

國立臺灣師範大學化學系

碩士學位論文

Department of Chemistry, National Taiwan Normal
University Master's Thesis

利用一價銨金屬催化芳基格任納試劑進行 1,4-位移
與具有高鏡相選擇性之去對稱化反應

Rhodium-Catalyzed Enantioselective
Desymmetrization of
2-(1,5-Dialkoxypent-3-yl) Phenyl Grignard
Reagents by 1,4-Shift

研究生：陳奕璇

Author: Yi-Hsuan Chen

指導教授：吳學亮 博士

Advisor: Dr. Hsyueh-Liang Wu

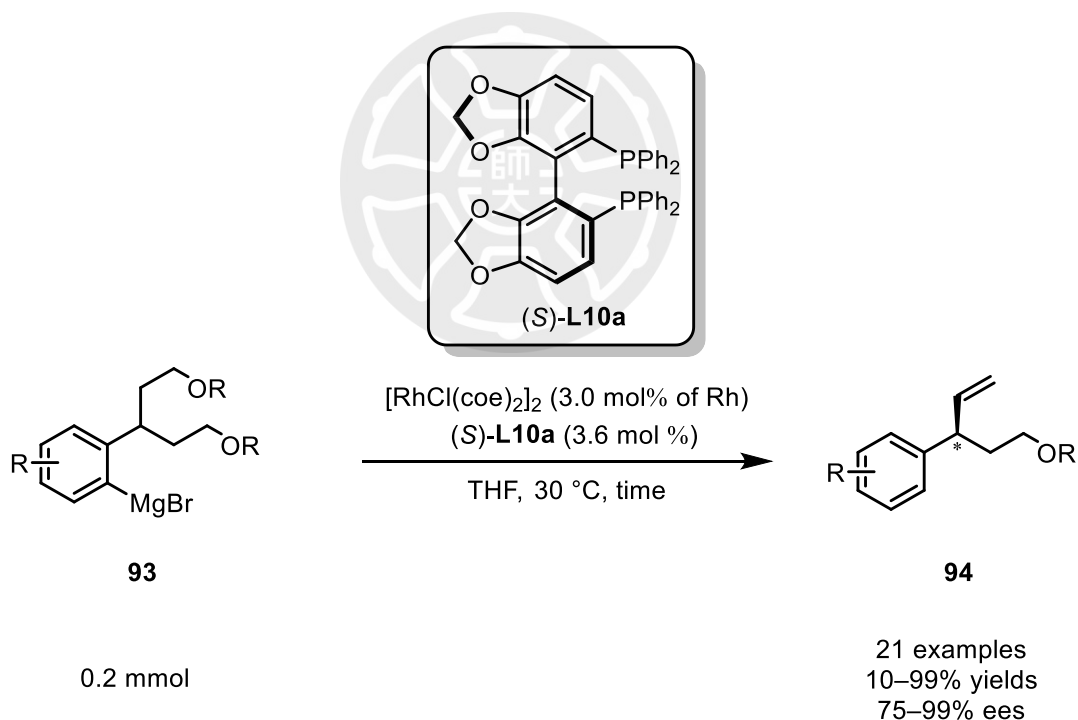
中華民國一十二年七月

July, 2023

中文摘要

本論文研究主題為探討使用一價銨金屬以及雙膦配基(*S*)-**L10a** 形成之催化劑，於溫度 30 °C 下，進行芳基格任亞試劑 **93** 分子內去對稱化反應。其經由銨金屬的 1,4-轉移及 β -烷氧基脫去反應生成掌性含末端烯類化合物 **94**，有 21 個例子，其產率為 10-99%，鏡像選擇性介於 75%至 99%。此外，本文藉 3 個氫氙標記實驗深入探討其反應機構。

有別於大部分文獻探討銨金屬經 1,4-轉移後形成之中間體再進行加成反應的應用，本篇為透過銨金屬催化劑 1,4-轉移之特性進行分子內去對稱化反應，並首度達到銨金屬由芳基銨中間體轉移至烷基銨中間體並生成高產率及高鏡像選擇性之末端烯類化合物，在藥物及材料之合成開發有其運用性。

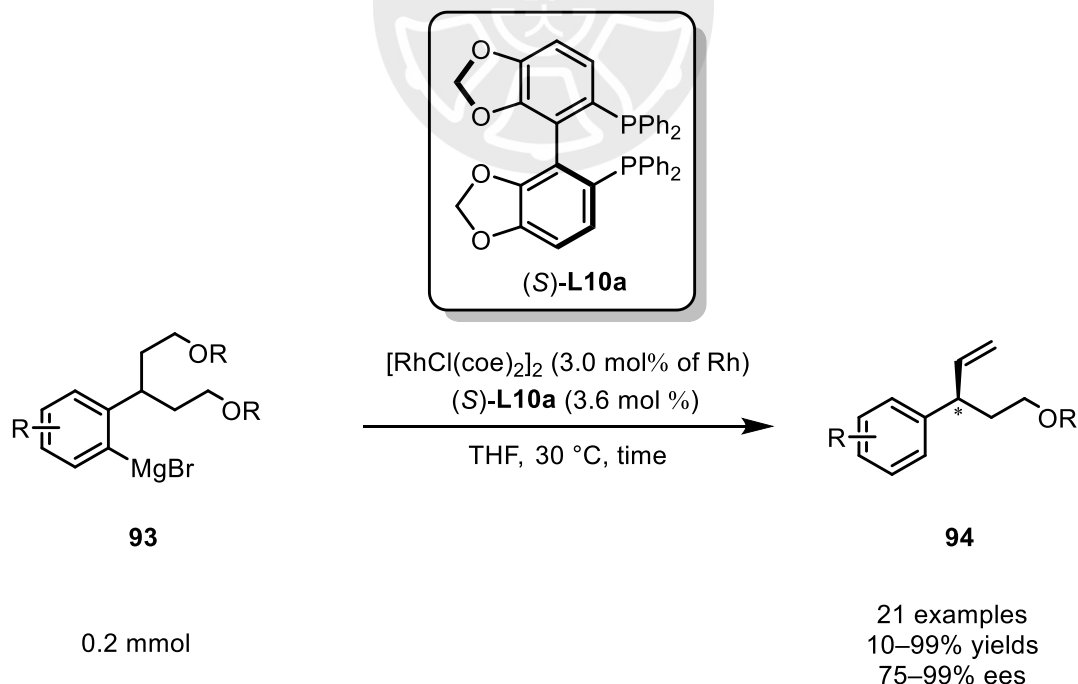


關鍵詞：一價銨金屬催化、分子內去對稱化反應、芳基格任亞試劑、1,4-銨轉移、 β -烷氧基脫去、鏡像選擇性

Abstract

This thesis aims to discuss an enantioselective intramolecular desymmetrization of aryl Grignard reagents. In the presence Rh(I)-catalyst, *in situ* generated from $[\text{RhCl}(\text{coe})_2]_2$ and (*S*)-Segphos (*S*)-**L10a**, the Grignard reagents **93** are transformed into chiral compound **94**, via 1,4-rhodium shift and beta-alkoxy elimination sequentially, in 10–99% yields and 79–99% ees. Additionally, a series of experiments of deuterium-labeling provide a mechanistic insight of this transformation.

Apart from most of the studies, focusing on the addition reactions of intermediates formed by 1,4-rhodium shift, this one is the first example of demonstrating synthesis of chiral intramolecular desymmetrization directly after 1,4- rhodium shift. With the high chemical yields and high enantioselectivities of the desired terminal alkenes, the transformation offers its synthetic potentials in drug synthesis.



Key words: Rhodium(I)-catalyzed reaction, intramolecular desymmetrization, aryl Grignard reagents, 1,4-rhodium shift, β -alkoxy elimination, enantioselective

目錄

中文摘要.....	i
Abstract	ii
目錄.....	iii
表目錄.....	iv
圖目錄.....	v
核磁共振光譜目錄.....	vii
第一章 緒論	1
第二章 文獻回顧.....	4
第三章 實驗設計.....	17
第四章 實驗結果與討論.....	18
一、 金屬試劑之篩選	18
二、 配基效應的探討	20
三、 反應溫度的優化	22
四、在最佳化條件下針對一系列進行反應性探討.....	23
第五章 立體結構與反應機構之探討.....	27
一、化合物 94am 絕對立體組態之探討	27
二、反應機構探討.....	28
三、反應鏡像選擇性探討.....	42
第六章 結論.....	44
第七章 實驗儀器、步驟及光譜數據.....	45
第八章 參考文獻.....	96

表目錄

表 4-1 金屬試劑之篩選.....	19
表 4-2 配基之篩選.....	21
表 4-3 反應溫度的優化.....	22
表 4-4 苯環 5 號位取代基效應之探討.....	25
表 4-5 苯環 4 號位取代基效應之探討.....	26



圖目錄

圖 1-1 檸檬酸去對稱化形成異檸檬酸	1
圖 1-2 Miura 教授以降冰片烯 3 藉由銻金屬催化不對稱加成反應	3
圖 2-1 Heck 教授發現有機鈀金屬化合物進行 1,4-轉移	4
圖 2-2 Hayashi 教授首次證明銻金屬 1,4-轉移	5
圖 2-3 Hayashi 教授對 1,4-轉移為可逆之反應證明	7
圖 2-4 Hayashi 教授利用一價銻金屬加成及 1,4-轉移進行合環反應	8
圖 2-5 Murakami 教授利用一價銻金屬 1,4-轉移進行合環反應	9
圖 2-6 Lautens 教授使用一價銻金屬催化環己二烯酮 45 的去對稱化反應	10
圖 2-7 Darses 教授對炔化合物 50 進行銻金屬催化去對稱化合環反應	11
圖 2-8 Hayashi 教授對烯基銻轉移成芳基銻之反應進行 DFT 計算	12
圖 2-9 Lam 教授對烯酮化合物 71 進行銻金屬催化去對稱化合環反應	13
圖 2-10 Murakami 教授首度於銻金屬催化反應中應用 β -消去手段	14
圖 2-11 Murakami 教授利用 β -醇鹽消去使銻金屬回至下一個循環	15
圖 2-12 Kochi 教授利用鈀催化烯基化合物 85 的芳基化及雙鍵異構化反應	16
圖 3-1 起始反應物結構設計	17
圖 4-1 試劑 93ae-z 及 93ae-t 製備	18
圖 5-1 羧酸銨鹽 94am-2 合成途徑及其 ORTEP	27
圖 5-2 本反應推測反應機構	28
圖 5-3 反應物 93ke-4D	28
圖 5-4 反應物 93ke-4D 設計理念	29
圖 5-5 94ke-4D 與 94 ke 600 Hz ^1H NMR 光譜比較圖	31
圖 5-6 94ke-4D ^1H NMR 光譜及 ^2H NMR 光譜比較圖	32
圖 5-7 反應物 93am-1D	32

圖 5-8 反應物 93am-1D 設計理念	33
圖 5-9 反應物 93am-1D 設計理念	34
圖 5-10 94am-1D 反應路徑圖	35
圖 5-11 94am-1D ^1H NMR 光譜及 ^2H NMR 光譜比較圖	36
圖 5-12 反應物 93am-4D	37
圖 5-13 反應物 93am-4D 設計理念	37
圖 5-14 94am-4D 與 94am 600Hz ^1H NMR 光譜比較圖	38
圖 5-15 94am-4D 反應路徑圖	39
圖 5-16 94am-4D ^1H NMR 光譜及 ^2H NMR 光譜比較圖	40
圖 5-17 氙標誌實驗	40
圖 5-18 反應機構	42
圖 5-19 銻-烷氧基消去可能的中間過渡態	43



核磁共振光譜目錄

1. ^1H NMR of 3-(2-bromophenyl)pentane-1,5-diol (91a).....	108
2. ^{13}C NMR of 3-(2-bromophenyl)pentane-1,5-diol (91a).....	109
3. ^1H NMR of 3-(2-bromo-5-methoxyphenyl)pentane-1,5-diol (91b).....	110
4. ^{13}C NMR of 3-(2-bromo-5-methoxyphenyl)pentane-1,5-diol (91b).....	111
5. ^1H NMR of 3-(2-bromo-5-ethoxyphenyl)pentane-1,5-diol (91c)	112
6. ^{13}C NMR of 3-(2-bromo-5-ethoxyphenyl)pentane-1,5-diol (91c)	113
7. ^1H NMR of 3-(5-(benzyloxy)-2-bromophenyl)pentane-1,5-diol (91d)	114
8. ^{13}C NMR of 3-(5-(benzyloxy)-2-bromophenyl)pentane-1,5-diol (91d)	115
9. ^1H NMR of 3-(2-bromo-5-fluorophenyl)pentane-1,5-diol (91e)	116
10. ^{13}C NMR of 3-(2-bromo-5-fluorophenyl)pentane-1,5-diol (91e)	117
11. ^{19}F NMR of 3-(2-bromo-5-fluorophenyl)pentane-1,5-diol (91e).....	118
12. ^1H NMR of 3-(2-bromo-5-chlorophenyl)pentane-1,5-diol (91f)	119
13. ^{13}C NMR of 3-(2-bromo-5-chlorophenyl)pentane-1,5-diol (91f)	120
14. ^1H NMR of 3-(2-bromo-5-(trifluoromethyl)phenyl)pentane-1,5-diol (91g) .	121
15. ^{13}C NMR of 3-(2-bromo-5-(trifluoromethyl)phenyl)pentane-1,5-diol (91g)	122
16. ^{19}F NMR of 3-(2-bromo-5-(trifluoromethyl)phenyl)pentane-1,5-diol (91g).	123
17. ^1H NMR of 3-(2-bromo-4-fluorophenyl)pentane-1,5-diol (91h).....	124
18. ^{13}C NMR of 3-(2-bromo-4-fluorophenyl)pentane-1,5-diol (91h).....	125
19. ^{19}F NMR of 3-(2-bromo-4-fluorophenyl)pentane-1,5-diol (91h)	126
20. ^1H NMR of 3-(2-bromo-4-chlorophenyl)pentane-1,5-diol (91i)	127
21. ^{13}C NMR of 3-(2-bromo-4-chlorophenyl)pentane-1,5-diol (91i)	128
22. ^1H NMR of 3-(2-bromo-4-methoxyphenyl)pentane-1,5-diol (91l)	129
23. ^{13}C NMR of 3-(2-bromo-4-methoxyphenyl)pentane-1,5-diol (91l)	130

24. ¹ H NMR of 3-(2-bromo-4-methylphenyl)pentane-1,5-diol (91k).....	131
25. ¹³ C NMR of 3-(2-bromo-4-methylphenyl)pentane-1,5-diol (91k).....	132
26. ¹ H NMR of 3-(1-bromonaphthalen-2-yl)pentane-1,5-diol (91m)	133
27. ¹³ C NMR of 3-(1-bromonaphthalen-2-yl)pentane-1,5-diol (91m)	134
28. ¹ H NMR of 1-bromo-2-(1,5-dimethoxypentan-3-yl)-4-methoxybenzene (92bm).....	135
29. ¹³ C NMR of 1-bromo-2-(1,5-dimethoxypentan-3-yl)-4-methoxybenzene (92bm).....	136
30. ¹ H NMR of 1-bromo-2-(1,5-diethoxypentan-3-yl)-4-ethoxybenzene (92cm)	137
31. ¹³ C NMR of 1-bromo-2-(1,5-diethoxypentan-3-yl)-4-ethoxybenzene (92cm)	138
32. ¹ H NMR of 4-(benzyloxy)-1-bromo-2-(1,5-dimethoxypentan-3-yl)benzene (92dm).....	139
33. ¹³ C NMR of 4-(benzyloxy)-1-bromo-2-(1,5-dimethoxypentan-3-yl)benzene (92dm).....	140
34. ¹ H NMR of 1-bromo-2-(1,5-dimethoxypentan-3-yl)-4-fluorobenzene (92em)	141
35. ¹³ C NMR of 1-bromo-2-(1,5-dimethoxypentan-3-yl)-4-fluorobenzene (92em)	142
36. ¹⁹ F NMR of 1-bromo-2-(1,5-dimethoxypentan-3-yl)-4-fluorobenzene (92em)	143
37. ¹ H NMR of 1-bromo-2-(1,5-dimethoxypentan-3-yl)-4-chlorobenzene (92fm)	144
38. ¹³ C NMR of 1-bromo-2-(1,5-dimethoxypentan-3-yl)-4-chlorobenzene (92fm)	145

39. ¹ H NMR of 1-bromo-2-(1,5-dimethoxypentan-3-yl)-4-(trifluoromethyl)benzene (92gm)	146
40. ¹³ C NMR of 1-bromo-2-(1,5-dimethoxypentan-3-yl)-4-(trifluoromethyl)benzene (92gm)	147
41. ¹⁹ F NMR of 1-bromo-2-(1,5-dimethoxypentan-3-yl)-4-(trifluoromethyl)benzene (92gm)	148
42. ¹ H NMR of 2-bromo-1-(1,5-dimethoxypentan-3-yl)-4-fluorobenzene(92hm)	149
43. ¹³ C NMR of 2-bromo-1-(1,5-dimethoxypentan-3-yl)-4-fluorobenzene(92hm)	150
44. ¹⁹ F NMR of 2-bromo-1-(1,5-dimethoxypentan-3-yl)-4-fluorobenzene (92hm)	151
45. ¹ H NMR of 2-bromo-4-chloro-1-(1,5-dimethoxypentan-3-yl)benzene (92im)	152
46. ¹³ C NMR of 2-bromo-4-chloro-1-(1,5-dimethoxypentan-3-yl)benzene (92im)	153
47. ¹ H NMR of 2-bromo-1-(1,5-dimethoxypentan-3-yl)-4-methylbenzene (92km)	154
48. ¹³ C NMR of 2-bromo-1-(1,5-dimethoxypentan-3-yl)-4-methylbenzene (92km)	155
49. ¹ H NMR of 1-bromo-2-(1,5-diethoxypentan-3-yl)benzene (92ae)	156
50. ¹³ C NMR of 1-bromo-2-(1,5-diethoxypentan-3-yl)benzene (92ae)	157
51. ¹ H NMR of 1-bromo-2-(1,5-diethoxypentan-3-yl)-4-fluorobenzene (92ee)..	158
52. ¹³ C NMR of 1-bromo-2-(1,5-diethoxypentan-3-yl)-4-fluorobenzene (92ee)	159
53. ¹⁹ F NMR of 1-bromo-2-(1,5-diethoxypentan-3-yl)-4-fluorobenzene (92ee) ..	160

54. ¹ H NMR of 2-bromo-4-chloro-1-(1,5-diethoxypentan-3-yl)benzene (92ie)..	161
55. ¹³ C NMR of 2-bromo-4-chloro-1-(1,5-diethoxypentan-3-yl)benzene (92ie).	162
56. ¹ H NMR of 1-bromo-2-(1,5-diethoxypentan-3-yl)-4-(trifluoromethyl)benzene (92ge)	163
57. ¹³ C NMR of 1-bromo-2-(1,5-diethoxypentan-3-yl)-4-(trifluoromethyl)benzene (92ge)	164
58. ¹⁹ F NMR of 1-bromo-2-(1,5-diethoxypentan-3-yl)-4-(trifluoromethyl)benzene (92ge)	165
59. ¹ H NMR of 2-bromo-1-(1,5-diethoxypentan-3-yl)-4-fluorobenzene (92he) .	166
60. ¹³ C NMR of 2-bromo-1-(1,5-diethoxypentan-3-yl)-4-fluorobenzene (92he)	167
61. ¹⁹ F NMR of 2-bromo-1-(1,5-diethoxypentan-3-yl)-4-fluorobenzene (92he)..	168
62. ¹ H NMR of 2-bromo-4-chloro-1-(1,5-diethoxypentan-3-yl)benzene (92ie) ..	169
63. ¹³ C NMR of 2-bromo-4-chloro-1-(1,5-diethoxypentan-3-yl)benzene (92ie).	170
64. ¹ H NMR of 2-bromo-1-(1,5-diethoxypentan-3-yl)-4-(trifluoromethyl)benzene (92je)	171
65. ¹³ C NMR of 2-bromo-1-(1,5-diethoxypentan-3-yl)-4-(trifluoromethyl)benzene (92je)	172
66. ¹⁹ F NMR of 2-bromo-1-(1,5-diethoxypentan-3-yl)-4-(trifluoromethyl)benzene (92je)	173
67. ¹ H NMR of 2-bromo-1-(1,5-diethoxypentan-3-yl)-4-methylbenzene (92ke)	174
68. ¹³ C NMR of 2-bromo-1-(1,5-diethoxypentan-3-yl)-4-methylbenzene (92ke)	175
69. ¹ H NMR of 2-bromo-1-(1,5-diethoxypentan-3-yl)-4-methoxybenzene (92le)	176
70. ¹³ C NMR of 2-bromo-1-(1,5-diethoxypentan-3-yl)-4-methoxybenzene (92le)	177
71. ¹ H NMR of 1-bromo-2-(1,5-diethoxypentan-3-yl)naphthalene (92me).....	178

72. ¹³ C NMR of <i>1-bromo-2-(1,5-diethoxypentan-3-yl)naphthalene</i> (92me).....	179
73. ¹ H NMR of <i>(R)-(5-methoxypent-1-en-3-yl)benzene</i> (94am).....	180
74. ¹³ C NMR of <i>(R)-(5-methoxypent-1-en-3-yl)benzene</i> (94am)	181
75. ¹ H NMR of <i>(R)-(5-ethoxypent-1-en-3-yl)benzene</i> (94ae).....	182
76. ¹³ C NMR of <i>(R)-(5-ethoxypent-1-en-3-yl)benzene</i> (94ae).....	183
77. ¹ H NMR of <i>(R)-1-methoxy-3-(5-methoxypent-1-en-3-yl)benzene</i> (94bm) ...	184
78. ¹³ C NMR of <i>(R)-1-methoxy-3-(5-methoxypent-1-en-3-yl)benzene</i> (94bm) ..	185
79. ¹ H NMR of <i>(R)-1-ethoxy-3-(5-methoxypent-1-en-3-yl)benzene</i> (94cm).....	186
80. ¹³ C NMR of <i>(R)-1-ethoxy-3-(5-methoxypent-1-en-3-yl)benzene</i> (94cm)	187
81. ¹ H NMR of <i>(S)-3-(3-ethoxyphenyl)-5-methoxypentan-1-ol</i> (95cm).....	188
82. ¹³ C NMR of <i>(S)-3-(3-ethoxyphenyl)-5-methoxypentan-1-ol</i> (95cm)	189
83. ¹ H NMR of <i>(R)-1-ethoxy-3-(5-ethoxypent-1-en-3-yl)benzene</i> (94ce)	190
84. ¹³ C NMR of <i>(R)-1-ethoxy-3-(5-ethoxypent-1-en-3-yl)benzene</i> (94ce)	191
85. ¹ H NMR of <i>(S)-5-ethoxy-3-(3-ethoxyphenyl)pentan-1-ol</i> (95ce)	192
86. ¹³ C NMR of <i>(S)-5-ethoxy-3-(3-ethoxyphenyl)pentan-1-ol</i> (95ce)	193
87. ¹ H NMR of <i>(R)-1-(benzyloxy)-3-(5-methoxypent-1-en-3-yl)benzene</i> (94dm)	
.....	194
88. ¹³ C NMR of <i>(R)-1-(benzyloxy)-3-(5-methoxypent-1-en-3-yl)benzene</i> (94dm)	
.....	195
89. ¹ H NMR of <i>(R)-1-fluoro-3-(5-methoxypent-1-en-3-yl)benzene</i> (94em).....	196
90. ¹³ C NMR of <i>(R)-1-fluoro-3-(5-methoxypent-1-en-3-yl)benzene</i> (94em)	197
91. ¹⁹ F NMR of <i>(R)-1-fluoro-3-(5-methoxypent-1-en-3-yl)benzene</i> (94em).....	198
92. ¹ H NMR of <i>(R)-1-chloro-3-(5-methoxypent-1-en-3-yl)benzene</i> (94fm).....	199
93. ¹³ C NMR of <i>(R)-1-chloro-3-(5-methoxypent-1-en-3-yl)benzene</i> (94fm)	200
94. ¹ H NMR of <i>(R)-1-chloro-3-(5-ethoxypent-1-en-3-yl)benzene</i> (94fe)	201

95. ¹³ C NMR of <i>(R)</i> -1-chloro-3-(5-ethoxypent-1-en-3-yl)benzene (94fe).....	202
96. ¹ H NMR of <i>(R)</i> -1-(5-methoxypent-1-en-3-yl)-3-(trifluoromethyl)benzene (94gm).....	203
97. ¹³ C NMR of <i>(R)</i> -1-(5-methoxypent-1-en-3-yl)-3-(trifluoromethyl)benzene (94gm).....	204
98. ¹⁹ F NMR of <i>(R)</i> -1-(5-methoxypent-1-en-3-yl)-3-(trifluoromethyl)benzene (94gm).....	205
99. ¹ H NMR of <i>(R)</i> -1-(5-ethoxypent-1-en-3-yl)-3-(trifluoromethyl)benzene (94ge)	206
100. ¹³ C NMR of <i>(R)</i> -1-(5-ethoxypent-1-en-3-yl)-3-(trifluoromethyl)benzene (94ge)	207
101. ¹ H NMR of <i>(R)</i> -1-fluoro-4-(5-methoxypent-1-en-3-yl)benzene (94hm)	208
102. ¹³ C NMR of <i>(R)</i> -1-fluoro-4-(5-methoxypent-1-en-3-yl)benzene (94hm)....	209
103. ¹⁹ F NMR of <i>(R)</i> -1-fluoro-4-(5-methoxypent-1-en-3-yl)benzene (94hm)	210
104. ¹ H NMR of <i>(S)</i> -3-(4-fluorophenyl)-5-methoxypentan-1-ol (95hm).....	211
105. ¹³ C NMR of <i>(S)</i> -3-(4-fluorophenyl)-5-methoxypentan-1-ol (95hm).....	212
106. ¹⁹ F NMR of <i>(S)</i> -3-(4-fluorophenyl)-5-methoxypentan-1-ol (95hm)	213
107. ¹ H NMR of <i>(R)</i> -1-(5-ethoxypent-1-en-3-yl)-4-fluorobenzene (94he).....	214
108. ¹³ C NMR of <i>(R)</i> -1-(5-ethoxypent-1-en-3-yl)-4-fluorobenzene (94he)	215
109. ¹⁹ F NMR of <i>(R)</i> -1-(5-ethoxypent-1-en-3-yl)-4-fluorobenzene (94he).....	216
110. ¹ H NMR of <i>(R)</i> -1-chloro-4-(5-methoxypent-1-en-3-yl)benzene (94im).....	217
111. ¹³ C NMR of <i>(R)</i> -1-chloro-4-(5-methoxypent-1-en-3-yl)benzene (94im).....	218
112. ¹ H NMR of <i>(S)</i> -3-(4-chlorophenyl)-5-methoxypentan-1-ol (95im)	219
113. ¹³ C NMR of <i>(S)</i> -3-(4-chlorophenyl)-5-methoxypentan-1-ol (95im)	220
114. ¹ H NMR of <i>(R)</i> -1-chloro-4-(5-ethoxypent-1-en-3-yl)benzene (94ie)	221

115. ^{13}C NMR of <i>(R)</i> -1-chloro-4-(5-ethoxypent-1-en-3-yl)benzene (94ie)	222
116. ^1H NMR of <i>(R)</i> -1-(5-ethoxypent-1-en-3-yl)-4-(trifluoromethyl)benzene (94je)	223
117. ^{13}C NMR of <i>(R)</i> -1-(5-ethoxypent-1-en-3-yl)-4-(trifluoromethyl)benzene (94je)	224
118. ^{19}F NMR of <i>(R)</i> -1-(5-ethoxypent-1-en-3-yl)-4-(trifluoromethyl)benzene (94jm).....	225
119. ^1H NMR of <i>(R)</i> -1-(5-methoxypent-1-en-3-yl)-4-methylbenzene (94km)	226
120. ^{13}C NMR of <i>(R)</i> -1-(5-methoxypent-1-en-3-yl)-4-methylbenzene (94km) ..	227
121. ^1H NMR of <i>(R)</i> -1-(5-ethoxypent-1-en-3-yl)-4-methylbenzene (94ke).....	228
122. ^{13}C NMR of <i>(R)</i> -1-(5-ethoxypent-1-en-3-yl)-4-methylbenzene (94ke)	229
123. ^1H NMR of <i>(R)</i> -1-(5-ethoxypent-1-en-3-yl)-4-methoxybenzene (94le).....	230
124. ^{13}C NMR of <i>(R)</i> -1-(5-ethoxypent-1-en-3-yl)-4-methoxybenzene (94le).....	231
125. ^1H NMR of <i>(R)</i> -2-(5-ethoxypent-1-en-3-yl)naphthalene (94me).....	232
126. ^{13}C NMR of <i>(R)</i> -2-(5-ethoxypent-1-en-3-yl)naphthalene (94me).....	233

縮寫對照表

縮寫	全名
9-BBN	9-borabicyclo[3.3.1]nonane
aq	aqueous
Ar	aryl (substituted aromatic ring)
BINAP	2,2'-bis(diphenylphosphino)-1,1'-binaphthyl
SEGPLIOS	4,4'-Bi-1,3-benzodioxole-5,5'-diylbis(diphenylphosphane)
cat.	catalytic
d	doublet (NMR)
DCM	dichloromethane
DMAP	4-dimethylaminopyridine
dr	diastereomeric ratio
ee	enantiomeric excess
ESI	Electrospray ionization
Et	ethyl
FTIR	Fourier transform infrared spectroscopy
h	hour
HPLC	high-performance liquid chromatography
m	multiplet (NMR)
<i>m</i>	meta
Me	methyl
MeOH	methanol
min	minute
mol	mole
M.p.	melting point
<i>n</i>	normal (unbranched alkyl chain)
NMR	nuclear magnetic resonance spectroscopy
OMe	methoxy
OEt	ethoxy

OBn	benzoxy
ORTEP	Oak Ridge thermal ellipsoid plot
<i>p</i>	para
Ph	phenyl
PiV ₂ O	trimethylacetic anhydride
ppm	parts-per-million
q	quartet (NMR)
rt	room temperature
s	singlet (NMR)
t	triplet (NMR)
temp.	temperature
THF	tetrahydrofuran
TLC	thin-layer-chromatography
Ts	<i>p</i> -toluenesulfonyl
α	alpha
β	beta

第一章 緒論

在有機分子中，當一個碳原子上具有四個不同的基團，其即為此分子的立體中心，亦可稱為掌性中心(chiral center)。

掌性(chirality)一詞源自於希臘語的手(cheir)，描述手掌與其鏡像無法重疊的現象。在有機化學中，具有掌性的分子及其鏡像分子稱為鏡像異構物(enantiomer)，同樣地看似相似卻無法重疊。在無其他掌性分子的環境中，鏡像異構物間的物理及化學性質幾乎相同，僅旋光性相反，此現象於西元 1847 年由巴斯德使用偏光鏡研究酒石酸晶體發現而得，開啟人類對鏡像異構物的認知。自然界生物體由許多有機掌性分子構成，生長代謝反應皆涉及單一鏡像異構物的反應，例如粒線體的檸檬酸循環，藉烏頭酸酶(Aconitase)的催化將具前掌性(prochiral)的檸檬酸(citrate) **1** 去對稱化(desymmetrization)成具掌性的異檸檬酸(isocitrate) **2**。(圖 1-1)

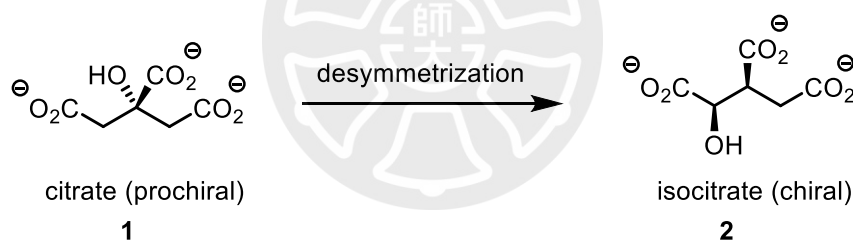


圖 1-1 檸檬酸去對稱化形成異檸檬酸

但直到 1960 年代反應停事件的發生，科學界才注意到鏡像異構物對人體不同的反應活性，並揭開研究生成或單離單一鏡像異構物的序幕。

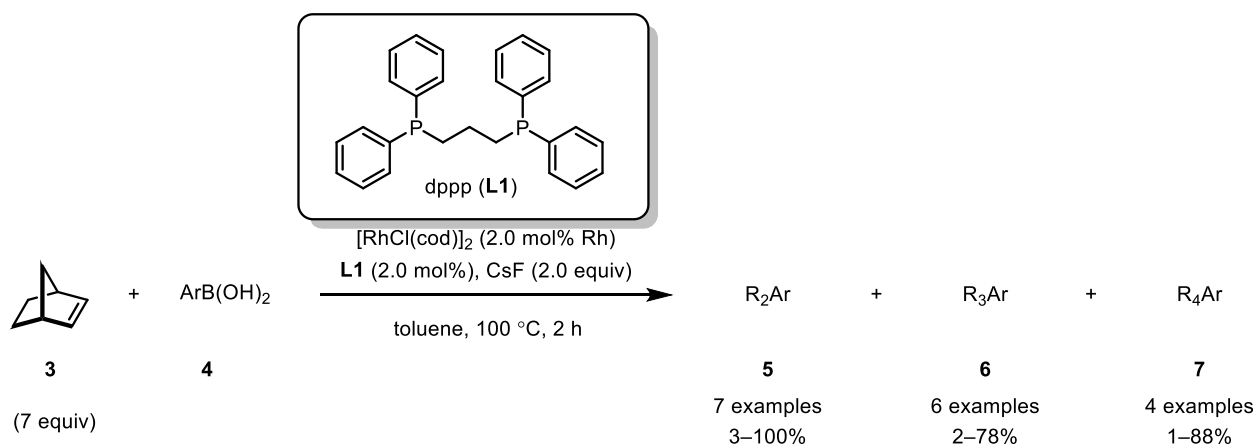
獲得單一鏡像異構物的策略可分為掌性分離與不對稱合成，前者為分離消旋化合物並得到單一鏡像異構物；後者為在製備過程中控制產物生成的立體組態，使欲得的組態佔多數。一般而言，不對稱合成可區分為以下三大種類：

