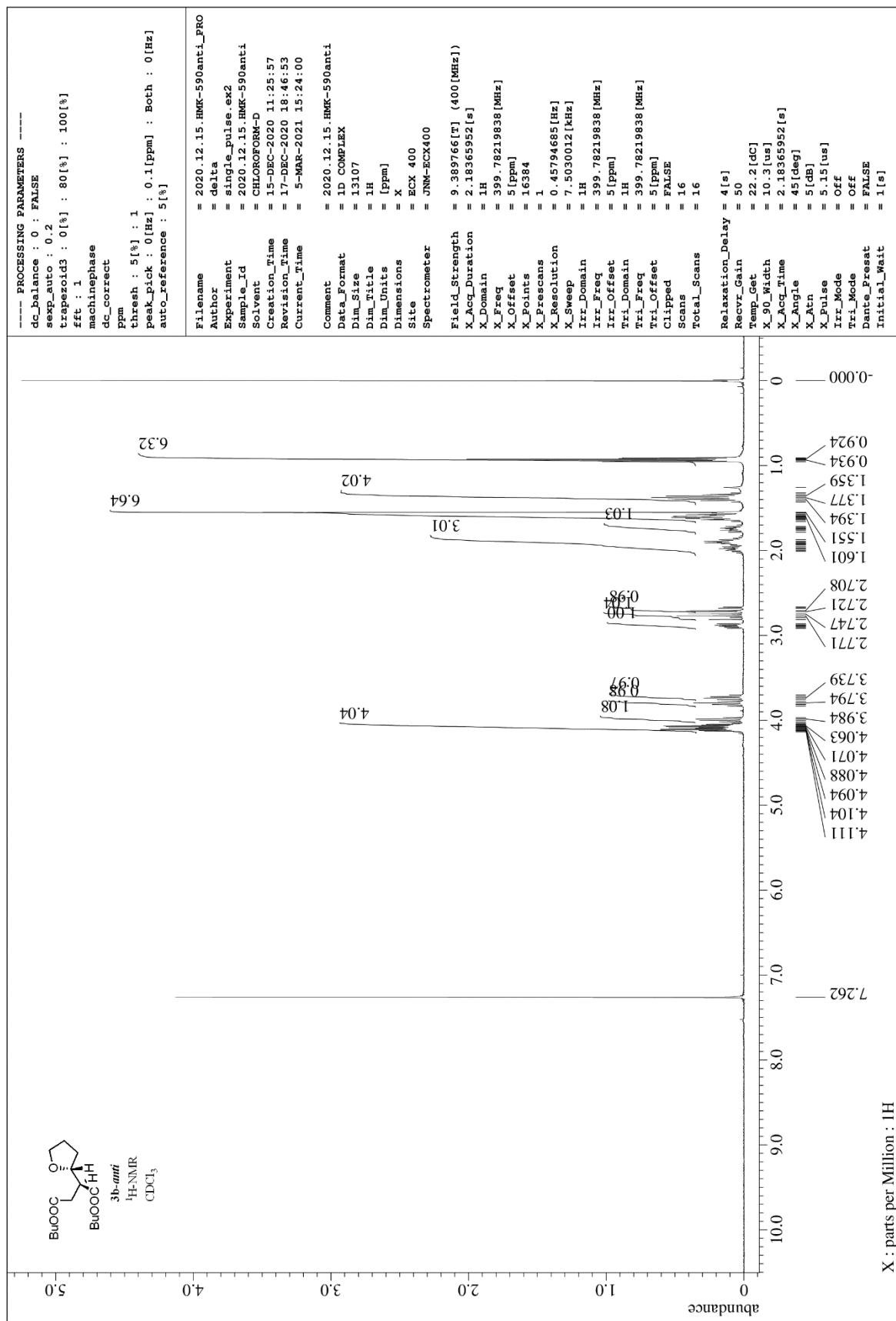


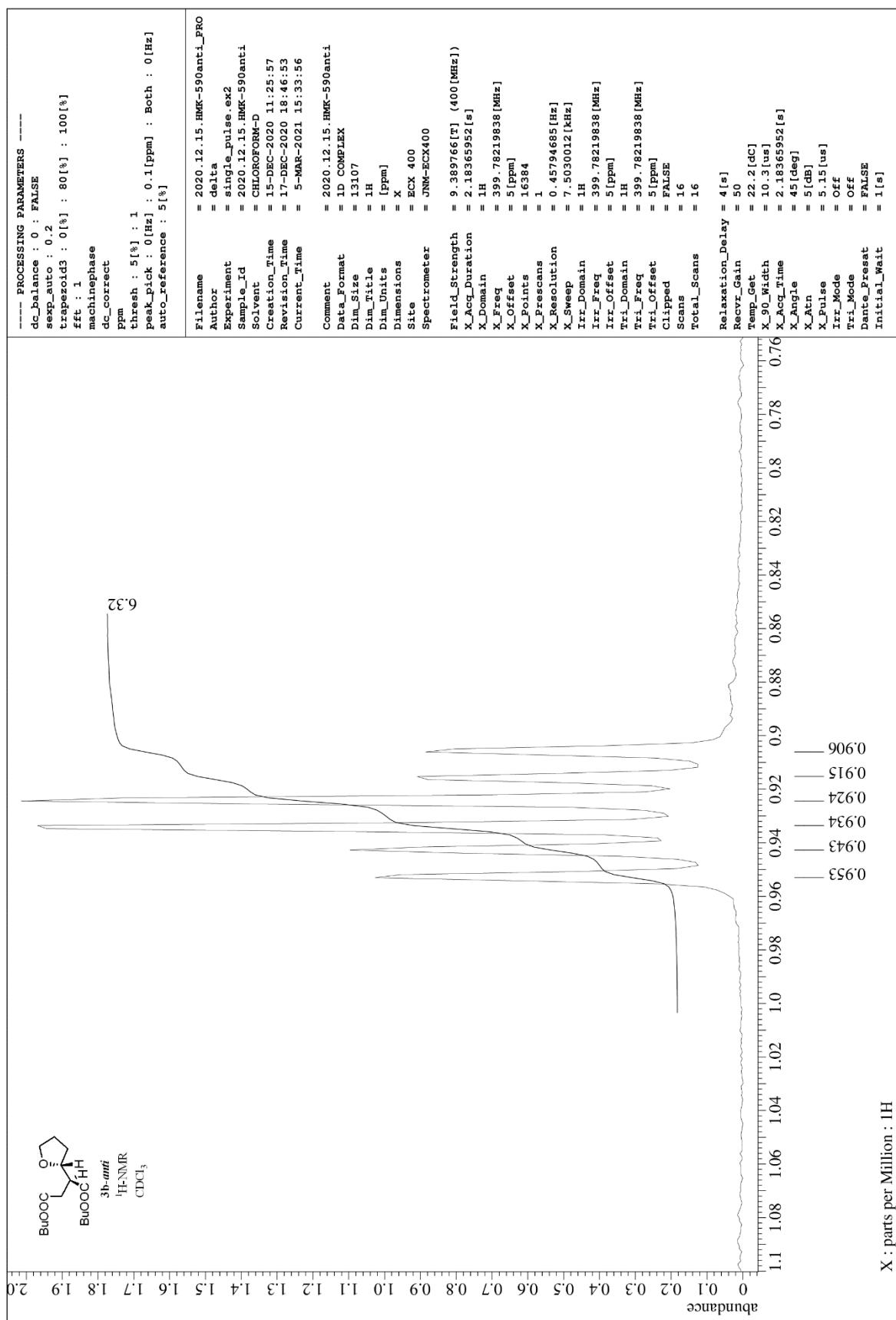


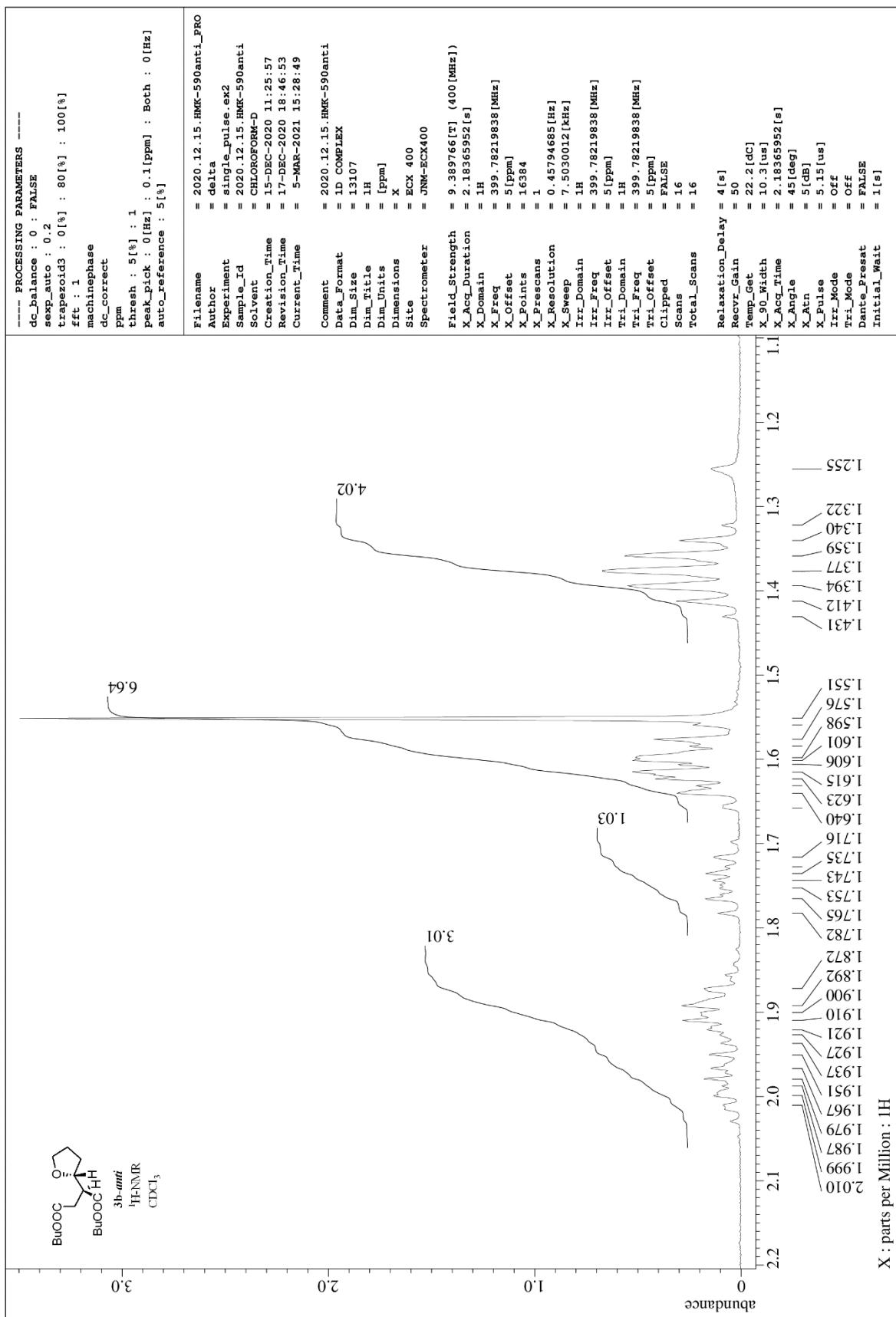


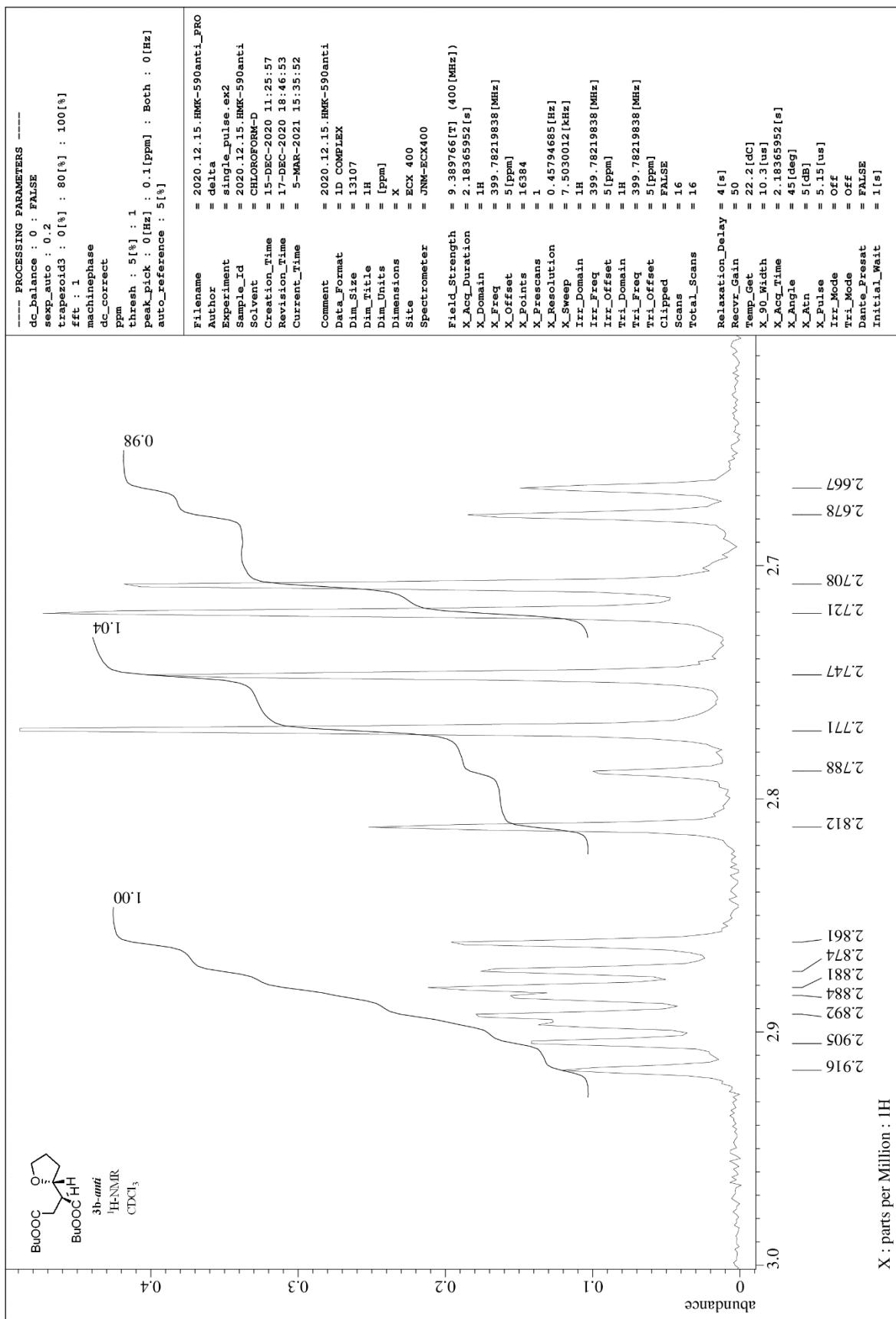


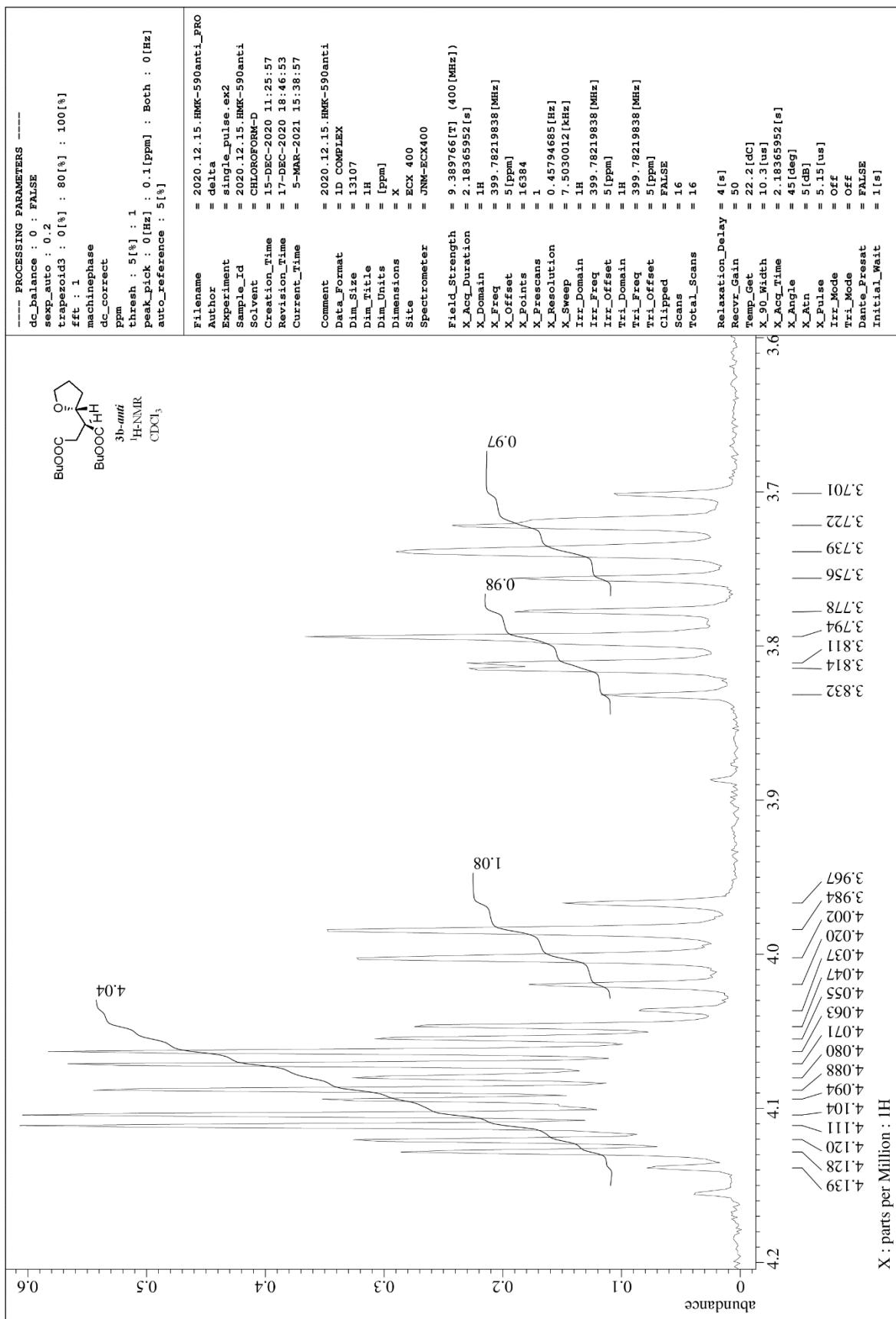