- (1) 掌性試劑 (chiral reagents)：使用已具掌性之分子進行多步合成。
- (2) 掌性輔助劑 (chiral auxiliaries)：暫時加入反應的化合物，連接上前手性的(prochiral)

分子後以立體障礙效應或電子效應控制組態的生成，反應後可回收，具經濟效益

(3) 掌性催化劑 (chiral catalysts)：催化量掌性催化劑與反應物生成高活性中間體，進行不對稱反應後脫去並參與另一分子起始物循環反應。其可分為有機催化劑及金屬催化劑，前者為使用碳、氫、氧、氮、硫為架構之分子為催化劑，後者以過渡金屬錯合物進行不對稱催化合成反應，其高催化效率使之成為研究最深且應用最廣的催化劑類型之一。

轉移現象是過渡金屬催化劑中重要的反應之一，有別於傳統上藉由氧化加成 (oxidative addition)、插入反應 (insertion)、轉移金屬化 (transmetalation) 形成碳-金屬中間體，轉移現象是另一種製備碳-金屬中間體的策略。其中銨金屬的 1,4-轉移 (1,4-Rh shift) 現象首次於 2000 年被發現。Miura 教授將降冰片烯 (norbornene, **3**) 與芳基硼酸 (boronic acid, **4**) 利用一價銨金屬催化進行加成反應，並獲得加成數次的產物。Miura 教授推測其機構為降冰片烯與芳基銨 (arylrhodim, **8**) 進行插入反應 (insertion)，形成中間體 **9**，再由碳氫鍵斷裂與分子內還原消去 (reductive elimination) 得中間體 **11**。另一分子降冰片烯 **3** 再與其反應形成中間體 **12**，如此重複循環，並透過水解得到產物。隨著降冰片烯 **3** 當量減少，水解與插入反應彼此競爭，因而得到苯環具不同數目取代基的產物。雖然 Miura 教授未設計實驗進一步驗證其假說，此反應是銨金屬碳-碳轉移的首次發現 (圖 1-2)。^[1]



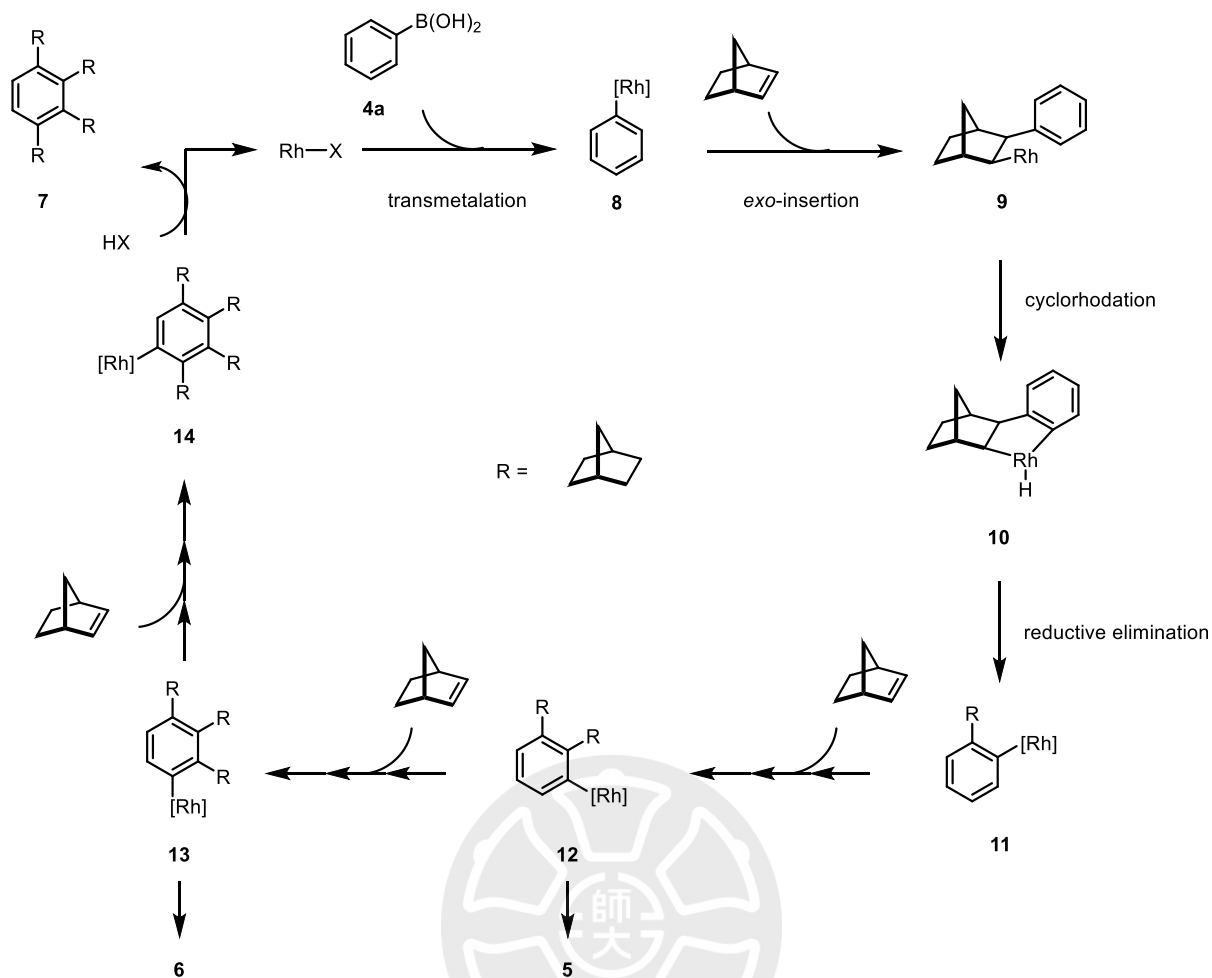


圖 1-2 Miura 教授以降冰片烯 **3** 藉由銑金屬催化不對稱加成反應

此後，銑金屬的轉移現象成為學界新興的研究主題。目前為止，銑金屬 1,4 轉移 (1,4-shift) 大多應用於形成芳基銑(arylrhodium)中間體，或是轉移至電子密度較大之碳上。至於銑金屬由苯環轉移至未有官能基修飾之烷基則未有文獻發表。本篇旨在研究首次以一價芳基銑 1,4-轉移至烷基的分子內去對稱化反應。

第二章 文獻回顧

由於過渡金屬的價軌域為 d 軌域，且越大週期的過渡金屬其 d 軌域越大，因此與其他原子的軌域經常重疊並造成此類過渡金屬形成的有機金屬化合物常有轉移的現象。分子內鈀金屬的 1,4-轉移由 Heck 教授意外發現。Heck 教授使用由苄基醋酸汞 (benzylmercury acetate, **15**) 及醋酸鈀 (palladium acetate) 經由轉移金屬化生成的苄基醋酸鈀 (benzylpalladium acetate, **16**) 及丙烯酸甲酯 (methyl acrylate, **17**) 進行反應，欲得加成產物烯酸酯 (enoate ester, **18**)，卻發現產物多數為肉桂酸甲酯 (methyl cinnamate, **19**)。因此 Heck 教授提出一種假設：一部分的鈀金屬化合物 **16** 經由六員環的中間體 **20** 在分子內重排，自烷基上轉移四個碳的位置至苯環上，形成中間體 **21**，再加成至丙烯酸甲酯 **17** 並消去形成肉桂酸甲酯 **19**。此例子為有機金屬化合物 1,4-轉移的首次發現 (圖 2-1)。^[2]

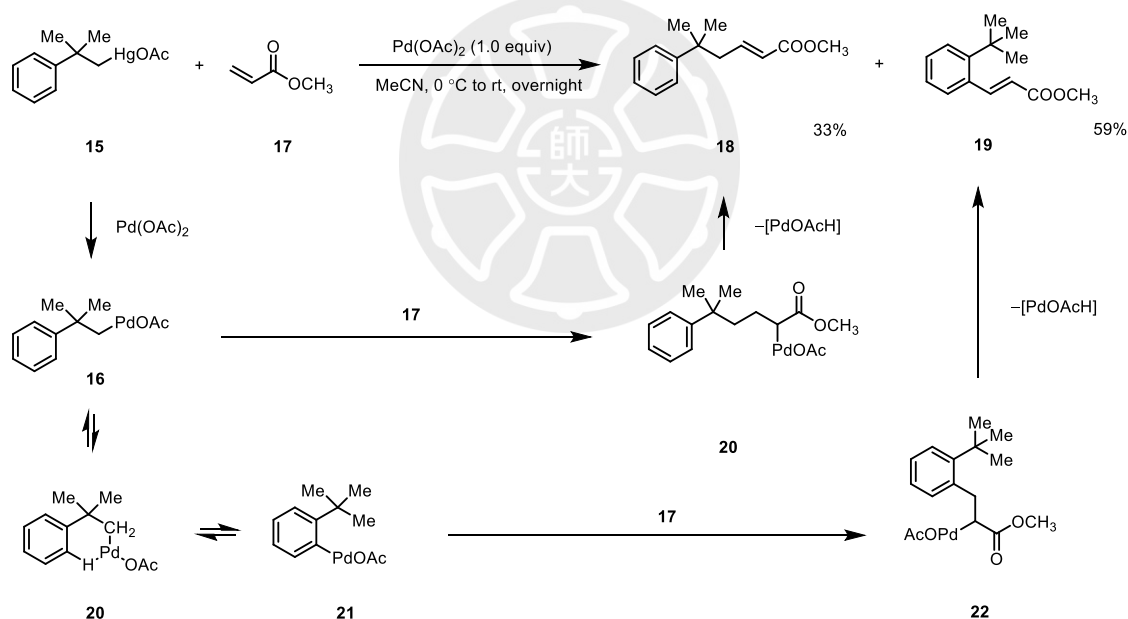


圖 2-1 Heck 教授發現有機鈀金屬化合物進行 1,4-轉移

自此，許多化學家投入過渡金屬 1,4-轉移反應的研究，鈷、銨、銨皆有例子。其中 Hayashi 教授於 2001 年發表的文獻，利用氙標記實驗證明銨金屬具有 1,4-轉移反應之現象 (圖 2-2)。^[3]此研究使用炔類化合物 **23** 與硼試劑 **4**、**24** 在一價銨金屬分別與 dppp(L1) 和 dppf(L2) 雙膦配基形成之催化劑催化下進行加成反應，得到烯類化合物 **25**。將質子來源換成重水進行氙標記實驗，反應最終得烯基鄰位具有氙原子的苯乙烯衍生物 **26**。

其反應機構如下：苯硼試劑 **4a** 與一價銨金屬進行轉移金屬化反應，形成苯基銨 **8**，其加成至內炔化合物(internal alkyne, **23a**)形成中間體 **27**。此時大部分原先在烯基上的銨金屬會 1,4-轉移至苯環上形成中間體 **28**，經重水質子化後形成產物 **26**。化合物 **26** 苯環上的氘即可證明 1,4-轉移是此反應的關鍵步驟，由其高產率也可得知烯基銨轉移至苯基銨為一快速的反應過程。

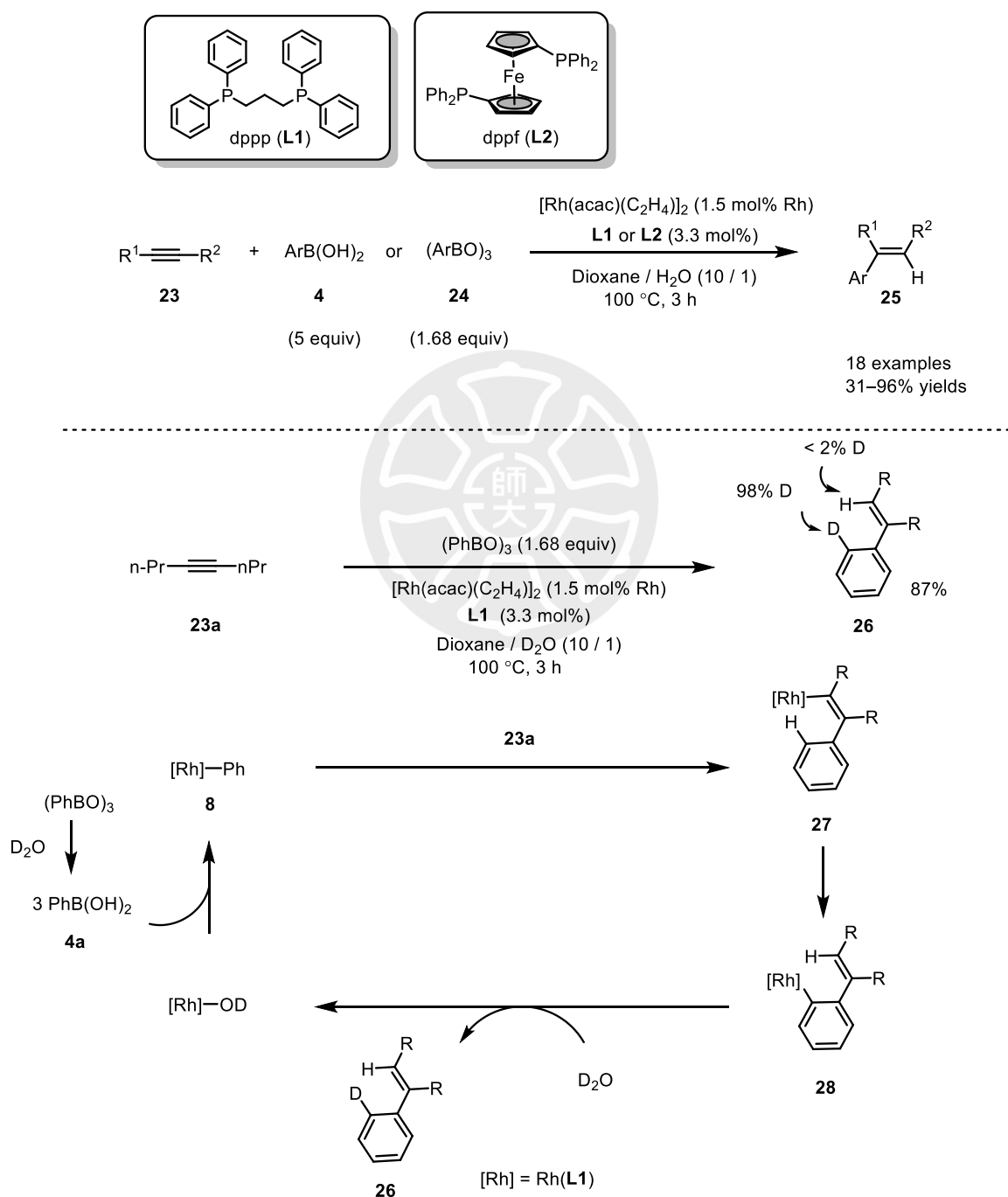


圖 2-2 Hayashi 教授首次證明銨金屬 1,4-轉移

銑金屬的 1,4-轉移反應被證明後，Hayashi 教授進一步於 2016 年利用氙標誌實驗證明銑金屬的 1,4-轉移為一個平衡反應。其利用一價銑金屬與雙烯配基形成之錯合物，催化 α,β -不飽和酮 **26** 與芳基硼鹽 **27** 的不對稱加成反應，有 22 個例子，72-97 % 的產率，高達 99.5% 的鏡像超越值。在氙標誌實驗中，使用氙代芳基硼鹽 **27a** 與 α,β -不飽和酮 **26a** 進行反應，得到兩種不同氙分布的化合物。推測其反應路徑其一為硼鹽化合物 **27a** 與一價銑轉移金屬化形成中間體 **29**，由於烷基銑(alkanylrhodium)中間體反應性較差，故先進行 1,4-轉移至苯環形成中間體 **30** 並加成至 α,β -不飽和酮 **26a**，得化合物 **28a**；另一路徑為苯基銑中間體 **30** 再度進行 1,4-轉移形成烷基銑中間體 **31**，當再度 1,4-轉移時選擇苯環另一側的碳，形成中間體 **32**，並加成至 α,β -不飽和酮 **26a** 得到化合物 **28b**(圖 2-3)。^[4]此實驗巧妙地利用產物中氙分布的差異證明 1,4-轉移是可逆反應，並得以窺見由於烷基銑中間體較不穩定，故銑金屬傾向 1,4-轉移形成苯基銑中間體。



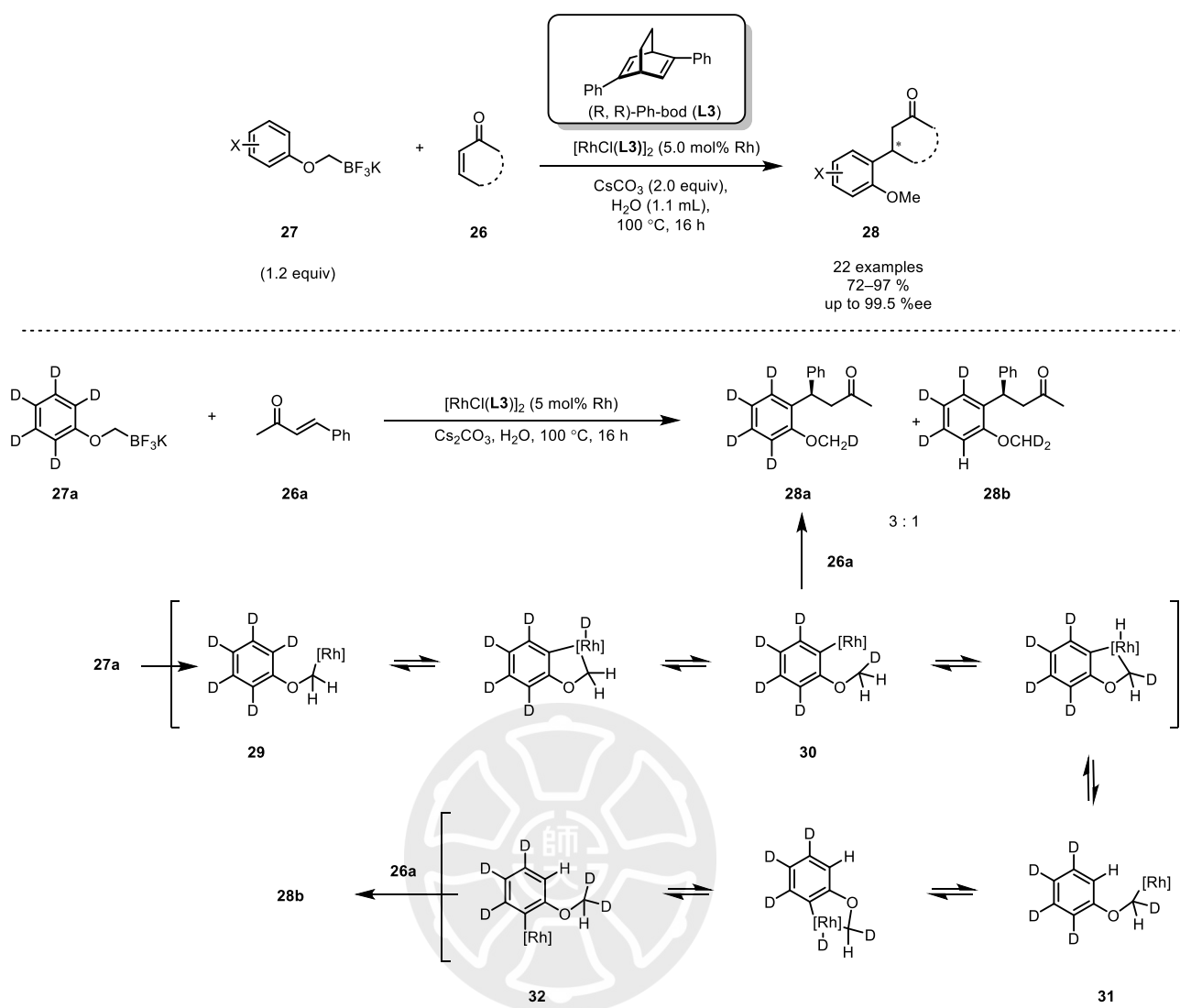


圖 2-3 Hayashi 教授對 1,4-轉移為可逆之反應證明

除了上述利用銨金屬 1,4-轉移之中間體再行加成反應的例子，合環反應為另一銨金屬 1,4-轉移的應用。例如 2006 年 Hayashi 教授發表的文獻中，使用實驗室自行製備之新型雙膦配基 **L4** 與一價銨金屬錯合形成之催化劑，利用銨金屬的加成反應及 1,4-轉移，將一系列化合物 **33** 進行分子內合環反應，形成一系列 1-二氫茚酮(1-indanone, **34**)衍生物。有 8 個例子，產率為 44%–67%，鏡相選擇性為 92–99%。其反應機構如下圖所示，首先銨錯合物與反應物 **33** 之羥基進行脫水反應形成中間體 **35**，再經由 β -H 脫去形成中間體 **36**。接著中間體 **36** 進行碳-銨插入反應形成的中間體 **37** 經由 1,4-轉移生成中間體 **38**，經由再度的碳-銨插入形成中間體 **39** 經水解後形成 1-二氫茚酮 **34** (圖 2-4)。^[5]

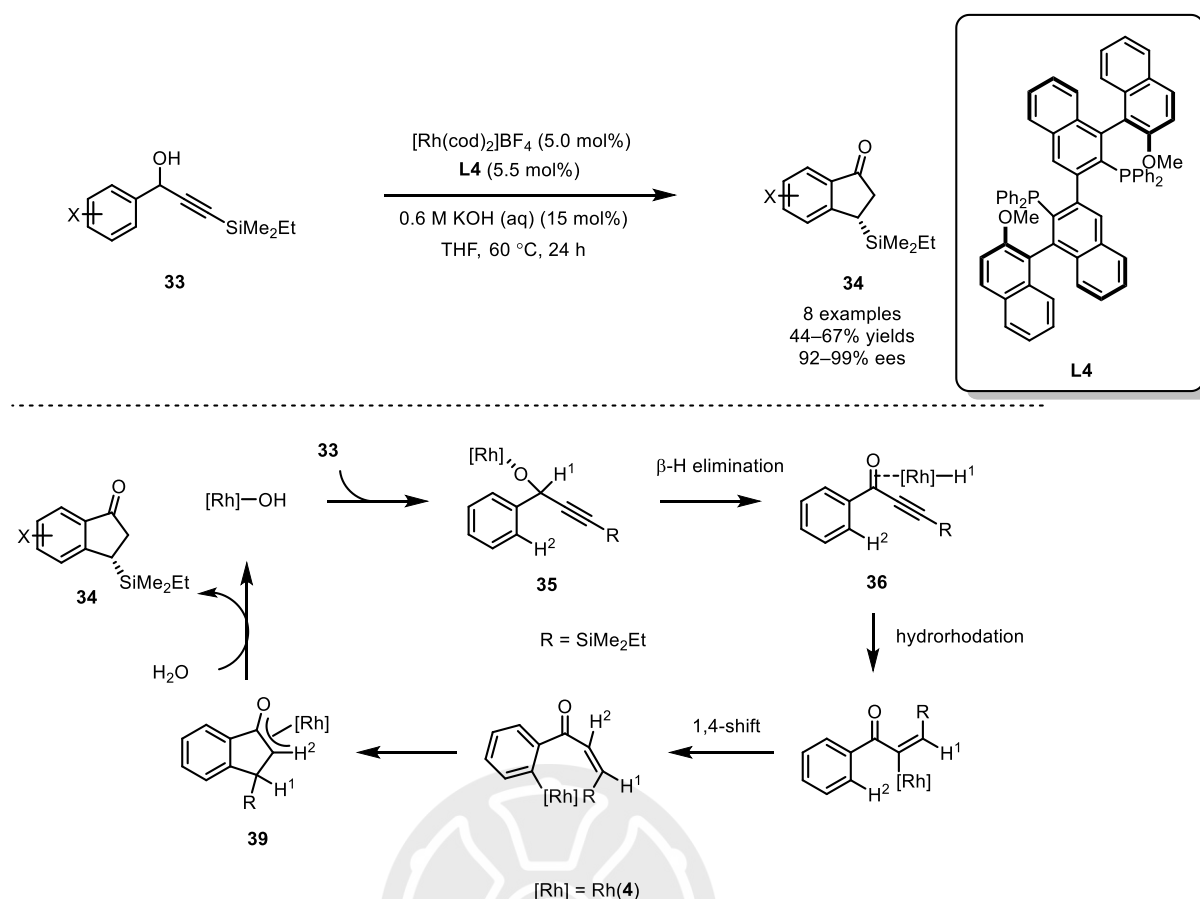


圖 2-4 Hayashi 教授利用一價銨金屬加成及 1,4-轉移進行合環反應

2005 年 Murakami 教授及其團隊利用一價銨金屬與雙膦配基 **L1** 形成之催化劑催化炔類化合物 **40** 與四苯硼鹽化合物 **41** 進行分子內合環反應，生成一系列四氫萘酮化合物 **42**，有 5 個例子，其為產率為 63–89%。其反應機構為：四苯硼鹽化合物 **41** 與一價銨金屬進行轉移金屬化後形成苯基銨中間體 **8**，其加成至炔類化合物 **40** 的三鍵上並形成烯基銨中間體 **43**，接下來經由 1,4-轉移形成苯基銨後，苯基加成至反應物結構中的酯基，並脫去銨醇鹽，合環形成四氫萘酮化合物 **42**。此反應提供一個不同於多數文獻添加質子來源，僅利用反應物本身可離去之結構使銨金屬回至下一個催化循環的想法，為綜合銨金屬 1,4-轉移分子內合環及 β -消去的文獻 (圖 2-5)。^[6]

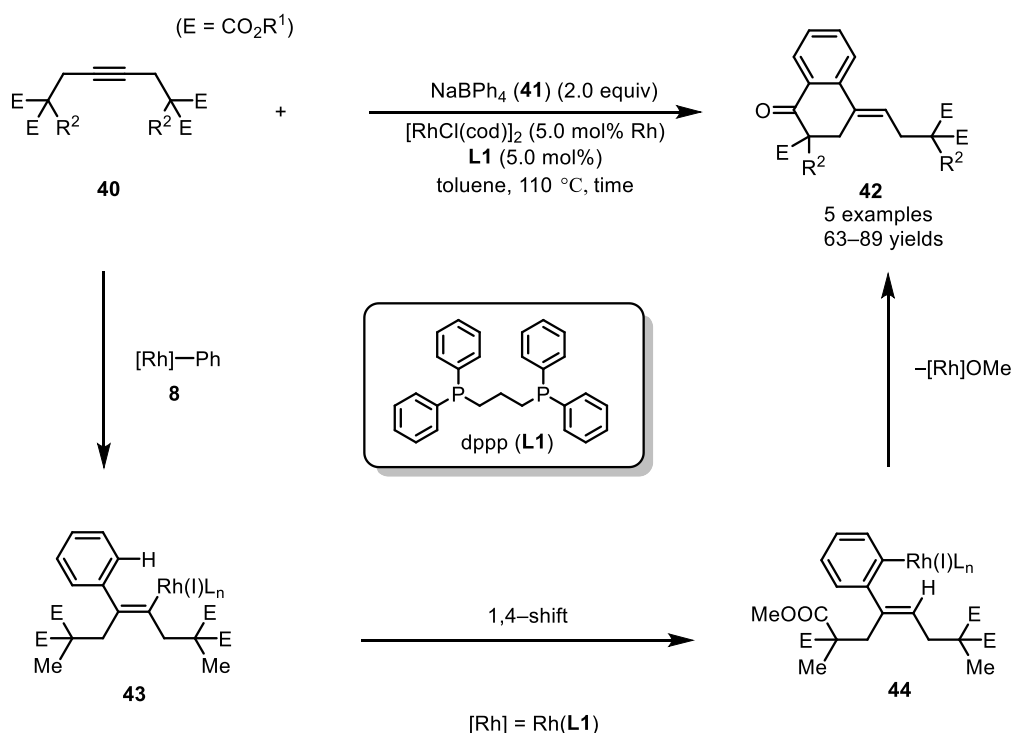


圖 2-5 Murakami 教授利用一價銨金屬 1,4-轉移進行合環反應

去對稱化(desymmetrization)於 IUPAC 金皮書的定義為使前掌性化合物丟失一個或一個以上的對稱元素之反應。去對稱化使一個簡單的具對稱結構之分子建構出立體中心，為一種有效率的反應策略。例如 2013 年，Lautens 教授發表利用一價銨金屬及雙烯配基 **L5** 生成之催化劑將前掌性的環己二烯酮化合物 **45** 去對稱化並生成環化產物 **46** 的合成方法。共 24 個例子，產率為 29–73%，鏡像選擇性為 48–90% ee。其反應機構如圖 2-5，芳基銨中間體 **47** 加成至環己二烯酮 **45** 的三鍵上形成中間體 **48**。中間體 **48** 中的烯基銨接著加成至環己烯酮的雙鍵上形成中間體 **49**，並經質子化後生成化合物 **46**。此反應生成兩個碳—碳鍵及建立兩個立體中心，為銨金屬催化反應去對稱化生成高掌性產物的例子之一。^[7]

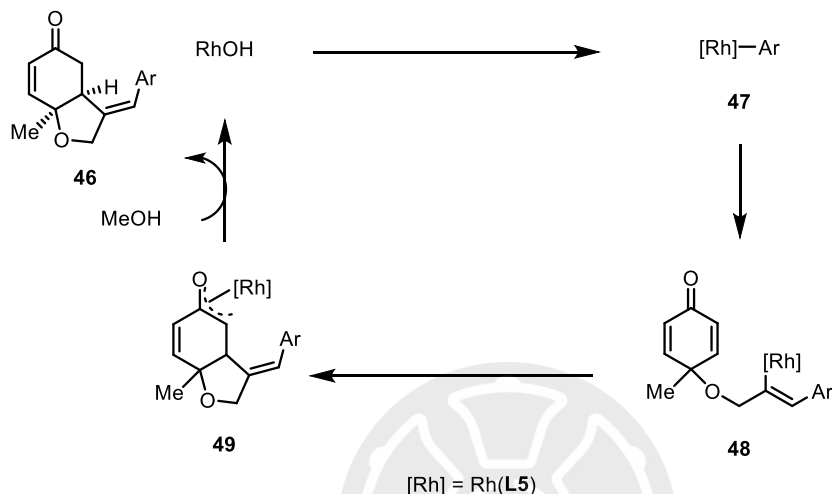
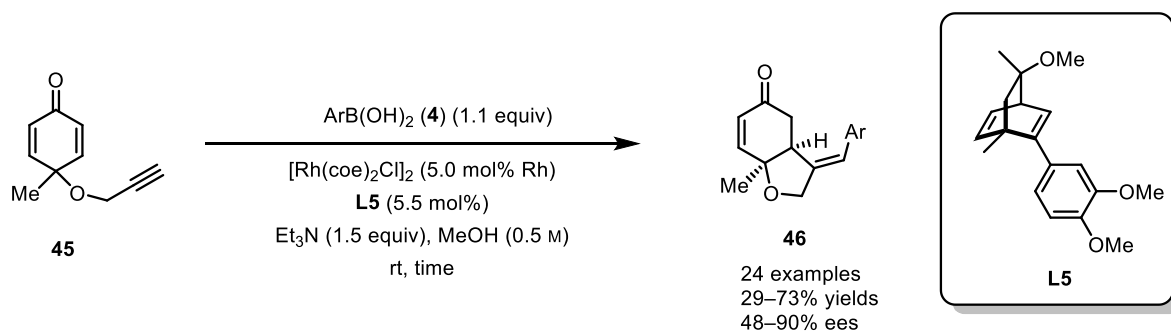


圖 2-6 Lautens 教授使用一價銨金屬催化環己二烯酮 **45** 的去對稱化反應

2020 年 Darses 教授與其團隊利用一價銨金屬催化將前掌性含炔類取代基的雙酮化合物 **50** 與芳基硼酸 **4** 進行不對稱加成合環反應，形成一系列具兩個四級碳立體中心的四氫萘醇(tetralol)產物 **51**，有 28 個例子，產率為 77–99%，鏡像超越值為 74–92%。參考其先前研究，三鍵化合物芳香環取代基的差異會影響加成的區域選擇性(regioselectivity)，起始物 **50** 因而選擇三氟甲基作為取代基。反應機構為一價銨金屬與硼酸轉移金屬化反應後形成芳基銨中間體，並具區域選擇性的插入三鍵化合物得中間體 **52** 後，經由 1,4-轉移至苯環形成中間體 **53**。此中間體最終進行 1,2 加成反應形成中間體 **54**，質子化後得到具兩個四極碳掌性中心的四氫萘醇產物 (圖 2-7)。^[8]此為結合銨金屬 1,4-轉移及金屬催化去對稱化的文獻。

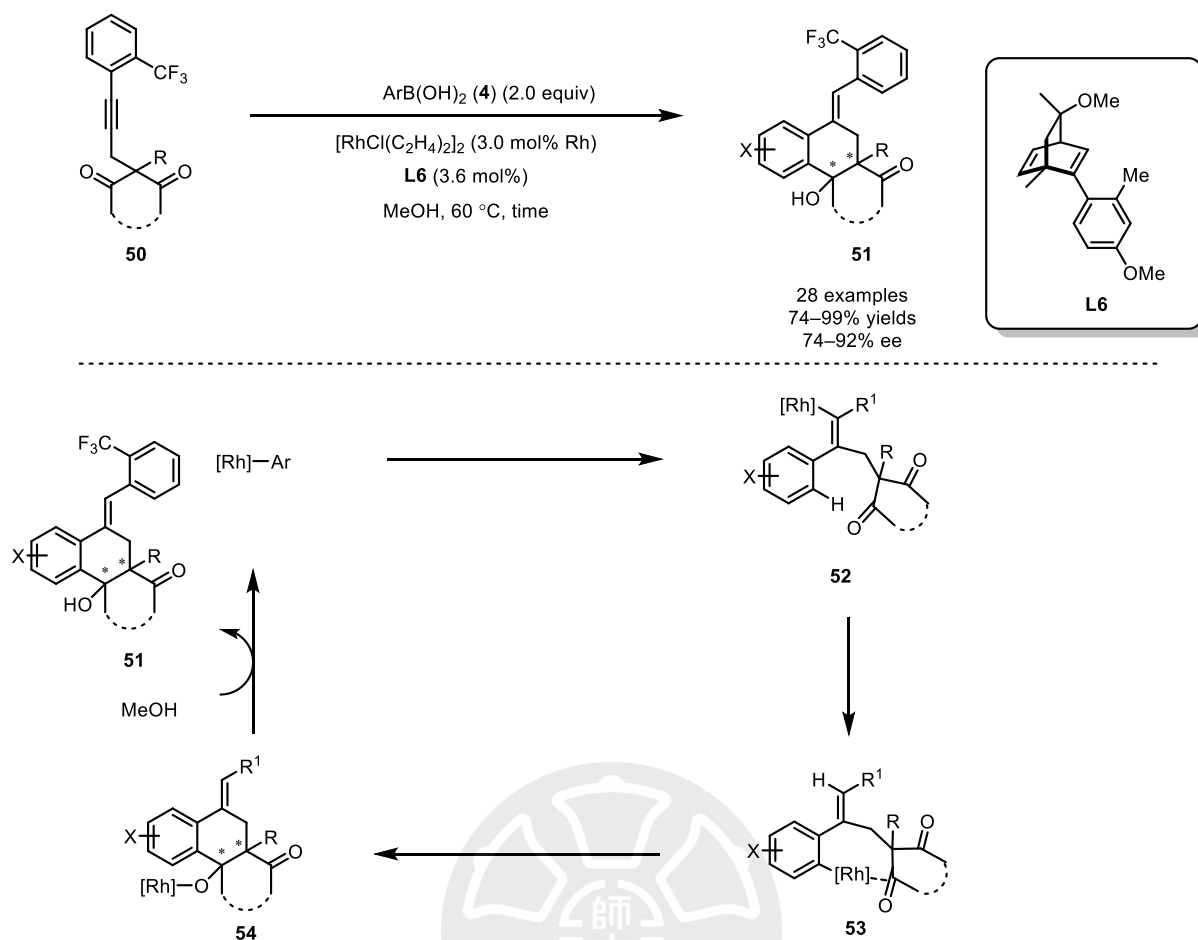


圖 2-7 Darses 教授對炔化合物 **50** 進行銨金屬催化去對稱化合環反應

綜合以上數篇關於銨金屬 1,4-轉移之文獻，多數銨金屬 1,4-轉移反應的例子傾向形成芳基銨(arylrhodium)中間體，原因為苯環的電子能穩定此中間體，有此可推得銨金屬較難轉移並停留至一般的 sp^3 結構。

2012 年 Hayashi 教授對於一價銨金屬催化雙苯乙烯硼酸(diphenylethenyl bornic acid, **56**)加成至環己烯酮(cyclohexanone, **55**)的反應進行密度泛函理論計算(DFT)。計算得知經 1,4-轉移之芳基銨中間體 **62** 的能量較烯基銨中間體 **58** 低，所以反應傾向進行 1,4-轉移。且氧化加成過度態 **59** 與烯基銨加成至環己烯酮形成的過度態 **68** 之自由能較還原消去過度態 **61** 與苯基銨加成至環己烯酮形成的過度態 **64** 自由能差大，故若苯基銨中間體 **62** 發生逆反應回至烯基銨中間體 **58**，其與 **68** 的高能量差也會使得反應往形成苯基銨中間體 **62** 移動，並生成能量較低化合物 **57**，佐證銨金屬 1,4-轉移為熱力學穩定結果 (圖

2-8)。[9]

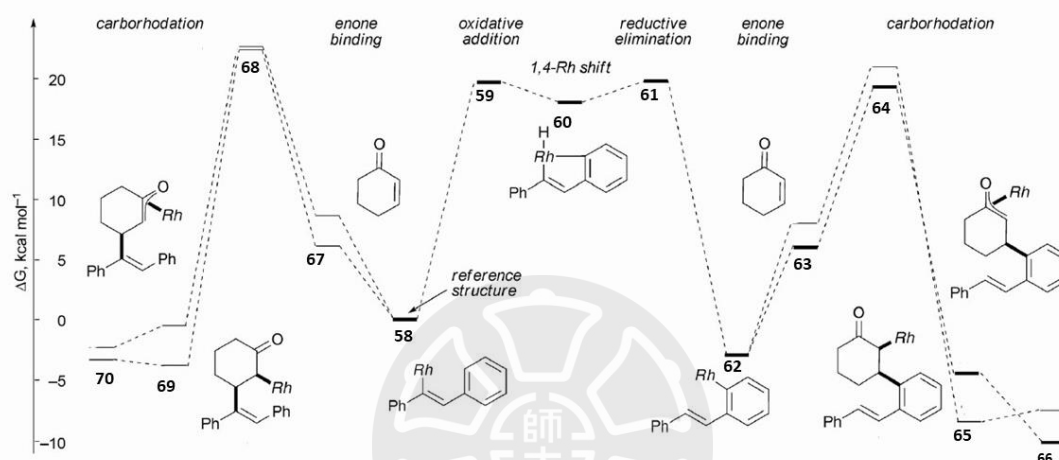
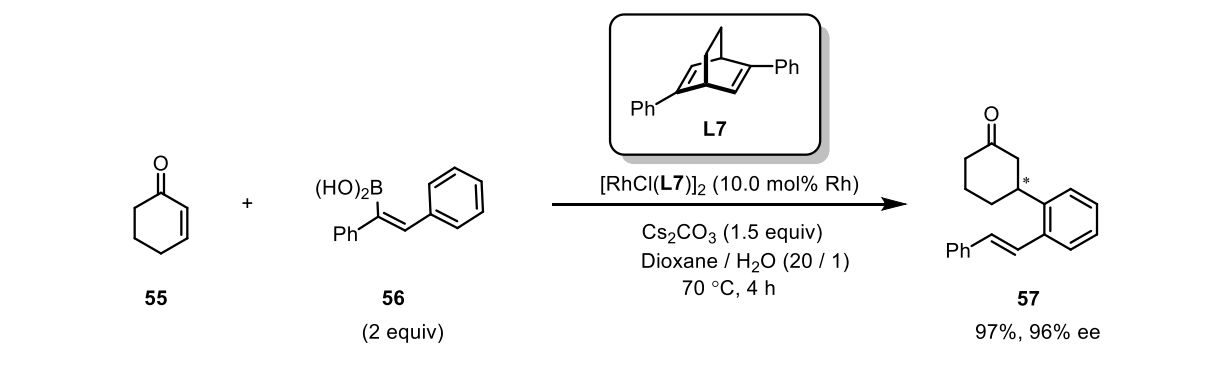


圖 2-8 Hayashi 教授對烯基銨轉移成芳基銨之反應進行 DFT 計算

雖已知苯基銨為一穩定及高反應活性之中間體，學界仍致力於突破此限制，期望開發出利用烷基銨的反應。2017 年 Lam 教授在一價銨金屬的催化下，烯炔酮化合物 (enynone) **71** 與芳基硼酯 **72** 進行去對稱化分子內合環反應，形成一系列具雙環[4.3.0]的結構。其反應機構為芳基硼酯與一價銨金屬進行金屬轉移後，插入化合物 **71** 之三鍵，形成烯基銨(alkenylrhodium)中間體 **74**，隨後進行 1,4 轉移形成烯丙基銨(allylrhodium)中間體 **75**，接著銨金屬進行分子內合環，質子化形成化合物 **73**。此反應設計為芳基硼酸上苯環 3,5 號位具取代基團阻擋 1,4-轉移至苯環，及多電子的烯丙基形成穩定的中間體，促使銨金屬由 sp^2 的 alkenyl 轉移至 sp^3 的 allyl 位，最後，親電性的羰基結構捕捉烯丙基銨，使反應順利進行。此文獻突破銨金屬 1,4-轉移常態，利用立體障礙效應及多電子的烯丙基位，生成烯丙基銨中間體。^[10]此文獻為銨金屬 1,4-轉移及分子內去對稱化的結合應用 (圖 2-9)。

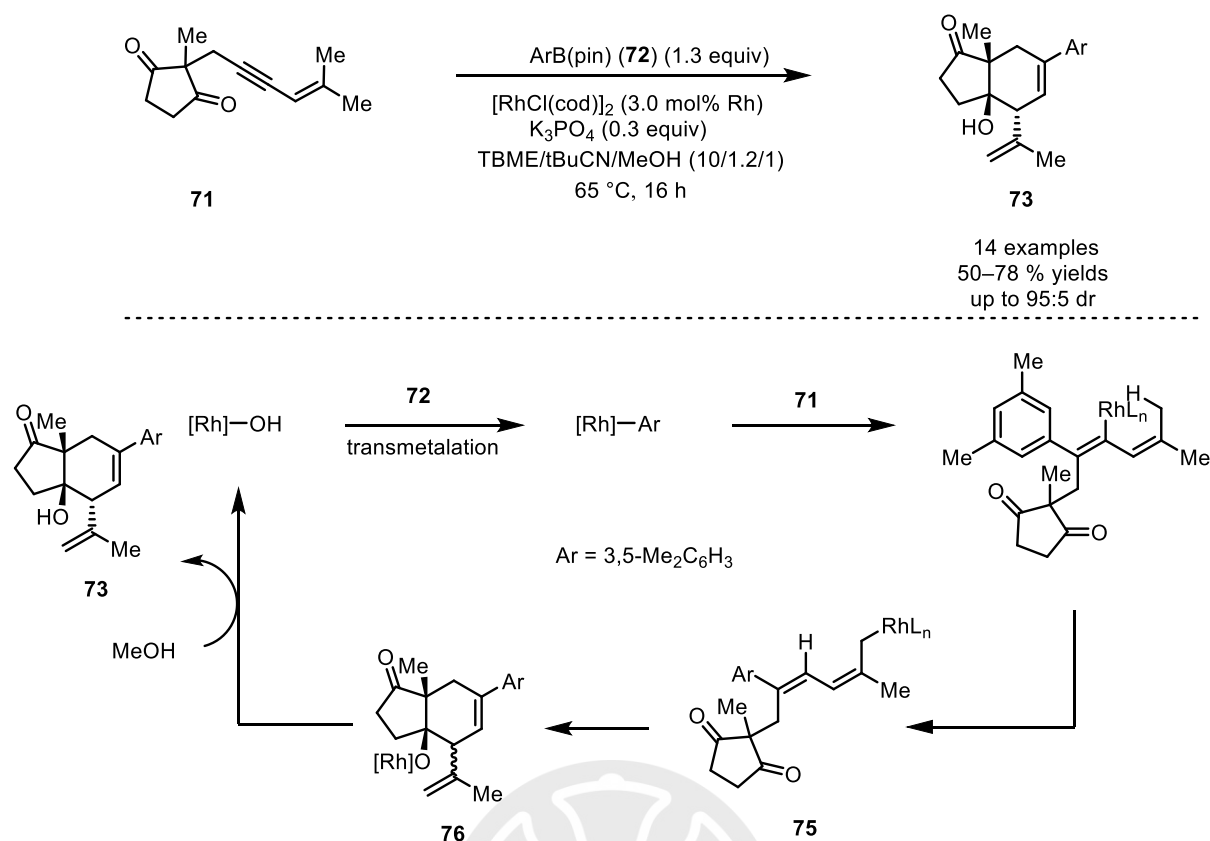


圖 2-9 Lam 教授對烯酮化合物 **71** 進行銨金屬催化去對稱化合環反應

β -醇鹽消去在銨金屬催化反應中的文獻最早可追溯至 2002 年由 Murakami 教授及其團隊利用一價銨金屬將芳基硼酸加成至降冰片二烯衍生物 **77** 的反應。首先芳基硼酸 **4** 和一價銨金屬與 **L8** 形成之催化劑進行金屬交換反應後加成至降冰片二烯衍生物 **77** 並形成生成中間體 **78**，接著進行分子內 β -醇鹽脫去生成中間體 **79**，質子化後形成產物 **80**。共 9 個例子，其產率為 53–94% (圖 2-10)。^[11]

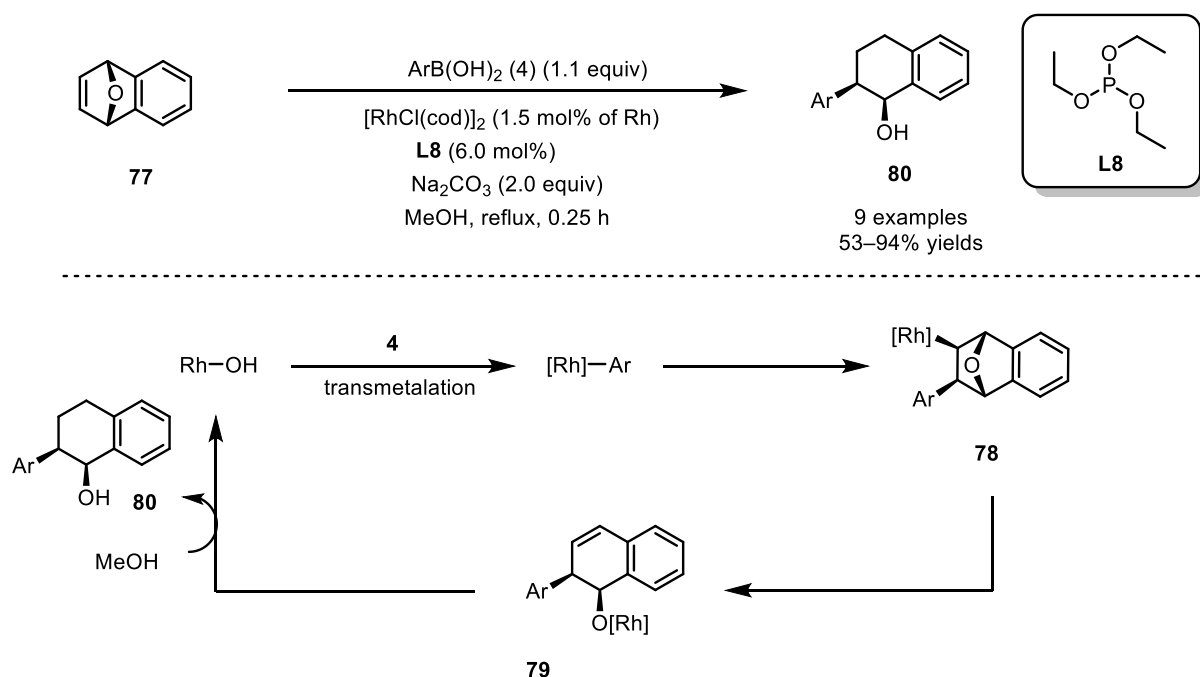


圖 2-10 Murakami 教授首度於銑金屬催化反應中應用 β -消去手段

2005 年 Murakami 教授及其團隊使用一價銑金屬催化前掌性 1,6-烯缺(1,6-enyne)化合物 **81** 及芳基硼酸 **4**，進行加成及合環反應，形成一系列去五員環產物 **82**。有 18 個例子，產率為 25–82%，大於 95:5 的鏡像異構物比例 (diastereomeric ratio)。其反應機構首先為芳基硼酸 **4** 與一價銑金屬經金屬轉移化得芳基銑中間體，其具區域選擇性的加成於三鍵形成烯基銑中間體 **83**，接著銑金屬以 5-*exo*-trig 形式加成至雙鍵上，形成烷基銑中間體 **84**，緊接銑金屬進行 β -醇鹽消去，即得環戊烷(cyclopentane)化合物 **82**。^[12]此文獻提供一個不需添加劑，僅利用反應物本身離去基結構使得銑金屬回至下一個催化循環的想法。(圖 2-11)

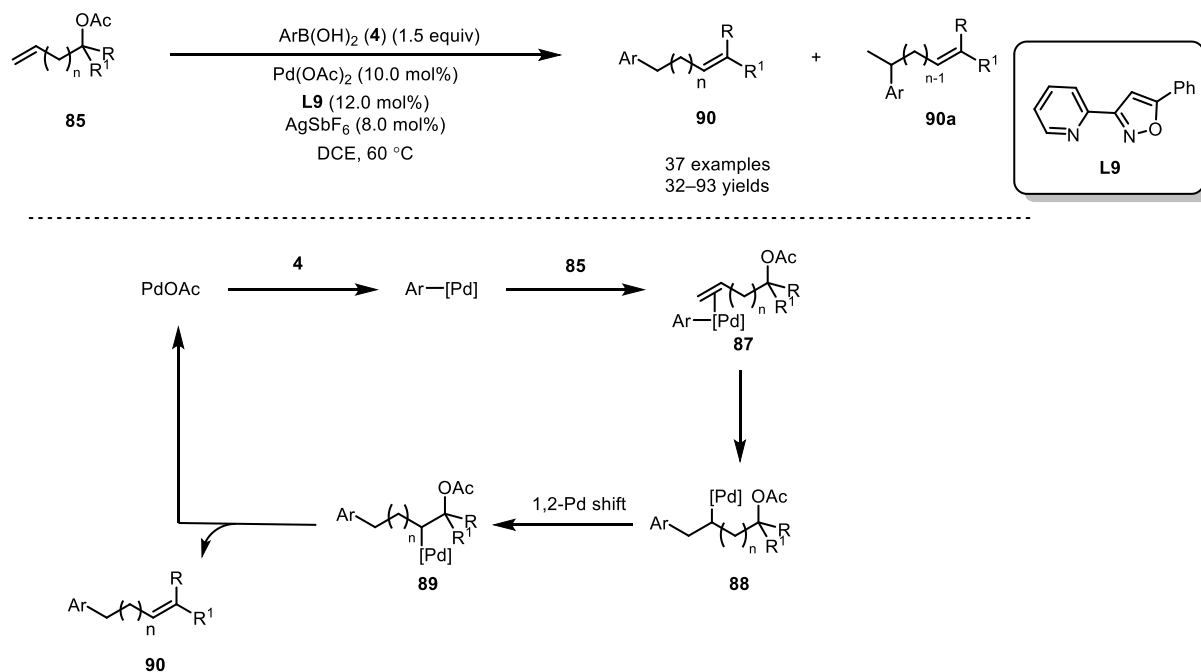


圖 2-12 Kochi 教授利用鈀催化烯基化合物 **85** 的芳基化及雙鍵異構化反應

綜合以上文獻，可以得知烷基鈀化合物相較苯基鈀化合物為一較不穩定之中間體，該如何誘發鈀金屬轉移至烷基上是一大考驗。另外， β -消去不僅能使鈀金屬催化反應條件簡單化，還有誘發反應行特定方向的效用，這些特性給予我們實驗設計的方向。

第三章 實驗設計

為突破目前銻金屬 1,4-轉移的領域，本論文嘗試設計一個能使一價銻金屬由苯基銻中間體轉移至烷基銻中間體的起始物。經由前述文獻可以得知，能進行 β -elimination 的醇鹽(alkoxide)不僅是一個良好的引導基團，其脫去後能與銻金屬形成銻醇鹽中間體，此中間體能使催化反應順利循環。因此我們設計了一個簡單的外消旋結構(圖 3-1)—苯基之 1 號碳預計為一個得以藉金屬轉移化引入一價銻金屬之金屬試劑；苯基之 2 號碳上接了一個異戊烷，其兩頭為醚類之結構。此設計限縮銻金屬的反應路徑，促使銻金屬進行 1,4-轉移及消去並生成立體中心為唯一之反應。

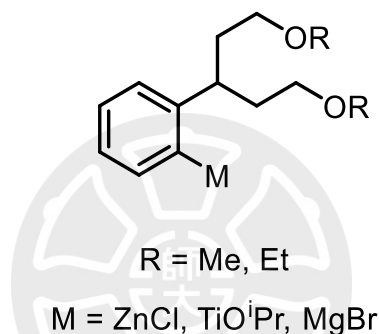


圖 3-1 起始反應物結構設計

第四章 實驗結果與討論

首先使用末端為乙醇基醚取代基之化合物 **92ae** 並製備成不同金屬試劑進行初步測試，由 1.5 mol% 的一價銨金屬二聚體 ($[\text{RhCl}(\text{coe})_2]_2$) 與 3.6 mol % 的 (*S*)-Segphos 雙磷配基 (**S**)-**L10** 形成的催化劑，在溫度 30 °C 且使用四氫呋喃為溶劑的條件下，進行去對稱化反應，可以得到一側乙基醇鹽 β 消去生成末端雙鍵之產物 **94ae**。由於金屬試劑在有水的環境中會立即被淬滅(quench)，導致無法有效利用薄層層析技術 (thin-layer chromatography) 追蹤反應，因此將反應時間固定為 6 小時。接下來，針對金屬試劑、配基、溫度，分別進行探討，期望篩選出最佳的反應條件。

一、金屬試劑之篩選

首先嘗試將化合物 **92ae** 製備成有機鋅金屬試劑再以一價銨金屬去對稱化反應。其製備方法如圖 4-1 所示，在 -78 °C 下將 **92ae** 之四氫呋喃溶液加入 0.9 當量正丁基鋰，反應 1 小時後，加入配置好的 1.3 當量 1 M 氯化鋅溶液，並將反應移至室溫反應 1 小時。金屬試劑濃度的測定方法為使用過當量的碘苄滅已知體積金屬試劑，並藉由內標準法於 ^1H NMR 光譜中推算其濃度。銨金屬催化劑催化反應的操作方式為，將 $[\text{RhCl}(\text{coe})_2]_2$ (3.0 mol% of Rh) 與雙磷配基 (**S**)-**L10** (3.6 mol%) 溶於 0.1 毫升四氫呋喃並攪拌直至顏色呈現酒紅，加入製備好之金屬試劑進行一價銨金屬催化反應，反應 6 小時後，透過 ^1H NMR 光譜分析粗產率為 5% (表 4-1, entry 1)。於本實驗室博士生蔡宇軒未發表之研究成果得知將化合物 **92ae** 製備成有機鈦金屬試劑時，其產物 **94ae** 產率提升至 26%，鏡像選擇性為 70% (表 4-1, entry 2)。

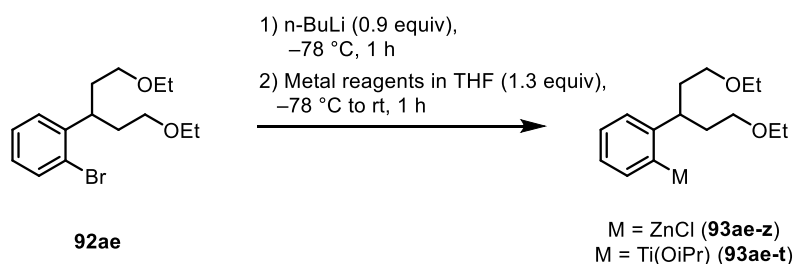
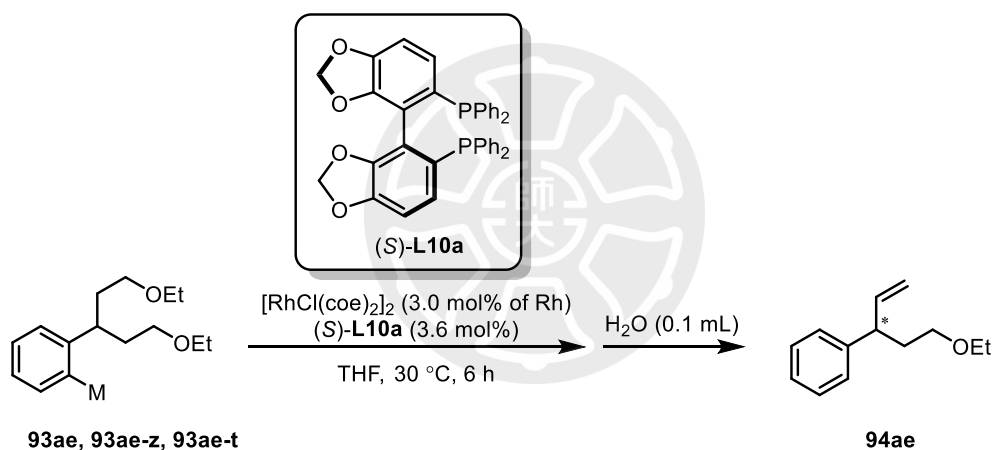


圖 4-1 試劑 **93ae-z** 及 **93ae-t** 製備

因為由有機鋰試劑製備成有機鋅及有機鈦試劑相對較不容易，恐造成反應的變數，又其反應結果不佳，因此嘗試製備成格任亞試劑並進行一價銨金屬催化反應。其製備方法為：一部分起始物 **92ae** 添加至含 1.3 當量鎂帶與四氫呋喃之反應瓶中，待其反應啟動，緩慢滴加剩餘起始物，並在室溫中反應 1 小時。其有機鎂試劑濃度測定同樣使用過量碘苄滅並經由 ^1H NMR 光譜配合內標準法推算其濃度。值得注意的地方是，格任亞試劑為一不均勻液體，使用時須確保溶液為均勻狀態。在相同的反應條件中以格任亞試劑做為一價銨金屬催化反應之起始物，其反應後生成產物 **94ae** 產率提升至 99%，鏡像選擇性為 95% (表 4-1, entry 3)。因此選擇將化合物 **92ae** 製備成格任亞試劑來進行後續一價銨金屬催化去對稱化之反應的條件探討。

表 4-1 金屬試劑之篩選



Entry	Metal Reagent	Isolated Yield (%)	ee (%) ^[b]
1	ZnCl ₂	5 ^[c]	-
2	TiCl(O ^{<i>i</i>} Pr) ₃	26	70
3	MgBr	99	95

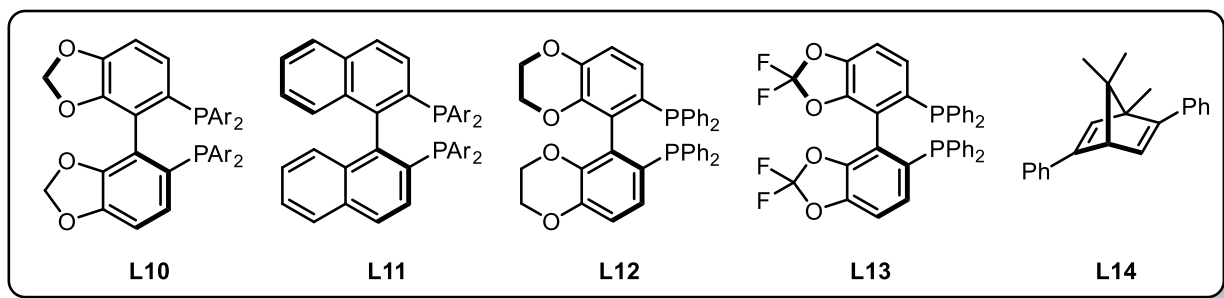
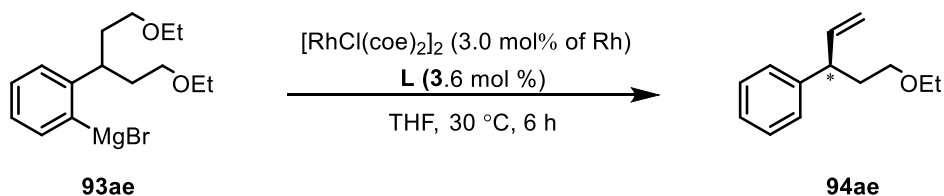
[a] The reaction was conducted with **93ae**, **93ae-z**, **93ae-t** (0.2 mmol) in the presence of *in situ* generated rhodium complex by $[\text{RhCl}(\text{coe})_2]_2$ (3 mol% Rh) and **(S)-L10a** in THF at 30 °C

[b] Determined by HPLC analysis. [c] Based on crude ^1H NMR analysis using 3,4,5-trimethoxy-benzaldehyde as an internal standard.

二、配基效應的探討

決定以格任亞試劑作為起始反應物後，緊接著針對以下幾種市售可得的軸掌性雙膦配基及掌性雙環 [2.2.1]雙烯配基來進行去對稱化的反應性測試，其結果列於表 4-2。由結果可以得知，原先使用(*S*)-Segphos ((*S*)-**L10a**)配基與一價銦金屬二聚體錯合生成催化劑，在 30 °C 下反應 6 小時，生成產物 **94ae** 的產率為 99%，鏡像超越值為 95% (entry 1)。當使用磷原子上芳基取代基 3,5 號位為甲基取代基的(*R*)-**L10b** 及有更大立體阻礙之取代基(*R*)-**L10c**，得到去對稱化產物的產率下降至 61%及 26%，鏡像超越值更下降至 90%及 20% (entry 2 and 3)。由此可知，當配基磷原子上的取代基過於擁擠，會造成此反應反應性及立體選擇性的下降。由(*S*)-**L11a** 及(*R*)-**L11b** 之反應亦可印證此推論(entry 4 and 5)：當使用(*S*)-**L11a** 配基產率可達 95%，其鏡像超越值為 93%。但嘗試使用掌性雙膦配基之磷原子上芳基為 3,5 號位甲基取代基的(*R*)-**L11b**，反應後產物 **94ae** 產率下降至 75%，鏡像超越值也下降至 88%。接著使用苯環上具 1,4-二噁烷骨架的配基(*S*)-Synphos ((*S*)-**L12**) 發現反應後產物 **94ae** 產率下降至 65%，鏡像超越值為 93%。當使用具有 4 個氟原子取代的(*S*)-**L10a** 架構之配基 (*R*)-Difluorophos ((*R*)-**L13**) 則發現產物產率僅有 57%，鏡像超越值更僅有 2%。此外使用掌性雙環 [2.2.1]雙烯配基 **L14**，則發現反應性顯著地下降，其產率僅有 11%，鏡像超越值為 3，接近消旋。當不額外添加掌性配基，反應則可得 53% 近乎外消旋的產物。綜合以上結果，最後選擇使用(*S*)-Segphos((*S*)-**L10a**)配基進行後續的實驗探討。

表 4-2 配基之篩選^[a]



Entry	L	Ar	Isolated Yield (%)	ee (%) ^[b]
1	(S)- L10a	C ₆ H ₅	99	95 (<i>R</i>)
2	(<i>R</i>)- L10b	3, 5-Me ₂ -C ₆ H ₃	61	90 (<i>S</i>)
3	(<i>R</i>)- L10c	3, 5- <i>t</i> Bu-4-MeO-C ₆ H ₂	26	20 (<i>S</i>)
4	(S)- L11a	C ₆ H ₅	95	93 (<i>R</i>)
5	(<i>R</i>)- L11b	3, 5-Me ₂ -C ₆ H ₃	75	88 (<i>S</i>)
6	(S)- L12	-	65	93 (<i>R</i>)
7	(<i>R</i>)- L13	-	57	2 (<i>S</i>)
8	L14	-	11	3
9	w/o L	-	53	2

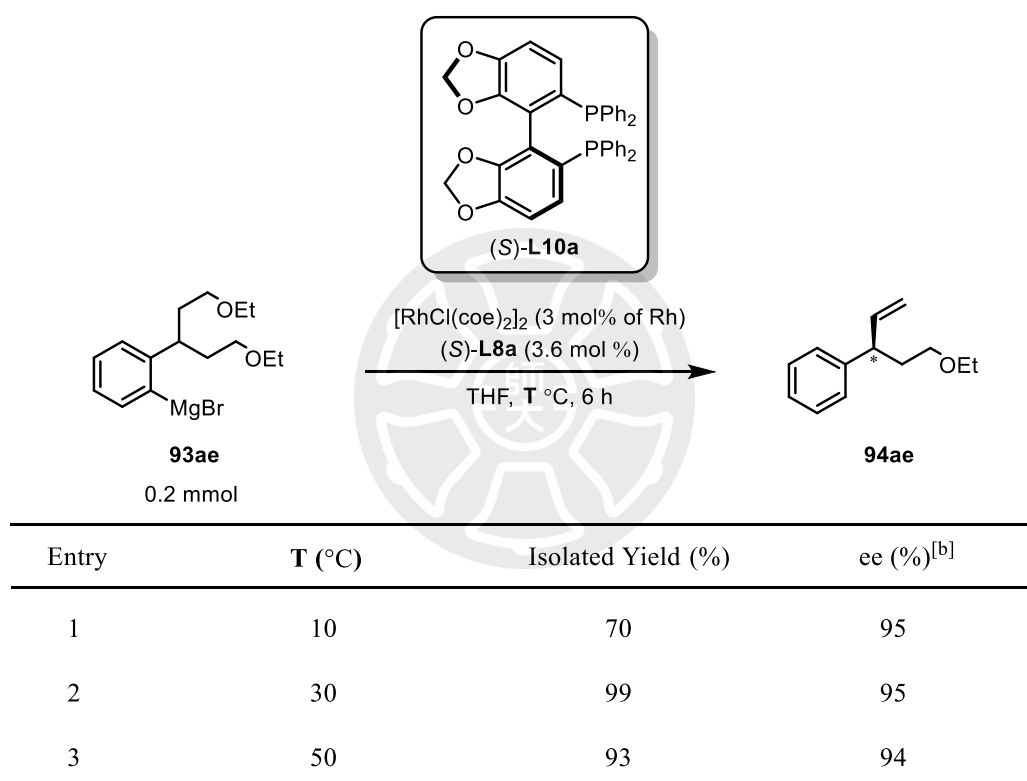
[a] The reaction was conducted with **93ae** (0.2 mmol) in the presence of *in situ* generated rhodium complex by [RhCl(coe)₂]₂ (3 mol% Rh) and **Ligand** in THF at 30 °C.