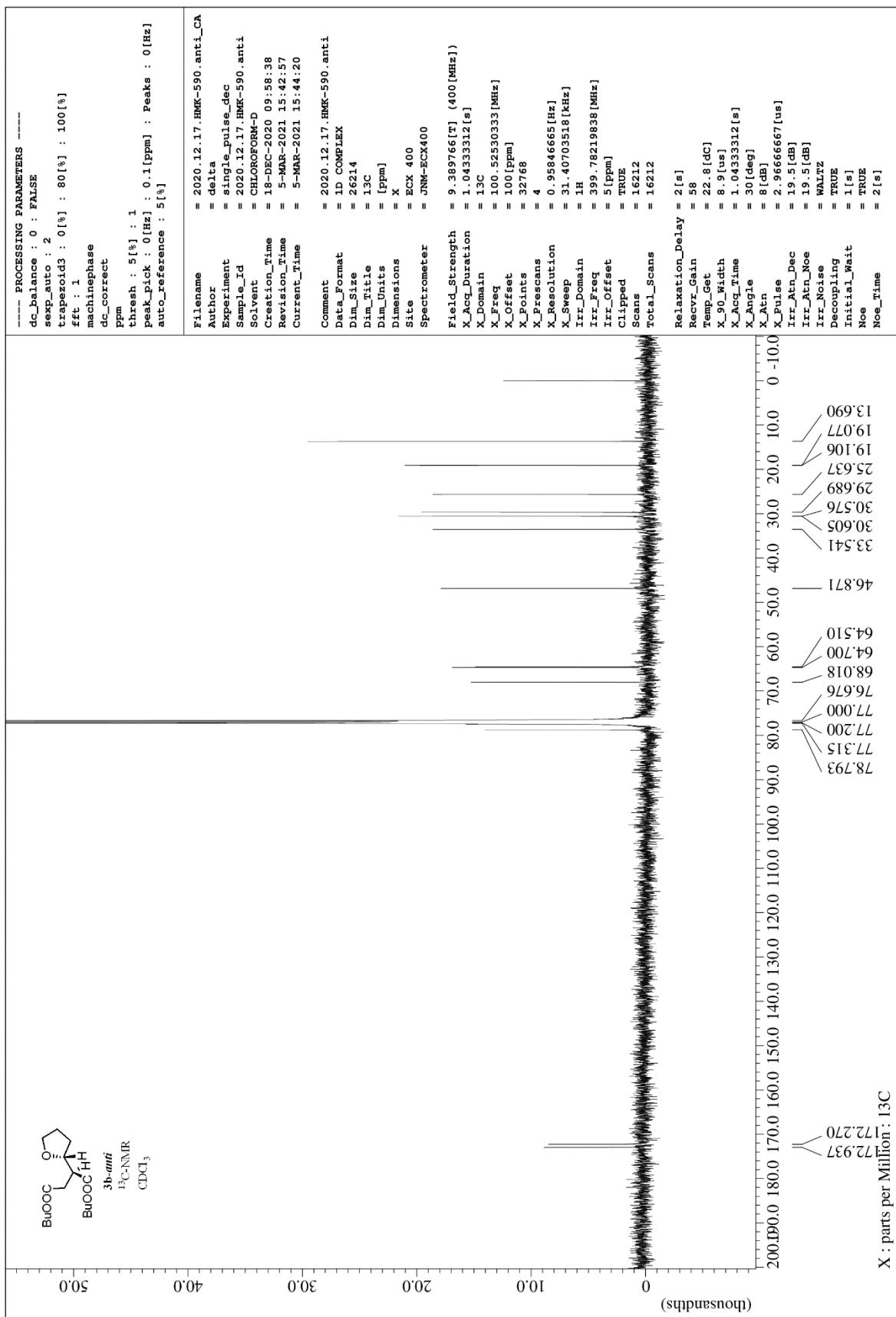


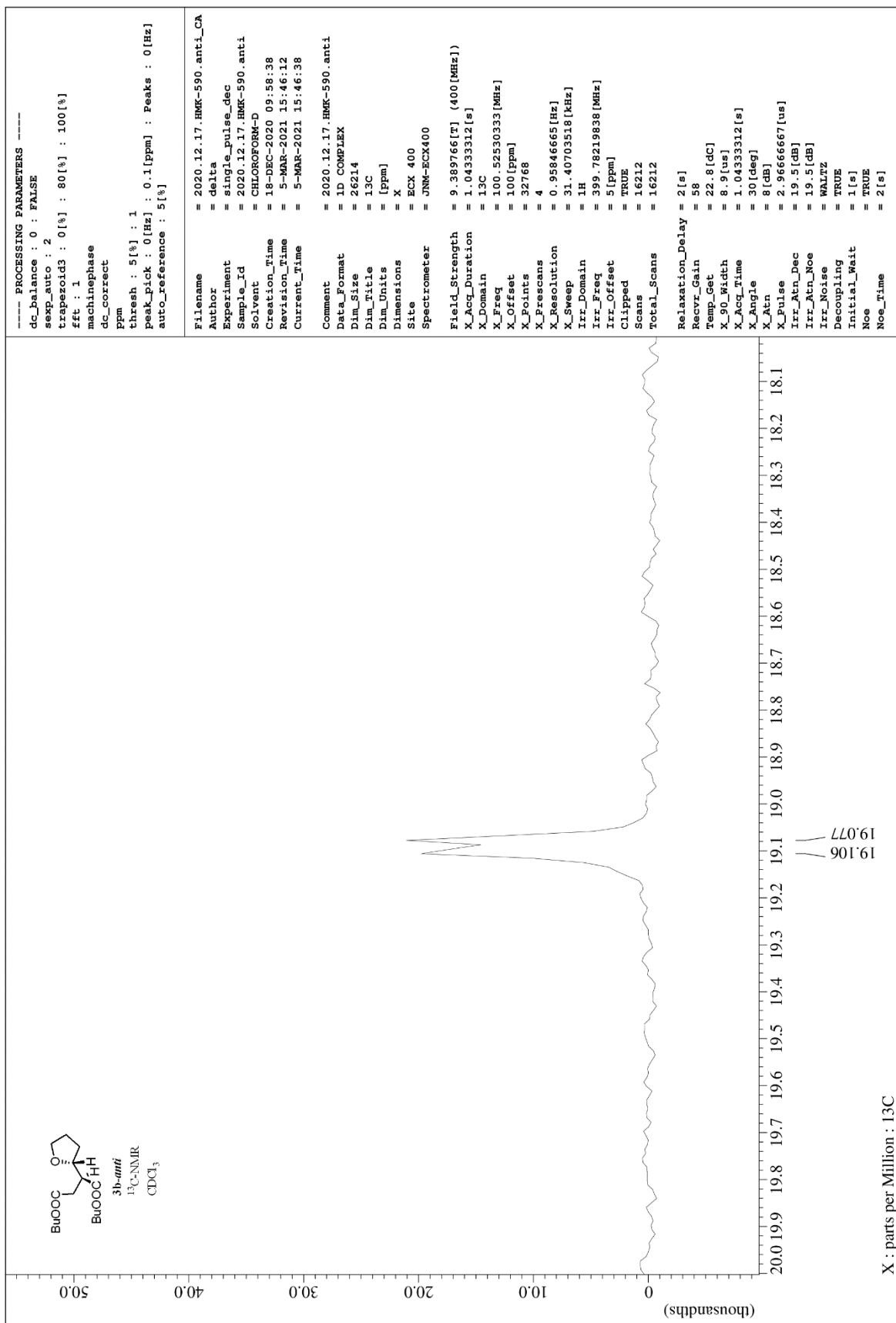


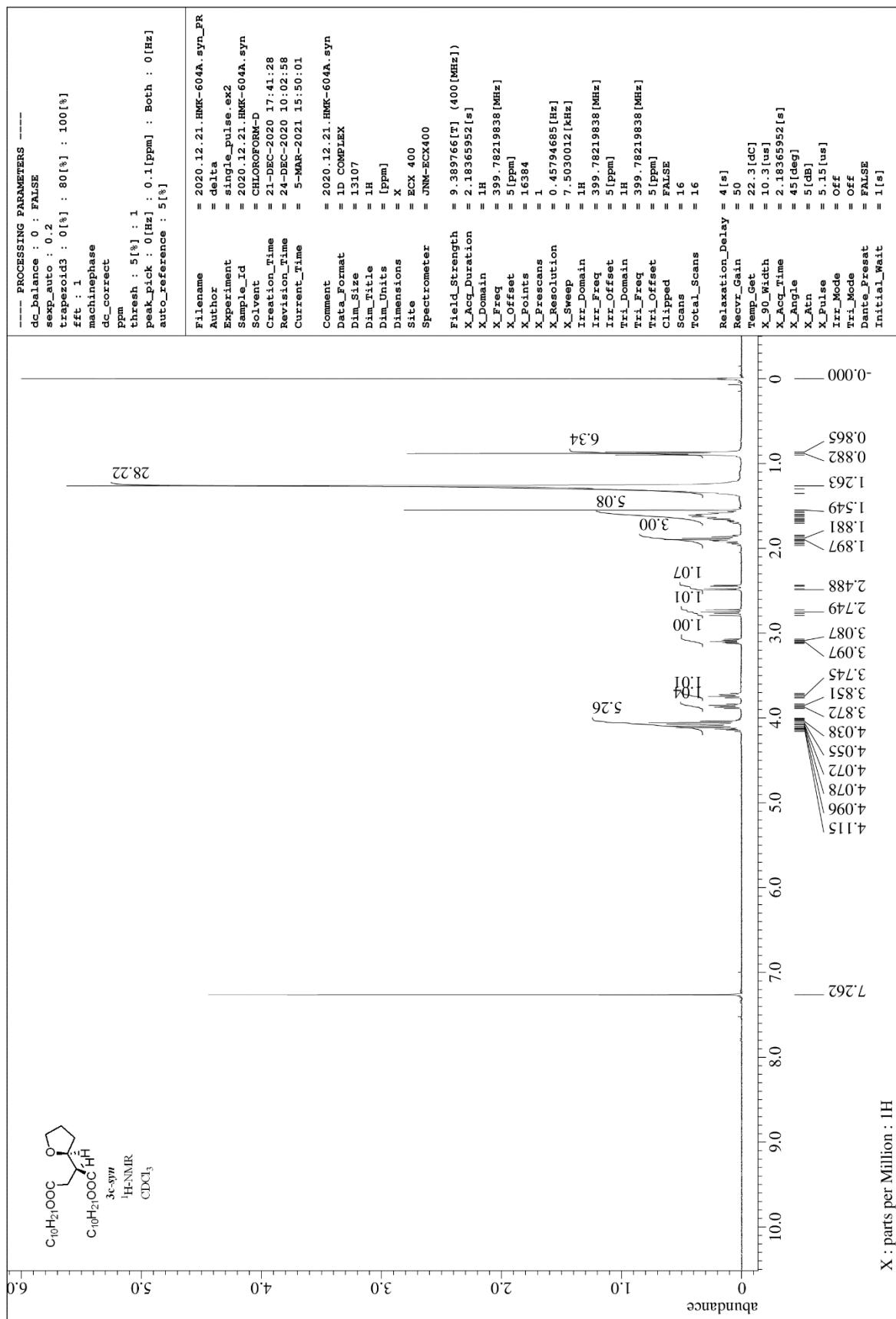


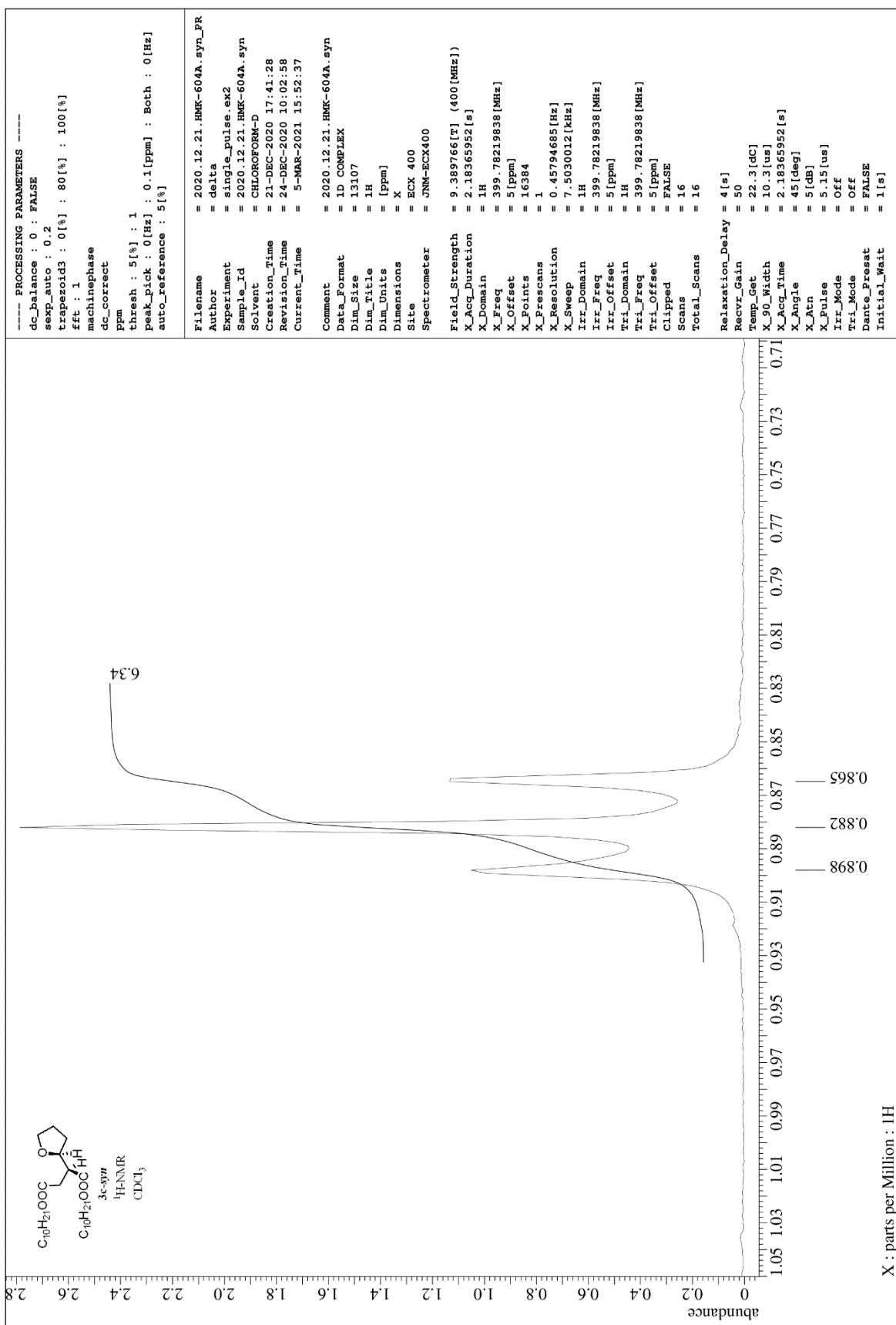


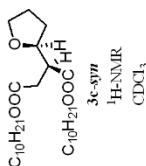












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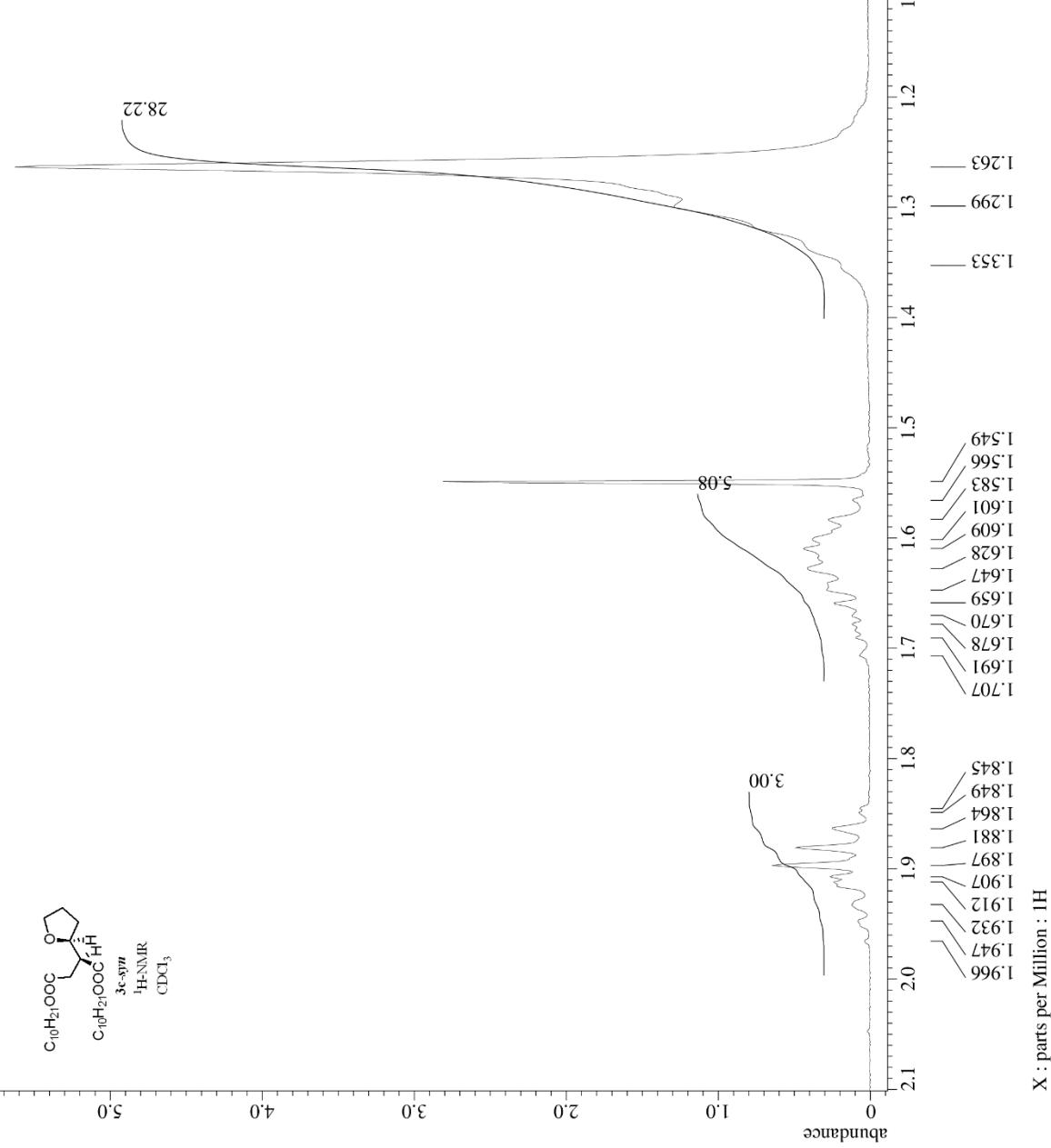
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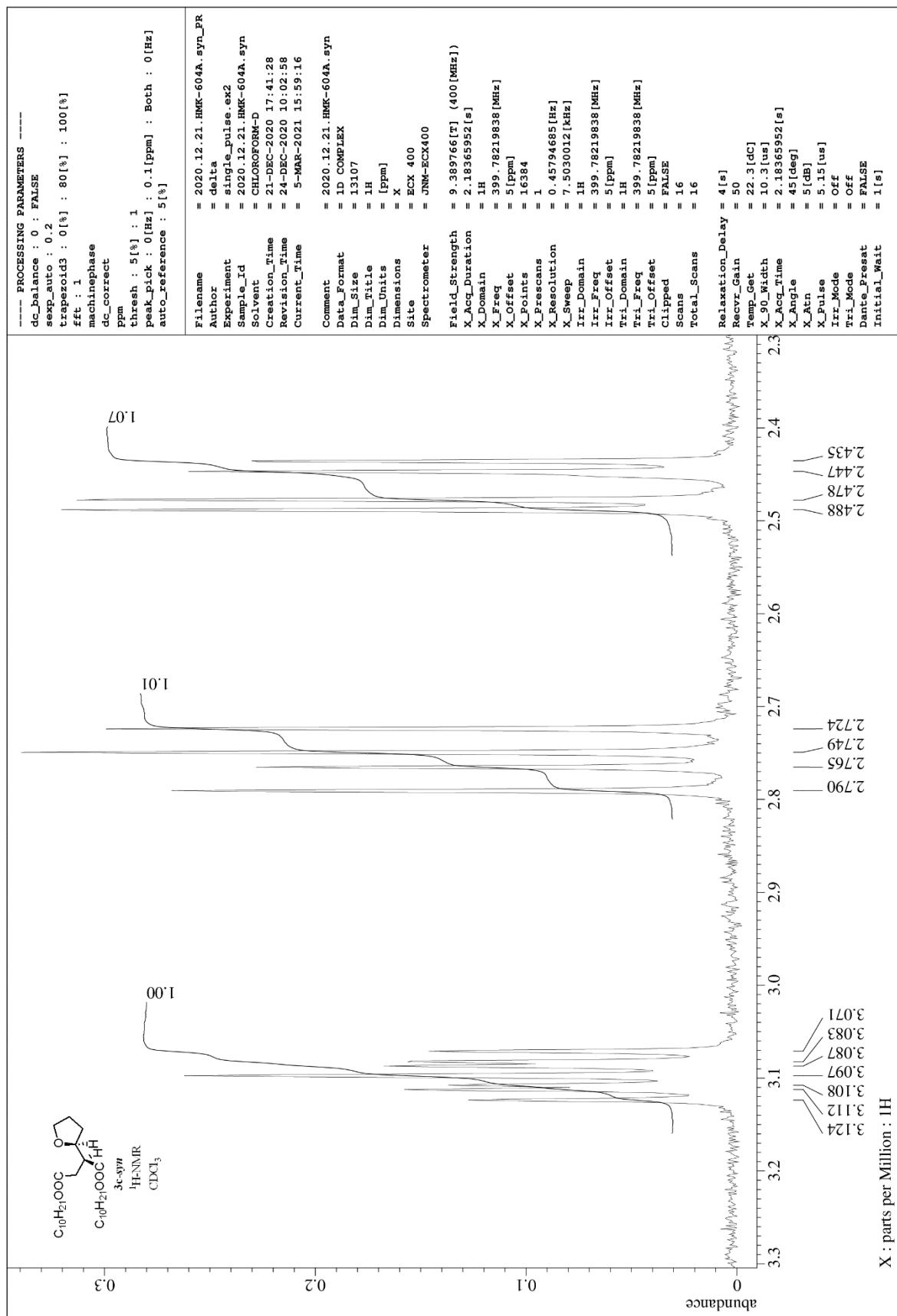