[b] Determined by HPLC analysis.

三、反應溫度的優化

篩選出有利的配基為(S)-L10a 後，針對反應溫度進行探討，其結果列於表 4-3。首先嘗試將溫度從 30 °C 降至 10 °C (entry 1)，產物 **94ae** 鏡像選擇性雖與 30 °C 下反應相同，但反應性卻遠遠不及，因此不選擇將反應溫度降低。接著嘗試升高反應溫度至 50 °C (entry 3)，其產率為 93%，鏡像超越值為 94%。其反應結果看似與 30 °C 下反應相似，但考慮產物為較不穩定的末端雙鍵結構，最終選擇維持 30 °C 為反應溫度。

表 4-3 反應溫度的優化^[a]



四、在最佳化條件下針對一系列進行反應性探討

經過前面一連串反應條件的優化後，最終篩選出的最佳化反應條件為：起始物格任亞試劑 **93ae** 經由 1.5 mol % 的一價銨金屬二聚體($[\text{RhCl}(\text{coe})_2]_2$)和 3.6 mol % 的配基(*S*)-**L10a** 形成的催化劑，催化進行去對稱化反應，反應時間 6 個小時。接下來，在最佳化條件下，針對具不同取代基及不同醇鹽離去基之芳基格任亞試劑參與反應時的反應性進行探討。(表 4-4)

首先使用離去基為甲氧基的格任納試劑 **93am** 進行反應，在最佳化條件下反應 6 小時，得到產物 **94am** 產率為 87%，鏡像超越值為 96%。與 **94ae** 進行比較，有著相似的鏡相超越值(95%)，稍下降的產率推測由於 **94am** 沸點較低，可能於純化步驟上揮發並損失其產率。

接著使用苯環 5 號位具不同烷氧基取代之格任亞試劑 **93bm**, **93cm**, **93ce**, **93dm** 進行反應，反應 6-12 小時可以發現，去對稱化產物 **94bm**, **94cm**, **94ce**, **94dm** 的產率(80%–33%)及鏡像超越值皆有下降的趨勢(75% ee–92% ee)，推測由於推電子基效應，使得取代基對位為多電子環境，苯基銨不易轉移至烷基上，進而影響產率。降低的鏡相超越值則推測由於立體障礙增加，使得鏡像選擇性降低。

使用苯環 5 號位具不同拉電子基取代之格任亞試劑 **93em**, **93ee**, **93fm**, **93fe**, **93gm**, **93ge** 進行反應，反應 12 小時，可以發現由鹵素取代的 **94em**, **94ee**, **94fm**, **94fe** 產率皆明顯下降(45%–10%)，而鏡像超越值的部分甲氧基為離去基之例子皆較乙氧基來得低(**94ee**, **94fe**)，推測由於甲氧基較易離去，造成鏡像選擇性較差。至於三氟甲基取代的 **94gm**, **94ge** 皆有較高的產率(88%, 85%)，**94gm** 的鏡像超越值也高達 99%。

接著表 4-5 探討苯環 4 號位具不同拉電子基取代之格任亞試劑 **93hm**, **93he**, **93im**, **93ie**, **93je** 在經過 12 小時的反應結果。可以發現其具有良好的產率(58%–81%)，其鏡像選擇性也保持在 (86% ee–93% ee)。

由苯環 4 號位具推電子取代基之格任亞試劑 **93km**, **93ke**, **93le**，在經過 6 小時的反應，其產物皆有良好的產率(71%–90%)，而鏡像選擇性則有(85% ee–97% ee)。探究其原因

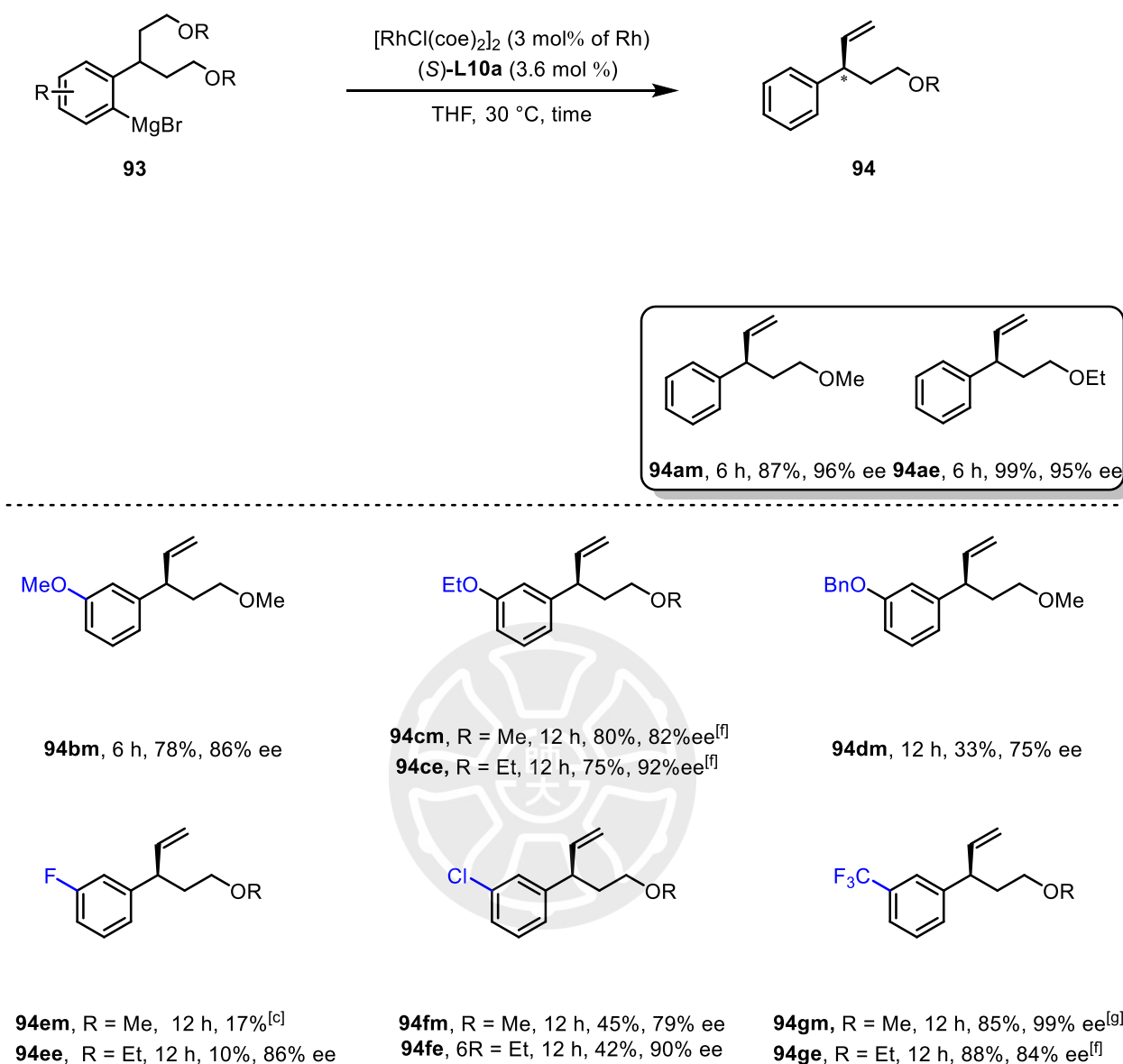
為推電子基間位之電子密度較為低，故苯基銦中間體得以轉移至烷基上。

而化合物 **94me** 則探討苯環立體障礙對於反應的影響，由其產率(13%)及還不錯的鏡相選擇性(86% ee)可以得知立體障礙也為影響反應進行的一大要素。

綜合以上結果，反應大致上吻合推拉電子基影響苯環共振的要素。若取代基使溴化鎂所在碳上電子密度高，進一步穩定苯基銦中間體，導致反應性降低。倘若溴化鎂所在碳上電子密度低，則有助於銦金屬 1,4-轉移的進行。烷氧基的差異則影響鏡像選擇性，幾乎所有乙氧基的例子其鏡像超越值皆優於甲氧基，推測 β -醇鹽消去與建構鏡像選擇性有一定的相關性。



表 4-4 苯環 5 號位取代基效應之探討^{[a][b]}



[a] The reaction was conducted with **93ae** (0.2 mmol) in the presence of *in situ* generated rhodium complex by $[\text{RhCl}(\text{coe})_2]_2$ (3 mol% Rh) and **(S)-L10** in THF at 30 °C.

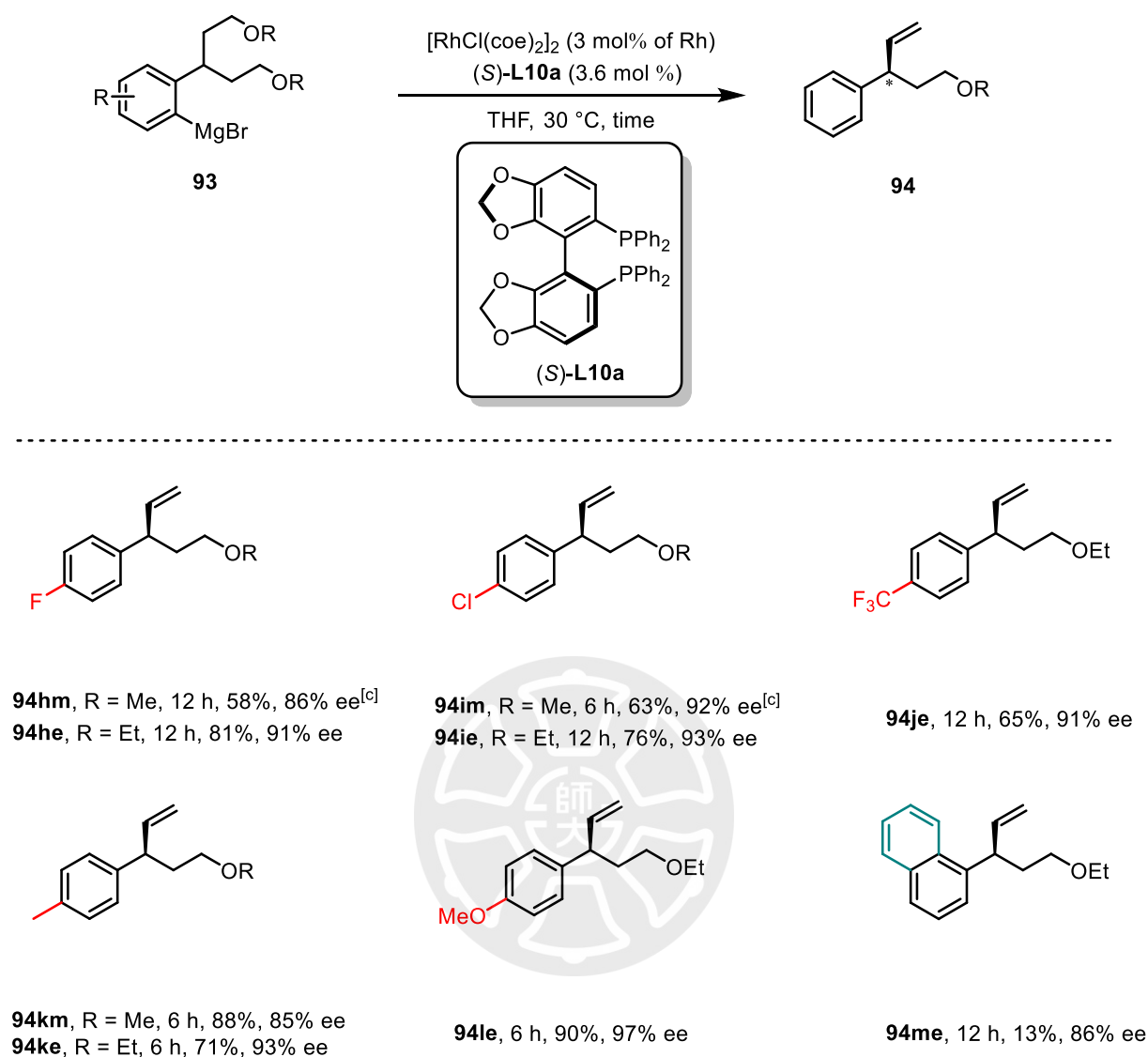
[b] Enantiomeric excess was determined by HPLC analysis. [c] Enantiomeric have not been determined.

[d] Based on crude ¹H NMR analysis using 3,4,5-trimethoxy-benzaldehyde as an internal standard.

[e] $[\text{RhCl}(\text{coe})_2]_2$ (6.0 mol%), **(S)-L8** (7.2 mol%). [f] Enantiomeric excess was determined by HPLC

analysis after hydroboration oxidation. [g] Purified by gel permeation chromatography.

表 4-5 苯環 4 號位取代基效應之探討^{[a][b]}



[a] The reaction was conducted with **93ae** (0.2 mmol) in the presence of *in situ* generated rhodium complex by $[\text{RhCl}(\text{coe})_2]_2$ (3 mol% Rh) and (S)-**L10** in THF at 30 °C.

[b] Enantiomeric excess was determined by HPLC analysis.

[c] Enantiomeric excess was determined by HPLC analysis after hydroboration oxidation.

第五章 立體結構與反應機構之探討

一、化合物 **94am** 絕對立體組態之探討

為鑑定本論文探討的一價銠金屬催化之去對稱化反應所產生之化合物 **94am** 的絕對立體組態，故將液狀化合物 **94am** 進行衍生化，以求產生固體便於再結晶後，晶體可進行 X 光單晶繞射解析，確認立體組態。方法如圖 5-1 所述，首先利用催化量的 RuCl_3 及過碘酸鈉進行氧化反應生成羧酸化合物 **94am-1**，再利用 (*R*) 組態之 2-苯基乙胺使之生成羧酸胺鹽化合物 **94am-2**。此鹽類化合物利用乙醚再結晶，數次後即得白色針狀固體。由 X 光單晶繞射解析得知 **94am-2** 羧酸部分的立體組態為 (*S*)，由於衍生化後基團順序的改變，回推起始物 **94am**，將其組態定義為 (*R*)。

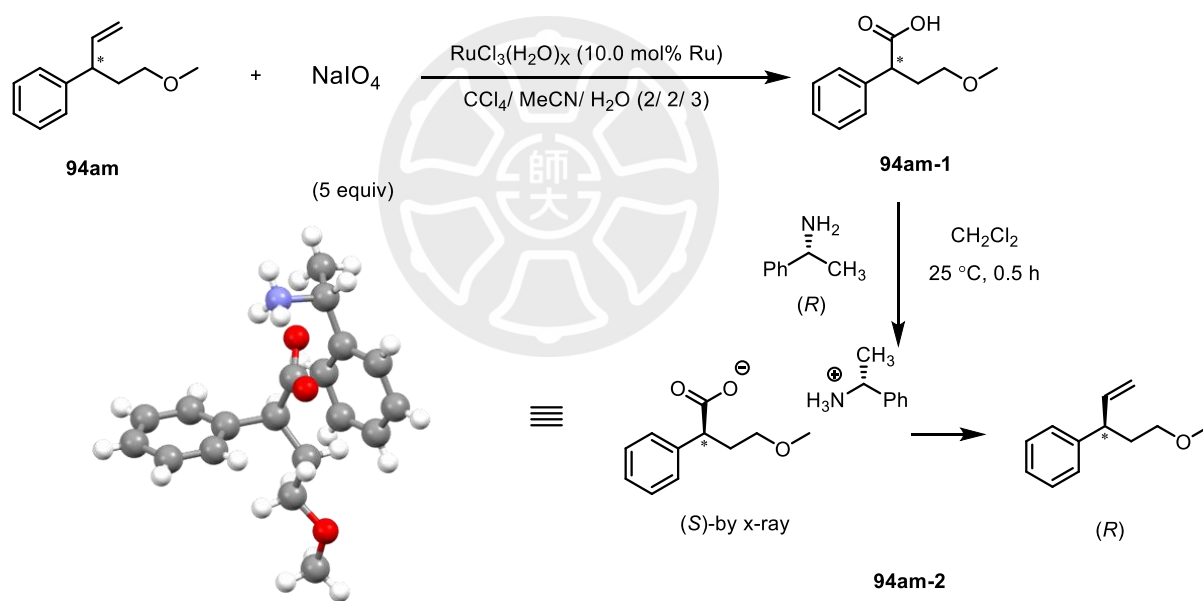


圖 5-1 羧酸銨鹽 **94am-2** 合成途徑及其 ORTEP

二、反應機構探討

圖 5-2 為本反應的推測反應機構：起始物格任納試劑 **93** 經由金屬交換反應形成的中間體 **95**，經由 1,4-轉移選擇性地轉移至 *pro-R* 的碳鏈上形成中間體 **96**，最後利用 β -烷氧基消去生成具高鏡相選擇性產物。但以上推測需經由實驗佐證其正確性，此假設方能成立。為了釐清銨金屬的 1,4-轉移是否為一個可逆反應，及銨金屬 1,4-轉移至碳鏈上時是否為鏡像選擇的關鍵步驟，我們設計了於碳鏈 2 號及 4 號位有氘原子取代的格任納試劑 **93ke-4D**(圖 5-3)來進行銨金屬催化反應。

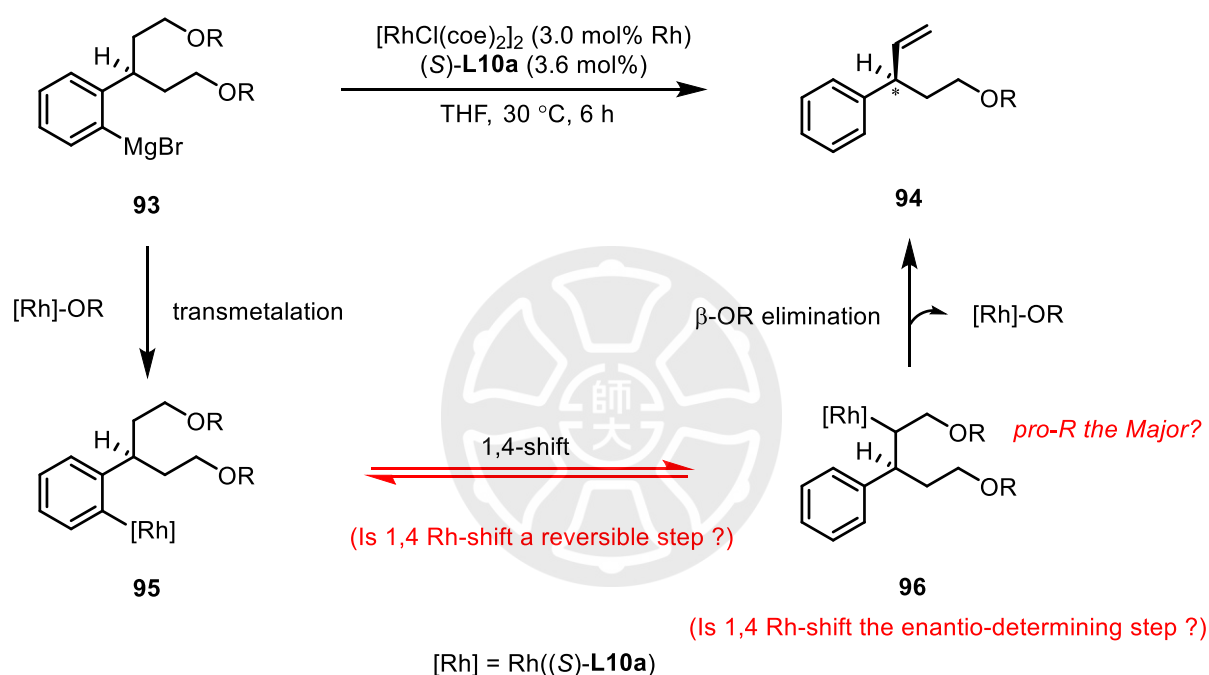


圖 5-2 本反應推測反應機構

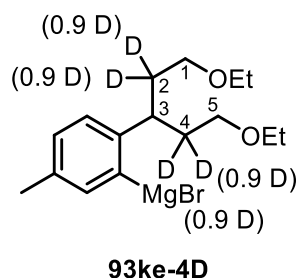


圖 5-3 反應物 **93ke-4D**

格任納試劑 **93ke-4D** 於 2 號及 4 號碳上將氫原子置換成氘原子，並有 90% 的置換率。預期此結構經催化反應後得到的產物 **94ke-4D** 得以證明：1) 銨金屬的 1,4-轉移是否發生 2) 銨金屬的 1,4-轉移在這個反應中為一個可逆反應與否 3) 銨金屬 1,4-轉移至烷基上是否為決定鏡相選擇性的關鍵步驟。實驗設計理念如圖 5-4。若反應確實經由銨金屬的 1,4-轉移，則銨金屬會與 2 號或是 4 號未上的氘原子進行交換並產生烷基銨中間體 **96ke-4D**，因此產物的苯環上將有氘原子的訊號，由苯環上的氘原子訊號證明銨金屬 1,4-轉移確實發生。除此之外，經由苯環上氘訊號的數量可以推測銨金屬的轉移是否為可逆反應。若烷基銨中間體 **96ke-4D** 再經由一次的銨金屬 1,4-轉移形成苯基銨中間體 **96ke-4D-1**，接著此中間體再進行一次銨金屬 1,4-轉移，形成烷基銨中間體 **96ke-4D-2**，此時苯環上整體的氘數量將大於 1，如中間體 **96ke-4D-2** 所示。另一方面，藉由觀察碳鏈中 2 號及 4 號碳殘存的氘原子數目，可以推測銨金屬是否傾向轉移至某一條碳鏈上，使銨金屬 1,4-轉移成為鏡像選擇性的決定性步驟。若銨金屬傾向轉移至 *pro-R* 的碳鏈上，會發現 *pro-S* 碳鏈上的氘原子維持與反應起始物 **93ke-4D** 相近的數目，如中間體 **96ke-4D** 所呈現的銨金屬未轉移的碳鏈維持 2 個氘原子的分布情況。

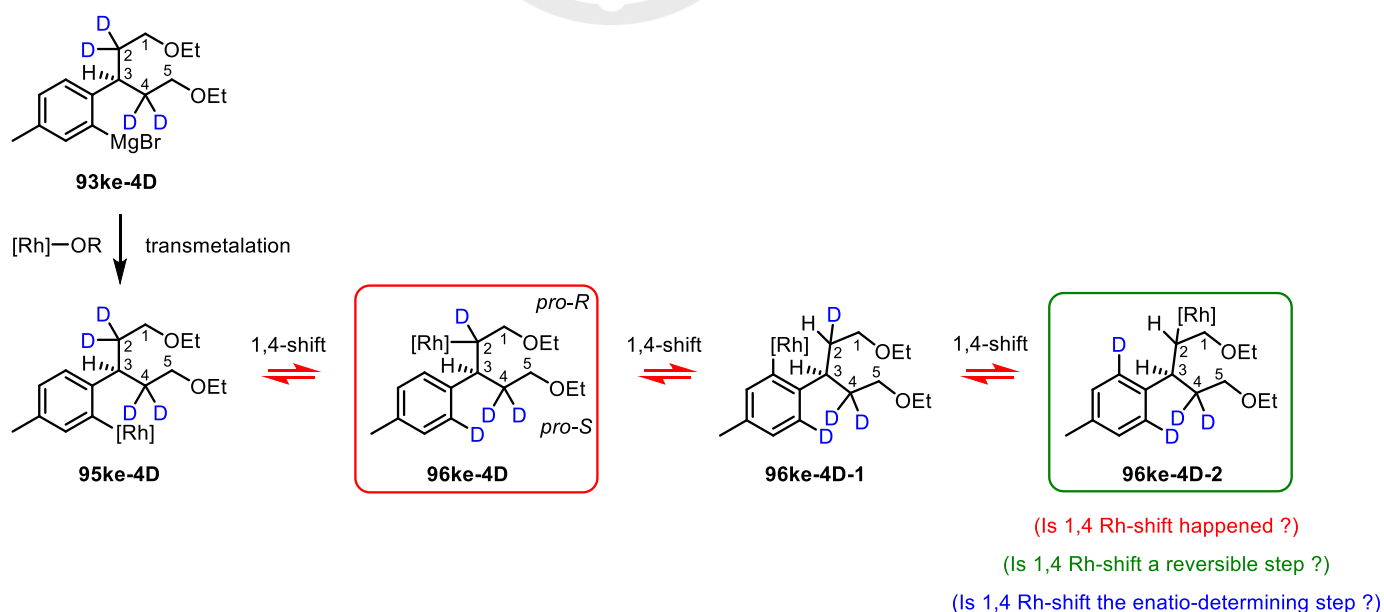
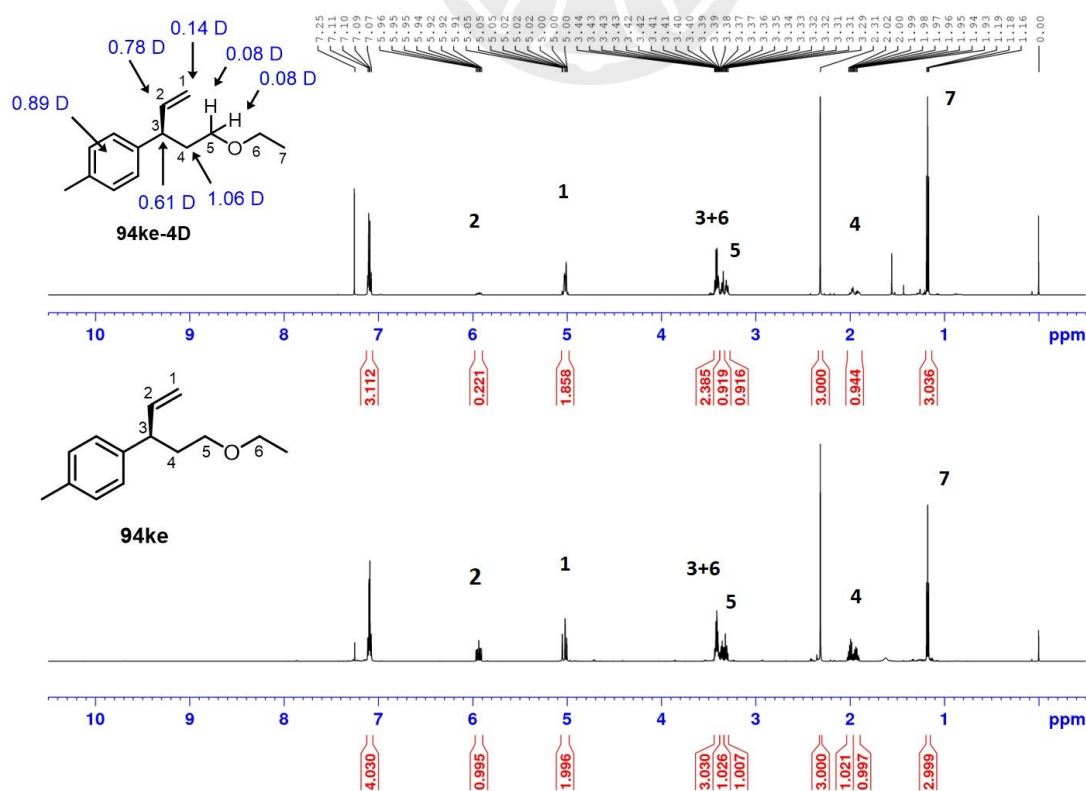


圖 5-4 反應物 **93ke-4D** 設計理念

以下分析格任納試劑 **93ke-4D** 在最佳反應條件下反應 6 小時的結果，反應得到產物

94ke-4D。首先，將 **94ke-4D** 與 **94ke** 的 600 Hz ^1H NMR 光譜進行比對如圖 5-5，由 **94ke-4D** 每一個峰相較 **94ke** 缺少的積分值確認氬原子的數量，可以發現苯環區的積分值為 3.11，因此確認苯環區有 0.89 個氬原子。由苯環區有氬原子的訊號證實反應曾利用銨金屬的 1,4-轉移產生中間體 **96ke-4D**。由於起始物 **93ke-4D** 2 號及 4 號碳僅有 90% 的氬原子，因此由苯環區氬原子的數量為 0.89 得以證明反應不曾經過中間體 **96ke-4D-2**，說明了銨金屬 1,4-轉移在此反應中不是一個可逆反應，銨金屬自苯環轉移至烷基後就不再轉移回至苯環上。

接著由 ^1H NMR 光譜解讀碳鏈中 2 號碳及 4 號碳氬原子的數量，可以發現 2 號碳上剩下 0.78 個氬，4 號碳上剩下 1.06 個氬。此結果說明銨金屬曾轉移至 2 號碳及 4 號碳上。因此，可以推斷銨金屬 1,4-轉移並非選擇性地轉移至某一條碳鏈上，此步驟也非鏡像選擇性的決定性步驟。除了苯環區以及碳鏈的 2 號碳和 4 號碳有氬原子的分布，碳鏈上的其他位置皆有氬原子的訊號，因此推測此反應的銨金屬不只經過 1,4-轉移移動，更有其他潛在的反應途徑，但需經由更多的氬標註實驗來證明。



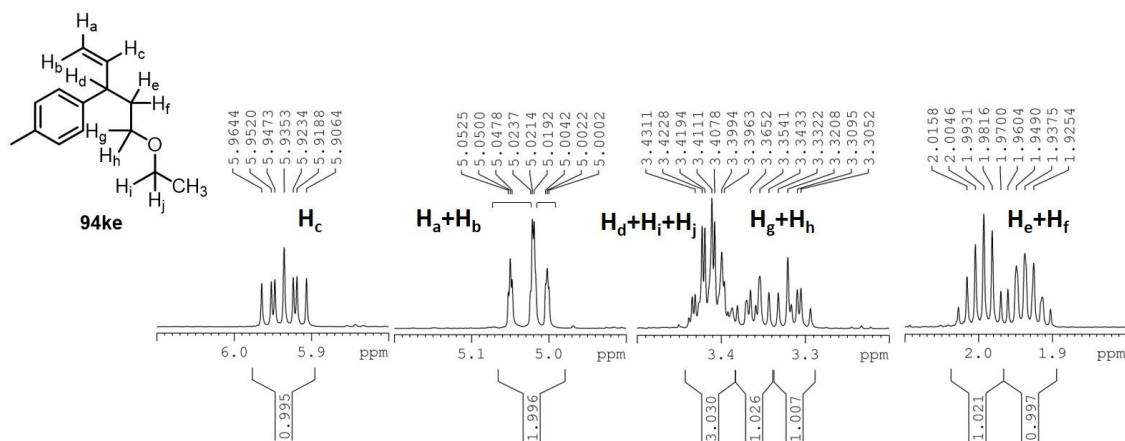


圖 5-5 94ke-4D 與 94 ke 600 Hz 1H NMR 光譜比較圖

除了利用上述 1H NMR 光譜中缺少的積分值確認氬原子的數量，也有利用 2H NMR 直接偵測分子中氬原子的分布及數量，其光譜如圖 5-6 所示。 2H NMR 光譜的化學位移與 1H NMR 光譜相同，由 2H NMR 光譜中可以看到苯環區以及碳鏈的所有位置皆有氬原子的訊號，與 1H NMR 光譜得出的結果相符。由於起始物 93ke-4D 的 2 號及 4 號碳上為 90% 的氬原子取代，即共有 3.6 個氬原子，將這些氬原子按氬譜的積分比例分配給 2H NMR 光譜中每一個峰，得到如圖 5-6 的積分值。其積分值與由氬譜計算出的氬原子數值相似，兩者可以相互映證氬原子的存在及分布比例。