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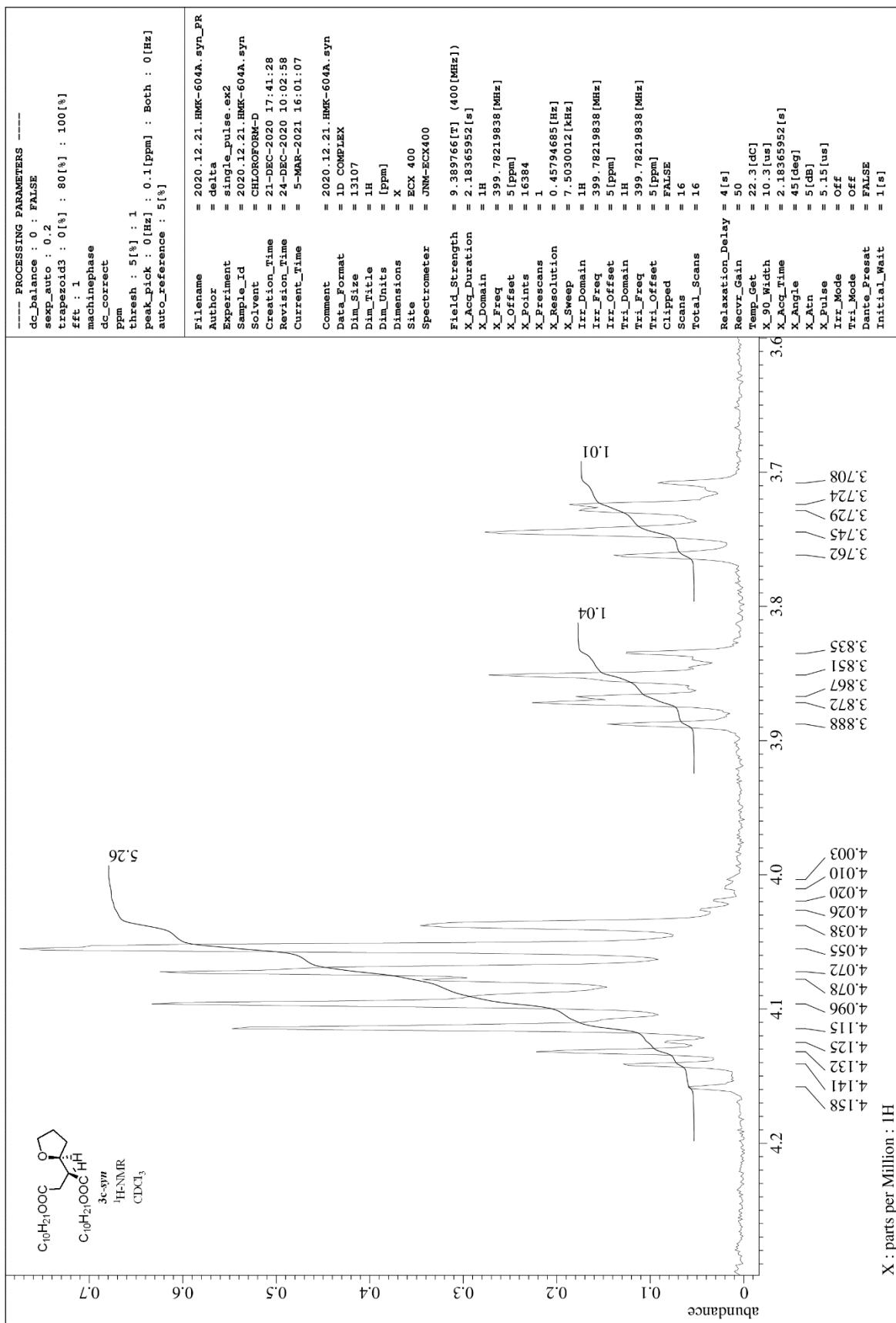
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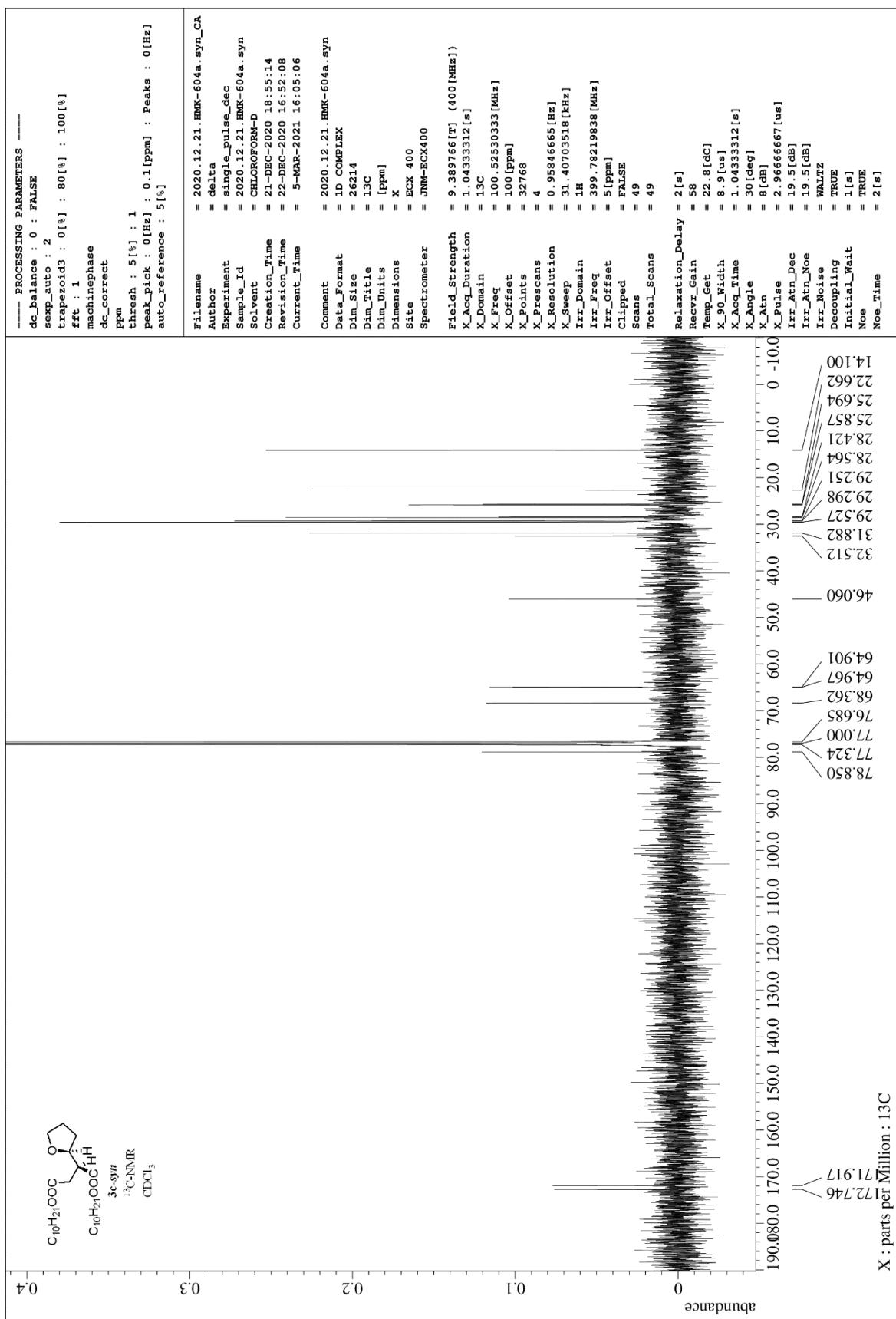
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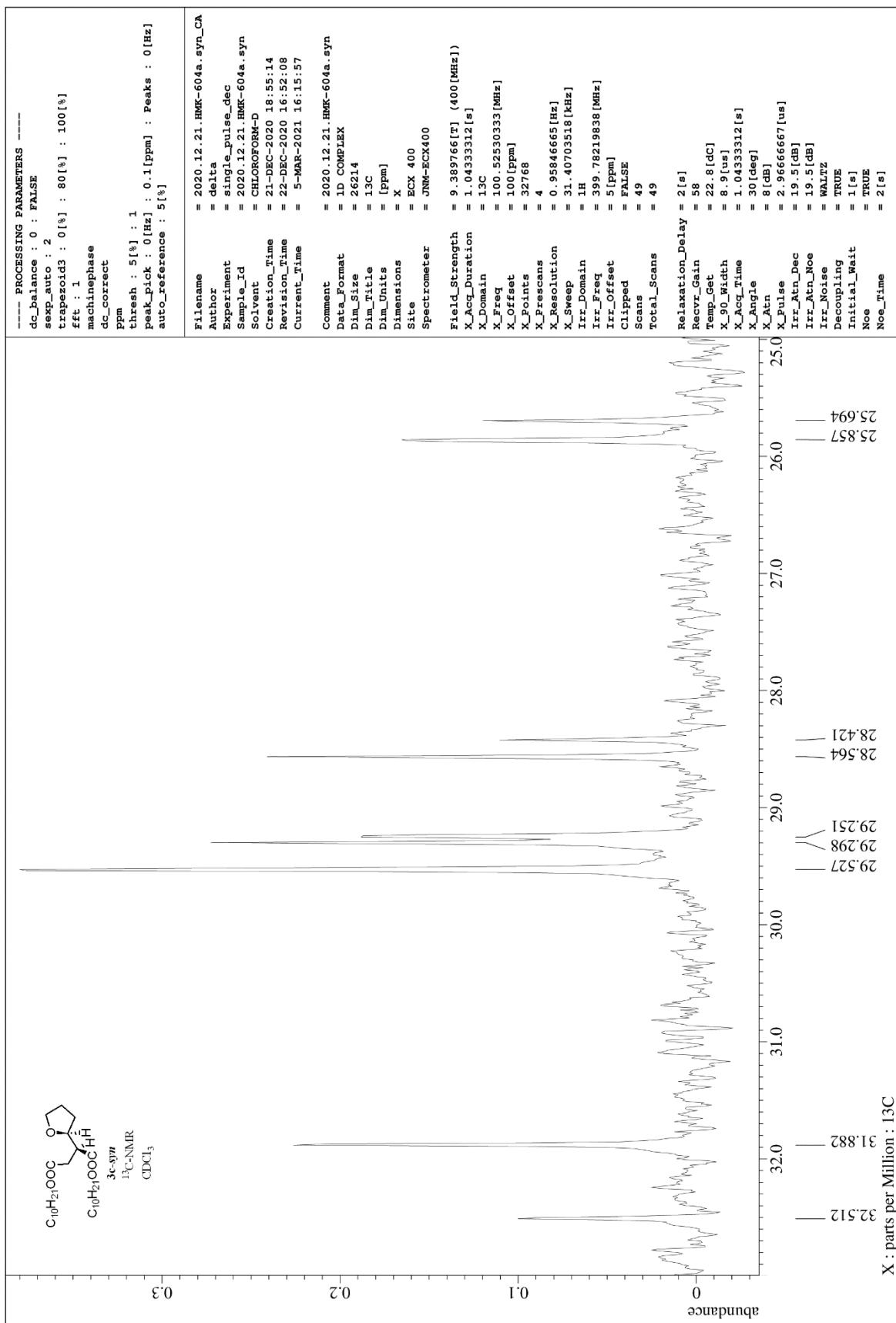
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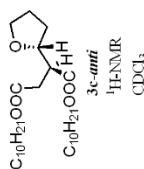