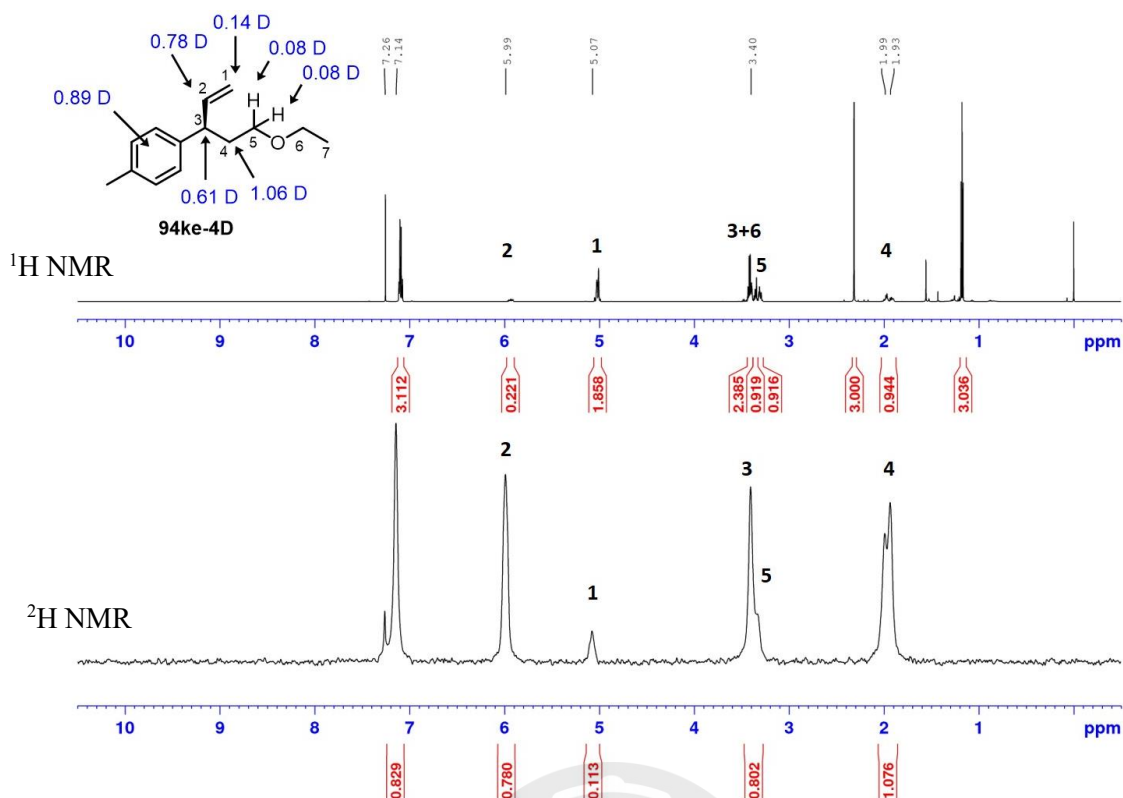
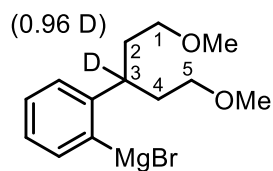


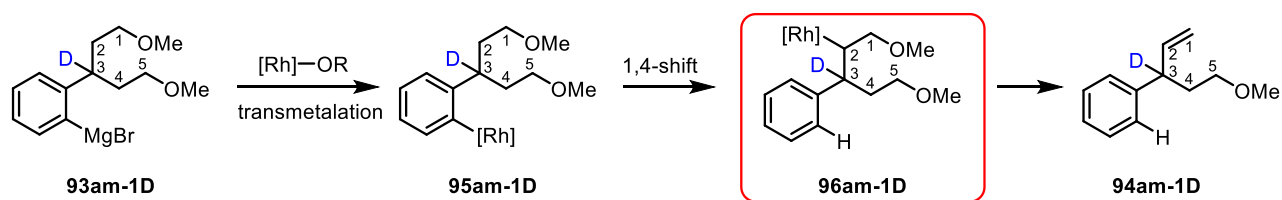
圖 5-6 94ke-4D ¹H NMR 光譜及 ²H NMR 光譜比較圖

有了上述的推論結果，接著設計於碳鏈 3 號位的碳有 96%氘原子取代的格任納試劑 **93am-1D**，如圖 5-7。其設計目的為觀察銨金屬經 1,4-轉移後是否直接進行 β -消去並獲得產物 **94am-1D**。若反應全程僅經過中間體 **96am-1D** 則將獲得僅 3 號碳上有氘取代的產物 **94am-1D**。相反地，若產物 **94am-1D** 不只 3 號碳有氘原子的訊號，則可以確定銨金屬 1,4-轉移並非銨金屬唯一的移動途徑。



93am-1D

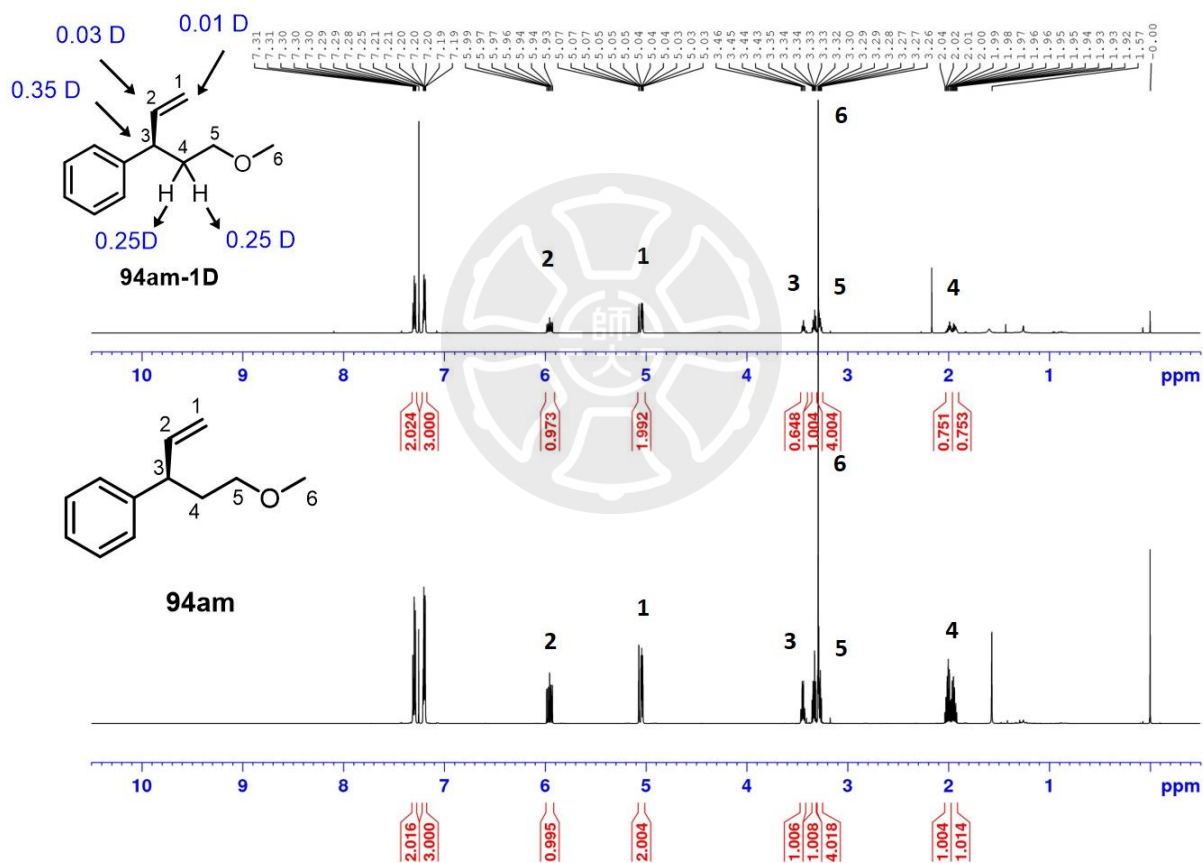
圖 5-7 反應物 **93am-1D**



Is **96am-1D** the only intermediate?

圖 5-8 反應物 **93am-1D** 設計理念

分析格任納試劑 **93am-1D** 在最佳反應條件下反應 6 小時獲得之產物 **94am-1D**，將其 600 Hz 1H NMR 光譜與 **94am** 之光譜進行比較，如圖 5-9 所示。



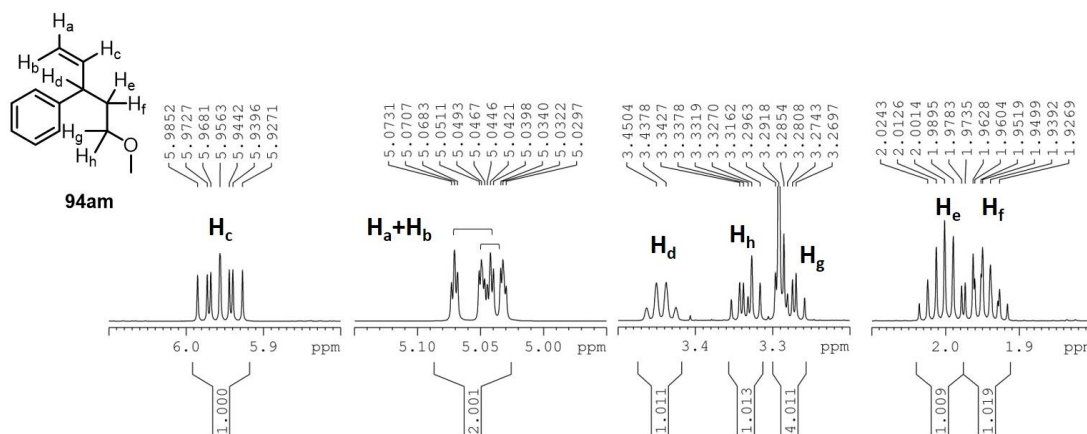


圖 5-9 反應物 **93am-1D** 設計理念

由產物 **94am-1D** 的光譜中可以發現碳鏈中 3 號碳的氬原子數量明顯由 0.96 減少至 0.35 個氬原子，以及氬原子遍布於碳鏈各處，因此確定銨金屬曾利用除了 1,4-轉移的路徑在碳鏈上移動。此結果也可與上述格任納試劑 **93ke-4D** 的反應結果相互映證。此外，4 號碳鏈中 0.5 個氬原子的訊號，綜合由格任納試劑 **93ke-4D** 反應結果得知的銨金屬會轉移至 2 號碳及 4 號的反應證據，推測其形成原因為一部分的銨金屬轉移至 4 號碳後，經由與 3 號碳上的氬原子進行 β -D 消去反應及 β -D 加成反應而造成。也由於 4 號碳上兩個氬分別的積分值相同，代表碳上兩個位置的氬數量相同，因此推測由於銨金屬 1,4-轉移至 4 號碳時，與其上兩個氬原子交換的機率是相同的，當進行同向 Rh-D 消去時，才會造成兩個氬被選擇的機率相同。綜合以上發現，推測其反應途徑如圖 5-10。

首先，銨金屬自中間體 **95am-1D** 隨機地 1,4-轉移至 *pro-R* 或 *pro-S* 的碳鏈上。其中轉移至 *pro-R* 碳鏈上的銨金屬進行 β -H 消去並得到與預期機構相同的 3 號碳上有氬原子取代的產物 **98**。

至於銨金屬轉移至 *pro-S* 的碳鏈上且隨機選擇氬進行交換所形成的 *pro-S*_{alk}SH 中間體 **99a** 及 *pro-S*_{alk}RH 中間體 **99b**，其中中間體 **99a** 經由與 3 號碳鏈上的氬原子進行同向 Rh-D 消去反應形成中間體 **100a** 及中間體 **99b** 經由碳鏈旋轉並與 3 號碳鏈上的氬原子進行同向消去形成中間體 **100b**。接著 Rh-D 再度加成至雙鍵上，分別形成中間

體 **101a** 及 **101b**，此時氬原子被留在 4 號碳上，以上為 **94am-1D** 碳鏈中 4 號位的兩個氬比例皆相同的主要原因。緊接著銨金屬與 2 號碳上的氬進行 Rh-H 消去反應，形成中間體 **102**。中間體 **102** 再進行一次 Rh-H 加成反應，使得銨金屬位在 2 號碳上並進行 β -甲氧基消去，最終形成 4 號碳有氬原子取代的化合物 **104**。這一連串銨金屬的 1,2-轉移促使銨金屬自 4 號碳似行走一般地移動至 2 號碳，被稱為鏈行走反應(chain-walking)。

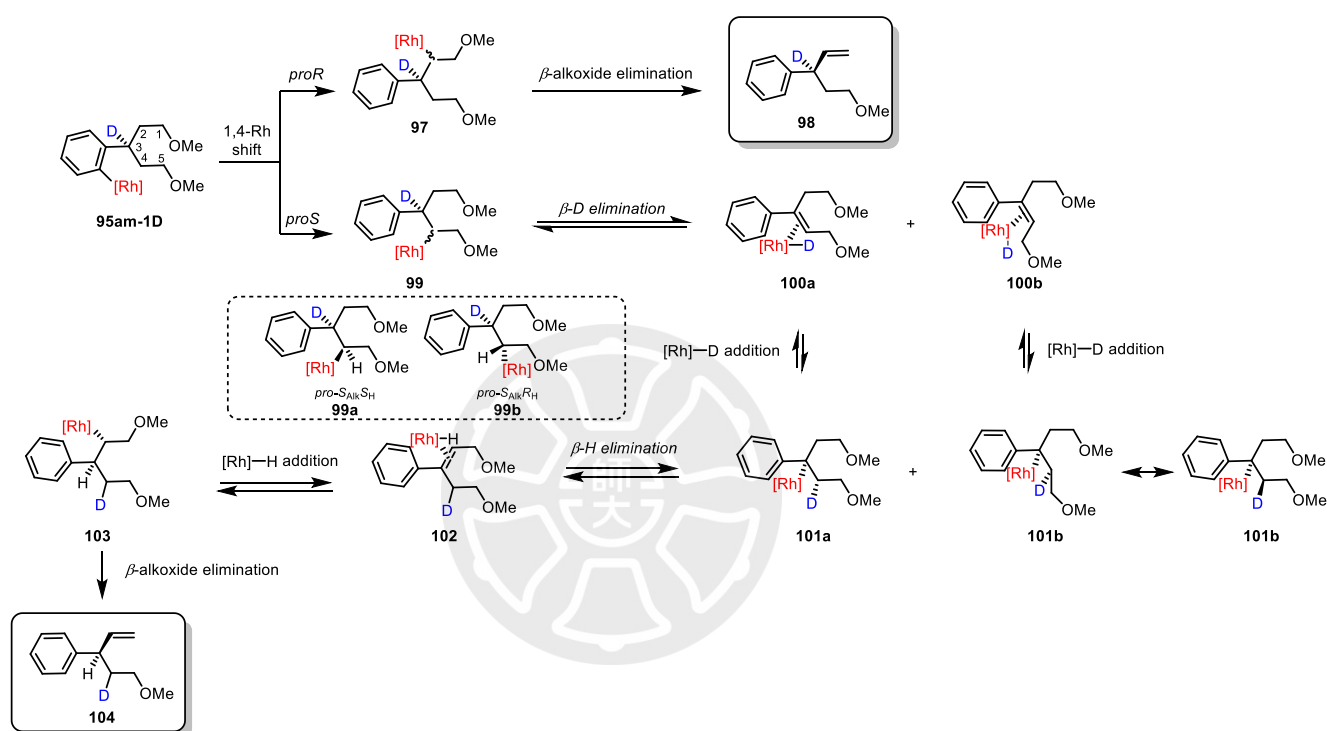


圖 5-10 **94am-1D** 反應路徑圖

圖 5-11 為化合物 **94am-1D** 的 ^1H NMR 光譜及 ^2H NMR 光譜比較圖，可以發現由 ^1H NMR 光譜鑑定出有氬原子的位置與 ^2H NMR 光譜中的峰值相對應，數值也大致相符。其中在 ^2H NMR 光譜中可以額外看到 5 號碳鏈上有相當微量的氬原子訊號，但礙於 ^2H NMR 光譜的解析度所以較難將其定量，僅能得知銨金屬的移動遍布所有位置，因此末端的 5 號碳才有氬原子的訊號。

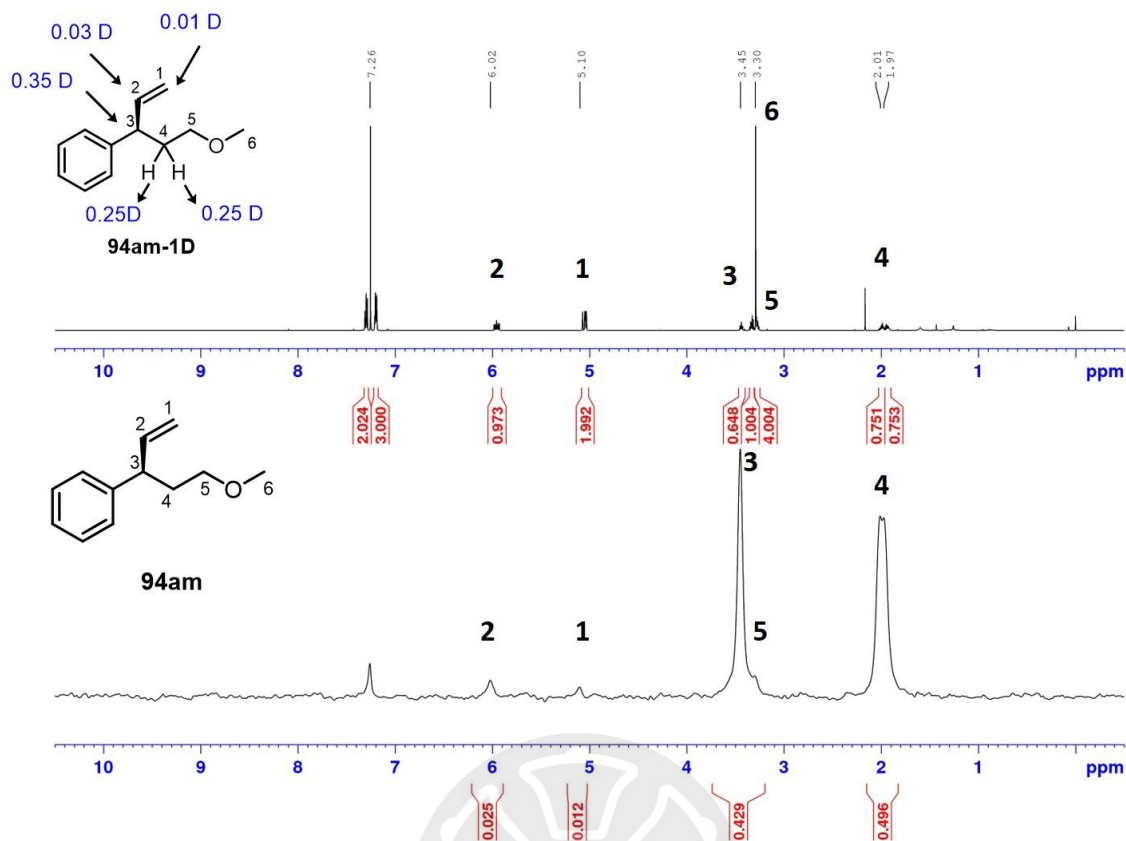


圖 5-11 94am-1D ^1H NMR 光譜及 ^2H NMR 光譜比較圖

為了瞭解銨金屬於末端碳鏈的移動情形，接著使用 1 號及 5 號碳上有 96% 氘原子取代的格任納試劑 **93am-4D** 進行反應(圖 5-12)，觀察銨金屬是否有移動至碳鏈末端 1 號及 5 號碳的現象。銨金屬 1,4-轉移至 2 號或 4 號碳後，銨金屬照理來說應該只會進行 β -甲氧基消去反應形成產物或是藉由銨金屬 1,2-轉移轉移至對向的碳鏈上，因此末端碳上的氘原子理應不會減少。但若末端碳上氘原子的數量減少，我們推測由於微量的機率銨金屬不優先與烷氧基進行消去，而是與氘原子進行銨金屬 1,2-轉移，如圖 5-13 所示。如此一來，將使得銨金屬移動至末端碳上，並使得原先位在末端碳鏈的氘原子移動至其他的位置。

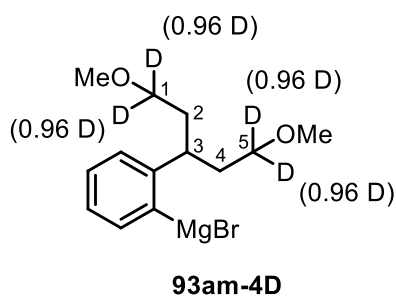


圖 5-12 反應物 **93am-4D**

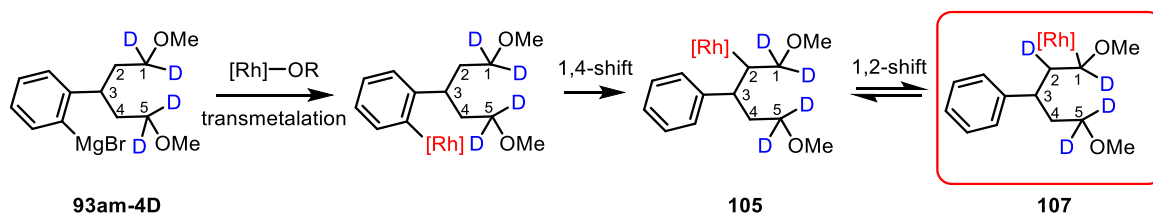


圖 5-13 反應物 **93am-4D** 設計理念

格任納試劑 **93am-4D** 反應 6 小時後，藉由 600 Hz ^1H NMR 光譜進行產物上氬原子分布的分析。由圖 5-14 可以發現碳鏈 1 及 5 號位置的氬原子有微量減少的現象，取而代之的是碳鏈中其他位置皆產生氬原子的訊號，因此證實我們的推測：當銨金屬轉移至 2 號及 4 號碳時，有極少部分的銨金屬不直接進行 β -烷氧基消去，而是會進行 β -D 消去，其反應路徑如圖 5-15 所示。

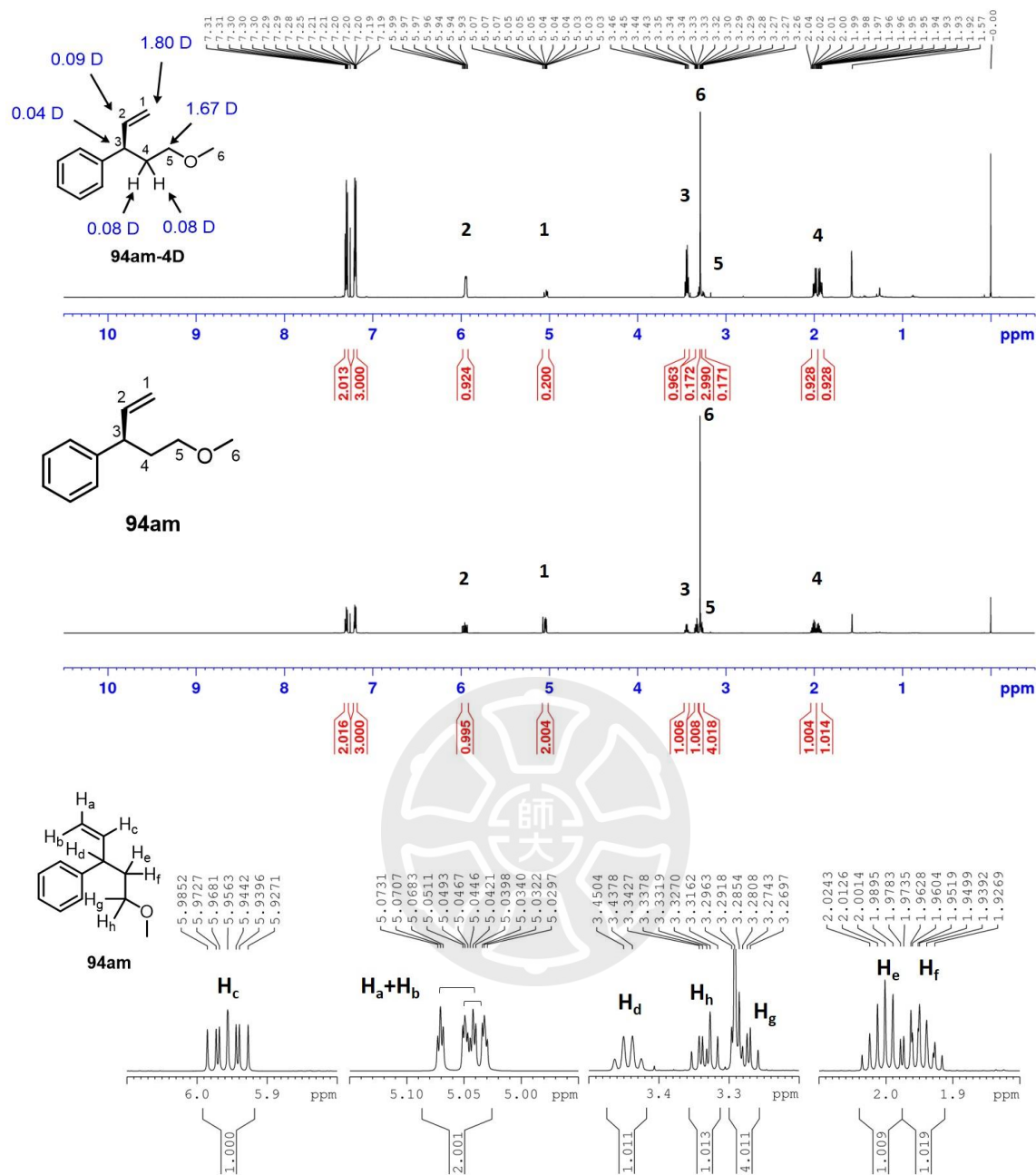


圖 5-14 **94am-4D** 與 **94am** 600MHz ^1H NMR 光譜比較圖

以圖 5-15 舉例說明當銨金屬轉移至 *pro-S*_{alk}SH 後造成 5 號碳鏈的氬原子微量減少的移動情形。

首先銨金屬經 1,4-轉移移動至 *pro-S*_{alk}SH 形成中間體 **105**，此時銨金屬並不直接與烷氧基進行消去，而是與氬原子進行 Rh-D 消去，形成中間體 **106**。接著 Rh-D 再加成回至雙鍵上，形成中間體 **107**。此時銨金屬位於碳鏈末端 5 號位的位置，氬原子位在碳鏈 4 號位的位置。接著銨金屬與 4 號碳鏈的氬原子進行 Rh-H 消去反應，並進行一

連串的 1,2-轉移反應，最終銨金屬轉移至碳鏈中的 2 號碳上並進行烷氧基消去形成化合物 **113**。

以上情形皆有微小機率發生於 *pro-S* 及 *pro-R* 之碳鏈中，因而造成 1 號及 5 號碳的氘原子有減少的情況。

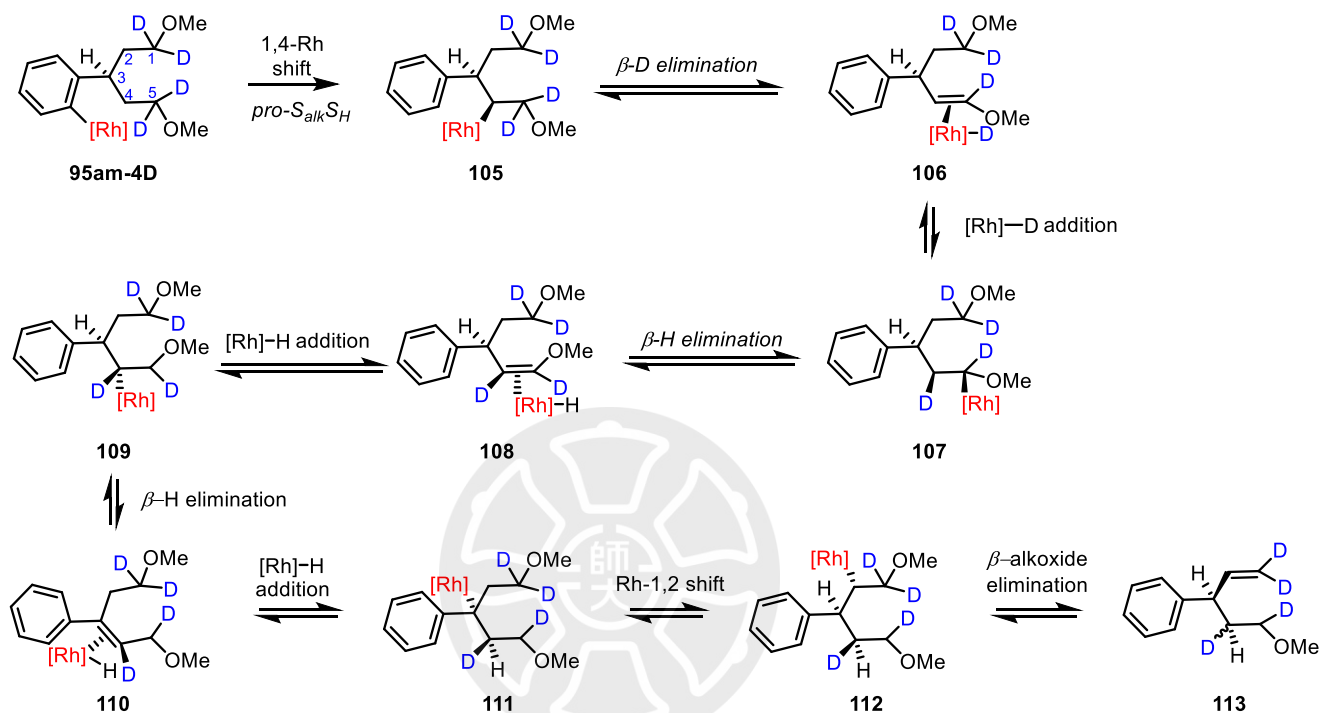


圖 5-15 **94am-4D** 反應路徑圖

將 **94am-4D** 之 ^1H NMR 光譜與 ^2H NMR 光譜進行對照，如圖 5-16 所示。兩張光譜計算出的氘原子數值相似，可以互相印證氘原子的存在。

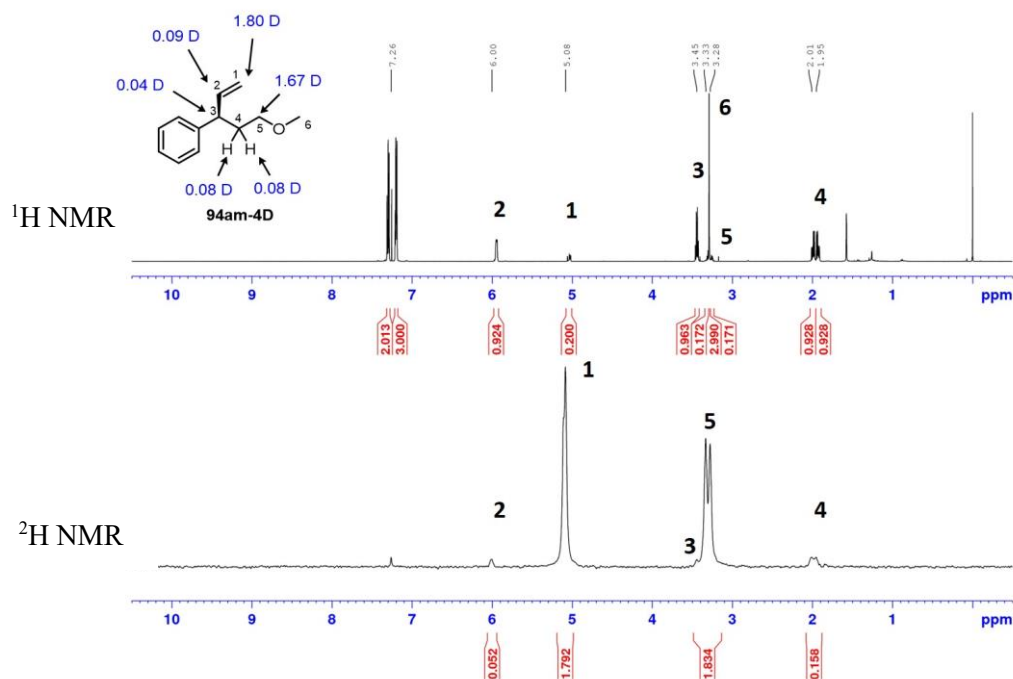


圖 5-16 94am-4D ¹H NMR 光譜及 ²H NMR 光譜比較圖

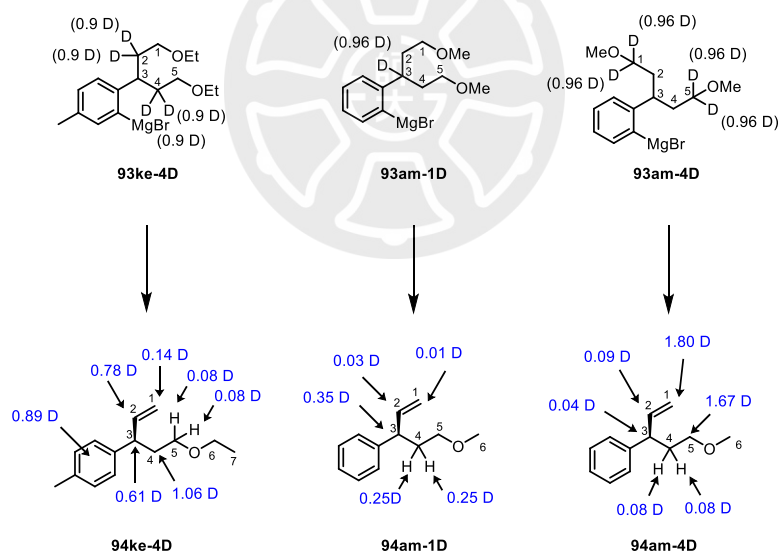


圖 5-17 氬標誌實驗

由碳鏈中 2 號及 4 號位有氬原子取代的格任納試劑 **93ke-4D** 反應形成的化合物 **94ke-4D** 苯環上的氬原子證明銨金屬的 1,4 轉移確實發生且非可逆反應。由其 2 號及 4 號碳的氬原子皆減少的結果確認形成產物立體中心的決定性步驟並非經由銨金屬轉移至碳鏈時決定，而是隨機轉移。此外，分布於碳鏈各處的氬原子透露 1,4-轉移並非唯一銨金屬唯一的移動方式。分析由 3 號位有氬原子取代的格任納試劑 **93am-1D** 反應生成的化合