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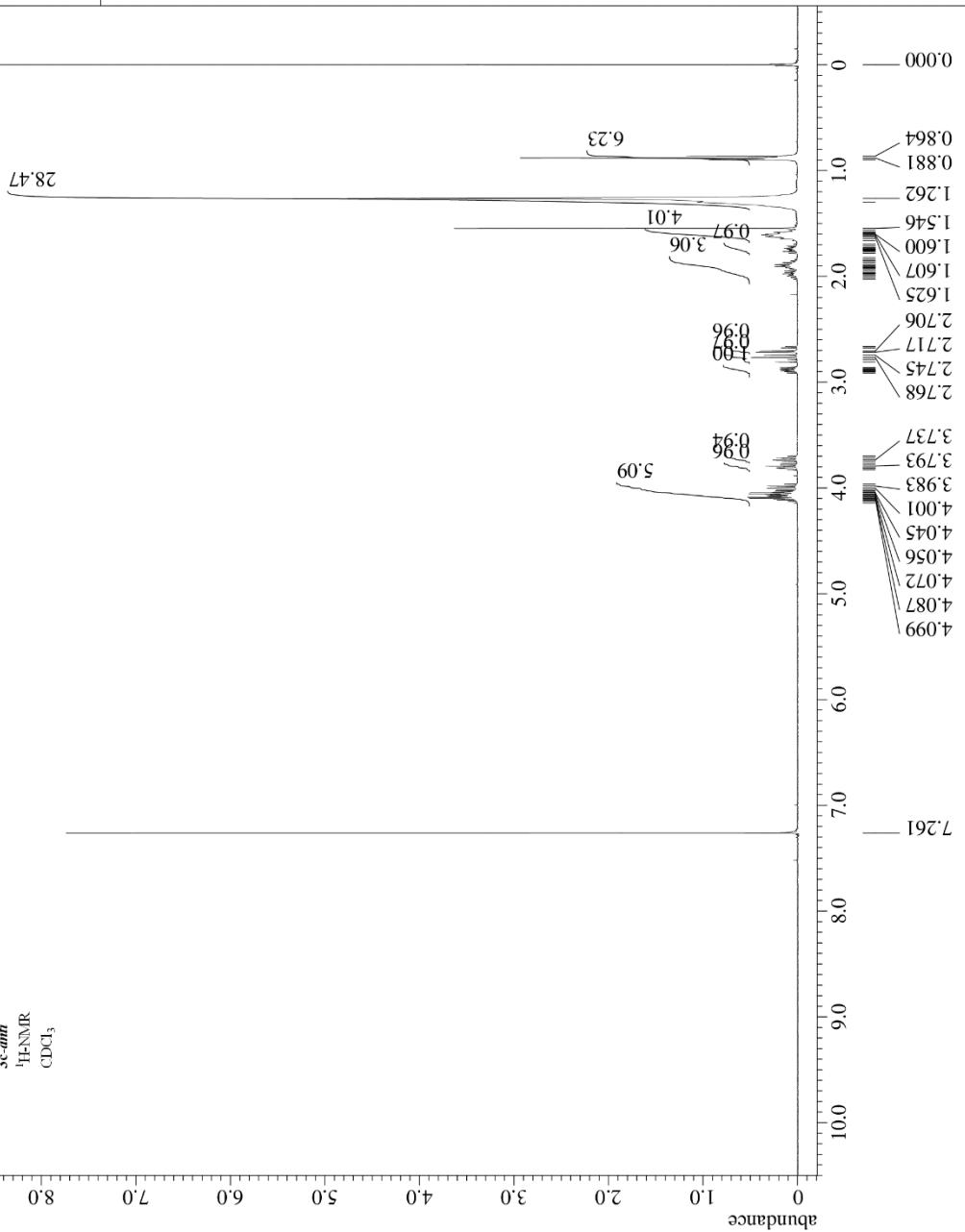
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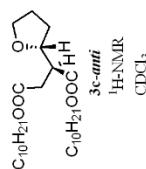
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X_Angle = 45 [deg]
X_Atn = 5 [dB]
X_Pulse = 5.15 [us]
Irr_Mode = OFF
Tri_Mode = OFF
Dante_Presat = FALSE
Initial_Wait = 1 [s]

```





6.23

C10H21OOC[C@H]2CC[C@H](C[C@H]2C(=O)O)C1
3c-anti
¹H-NMR
CDCl₃