物 **94am-1D**，其 3 號碳上減少的氬原子及 4 號碳增加的氬原子證明銨金屬會轉移至 *pro-S* 碳鏈上，且藉由 1,2-轉移移動至 *pro-R* 的碳鏈上，再進行 β -烷氧基消去生成產物。由 4 號碳上兩個相同數量的氬原子，進一步得知銨金屬在 1,4-轉移時選擇交換的氬原子是隨機選擇的。至於由 **93am-4D** 反應生成的 **94am-4D** 則說明銨金屬有微量的機率不會第一時間進行 β -烷氧基消去，而是先進行 Rh-D 消去並再進行 1,2-轉移使得銨金屬移動至末端碳鏈。

歸納以上的發現，推測的反應機構如圖 5-18：首先，格任亞試劑 **93** 與經由 (*S*)-**L10a** 與一價銨金屬形成之催化劑進行金屬交換反應，形成中間體 **95**。此時芳基銨將隨機選擇 1,4-轉移至 *pro-R* 或者 *pro-S* 的碳鏈上。若選擇轉移至 *pro-R* 的碳鏈上，則進行 β -烷氧基消去反應，生成化合物 **94**。另一方面，若芳基銨轉移至 *pro-S* 的碳鏈上，則因為轉移至 *pro-S*_{alk}R_H 與 *pro-S*_{alk}S_H 的差別在經由 Rh-H 消去後分別形成中間體 **II-b₁** 及 **II-b₂**。接著經由 Rh-H 的再插入反應形成中間體 **III-b**，而後再進行一次 β -H 消去及再插入反應形成中間體 **V**，透過 β -烷氧基消去反應，得到化合物 **94**。

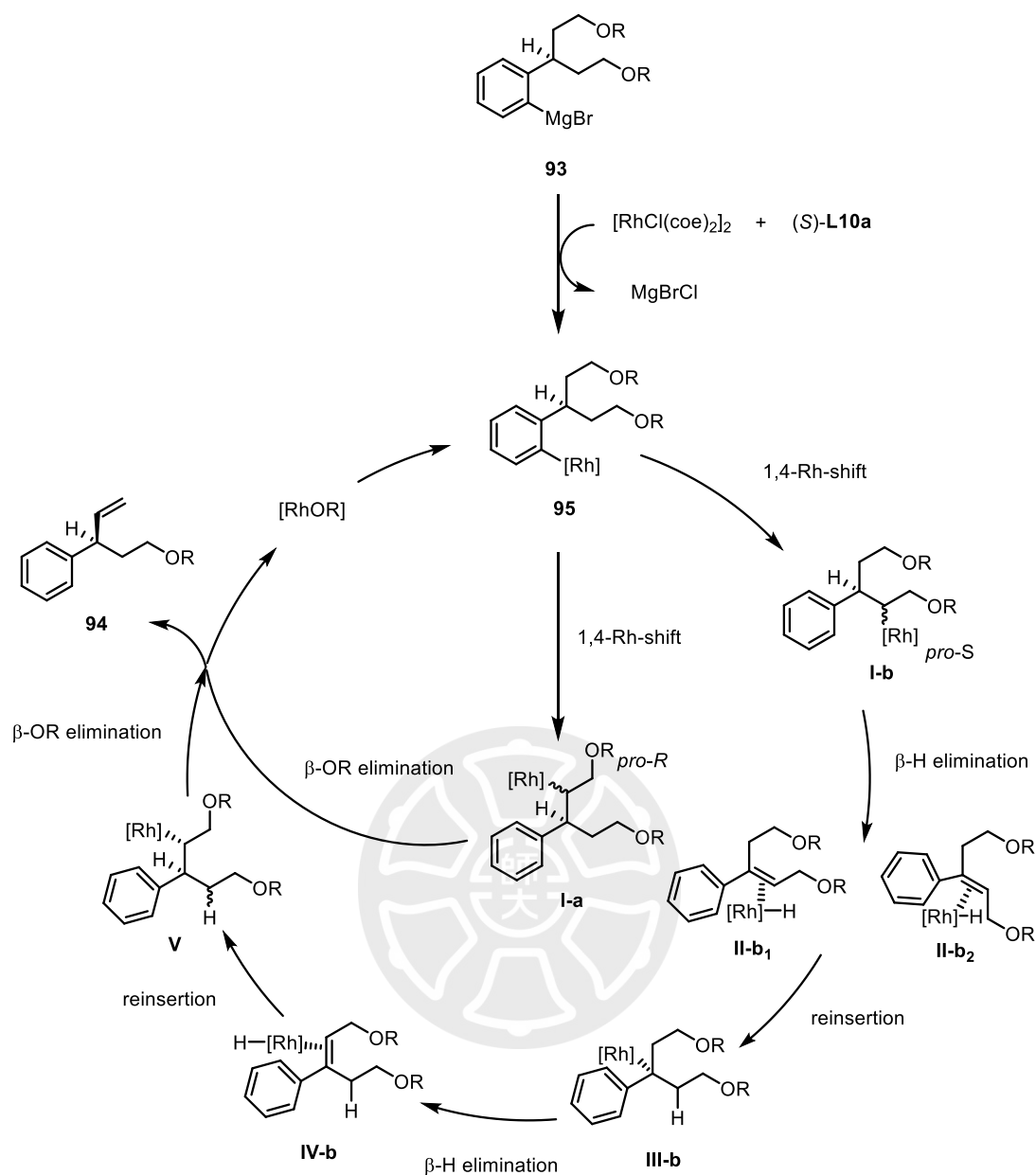


圖 5-18 反應機構

三、反應鏡像選擇性探討

經由前面氬標誌實驗歸納的結果，得知銨金屬進行 β -烷氧基消去為此反應的鏡像選擇性決定步驟。因此將可能發生的中間過渡態繪製成圖 5-19。

若銨金屬與 $pro\text{-}R_{\text{alk}}\text{S}_\text{H}$ 及 $pro\text{-}S_{\text{alk}}\text{S}_\text{H}$ 的氫原子進行交換，如圖 5-19 a) 及 5-19 b) 所示。由於 (S)-SEGPHOS 的立體障礙的阻擋，因此不傾向以這兩個過渡態進行消去。

若銨金屬與 $pro\text{-}S_{\text{alk}}\text{R}_\text{H}$ 及 $pro\text{-}R_{\text{alk}}\text{R}_\text{H}$ 的氫原子交換，由於銨金屬會與對向碳鏈中的

氧原子進行配位，形成一個穩定的六圓環並降低銨金屬進行烷氧基消去的能力。因此結構中越不容易形成六圓環的中間過渡態為最容易進行消去的狀態。圖 5-19 d) 中由於起始物結構中苯環的立體障礙與(S)-SEGPHOS 的苯環相斥，不利六圓環的形成，因此推測本反應的鏡像選擇性決定步驟為經由過渡態圖 5-19 d) 進行銨金屬的 β -烷氧基消去。

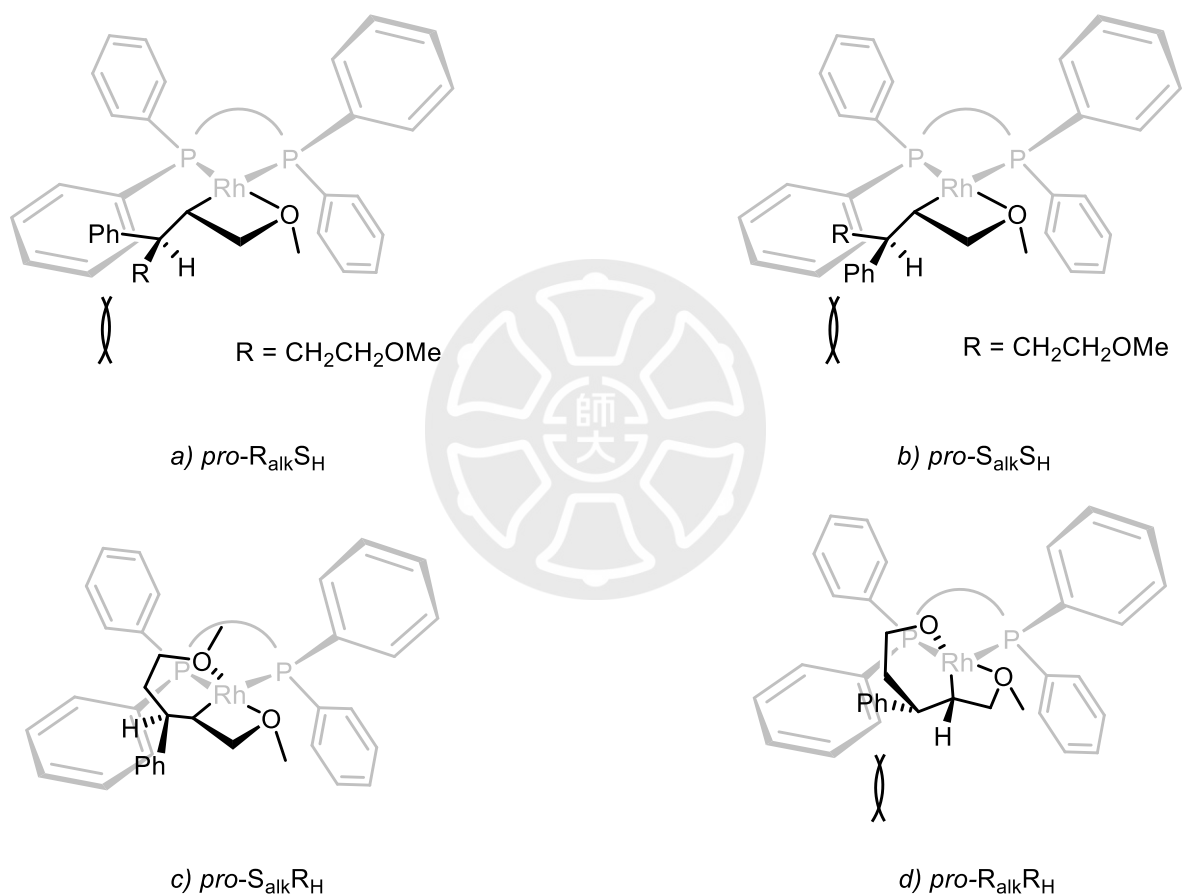
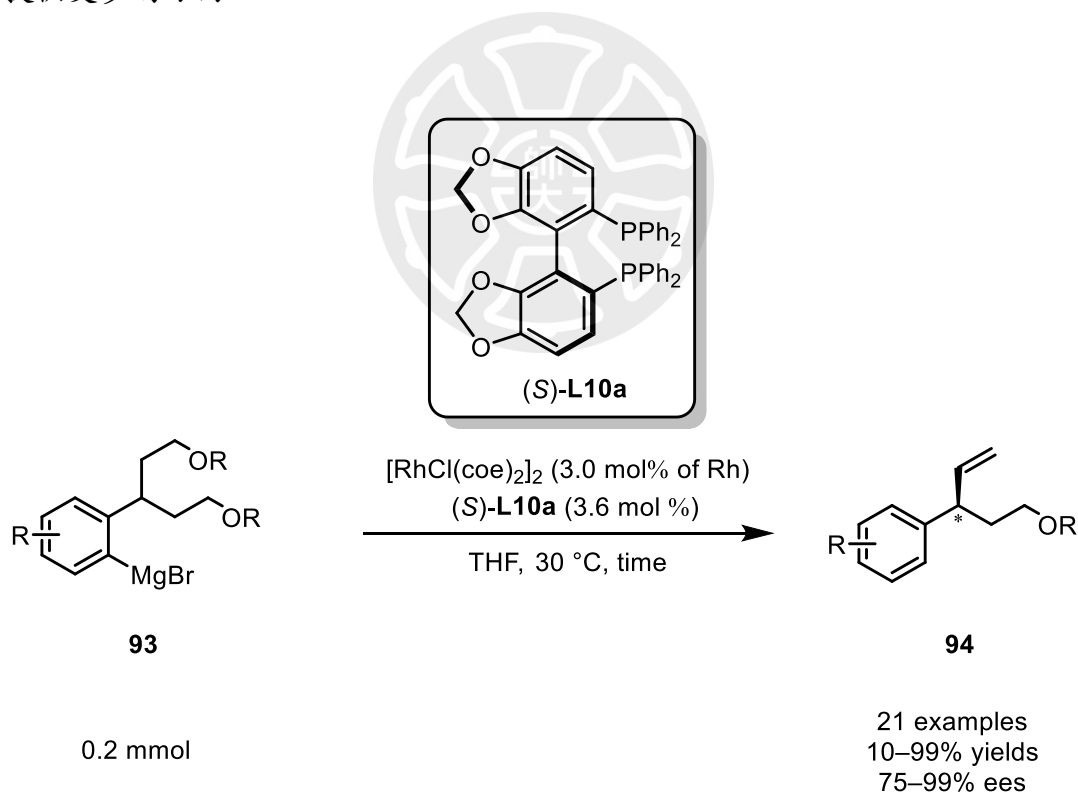


圖 5-19 銨-烷氧基消去可能的中間過渡態

第六章 結論

本文主題為探討一價銨金屬氯化二環辛烯基銨二聚物($[\text{RhCl}(\text{coe})_2]_2$)搭配雙膦配體(*S*)-**L10a**錯合而成的一價銨金屬催化劑所催化的去對稱化反應。此反應利用格任納試劑做為起始物，並與一價銨金屬轉移金屬化至苯環上形成苯基銨中間體，運用 β -烷氧基消去為驅動力，突破芳基銨較難以 1,4-轉移至烷基銨的特性，形成一系列具高選擇性的末端雙鍵產物，共 21 個例子，產率為 10–99%，鏡像超越值則介於 70%–99%。

文內更利用三個氘標誌實驗，證實掌性中心的建立為利用銨金屬隨機的 1,4-轉移，以及由 β -氫消去再加成的反應，使銨金屬傾向移動至 *pro-R* 的碳鏈上進行 β -烷氧基消去形成產物 **94**。此研究開發了一個新穎的銨金屬 1,4-轉移反應，將為後續銨金屬的反應開發提供更多的方向。



第七章 實驗儀器、步驟及光譜數據

7-1 分析儀器

1. 核磁共振光譜儀(nuclear magnetic resonance spectroscopy, 簡稱 NMR)：

以 Bruker Avance III HD-400 MHz NMR 和 Bruker Avance-600 NMR 核磁共振光譜儀測定樣品；以氘化氯仿(chloroform-d, CDCl_3)或氘代甲醇(methanol-d₄, CD_3OD)為溶劑；以 ppm 為化學位移(chemical shift)之單位。

2. 氫核磁共振光譜(^1H NMR)的化學位移以氯仿(chloroform)為內標準品，定義其化學位移 7.26 ppm，或以四甲基矽烷(tetramethyl silane, TMS)為內標準品，定義其化學位移為 0 ppm。或以氘代甲醇為內標準品，定義其化學位移 3.31 ppm。分裂形式(splitting pattern)定義如下：單峰(s, singlet)、雙重峰(d, doublet)、三重峰(t, triplet)、四重峰(q, quartet)、多重峰(m, multiplet)；耦合常數(coupling constant)以 J 表示，單位為 Hz。光譜數據紀錄依序：化學位移(分裂形式，耦合常數，氫數)。碳核磁共振光譜(^{13}C NMR)亦以同型儀器操作，其化學位移以氘化氯仿(chloroform-d, CDCl_3)為內標準品，並定義其化學位移為 77.0 ppm；以氘代甲醇(methanol-d₄, CD_3OD)為內標準品，並定義其化學位移為 49.3 ppm。氟核磁共振光譜(^{19}F NMR)也是以同型儀器操作。

3. 傅立葉轉換紅外線光譜儀(Fourier transform infrared spectroscopy, 簡稱 FTIR)：

使用 Bruker 型光譜儀為測定儀器，光譜單位為波數(cm^{-1})。

4. 高解析質譜分析儀(high resolution mass spectrometer, 簡稱 HRMS)：

使用 JEOL JMS-700 型質譜儀做為測定儀器。以飛行式正離子電灑游離法(time-of-flight-electrospray ionization, 簡稱 TOF-ESI)進行分析，係委託國立臺灣師範大學貴重儀器使用中心技術專員王靜羣小姐代測。

5. X-Ray 單晶繞射儀(X-ray single crystal diffractometer, SC-XRD)：

使用荷蘭 Bruker Enraf-Nonius Kappa CCD 單晶繞射儀做為測定儀器，係委託國立臺灣師範大學化學系助教郭頂審先生代測。

6.薄層層析術(thin-layer chromatography，簡稱 TLC)：

使用 MACHEREY-NAGEL，Silica gel pore size 60 Å with fluorescent indicator UV254，0.20 mm 厚度的鋁箔薄片進行溶劑的展開，並以紫外光或顯色劑檢視。

7.管柱層析術(column chromatography)：

使用 KM3 SCIENTIFIC CORPORATION，Silica gel 45–75 µm 做為填充物。

8.旋光計(polarimeter)：使用 JASCO P-2000 Polarimeter 作為測定儀器。測量前先以溶劑進行背景校正。比旋光度記錄為 $[\alpha]$

9.熔點(melting point，簡稱 m.p.)：使用 Mel-Temp 熔點測定儀測定。

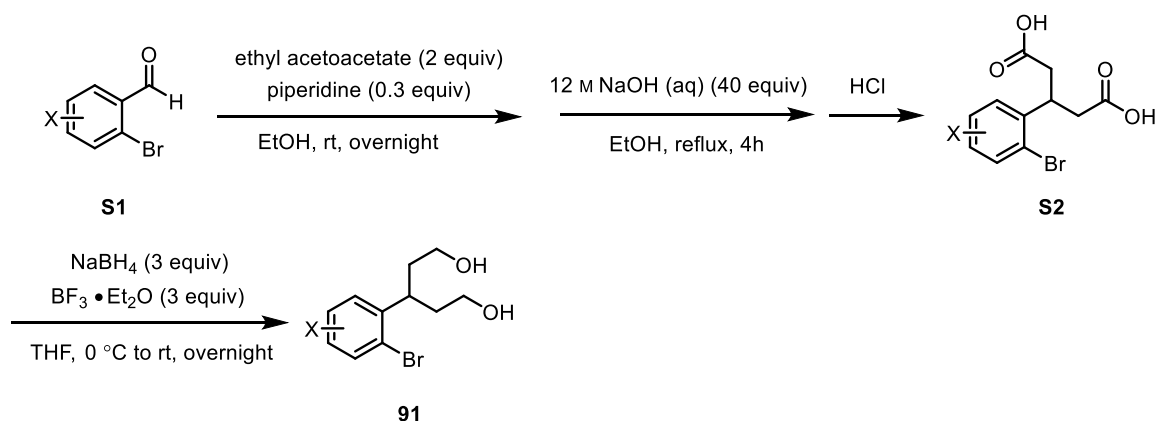
10.高效能液相層析儀(high-performance liquid chromatography，簡稱 HPLC)：

使用 Hitachi 7000 系列高效能液相層析系統，包括自動取樣器(Hitachi L-7200 Autosampler)、幫浦(Hitachi L-7100 Pump)、介面控制器(Hitachi D-7000 Interface)、偵測器(Hitachi L-7450H Diode Array Detector)。使用 CHIRALPAK 管柱(Daicel Chemical Ind., Ltd.，AD-H 4.6 mm×250 mm、IA 4.6 mm×250 mm 或 CHIRALCEL 管柱(Daicel Chemical Ind., Ltd.，OD-H 4.6 mm×250mm、OJ-H 4.6 mm×250 mm)進行實驗。

所有實驗所使用之市售化學藥品及溶劑均為分析級或試藥級。純化、除水乾燥皆依標準處理手續進行。反應皆在氬氣或氮氣環境下以磁石攪拌子攪拌之，並在加熱攪拌器上進行。反應瓶於真空系統下經高溫烘槍烘烤，冷卻後再填充氬氣使用。

7-2 實驗步驟 (Experimental procedures)

Preparation of 3-(2-bromophenyl)pentane-1,5-diol (**91**)^[15]



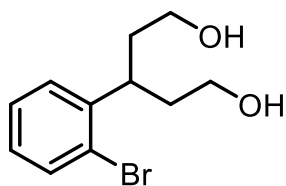
Step 1

Commercially available Bromobenzaldehyde **S1** (15 mmol) were dissolved in (30mL) EtOH and followed by adding ethyl acetoacetate (x mL) and piperidine (x mL) and stirred at room temperature for 12 h. And then, 12 M NaOH (aq) were added and reflux for 4 h. Ethanol was removed under reduced pressure before HCl was added at 0 °C until the PH of solution was 1. After all, the solution was extracted by EtOAc and washed with brine, dried over anhydrous Na₂SO₄, filtered and concentrated under reduced pressure. At last, wash with Hexane to get acid **S2** as yellow pale powder.

Step 2

In inert atmosphere, a THF solution of acid **S2** was added NaBH₄ (45 mmol) at 0°C, then BF₃•Et₂O (5.5 ml) was added after 20 minutes. The reaction stirred under room temperature for 12 h. And then, the mixture quenched by iced water and extracted by EtOAc, wash with brine, dried over anhydrous Na₂SO₄, filtered and concentrated under reduced pressure to get the crude. By column chromatography on silica gel, the product **91** was afforded as white solid.

3-(2-bromophenyl)pentane-1,5-diol (91a)



Isolated as a white solid: 68 % yield

M.p. = 91–92 °C.

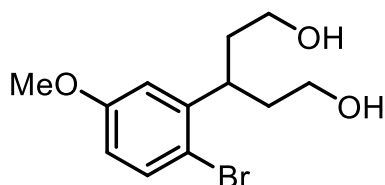
¹H NMR (CD₃OD, 400 MHz): δ 7.55 (d, J = 7.8 Hz, 1H), 7.34–7.33 (m, 2H), 7.09 (ddd, J = 8.1, 5.2, 3.7, 1H), 3.50–3.36 (m, 5H), 1.98–1.83 (m, 4H)

¹³C NMR (CD₃OD, 100 MHz): δ 145.6, 134.2, 129.5, 129.3, 129.1, 126.5, 61.2, 40.3, 38.6

FTIR (KBr, neat) $\tilde{\nu}$ 3280, 3065, 2942, 2881, 2364, 2344, 1923, 1727, 1717, 1563, 1470, 1438, 1353, 756 cm⁻¹

HRMS (ESI-TOF) m/z : [M+H]⁺ Calcd for C₁₁H₁₆O₂Br 259.0334; Found 259.0329

3-(2-bromo-5-methoxyphenyl)pentane-1,5-diol (91b)



Isolated as a white solid: 67 % yield

M.p. = 90°C.

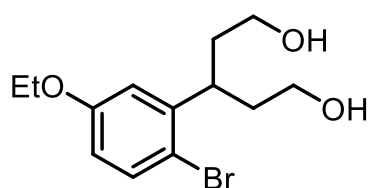
¹H NMR (CD₃OD, 400 MHz): δ 7.22 (d, J = 8.7 Hz, 1H), 7.10 (d, J = 2.6 Hz, 1H), 6.93 (dd, J = 8.7, 2.7 Hz, 1H), 3.77 (s, 3H), 3.41 (m, 5H), 1.87 (m, 4H)

¹³C NMR (CD₃OD, 100 MHz): δ 160.1, 137.2, 129.8, 126.4, 119.1, 115.6, 61.3, 59.3, 40.5, 37.9

FTIR (KBr, neat) $\tilde{\nu}$ 3363, 2940, 2881, 2061, 1604, 1565, 1493, 1440, 1238, 1036, 816, 695, 673, 604, 486

HRMS (ESI-TOF) m/z : [M+H]⁺ Calcd for C₁₂H₁₈O₃Br 289.0439; Found 289.0449

3-(2-bromo-5-ethoxyphenyl)pentane-1,5-diol (91c)



Isolated as a white solid: 57 % yield

M.p. = 84–85 °C.

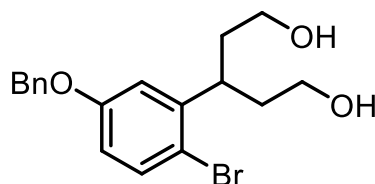
¹H NMR (CD₃OD, 400 MHz): δ 7.41 (d, *J* = 8.8 Hz, 1H), 6.85 (d, *J* = 3.0 Hz, 1H), 6.69 (dd, *J* = 8.8, 3.0 Hz, 2H), 4.01 (q, *J* = 7.0 Hz, 2H), 3.50–3.37 (m, 5H), 1.95–1.83 (m, 4H), 1.38 (t, *J* = 7.0 Hz, 3H)

¹³C NMR (CD₃OD, 100 MHz): δ 160.5, 146.5, 134.7, 116.6, 115.7, 115.4, 65.0, 61.2, 40.3, 38.9, 15.4

FTIR (KBr, neat) $\tilde{\nu}$ 3315, 2976, 2939, 2882, 1595, 1568, 1469, 1292, 1235, 878, 794, 637 cm⁻¹

HRMS (ESI-TOF) *m/z*: [M+H]⁺ Calcd for C₁₃H₂₀O₃Br 303.0596; Found 303.0599

3-(5-(benzyloxy)-2-bromophenyl)pentane-1,5-diol (91d)



Isolated as khaki oil: 82% yield

¹H NMR (CD₃OD, 400 MHz): δ 7.44–7.42 (m, 3H), 7.39–7.35 (m, 2H), 7.32–7.28 (m, 1H), 6.93 (d, *J* = 3.0 Hz, 3H), 6.78 (dd, 8.8, 3.0 Hz), 5.08 (s, 1H), 3.47–3.35 (m, 5H), 1.94–1.78 (m, 4H)

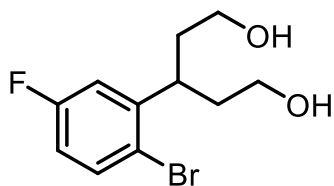
¹³C NMR (CD₃OD, 100 MHz): δ 160.3, 146.6, 138.7, 134.8, 129.8, 129.3, 128.9, 116.1, 71.6, 61.2, 40.2, 38.9

FTIR (KBr, neat) $\tilde{\nu}$ 3357, 3090, 3065, 3033, 2941, 2879, 2367, 2345, 1593, 1568, 1287, 1233, 738, 697, 652 cm⁻¹

HRMS (ESI-TOF) *m/z*: [M+H]⁺ Calcd for C₁₈H₂₂O₃Br 365.0752; Found 365.0759

3-(2-bromo-5-fluorophenyl)pentane-1,5-diol (91e)

Isolated as a white solid: 66 % yield



M.p. = 104–107 °C.

¹H NMR (CD₃OD, 400 MHz): δ 7.57 (dd, *J* = 8.8, 5.6 Hz, 1H), 7.12 (dd, *J* = 10.1, 3.0 Hz, 1H), 6.90 (ddd, *J* = 8.8, 7.9, 3.1 Hz, 1H), 3.45 (m, 5H), 1.89 (m, 4H)

¹³C NMR (CD₃OD, 100 MHz): δ 164.2 (d, *J*_{CF} = 244.1 Hz), 148.2 (d, *J*_{CF} = 6.5 Hz), 135.6 (d, *J*_{CF} = 8.0 Hz), 120.5, 116.3 (d, *J*_{CF} = 22.7 Hz), 61.0, 49.9, 49.7, 49.5, 49.1, 48.9, 48.7, 40.0, 39.0

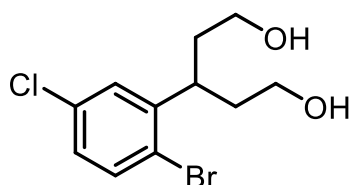
¹⁹F NMR (CDCl₃, 376 MHz): δ –116.2

FTIR (KBr, neat) $\tilde{\nu}$ 3313, 2943, 2879, 2357, 2340, 1603, 1577, 1468, 1406, 1263, 1224, 872, 809, 742 cm^{–1}

HRMS (ESI-TOF) *m/z*: [M+H]⁺ Calcd for C₁₁H₁₅O₂FBr 277.0239; Found 277.0238

3-(2-bromo-5-chlorophenyl)pentane-1,5-diol (91f)

Isolated as a white solid: 60% yield



M.p. = 86–87 °C.

¹H NMR (CD₃OD, 400 MHz): δ 7.54 (d, *J* = 8.6 Hz, 1H), 7.35 (d, *J* = 2.6 Hz, 1H), 7.13 (dd, *J* = 8.5, 2.5 Hz, 1H), 3.38–3.50 (m, 5H), 1.80–1.98 (m, 4H)

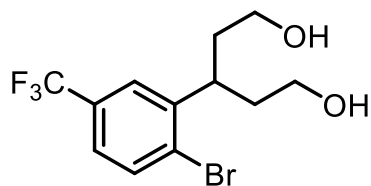
¹³C NMR (CD₃OD, 100 MHz): δ 147.9, 135.5, 135.3, 129.5, 129.3, 124.4, 61.0, 50.5, 49.9, 49.7, 49.5, 49.1, 48.9, 48.7, 40.0, 38.9

FTIR (KBr, neat) $\tilde{\nu}$ 3334, 2942, 2880, 2365, 2344, 1580, 1556, 1460, 1043, 1022, 880, 809, 748, 719 cm^{–1}

HRMS (ESI-TOF) *m/z*: [M+H]⁺ Calcd for C₁₁H₁₅O₂ClBr 292.9944; Found 292.9959

3-(2-bromo-5-(trifluoromethyl)phenyl)pentane-1,5-diol (91g)

Isolated as a white solid: 65% yield



M.p. = 87–88°C.

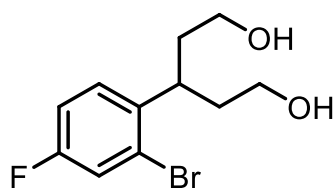
¹H NMR (CD₃OD, 400 MHz): δ 7.77 (d, *J* = 8.3 Hz, 1H), 7.61 (d, *J* = 2.0 Hz, 1H), 7.41 (dd, *J* = 8.4, 2.0 Hz, 1H), 3.63–3.56 (m, 1H), 3.50–3.39 (m, 4H), 2.03–1.84 (m, 4H)

¹³C NMR (CD₃OD, 100 MHz): δ 147.3, 135.2, 131.7 (q, *J*_{CF} = 32.3 Hz), 130.6, 126.2, 125.7 (q, *J*_{CF} = 270.0 Hz), 125.7 (q, *J*_{CF} = 3.5 Hz), 60.9, 39.9, 38.9

FTIR (KBr, neat) $\tilde{\nu}$ 3358, 2951, 2885, 1609, 1579, 1478, 1446, 1410, 1328, 1126, 996, 907, 826, 730, 665, 566 cm⁻¹

HRMS (ESI-TOF) *m/z*: [M+H]⁺ Calcd for C₁₂H₁₅O₂BrF₃ 327.0208; Found 327.0212

3-(2-bromo-4-fluorophenyl)pentane-1,5-diol (91h)



Isolated as khaki oil: 60 % yield

¹H NMR (CD₃OD, 400 MHz): 7.37–7.34 (m, 2H), 7.13 (ddd, *J* = 8.4, 8.4, 2.7, 1H), 3.48–3.37 (m, 5H), 1.97–1.79 (m, 4H)

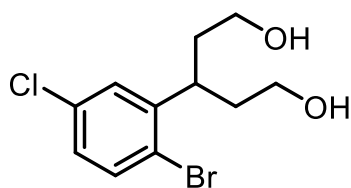
¹³C NMR (CD₃OD, 100 MHz): δ 162.3 (d, *J*_{CF} = 246.2 Hz), 141.7 (d, *J*_{CF} = 8.8 Hz), 130.6, 126.2 (d, *J*_{CF} = 8.4 Hz), 120.9 (d, *J*_{CF} = 24.1 Hz), 116.3 (d, *J*_{CF} = 21.0 Hz), 61.1, 40.3, 38.0

¹⁹F NMR (CD₃OD, 376 MHz): δ –116.9

FTIR (KBr, neat) $\tilde{\nu}$ 3333, 2942, 2881, 1891, 1599, 1486, 1265, 1228, 1046, 859, 819, 732, 696, 672, 596 cm⁻¹

HRMS (ESI-TOF) *m/z*: [M+H]⁺ Calcd for C₁₁H₁₅O₂FBr 277.0239; Found 277.0251

3-(2-bromo-4-chlorophenyl)pentane-1,5-diol (91i)



Isolated as khaki oil: 62 % yield

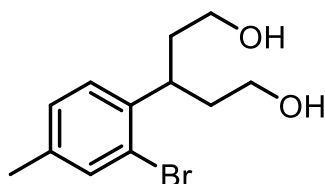
¹H NMR (CD₃OD, 400 MHz): δ 7.60 (d, *J* = 2.0 Hz, 1H), 7.37–7.32 (m, 2H), 3.49–3.37 (m, 5H), 1.97–1.80 (m, 4H)

¹³C NMR (CD₃OD, 100 MHz): δ 144.4, 133.6, 133.4, 130.5, 129.4, 126.6, 60.9, 40.0, 38.1

FTIR (KBr, neat) $\tilde{\nu}$ 3334, 2942, 2880, 2365, 2344, 1460, 1389, 1353, 1101, 1043, 1022, 880, 809, 748, 719, 475, 458 cm⁻¹

HRMS (ESI-TOF) *m/z*: [M+H]⁺ Calcd for C₁₁H₁₅O₂ClBr 292.9944; Found 292.994

3-(2-bromo-4-methylphenyl)pentane-1,5-diol (91k)



Isolated as khaki oil: 78% yield

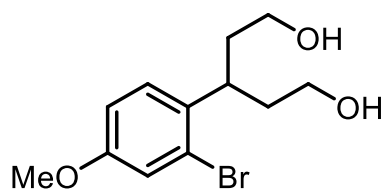
¹H NMR (CD₃OD, 400 MHz): δ 7.40 (d, *J* = 0.84 Hz, 1H), 7.21–7.14 (m, 2H), 3.48–3.35 (m, 5H), 2.29 (s, 3H), 1.95–1.80 (m, 4H)

¹³C NMR (CD₃OD, 100 MHz): δ 142.3, 139.3, 134.4, 130.1, 129.1, 126.2, 61.2, 40.3, 38.2, 20.9

FTIR (KBr, neat) $\tilde{\nu}$ 3351, 2942, 2879, 2361, 2341, 1490, 1215, 1033, 821, 773, 673, 568, 515 cm⁻¹

HRMS (ESI-TOF) *m/z*: [M+H]⁺ Calcd for C₁₂H₁₈O₂Br 273.0490; Found 273.0479

-(2-bromo-4-methoxyphenyl)pentane-1,5-diol (91l)



Isolated as khaki oil: 68% yield

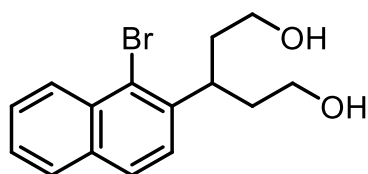
¹H NMR (CD₃OD, 400 MHz): δ 7.23 (d, *J* = 8.7 Hz, 1H), 7.11 (d, *J* = 2.6 Hz, 1H), 6.93 (dd, *J* = 8.7, 2.7 Hz, 1H), 3.77 (s, 1H), 3.48–3.35 (m, 5H), 1.94–1.78 (m, 4H)

¹³C NMR (CD₃OD, 100 MHz): δ 159.9, 137.1, 129.7, 126.4, 119.0, 115.5, 61.2, 56.3, 40.3, 37.7

FTIR (KBr, neat) $\tilde{\nu}$ 3345, 2941, 2882, 2359, 2342, 2059, 1892, 1064, 1564, 1493, 1461, 1440, 1285, 1036, 841, 816, 695, 605 cm⁻¹

HRMS (ESI-TOF) *m/z*: [M+Na]⁺ Calcd for C₁₂H₁₇O₃BrNa 311.0259; Found 311.0266

3-(1-bromonaphthalen-2-yl)pentane-1,5-diol (91m)



Isolated as a white solid: 70% yield

M.p. = 105–107.°C.

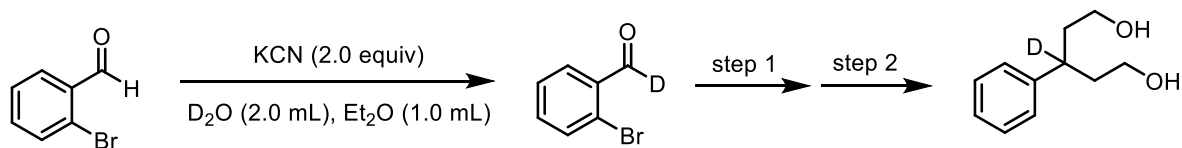
¹H NMR (CD₃OD, 400 MHz): δ 8.30 (d, *J* = 8.7 Hz, 1H), 7.83 (t, *J* = 7.5 Hz, 2H), 7.58 (ddd, *J* = 8.0, 7.3, 1.3 Hz, 1H), 7.50 (ddd, *J* = 8.0, 7.0, 1.1 Hz, 1H), 7.44 (d, *J* = 8.6 Hz, 1H), 3.87 (m, 1H), 3.53–3.46 (m, 2H), 3.42–3.36 (m, 2H), 2.13–1.90 (m, 4H)

¹³C NMR (CD₃OD, 100 MHz): δ 159.9, 137.1, 129.7, 126.4, 119.0, 115.5, 61.2, 56.3, 40.3, 37.7

FTIR (KBr, neat) $\tilde{\nu}$ 3350, 3054, 2943, 2879, 2363, 2343, 1554, 1501, 1047, 1000, 963, 812, 772, 749, 647, 530 cm⁻¹

HRMS (ESI-TOF) *m/z*: [M+H]⁺ Calcd for C₁₅H₁₈O₂Br 309.0490; Found 309.0481

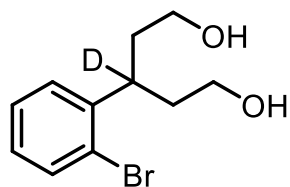
Preparation of 3-(2-bromophenyl)pentane-3-d-1,5-diol^[16]



Firstly, added Bromobenzaldehyde (2.0 mmol), KCN (4.0 mmol), Ether (1.0 mL), D₂O (2.0 mL) in the sample vial and stir vigorously at room temperature. After 140 h, the reaction extracted by ether, dried over anhydrous Na₂SO₄, filtered and concentrated under reduced pressure to get the crude. By column chromatography on silica gel, the product was afforded as lightly yellow oil in 50% yield with 96% of deuterium.

With the D-bromobenzaldehyde in hand, follow the general procedure of preparing 3-(2-bromophenyl)pentane-1,5-diol to get 3-(2-bromophenyl)pentane-3-d-1,5-diol.

3-(2-bromophenyl)pentane-3-d-1,5-diol (91a-1D)



Isolated as white solid: 64 % yield

M.p. = 96–97 °C.

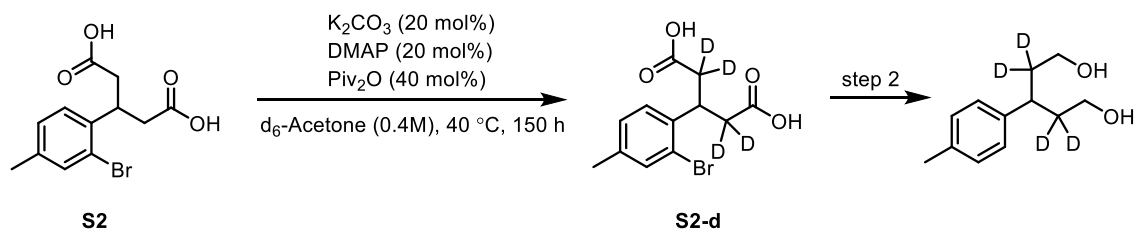
96% D

¹H NMR (CD₃OD, 400 MHz): δ 7.55, (d, *J* = 8.0 Hz, 1H) 7.35–7.31 (m, 2H), 7.09 (ddd, *J* = 8.0, 4.0, 1.2 Hz, 1H), 3.50–3.33 (m, 4H), 1.94–1.83 (m, 4H)

FTIR (KBr, neat) $\tilde{\nu}$ 3253, 2935, 2859, 2365, 2344, 1456, 1422, 1301, 1275, 1053, 1025, 795, 754, 656, 567 cm⁻¹

HRMS (ESI-TOF) *m/z*: [M+H]⁺ Calcd for C₁₁O₂BrH₁₅D 260.0396; Found 260.0382

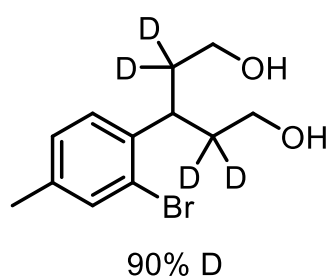
Preparation of 3-(2-bromo-4-methylphenyl)pentane-2,2,4,4-d₄-1,5-diol^[17]



To a vial equipped with a stir bar, 3-(2-bromo-4-methylphenyl)pentanedioic acid **S2** (9.83 mmol), K₂CO₃ (1.97 mmol), DMAP (1.97 mmol), and Piv₂O (3.93 mmol) was added before d₆-Acetone was added. The reaction stirred in 40 °C for 150 h. After all, quench with D₂O and then extracted the mixture with 1M HCl and DCM, washed with brine, dried over anhydrous Na₂SO₄, filtered and concentrated under reduced pressure. Residual Piv₂O can be removed by formic acid/DCM = 1/4 under the reduced pressure.

The reduction of acid **S2-d** used the same way which mentioned before. The total yield of the diol is 74%.

3-(2-bromo-4-methylphenyl)pentane-2,2,4,4-d₄-1,5-diol (**91a-4D**)



Isolated as a white solid: 74% yield

M.p. = 68–69 °C.

¹H NMR (CD₃OD, 400 MHz): δ 7.38 (s, 1H), 7.20–7.13 (m, 2H), 3.46–3.36 (m, 5H), 2.28 (s, 1H), 1.89–1.83 (m, 0.4H),

¹³C NMR (CD₃OD, 100 MHz): δ 142.3, 139.3, 134.4, 130.4, 130.1, 129.1, 126.2, 61.1, 39.6 (m), 38.0

FTIR (KBr, neat) $\tilde{\nu}$ 3351, 2942, 2879, 2361, 2338, 1488, 1215, 1033, 821, 773, 662, 558, 515

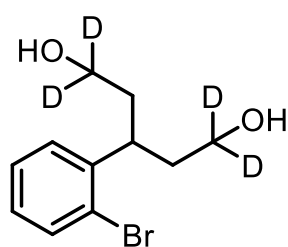
cm⁻¹

HRMS (ESI-TOF) *m/z*: [M+Na]⁺ Calcd for C₁₂H₁₃D₄O₂NaBr 299.0561; Found 299.0569

Preparation of 3-(2-bromophenyl)pentane-1,1,5,5-d₄-1,5-diol

In inert atmosphere, a stirred THF solution of acid **S2** was added NaBD₄ (45 mmol) at 0°C, then BF₃•Et₂O (5.5 mL) was added after 20 minutes. The reaction stirred under room temperature for 12 h. After all, the mixture quenched by iced water and extracted by EtOAc, wash with brine, dried over anhydrous Na₂SO₄, filtered and concentrated under reduced pressure to get the crude. By column chromatography on silica gel, the product was afforded as white solid.

3-(2-bromophenyl)pentane-1,1,5,5-d₄-1,5-diol (91a-4D)



96% D

Isolated as white solid : 75 % yield

M.p. = 100–101 °C.

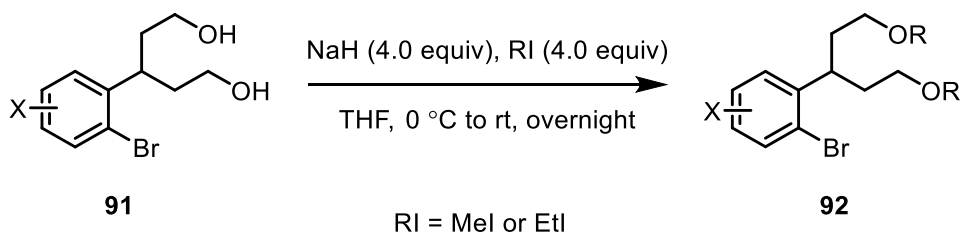
¹H NMR (CD₃OD, 400 MHz): δ 7.54, (d, *J* = 8.0 Hz, 1H), 7.34 (d, *J* = 4.0 Hz, 2H), 7.08 (ddd, *J* = 8.0, 4.0, 1.2 Hz, 1H), 3.50–3.43 (m, 1H), 1.94–1.83 (m, 4.34)

¹³C NMR (CD₃OD, 100 MHz): δ 145.6, 134.2, 129.5, 129.3, 129.1, 126.6, 60.5 (m), 40.1, 38.6

FTIR (KBr, neat) $\tilde{\nu}$ 3253, 2935, 2860, 2362, 2346, 1456, 1422, 1305, 1275, 1053, 1021, 788, 750, 653, 567 cm⁻¹

HRMS (ESI-TOF) *m/z*: [M+Na]⁺ Calcd for C₁₁H₁₁D₄O₂NaBr 285.0404; Found 285.0395

Preparation of 3-(2-bromophenyl)pentane-1,5-diethers (92)^[18]



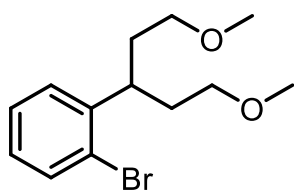
General procedure:

To a stirred solution of diol in THF (0.4 M based on diol) was added NaH (60 wt% in mineral oil) at 0 °C. After 30 minutes, RI was added and the reaction stirred at room temperature for 12 h. At last, the mixture quenched by iced water and extracted with EtOAc. The combined organic layer was washed with brine, dried over anhydrous Na₂SO₄ and concentrated under reduced pressure. The crude residue was purified by silica gel column chromatography to get transparent oil.

92am–92im and **92km** is using MeI as RI reagents.

92ce, **92ee–92me** is using EtI as RI reagents.

1-bromo-2-(1,5-dimethoxypentan-3-yl)benzene (92am)



Isolated as transparent oil: 70 % yield

^1H NMR (CDCl_3 , 400 MHz): δ 7.54 (d, $J = 8.1$ Hz, 1H), 7.30–7.22 (m, 2H), 7.06 (ddd, $J = 7.9$, 7.1, 1.2 Hz, 1H), 3.50–3.43 (m, 1H), 3.25 (s, 6H), 3.24–3.20 (t, $J = 6.9$ Hz, 4H), 2.02–1.84 (m, 4H)

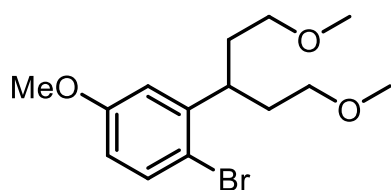
^{13}C NMR (CDCl_3 , 100 MHz): δ 143.7, 132.8, 127.7, 127.6, 127.5, 125.2, 70.4, 58.4, 37.5, 36.1

FTIR (KBr, neat) $\tilde{\nu}$ 3058, 2978, 2870, 2828, 1590, 1565, 1470, 1389, 1190, 1118, 954, 756, 726, 661, 454 cm^{-1}

HRMS (ESI-TOF) m/z : $[\text{M}+\text{H}]^+$ Calcd for $\text{C}_{13}\text{H}_{20}\text{O}_2\text{Br}$ 287.0647 ; Found 287.0654



1-bromo-2-(1,5-dimethoxypentan-3-yl)-4-methoxybenzene (92bm)



Isolated as light yellow oil: 83 % yield

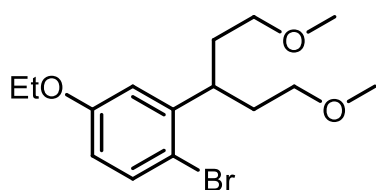
¹H NMR (CDCl₃, 400 MHz): δ 7.43 (d, *J* = 8.8 Hz, 1H), 6.77 (d, *J* = 3.0 Hz, 1H), 6.64 (dd, *J* = 8.8, 3.0 Hz, 1H), 3.78 (s, 1H), 3.43–3.37 (m, 1H), 3.26 (s, 6H), 3.23 (t, *J* = 7.0 Hz, 4H), 2.00–1.80 (m, 4H)

¹³C NMR (CDCl₃, 100 MHz): δ 159.2, 144.8, 133.2, 116.7, 115.7, 113.6, 113.1, 70.4, 58.5, 55.3, 37.7, 36.2

FTIR (KBr, neat) $\tilde{\nu}$ 3072, 2928, 2832, 2756, 2061, 1595, 1471, 1414, 1390, 1289, 1289, 1190, 1165, 1118, 1047, 1014, 954, 871, 805, 604, 471

HRMS (ESI-TOF) *m/z*: [M+H]⁺ Calcd for C₁₄H₂₂O₃Br 317.0752; Found 317.0750

1-bromo-2-(1,5-diethoxypentan-3-yl)-4-ethoxybenzene (92cm)



Isolated as light yellow oil: 67 % yield

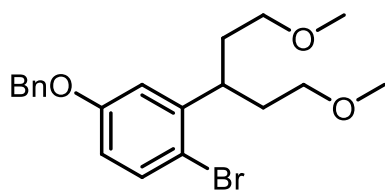
¹H NMR (CDCl₃, 400 MHz): δ 7.41 (d, *J* = 8.8 Hz, 1H), 6.77 (d, *J* = 3.0 Hz, 1H), 6.64 (dd, *J* = 8.8, 3.0 Hz, 1H), 3.98 (q, *J* = 7.0 Hz, 2H), 3.42–3.36 (m, 1H), 3.26 (s, 6H), 3.25–3.21 (m, 4H), 2.00–1.80 (m, 4H)

¹³C NMR (CDCl₃, 100 MHz): δ 158.6, 144.9, 133.7, 113.7, 70.6, 63.6, 58.6, 36.3, 14.8

FTIR (KBr, neat) $\tilde{\nu}$ 2979, 2926, 2870, 2829, 1594, 1569, 1469, 1392, 1288, 1236, 1193, 1051, 960, 873, 799, 773, 638 cm⁻¹

HRMS (ESI-TOF) *m/z*: [M+H]⁺ Calcd for C₁₅H₂₄O₃Br 331.0909; Found 331.0916

4-(benzyloxy)-1-bromo-2-(1,5-dimethoxypentan-3-yl)benzene (92dm)



Isolated as light yellow oil: 58% yield

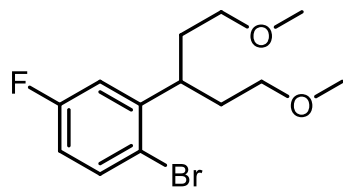
¹H NMR (CDCl₃, 400 MHz): δ 7.44 (m, 6H), 6.83 (d, *J* = 3.0 Hz, 1H), 6.71 (dd, *J* = 8.8, 3.0 Hz, 1H), 5.03 (s, 2H), 3.43–3.37 (m, 1H), 3.25 (s, 6H), 3.20 (t, *J* = 6.8 Hz, 4H), 1.98–1.77 (m, 4H)

¹³C NMR (CDCl₃, 100 MHz): δ 158.3, 144.9, 136.5, 133.3, 128.6, 128.0, 127.5, 114.2, 70.4, 70.2, 58.6, 37.7, 36.2

FTIR (KBr, neat) $\tilde{\nu}$ 3033, 2926, 2870, 2754, 2061, 1953, 1727, 1593, 1568, 1468, 1384, 1289, 1234, 1169, 1118, 1013, 953, 872, 801, 737, 697, 620, 514, 463 cm⁻¹

HRMS (ESI-TOF) *m/z*: [M+H]⁺ Calcd for C₂₀H₂₆O₃Br 393.1065; Found 393.1055

1-bromo-2-(1,5-dimethoxypentan-3-yl)-4-fluorobenzene (92em)



Isolated as light yellow oil: 84 % yield

¹H NMR (CDCl₃, 400 MHz): δ 7.51 (dd, *J* = 8.8, 5.5 Hz, 1H), 6.95 (dd, *J* = 9.9, 3.0 Hz, 1H), 6.81 (ddd, *J* = 8.7, 7.8, 3.0, 1H), 3.49–3.42 (m, 1H), 3.27–3.17 (m, 4H), 3.26 (s, 6H), 2.01–1.78 (m, 4H)

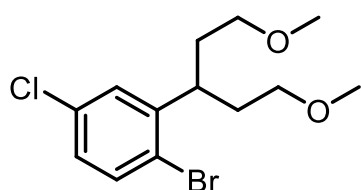
¹³C NMR (CDCl₃, 100 MHz): δ 162.0 (d, *J*_{CF} = 245 Hz), 146.1 (d, *J*_{CF} = 5.8 Hz), 133.6 (d, *J*_{CF} = 7.4 Hz), 119.0, 114.6 (d, *J*_{CF} = 22.1 Hz), 70.0, 58.1, 37.7, 35.8

¹⁹F NMR (CDCl₃, 376 MHz): δ –114.1

FTIR (KBr, neat) $\tilde{\nu}$ 2871, 2829, 1604, 1579, 1469, 1269, 1118, 1026, 950, 871, 809, 717, 608, 585cm⁻¹

HRMS (ESI-TOF) *m/z*: [M+H]⁺ Calcd for C₁₃H₁₉O₂FBr 305.0552 ; Found 305.0552

1-bromo-2-(1,5-dimethoxypentan-3-yl)-4-chlorobenzene (92fm)



Isolated as light yellow oil: 84 % yield

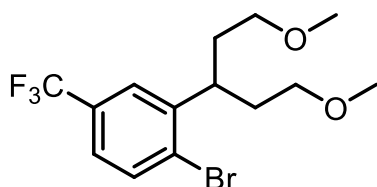
¹H NMR (CDCl₃, 400 MHz): δ 7.47 (d, *J* = 8.6 Hz, 1H), 7.20 (d, *J* = 2.6 Hz, 1H), 7.04 (dd, *J* = 8.5, 2.5 Hz, 1H), 3.49–3.41 (m, 1H), 3.27–3.16 (m, 4H), 3.26 (s, 6H), 2.01–1.78 (m, 4H)

¹³C NMR (CDCl₃, 100 MHz): δ 145.9, 133.9, 133.7, 128.0, 127.8, 70.3, 58.5, 37.8, 36.1

FTIR (KBr, neat) $\tilde{\nu}$ 2979, 2925, 2365, 2344, 2067, 1992, 1886, 1751, 1581, 1556, 1460, 1389, 1188, 1120, 1022, 954, 925, 879, 864, 810, 718, 695 cm⁻¹

HRMS (ESI-TOF) *m/z*: [M+H]⁺ Calcd for C₁₃H₁₉O₂ClBr 321.0257 ; Found 321.0259

1-bromo-2-(1,5-dimethoxypentan-3-yl)-4-(trifluoromethyl)benzene (92gm)



Isolated as light yellow oil: 68 % yield

¹H NMR (CDCl₃, 400 MHz): δ 7.68 (d, *J* = 8.3 Hz, 1H), 7.49 (d, *J* = 2.0 Hz, 1H), 7.32 (dd, *J* = 8.4, 2.1 Hz), 3.62–3.58 (m, 1H), 3.30–3.17 (m, 4H), 3.25 (s, 1H), 2.07–1.87 (m, 4H)

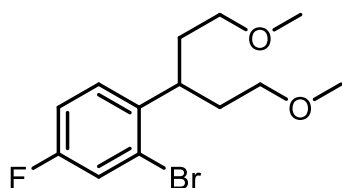
¹³C NMR (CDCl₃, 100 MHz): δ 145.2, 133.4, 129.9 (q, *J*_{CF} = 32.4 Hz), 129.0, 124.7, 124.1 (q, *J*_{CF} = 3.3 Hz), 123.8 (q, *J*_{CF} = 270.6 Hz), 70.1, 58.3, 37.7, 35.8

¹⁹F NMR (CDCl₃, 376 MHz): δ -62.66

FTIR (KBr, neat) $\tilde{\nu}$ 2928, 2872, 1607, 1477, 1409, 1329, 1170, 1125, 1023, 956, 900, 869, 824, 730 cm⁻¹

HRMS (ESI-TOF) *m/z*: [M+H]⁺ Calcd for C₁₄H₁₉O₂F₃Br 355.0521 ; Found 355.0521

2-bromo-1-(1,5-dimethoxypentan-3-yl)-4-fluorobenzene(92hm)



Isolated as light yellow oil: 70% yield

¹H NMR (CDCl₃, 400 MHz): δ 7.29 (dd, *J* = 8.4, 2.7 Hz, 1H), 7.19 (dd, *J* = 8.7, 6.0, 1H), 7.02 (td, *J* = 8.1, 2.6 Hz, 1H), 3.47–3.41 (m, 1H), 3.28–3.16 (m, 4H), 3.25 (s, 6H), 2.05–1.81 (m, 4H)

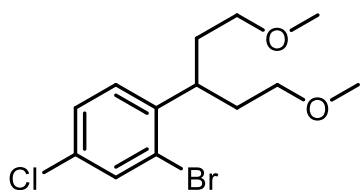
¹³C NMR (CDCl₃, 100 MHz): δ 160.2 (d, *J*_{CF} = 247 Hz), 139.5, 128.3, 124.7 (d, *J*_{CF} = 7.7 Hz), 119.4 (d, *J*_{CF} = 23.7 Hz), 114.6 (d, *J*_{CF} = 20.7 Hz), 70.0, 58.1, 36.7, 36.0

¹⁹F NMR (CDCl₃, 376 MHz): δ –114.8

FTIR (KBr, neat) $\tilde{\nu}$ 2926, 2870, 2355, 2326, 2064, 1889, 1599, 1486, 1265, 1120, 955, 860, 819, 732, 672, 594 cm^{–1}

HRMS (ESI-TOF) *m/z*: [M+H]⁺ Calcd for C₁₃H₁₉O₂FBr 305.0552; Found 305.0561

2-bromo-4-chloro-1-(1,5-dimethoxypentan-3-yl)benzene (92im)



Isolated as light yellow oil : 92% yield

¹H NMR (CDCl₃, 400 MHz): δ 7.56 (d, *J* = 2.2 Hz, 1H), 7.28 (dd, *J* = 8.4, 2.1 Hz, 1H), 7.16 (d, *J* = 8.4 Hz, 1H), 3.48–3.41 (m, 1H), 3.25 (s, 6H), 3.25–3.16 (m, 4H), 2.0–1.76 (m, 4H)

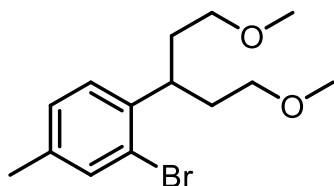
¹³C NMR (CDCl₃, 100 MHz): δ 142.4, 132.2, 12.1, 128.5, 127.8, 125.3, 70.2, 58.3, 37.0, 36.0

FTIR (KBr, neat) $\tilde{\nu}$ 2925, 2870, 1584, 1555, 1470, 1385, 1356, 1189, 1120, 1033, 955, 867, 821, 790, 756, 724, 690, 590, 571 cm^{–1}

HRMS (ESI-TOF) *m/z*: [M+H]⁺ Calcd for C₁₃H₁₉O₂ClBr 321.0257; Found 321.0266

2-bromo-1-(1,5-dimethoxypentan-3-yl)-4-methylbenzene (92km)

Isolated as light yellow oil: 78% yield



¹H NMR (CDCl₃, 400 MHz): δ 7.37 (s, 1H), 7.12–7.04, (m, 2H), 3.44–3.36 (m, 1H), 3.25 (s, 6H), 3.21 (t, *J* = 6.9 Hz, 4H), 2.29 (s, 3H), 1.99–1.80 (m, 4H)

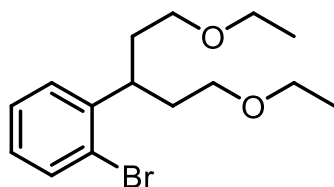
¹³C NMR (CDCl₃, 100 MHz): δ 140.5, 137.5, 133.2, 128.6, 127.4, 125.0, 70.5, 58.5, 37.1, 36.3, 20.5

FTIR (KBr, neat) $\tilde{\nu}$ 2869, 2828, 2365, 2341, 2065, 1908, 1490, 1451, 1389, 1189, 1120, 1038, 954, 856, 821, 729, 673, 591, 572, 465, 443 cm⁻¹

HRMS (ESI-TOF) *m/z*: [M+H]⁺ Calcd for C₁₄H₂₂O₂Br 301.0803; Found 301.0794

1-bromo-2-(1,5-diethoxypentan-3-yl)benzene (92ae)

Isolated as light yellow oil: 68 % yield



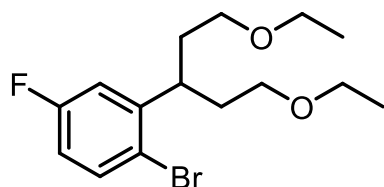
¹H NMR (CDCl₃, 400 MHz): δ 7.53 (dd, *J* = 8.0, 1.2 Hz, 1H), 7.30–7.22 (m, 2H), 7.04 (ddd, *J* = 8.0, 7.0, 2.1 Hz, 1H), 3.48 (m, 1H), 3.37 (q, *J* = 7.0 Hz, 4H), 3.26 (t, *J* = 6.9 Hz, 4H), 2.03–1.83 (m, 4H), 1.14 (t, *J* = 7.0 Hz, 6H)

¹³C NMR (CDCl₃, 100 MHz): δ 143.9, 132.8, 127.9, 127.6, 127.5, 125.5, 68.4, 66.1, 37.6, 36.5, 15.2

FTIR (KBr, neat) $\tilde{\nu}$ 2974, 2930, 2863, 2366, 2344, 1947, 1921, 1470, 1440, 1378, 1114, 1022, 755, 725, 661, 591, 575 cm⁻¹

HRMS (ESI-TOF) *m/z*: [M+H]⁺ Calcd for C₁₅H₂₄O₂Br 315.0960; Found 315.0970

1-bromo-2-(1,5-diethoxypentan-3-yl)-4-fluorobenzene (92ee)



Isolated as light yellow oil : 54% yield

¹H NMR (CDCl₃, 400 MHz): δ 7.49 (dd, *J* = 8.8, 5.6 Hz, 1H), 6.95 (dd, *J* = 9.9, 3.0 Hz), 6.79 (ddd, *J* = 8.7, 7.6, 3.1 Hz, 1H), 3.50–3.43 (m, 1H), 3.37 (q, *J* = 7.0 Hz, 4H), 3.28–3.23 (m, 4H), 2.02–1.78 (m, 4H), 1.14 (t, *J* = 7.0 Hz, 6H)

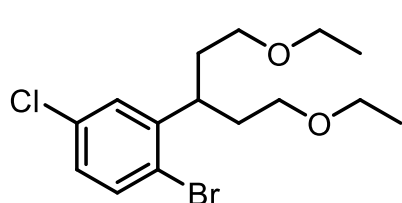
¹³C NMR (CDCl₃, 100 MHz): δ 162.1 (d, *J*_{CF} = 245 Hz), 146.2 (d, *J*_{CF} = 22.3 Hz), 133.7 (d, *J*_{CF} = 7.4 Hz), 119.2, 114.7 (d, *J*_{CF} = 22.3 Hz), 68.0, 65.9, 37.9, 36.2

¹⁹F NMR (CDCl₃, 376 MHz): δ –114.42

FTIR (KBr, neat) $\tilde{\nu}$ 2975, 2932, 2864, 1604, 1579, 1469, 1378, 1225, 1117, 1026, 954, 941, 871, 808, 717, 701, 608, 585 cm^{–1}

HRMS (ESI-TOF) *m/z*: [M+H]⁺ Calcd for C₁₅H₂₃O₂FBr 333.0865; Found 333.0854

1-bromo-4-chloro-2-(1,5-diethoxypentan-3-yl)benzene (92fe)



Isolated as light yellow oil : 73% yield

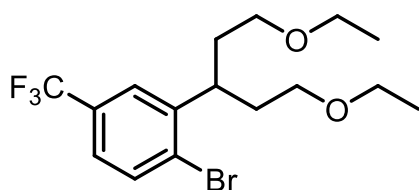
¹H NMR (CDCl₃, 400 MHz): δ 7.47 (d, *J* = 8.5 Hz, 1H), 7.20 (d, *J* = 2.6 Hz), 7.04 (dd, *J* = 8.7, 2.5 Hz, 1H), 3.50–3.43 (m, 1H), 3.37 (q, *J* = 7.0 Hz, 4H), 3.30–3.20 (m, 4H), 2.03–1.94 (m, 2H), 1.88–1.79 (m, 2H), 1.15 (t, *J* = 7.0 Hz, 6H)

¹³C NMR (CDCl₃, 100 MHz): δ 145.9, 133.8, 133.6, 128.1, 127.7, 123.2, 68.1, 66.1, 37.9, 36.4, 15.2

FTIR (KBr, neat) $\tilde{\nu}$ 3059, 2974, 2928, 2862, 1581, 1556, 1460, 1378, 1298, 1277, 1210, 1114, 1022, 679, 808, 719, 699, 583, 477, 459 cm^{–1}

HRMS (ESI-TOF) *m/z*: [M+H]⁺ Calcd for C₁₅H₂₃O₂ClBr 349.0570; Found 349.0572

1-bromo-2-(1,5-diethoxypentan-3-yl)-4-(trifluoromethyl)benzene (92ge)