```

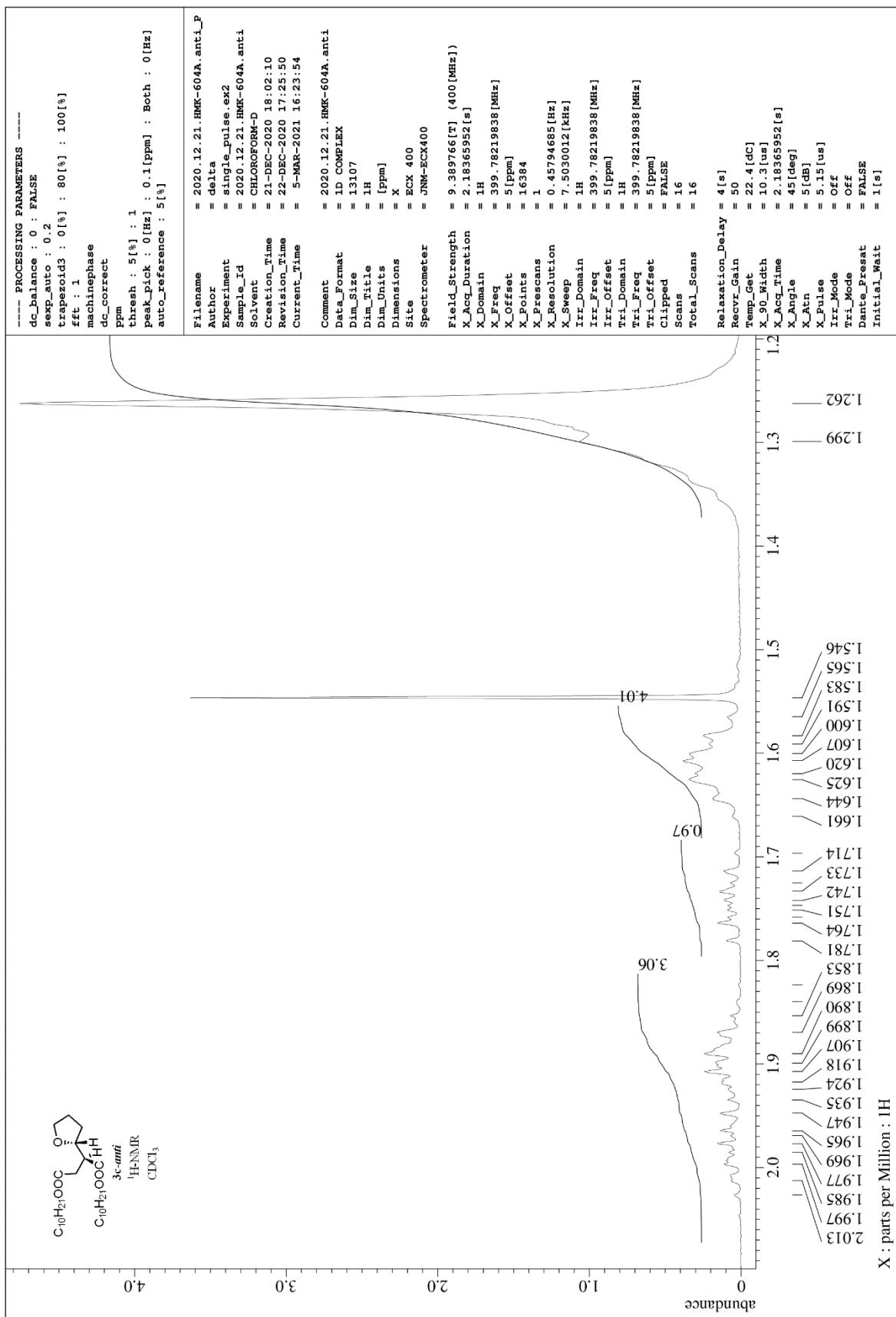
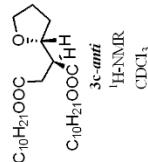
----- PROCESSING PARAMETERS -----
dc_balance : 0 : FALSE
sep_auto : 0.2
trapezoid3 : 0[%] : 80[%] : 100[%]
fft : 1
machinephase
dc_correct
Ppm
thresh : 5[%] : 1
peak_pick : 0[Hz] : 0.1[ppm] : Both : 0[Hz]
auto_reference : 5[%]

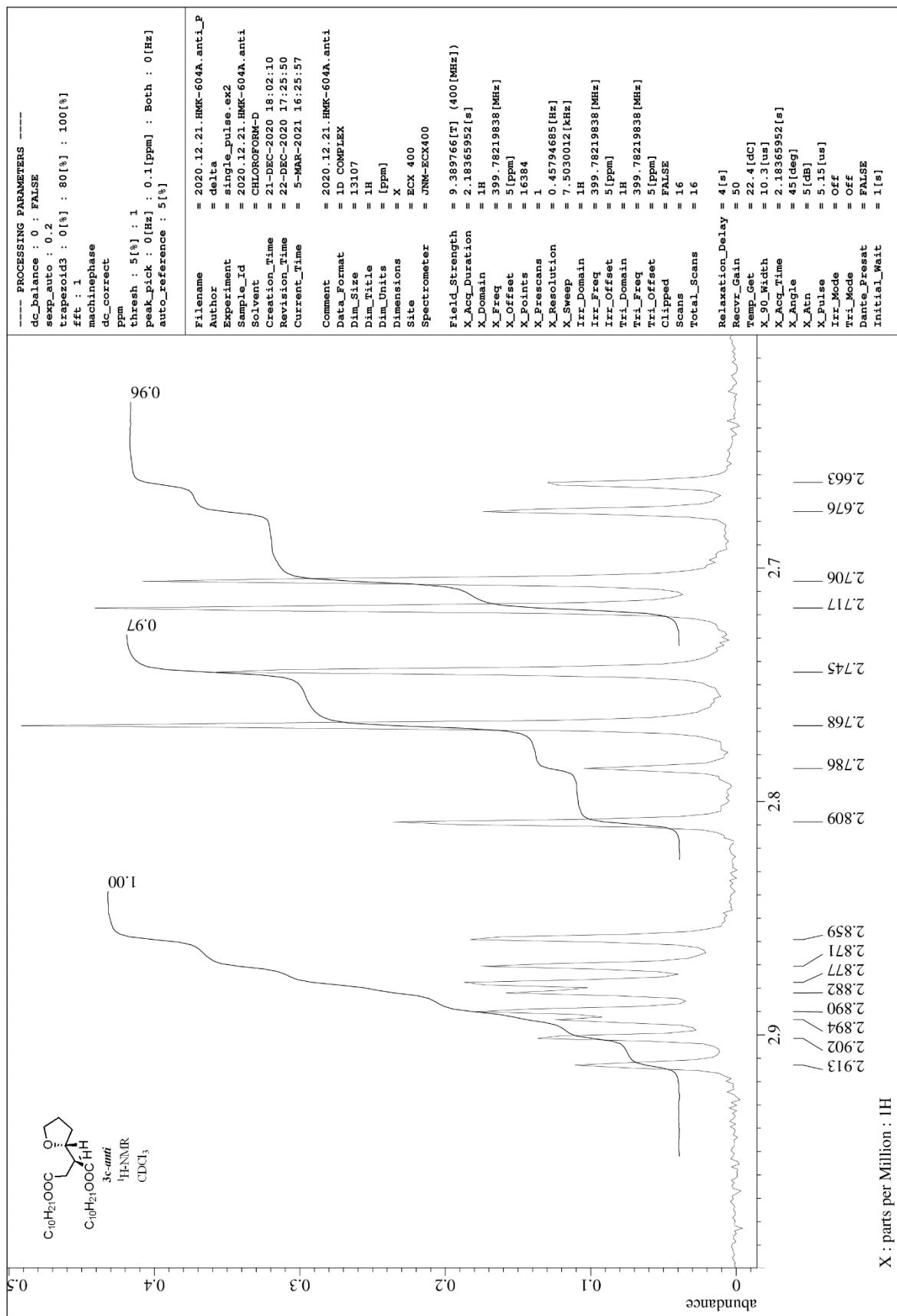
----- FILENAMES -----
Filename = 2020.12.21.HMK-604A.ant1_
Author = delta
Experiment = single-pulse.ex2
Sample_Id = 2020.12.21.HMK-604A.ant1
Solvent = CHLOROFORM-D
Creation_Time = 21-DEC-2020 18:02:10
Revision_Time = 22-DEC-2020 17:25:50
Current_Time = 5-MAR-2021 16:22:02
Comment = 2020.12.21.HMK-604A.ant1
Data_Format = 1D COMPLEX
Dim_Size = 13107
Dim_Title = 1H
Dim_Units = [ppm]
Dimensions = X
Site = ECX 400
Spectrometer = JNM-ECK400

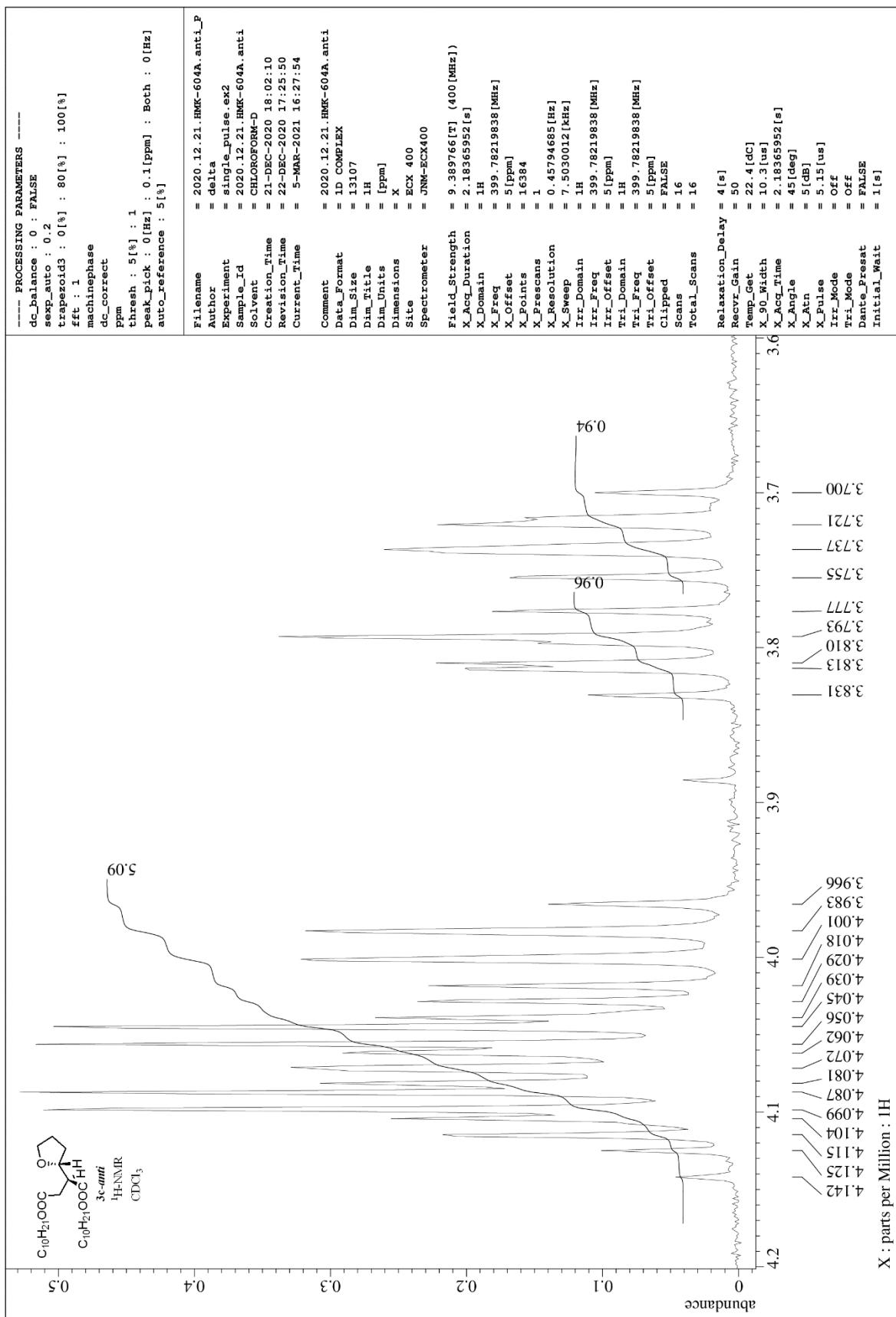
----- FIELD, STRENGTH -----
Field_Strength = 9.389766 [T] (400 [MHz])
X_Acq_Duration = 2.1833695 [s]
X_Domain = 1H
X_Freq = 399.78219838 [MHz]
X_Offset = 5 [ppm]
X_Points = 16384
X_Prescans = 1
X_Resolution = 0.45794685 [Hz]
X_Sweep = 7.5030012 [kHz]
Irr_Domain = 1H
Irr_Freq = 399.78219838 [MHz]
Irr_Offset = 5 [ppm]
Tri_Domain = 1H
Tri_Freq = 399.78219838 [MHz]
Tri_Offset = 5 [ppm]
Clipped = FALSE
Scans = 16
Total_Scans = 16

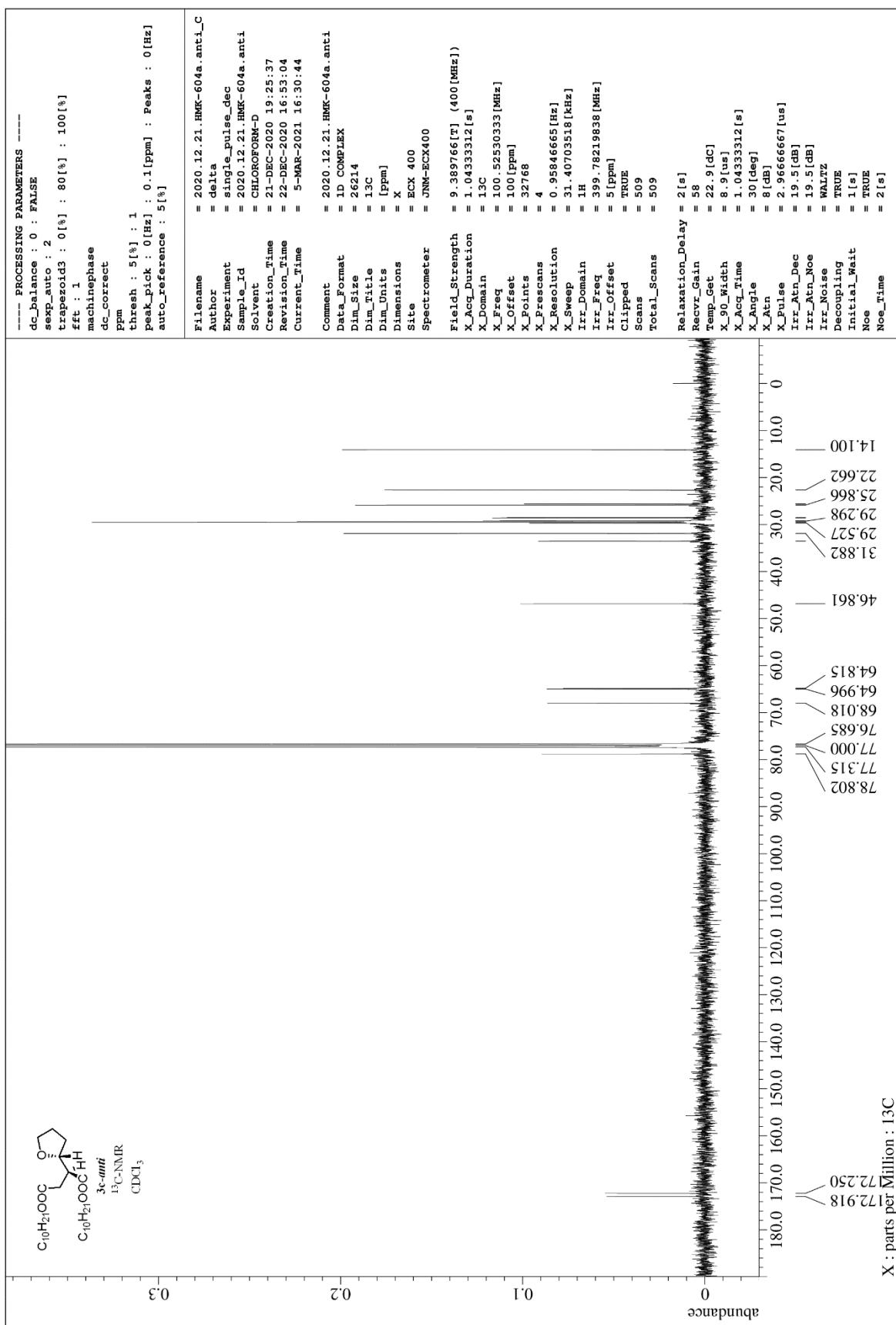
----- RELAXATION -----
Relaxation_Delay = 4 [s]
Recv_Gain = 50
Temp_Get = 22.4 [dc]
X_90_Width = 10.3 [us]
X_Acc_Time = 2.1336952 [s]
X_Angle = 45 [deg]
X_Atn = 5 [dB]
X_Pulse = 5.15 [us]
Irr_Mode = Off
Tri_Mode = Off
Dante_Presat = FALSE
Initial_Wait = 1 [s]

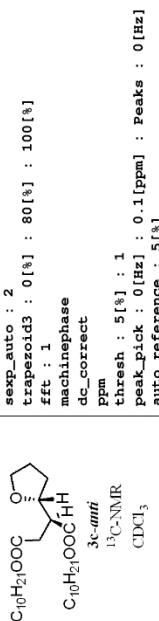
```











----- PROCESSING PARAMETERS -----

dc_balance : 0	: FALSE	
sexp_auto : 2		
trapezoid : 0 [%]	: 80 [%]	: 100 [%]
fft : 1		
machinephase		
dc_correct		
Fppm		
thresh : 5 [%]	: 1	
peak_pick : 0 [Hz]	: 0.1 [ppm]	: Peaks : 0 [Hz]
auto_reference : 5 [%]		
Filename	= 2020.12.21.HMK-604a.ant.i_C	
Author	= delta	
Experiment	= single_pulse_dec	
Sample_Id	= 2020.12.21.HMK-604a.ant.i	
Solvent	= CHLOROFORM-D	
Creation_Time	= 21-DEC-2020 19:25:37	
Revision_Time	= 5-MAR-2021 16:33:12	
Current_Time	= 5-MAR-2021 16:33:33	
Comment	= 2020.12.21.HMK-604a.ant.i	
Data_Format	= 1D COMPLEX	
Dim_Size	= 26214	
Dim_Title	= 13C	
Dim_Units	= [ppm]	
Dimensions	= X	
Site	= ECX-ECK400	
Spectrometer	= JNM-ECK400	
Field_Strength	= 9.389766 [T] (400 [MHz])	
X_Acq_Duration	= 1.04933312 [s]	
X_Domain	= 13C	
X_Freq	= 100.52530333 [MHz]	
X_Offset	= 100 [ppm]	
X_Points	= 32768	
X_Prescans	= 4	
X_Resolution	= 0.95846665 [Hz]	
X_Sweep	= 31.40703518 [kHz]	
Irr_Domain	= 1H	
Irr_Freq	= 399.78219838 [MHz]	
Irr_Offset	= 5 [ppm]	
Clipped	= TRUE	
Scans	= 509	
Total_Scans	= 509	
Relaxation_Delay	= 2 [s]	
Recvr_Gain	= 58	
Temp_Get	= 22.9 [dC]	
X_R0_Width	= 8.9 [us]	
X_Acq_Time	= 1.0433312 [s]	
X_Angle	= 30 [deg]	
X_Atn	= 8 [dB]	
X_Pulse	= 2.9666667 [us]	
Irr_Atn_Dec	= 19.5 [dB]	
Irr_Atn_Neg	= 19.5 [dB]	
Irr_Noise	= WALTZ	
Decoupling	= TRUE	
Initial_Wait	= 1 [s]	
Noe	= TRUE	
Noe_Time	= 2 [s]	