Isolated as light yellow oil: 67% yield

¹H NMR (CDCl₃, 400 MHz): δ 7.66 (d, *J* = 8.4 Hz, 1H), 7.48 (d, *J* = 2.0 Hz, 1H), 7.30 (ddd, *J* = 8.3, 2.2, 0.8 Hz, 1H), 3.61–3.54 (m, 1H), 3.36 (q, *J* = 7.2 Hz, 4H), 3.31–3.20 (m, 4H), 2.06–1.84 (m, 4H), 1.14 (t, *J* = 7.0 Hz, 6H)

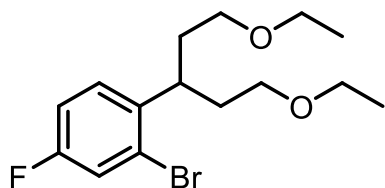
¹³C NMR (CDCl₃, 100 MHz): δ 145.3, 133.4, 130.1 (q, *J*_{CF} = 32.5 Hz), 129.2, 124.9, 124.1, (q, *J*_{CF} = 3.4 Hz), 123.9 (q, *J*_{CF} = 270.6 Hz), 68.1, 66.1, 38.0, 36.2, 15.1

¹⁹F NMR (CDCl₃, 376 MHz): δ –62.7

FTIR (KBr, neat) $\tilde{\nu}$ 2977, 2933, 2865, 1606, 1578, 1476, 1444, 1328, 11770, 1130, 1023, 899, 823, 729, 660, 469, 425 cm^{–1}

HRMS (ESI-TOF) *m/z*: [M+H]⁺ Calcd for C₁₆H₂₃O₂F₃Br 383.0834 ; Found 383.0840

2-bromo-1-(1,5-diethoxypentan-3-yl)-4-fluorobenzene (92he)



Isolated as light yellow oil: 50% yield

¹H NMR (CDCl₃, 400 MHz): δ 7.28 (dd, *J* = 8.4, 2.6 Hz, 1H), 7.19 (dd, *J* = 8.7, 6.0 Hz, 1H), 7.02 (ddd, *J* = 8.3, 8.3, 2.6 Hz, 1H), 3.50–3.42 (m, 1H), 3.36 (q, *J* = 7.0 Hz, 4H), 3.26–3.22 (m, 4H), 2.02–1.94 (m, 2H), 1.87–1.78 (m, 2H), 1.14 (t, *J* = 7.0 Hz, 6H)

¹³C NMR (CDCl₃, 100 MHz): δ 160.3 (d, *J*_{CF} = 247.3 Hz), 139.6, 128.4, 124.9 (d, *J*_{CF} = 9.4 Hz), 119.5 (d, *J*_{CF} = 23.7 Hz), 114.7 (q, *J*_{CF} = 20.4 Hz), 68.1, 66.0, 36.8, 36.4, 15.0

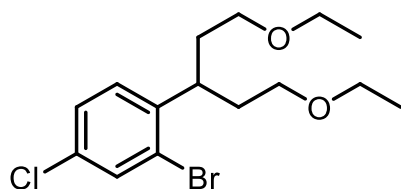
¹⁹F NMR (CDCl₃, 376 MHz): δ –115.1

FTIR (KBr, neat) $\tilde{\nu}$ 2975, 2933, 2864, 2801, 1599, 1486, 1354, 1229, 1114, 1030, 860, 818,

730, 693, 672, 586, 459 cm^{-1}

HRMS (ESI-TOF) m/z : $[\text{M}+\text{H}]^+$ Calcd for $\text{C}_{15}\text{H}_{23}\text{O}_2\text{FBr}$ 333.0865 ; Found 333.0858

2-bromo-4-chloro-1-(1,5-diethoxypentan-3-yl)benzene (92ie)



Isolated as light yellow oil : 68% yield

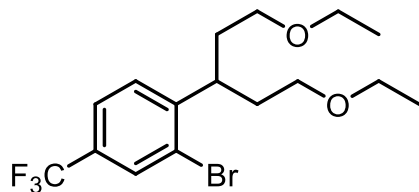
^1H NMR (CDCl_3 , 400 MHz): δ 7.56 (d, $J = 2.2$ Hz, 1H), 7.27 (dd, $J = 8.4, 2.2$ Hz, 1H), 7.17 (d, $J = 8.4$ Hz, 1H), 3.47–3.44 (m, 1H), 3.37 (q, $J = 7.0$ Hz, 4H), 3.28–3.20 (m, 4H), 2.02–1.79 (m, 4H), 1.14 (t, $J = 7.0$ Hz, 6H)

^{13}C NMR (CDCl_3 , 100 MHz): δ 142.6, 132.3, 132.2, 128.7, 127.9, 125.6, 68.2, 66.2, 37.2, 36.4, 15.1

FTIR (KBr, neat) $\tilde{\nu}$ 2975, 2932, 2864, 1971, 1898, 1584, 1555, 1470, 1379, 1114, 1032, 867, 820, 789, 723, 672, 638, 589, 460, 442 cm^{-1}

HRMS (ESI-TOF) m/z : $[\text{M}+\text{Na}]^+$ Calcd for $\text{C}_{15}\text{H}_{23}\text{O}_2\text{ClBr}$ 349.0570 ; Found 349.0572

2-bromo-1-(1,5-diethoxypentan-3-yl)-4-(trifluoromethyl)benzene (92je)



¹H NMR (CDCl₃, 400 MHz): δ 7.80 (d, *J* = 1.1 Hz, 1H), 7.53 (dd, *J* = 1.3, 8.2 Hz, 1H), 7.37 (d, *J* = 8.1, 1H), 3.62–3.53 (m, 1H), 3.36 (q, *J* = 7.0 Hz, 1H), 3.31–3.21 (m, 4H), 2.07–1.97 (m, 2H), 1.93–1.81 (m, 2H), 1.13 (t, *J* = 7.0 Hz, 6H)

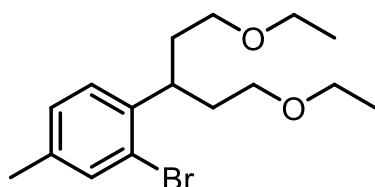
¹³C NMR (CDCl₃, 100 MHz): δ 148.4, 129.6, 129.6 (q, *J*_{CF} = 32.8 Hz), 128.3, 125.4, 124.2, 123.1 (q, *J*_{CF} = 270.6 Hz), 68.0, 66.0, 37.9, 36.2, 15.0

¹⁹F NMR (CDCl₃, 376 MHz): δ –62.7

FTIR (KBr, neat) $\tilde{\nu}$ 2975, 2933, 2864, 2801, 1601, 1488, 1354, 1222, 1114, 1020, 850, 785, 721, 672, 632, 589, 460, 440 cm^{–1}

HRMS (ESI-TOF) *m/z*: [M+H]⁺ Calcd for C₁₆H₂₃O₂BrF₃ 383.0834 ; Found 383.0836

2-bromo-1-(1,5-diethoxypentan-3-yl)-4-methylbenzene (92ke)



Isolated as light yellow oil: 70 % yield

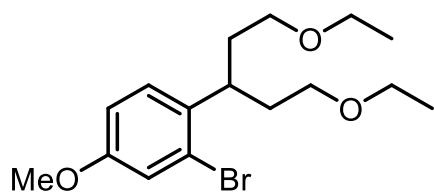
¹H NMR (CDCl₃, 400 MHz): δ 7.36 (s, 1H), 7.12–7.06 (m, 2H), 3.45–3.34 (m, 5H), 3.25 (t, *J* = 7.3 Hz, 4H), 2.29 (s, 3H), 2.01–1.82 (m, 4H), 1.14 (t, *J* = 7.2 Hz, 6H)

¹³C NMR (CDCl₃, 100 MHz): δ 140.2, 136.6, 132.5, 128.0, 127.0, 124.6, 67.7, 65.4, 36.6, 36.0, 19.9, 14.6

FTIR (KBr, neat) $\tilde{\nu}$ 2975, 2930, 2864, 2365, 2344, 1606, 1490, 1444, 1219, 1035, 873, 853, 820, 754, 728, 673, 592, 571, 459 cm^{–1}

HRMS (ESI-TOF) *m/z*: [M+H]⁺ Calcd for C₁₆H₂₆O₂Br 329.1116 ; Found 329.1111

-bromo-1-(1,5-diethoxypentan-3-yl)-4-methoxybenzene(92le)



Isolated as light yellow oil: 72% yield

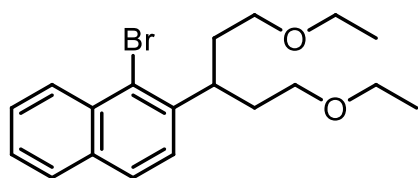
¹H NMR (CDCl₃, 400 MHz): δ 7.12 (d, *J* = 8.6 Hz, 1H), 7.07 (d, *J* = 2.7 Hz, 1H), 6.87 (dd, *J* = 8.7, 2.7 Hz, 1H), 3.78 (s, 3H), 3.40–3.35 (m, 1H), 3.37 (q, *J* = 7.0 Hz, 4H), 3.24 (t, *J* = 7.0 Hz, 4H), 2.00–1.79 (m, 4H), 1.15 (t, *J* = 7.0 Hz, 6H)

¹³C NMR (CDCl₃, 100 MHz): 157.4, 135.0, 127.4, 124.7, 116.9, 113.4, 67.6, 65.2, 54.4, 36.0, 14.5

FTIR (KBr, neat) $\tilde{\nu}$ 2974, 2933, 2863, 1604, 1565, 1493, 1441, 1378, 1355, 1284, 1238, 1113, 1036, 856, 840, 817, 729, 693, 603, 546, 464, 443 cm⁻¹

HRMS (ESI-TOF) *m/z*: [M+H]⁺ Calcd for C₁₆H₂₆O₃Br 345.1065 ; Found 345.1054

1-bromo-2-(1,5-diethoxypentan-3-yl)naphthalene(92me)



Isolated as light yellow oil : 70% yield

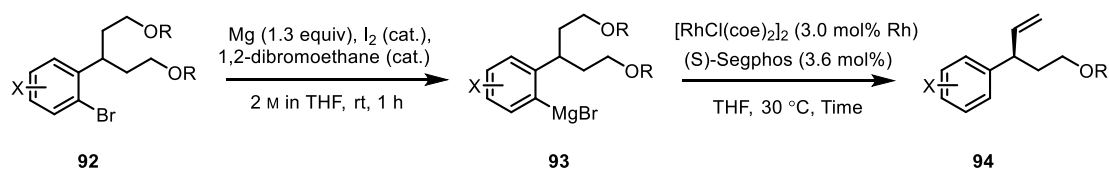
¹H NMR (CDCl₃, 400 MHz): δ 8.35 (d, *J* = 7.8 Hz, 1H), 7.79 (t, *J* = 8.0 Hz, 2H), 7.59 (ddd, *J* = 8.5, 7.0, 1.3 Hz, 1H), 7.50 (ddd, *J* = 8.5, 7.0, 1.3 Hz, 1H), 7.37 (d, *J* = 8.5 Hz, 1H), 3.92–3.84 (m, 1H), 3.33 (ddd, *J* = 7.0, 7.0, 1.7 Hz, 4H), 3.28–3.20 (m, 4H), 2.11–1.95 (m, 4H), 1.12 (t, *J* = 6.9 Hz, 6H)

¹³C NMR (CDCl₃, 100 MHz): 141.5, 133.2, 132.3, 127.9, 127.8, 127.1, 125.9, 124.7, 124.5, 68.2, 65.9, 38.4, 36.4, 15.0

FTIR (KBr, neat) $\tilde{\nu}$ 2974, 2930, 2863, 1952, 1912, 1501, 1442, 1377, 1355, 1258, 1231, 1114, 1034, 964, 862, 816, 749, 669, 641, 532 cm⁻¹

HRMS (ESI-TOF) *m/z*: [M+H]⁺ Calcd for C₁₉H₂₆O₂Br 365.1116 ; Found 365.1114

General Procedures for Rhodium-Catalyzed Asymmetric Desymmetrization



Step 1

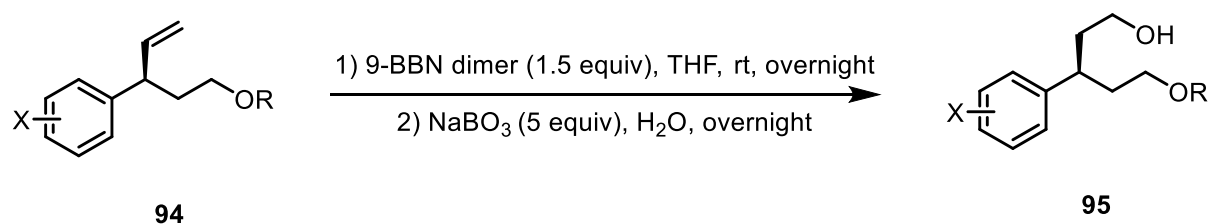
A two-neck bottle which had been heated at reduced pressure equipped with 5.2 mmol of Magnesium turnings and a condenser before added THF, a grain of I₂ and 2 drops of 1,2-dibromoethane. While the reaction was triggered, Bromobenzene **92** (4 mmol) added dropwise and stirred under argon atmosphere at room temperature for 1 h.

Absorb 0.1 ml of the Grignard reagent and quench by excess of iodine. By the addition of internal standard, concentration of Grignard reagent could be detected.

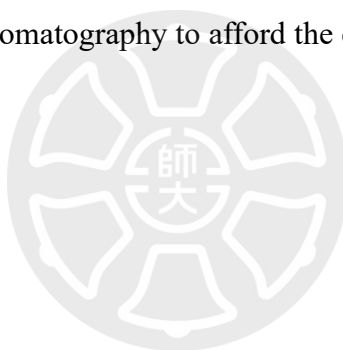
Step 2

Under the N₂ atmosphere, 1.5 mol% of [RhCl(coe)₂]₂ and 3.6 mol% of (S)-Segphos stirred until the reaction turn burgundy red. After all, 0.2 mmol of Grignard reagent was added and stirred at 30 °C for 6 h or 12 h. The reaction was quenched by water and extracted by EtOAC, wash with brine, dried over anhydrous Na₂SO₄, filtered and concentrated under reduced pressure then purified by column chromatography on silica gel to afford the desired product.

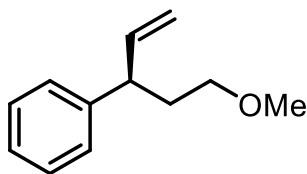
Procedure of hydroboration oxidation to determined Enantiomeric excess of (94cm, 94hm, 94im)



To a solution of **94** in dry THF (1 mL) was added 9-BBN dimer (1.5 equiv) at room temperature. The reaction mixture was stirred for 12 h, and then added NaBO₃ (5 equiv) and H₂O (1 mL), at 0 °C. The reaction was stirred at room temperature for 12 h. After all, the mixture extracted with EtOAc and dried over Na₂SO₄. The solution was concentrated in vacuo, and residue was purified by silical gel column chromatography to afford the corresponding alcohol **95**.



(*R*)-(5-methoxypent-1-en-3-yl)benzene (94am)



Isolated as a transparent oil: 87% yield after 6 h, 96% ee.

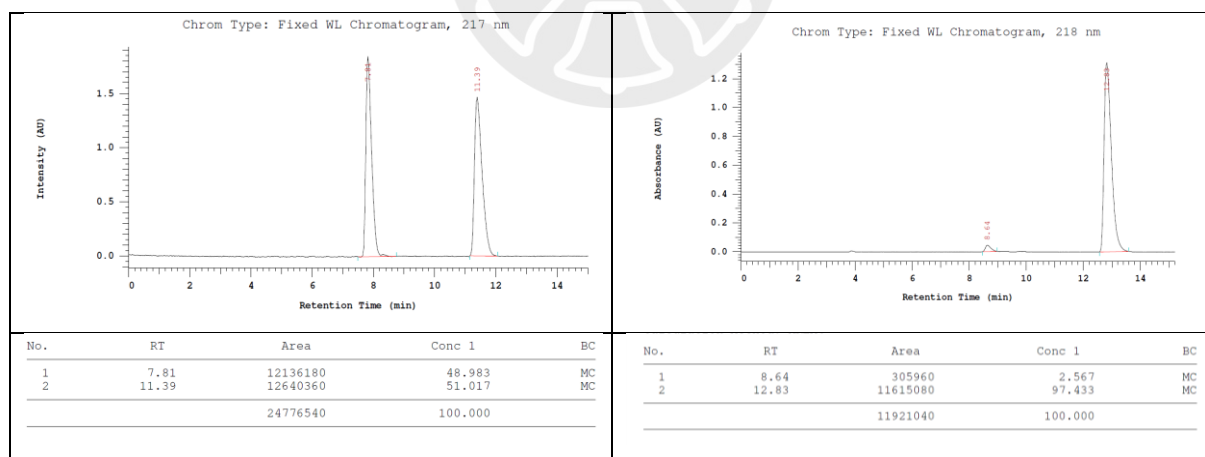
The ee was determined on CHIRALPAK IB column with hexane, flow rate = 1.0 mL / min, wavelength = 218 nm. Retention time: 8.64 min [*(S)*-enantiomer], 12.8 min [*(R)*-enantiomer]. $[\alpha]_D^{28} = +7.2$ (c 1.00, CHCl₃).

¹H NMR (CDCl₃, 400 MHz): δ 7.32–7.28 (m, 2H), 7.21–7.18 (m, 3H), 5.96 (ddd, $J = 17.4$, 10.2, 7.5 Hz, 1H), 5.06 (dt, $J = 17.1$, 1.2 Hz, 1H), 5.04 (dt, $J = 10.0$, 1.2 Hz, 1H), 3.44 (q, $J = 7.6$ Hz, 1H), 3.33 (dt, $J = 9.4$, 6.4 Hz, 1H), 3.29 (s, 3H), 3.27 (dt, $J = 9.5$, 6.6 Hz, 1H), 2.2 (m, 2H)

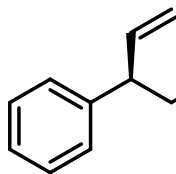
¹³C NMR (CDCl₃, 100 MHz): δ 143.8, 141.7, 128.5, 127.6, 126.3, 114.3, 70.4, 58.5, 46.1, 35.0

FTIR (KBr, neat) $\tilde{\nu}$ 3060, 2972, 2862, 1634, 1598, 1490, 1448, 1372, 1108, 1025, 995, 915, 762, 696 cm⁻¹

HRMS (ESI-TOF) m/z : $[M+H]^+$ Calcd for C₁₂H₁₇O 177.1279; Found 177.1284



(R)-(5-ethoxypent-1-en-3-yl)benzene (94ae)



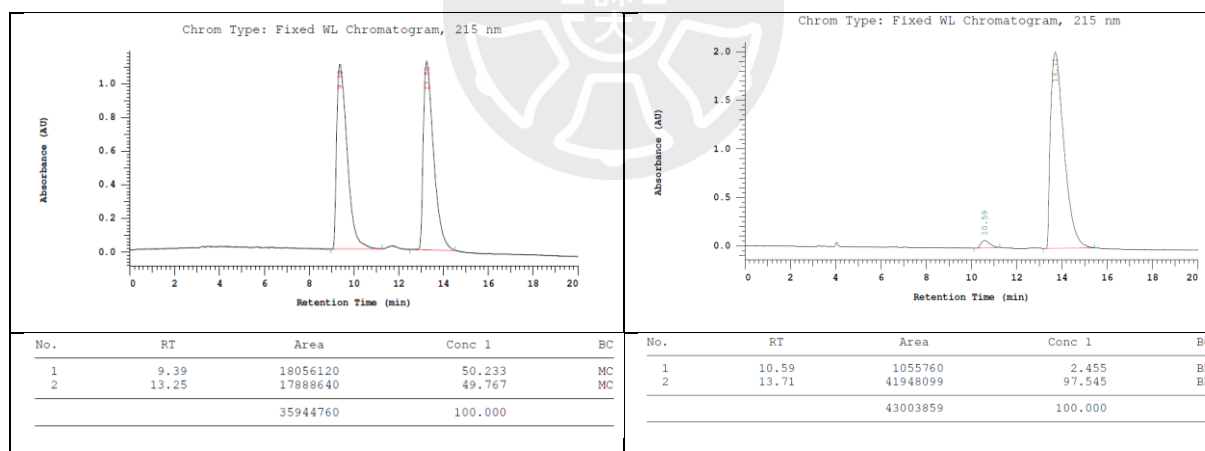
Isolated as a transparent oil: 99 % yield after 6 h, 95% ee. The ee was determined on CHIRALPAK IB column with hexane, flow rate = 1.0 mL / min, wavelength = 215 nm. Retention time: 10.59 min [(S)-enantiomer], 13.71 min [(R)-enantiomer]. $[\alpha]_D^{28} = +6.3$ (c 1.00, CHCl₃).

¹H NMR (CDCl₃, 400 MHz): δ 7.32–7.28 (m, 2H), 7.21–7.18 (m, 3H), 5.96 (ddd, $J = 17.4, 10.3, 7.4$ Hz, 1H), 5.05 (dt, $J = 7.2, 1.4$ Hz, 1H), 5.04 (dt, $J = 10.1, 1.3$ Hz, 1H), 3.48–3.28 (m, 5H), 2.07–1.90 (m, 2H), 1.18 (t, $J = 7.0$ Hz, 3H)

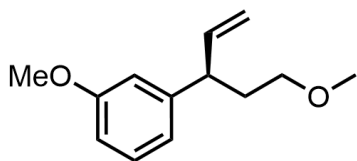
¹³C NMR (CDCl₃, 100 MHz): δ 143.8, 141.8, 128.4, 127.6, 126.2, 114.1, 68.3, 66.1, 46.1, 35.0, 15.2

FTIR (KBr, neat) $\tilde{\nu}$ 3063, 2976, 2932, 2865, 2366, 2344, 1638, 1601, 1493, 1453, 1414, 1378, 1113, 1027, 915, 762, 701 cm⁻¹

HRMS (ESI-TOF) m/z : [M+H]⁺ Calcd for C₁₃H₁₉O 191.1436; Found 191.1446



(R)-1-methoxy-3-(5-methoxypent-1-en-3-yl)benzene (94bm)



Isolated as a transparent oil: 78% yield after 6 h, 88% ee.

The ee was determined on CHIRALPAK ASH column with hexane/2-propanol = 300:1, flow rate = 1.0 mL / min, wavelength = 217 nm. Retention time: 7.20 min [(S)-enantiomer], 8.61 min [(R)-enantiomer]

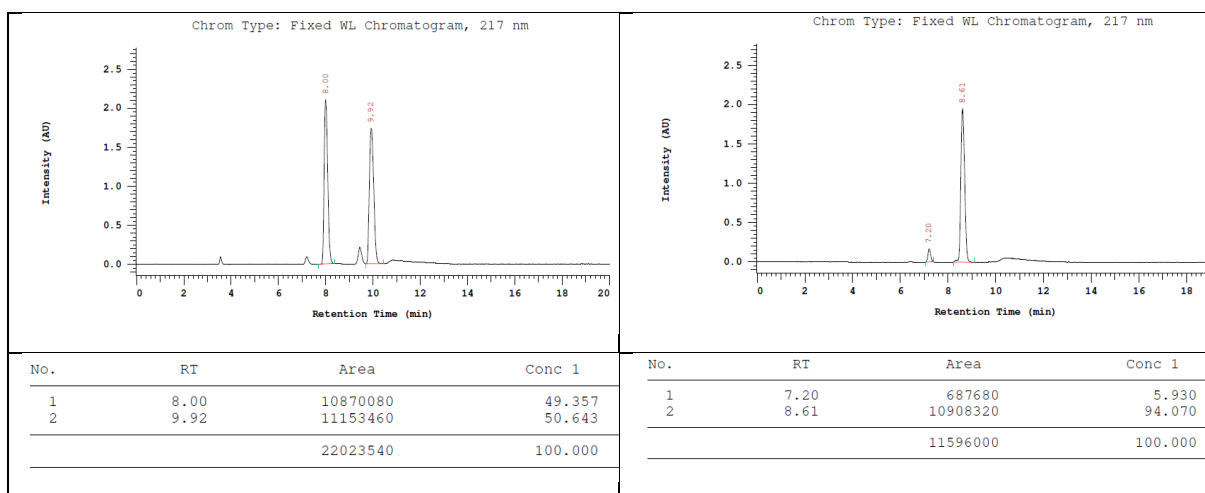
$[\alpha]_D^{28} = +11.3$ (c 1.00, CHCl₃).

¹H NMR (CDCl₃, 400 MHz): δ 7.24–7.19 (m, 1H), 6.80–6.73 (m, 3H), 5.94 (ddd, $J = 17.1$, 10.0, 7.4 Hz, 1H), 5.06 (dt, $J = 17.1$, 1.3 Hz, 1H), 5.04 (dt, $J = 8.8$, 1.1 Hz, 1H), 3.79 (s, 1H), 3.42 (q, $J = 7.6$ Hz, 1H), 3.33 (dt, $J = 9.4$, 6.4 Hz, 1H), 3.29 (s, 1H), 3.30–3.25, (m, 1H), 2.03–1.89 (m, 2H)

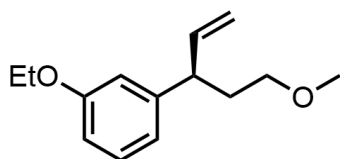
¹³C NMR (CDCl₃, 100 MHz): δ 159.7, 145.5, 141.5, 129.4, 120.0, 114.3, 113.5, 70.4, 58.5, 55.1, 46.1, 34.9

FTIR (KBr, neat) $\tilde{\nu}$ 2978, 2936, 2873, 2833, 1835, 1600, 1487, 1454, 1262, 1155, 1118, 1047, 998, 916, 874, 781, 701, 568, 463 cm⁻¹

HRMS (ESI-TOF) m/z : [M+H]⁺ Calcd for C₁₃H₁₉O₂ 207.1385; Found 207.1377



(R)-1-ethoxy-3-(5-methoxypent-1-en-3-yl)benzene (94cm)



Isolated as a transparent oil: 43% yield after 12 h, 82% ee.

Enantiomeric excess was determined via derivatization.

$[\alpha]_D^{28} = +14.2$ (c 1.00, CHCl₃).

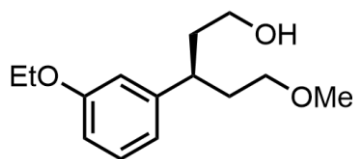
¹H NMR (CDCl₃, 400 MHz): δ 7.23–7.18 (td, $J = 7.5, 1.2$ Hz, 1H), 6.79–6.72 (m, 3H), 5.94 (ddd, $J = 17.3, 10.3, 7.4$ Hz, 1H), 5.06 (dt, $J = 17.2, 1.5$ Hz, 1H), 5.03 (dt, $J = 10.0, 1.3$ Hz, 1H), 4.02 (q, $J = 7.0$ Hz, 2H), 3.40 (q, $J = 7.6$ Hz, 1H), 3.33 (dt, $J = 9.4, 6.5$ Hz, 1H), 3.29 (s, 1H), 3.29–3.25, (m, 1H), 2.03–1.89 (m, 2H), 1.40 (t, $J = 7.0$ Hz, 3H)

¹³C NMR (CDCl₃, 100 MHz): δ 159.1, 145.4, 141.6, 129.4, 120.0, 114.3, 114.1, 70.5, 63.3, 58.5, 46.1, 34.9, 14.9

FTIR (KBr, neat) $\tilde{\nu}$ 2979, 2929, 2874, 2362, 2341, 1721, 1601, 1478, 1449, 1264, 1158, 1117, 1052, 915, 777, 701, 462 cm⁻¹

HRMS (ESI-TOF) m/z : [M+H]⁺ Calcd for C₁₄H₂₁O₂ 221.1542; Found 221.1549

(S)-3-(3-ethoxyphenyl)-5-methoxypentan-1-ol (95cm)



Isolated as a transparent oil, 82% ee. The ee was determined on CHIRALPAK ASH column with hexane/2-propanol = 90:10, flow rate = 1.0 mL/ min, wavelength = 220 nm. Retention time: 6.8 min [(*R*)-enantiomer], 10.2 min [(*S*)-enantiomer]

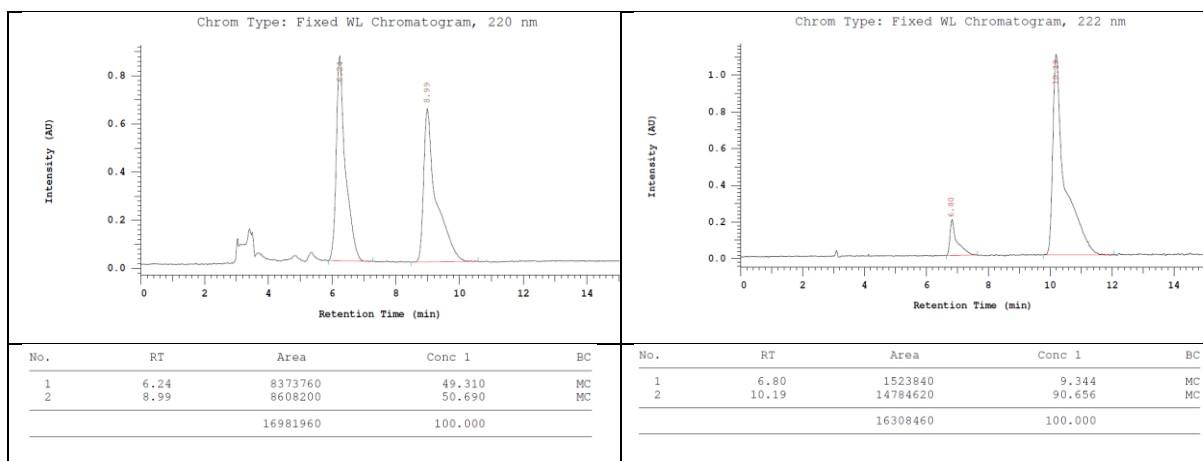
$[\alpha]_D^{28} = +40.5$ (c 1.00, CHCl₃).

¹H NMR (CDCl₃, 400 MHz): 7.22–7.18 (t, *J* = 6.0 Hz, 1H), 6.77–6.73 (m, 3H), 4.02(q, *J* = 7.0 Hz, 2H), 3.58–3.46 (m, 1H), 3.28–3.14 (m, 2H), 3.26 (s, 1H), 2.84 (sep, *J* = 5.0 Hz, 1H), 1.97–1.79 (m, 4H), 1.41 (t, *J* = 7.0 Hz, 3H)

¹³C NMR (CDCl₃, 400 MHz): 159.1, 146.1, 129.5, 120.0, 114.1, 111.9, 70.6, 63.3, 61.1, 58.6, 39.5, 39.1, 36.6, 14.9

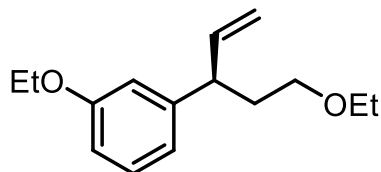
FTIR (KBr, neat) $\tilde{\nu}$ 3407, 2932, 2875, 1583, 1451, 1392, 1256, 1159, 1050, 959, 876, 778, 703 cm⁻¹

HRMS (ESI-TOF) *m/z*: [M+H]⁺ Calcd for C₁₄H₂₃O₃ 239.1647; Found 239.1646



(R)-1-ethoxy-3-(5-ethoxypent-1-en-3-yl)benzene (94ce)

Isolated as a transparent oil: 75% yield after 12 h, 92% ee.



Enantiomeric excess was determined via derivatization.

$[\alpha]_{\text{D}}^{28} = +16.4$ (c 1.00, CHCl_3).

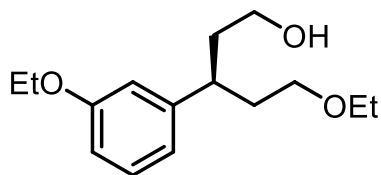
^1H NMR (CDCl_3 , 400 MHz): δ 7.0 (t, $J = 7.7$ Hz, 1H), 6.79–6.72 (m, 3H), 5.94 (ddd, $J = 17.4$, 10.3, 7.4 Hz, 1H), 5.06 (dt, $J = 15.5$, 1.3 Hz, 1H), 5.02, (dt, $J = 8.6$, 1.2 Hz, 1H), 4.11 (q, $J = 7.0$ Hz, 2H), 3.42 (q, $J = 7.0$ Hz, 2H), 3.44–3.34 (m, 2H), 3.31 (dt, $J = 9.4$, 6.7 Hz, 2H), 2.04–1.90 (m, 2H), 1.40 (t, $J = 7.0$ Hz, 3H), 1.18 (t, $J = 7.0$ Hz, 3H)

^{13}C NMR (CDCl_3 , 100 MHz): δ 159.1, 145.5, 141.7, 129.3, 120.0, 114.2, 114.1, 111.9, 68.3, 66.1, 63.2, 46.2, 35.0, 15.2, 14.8

FTIR (KBr, neat) $\tilde{\nu}$ 2976, 2932, 2866, 1595, 1569, 1469, 1378, 1287, 1235, 1114, 1016, 872, 768, 639 cm^{-1}

HRMS (ESI-TOF) m/z : $[\text{M}+\text{H}]^+$ Calcd for $\text{C}_{15}\text{H}_{23}\text{O}_2$ 235.1698; Found 235.1690

(S)-5-ethoxy-3-(3-ethoxyphenyl)pentan-1-ol (95ce)



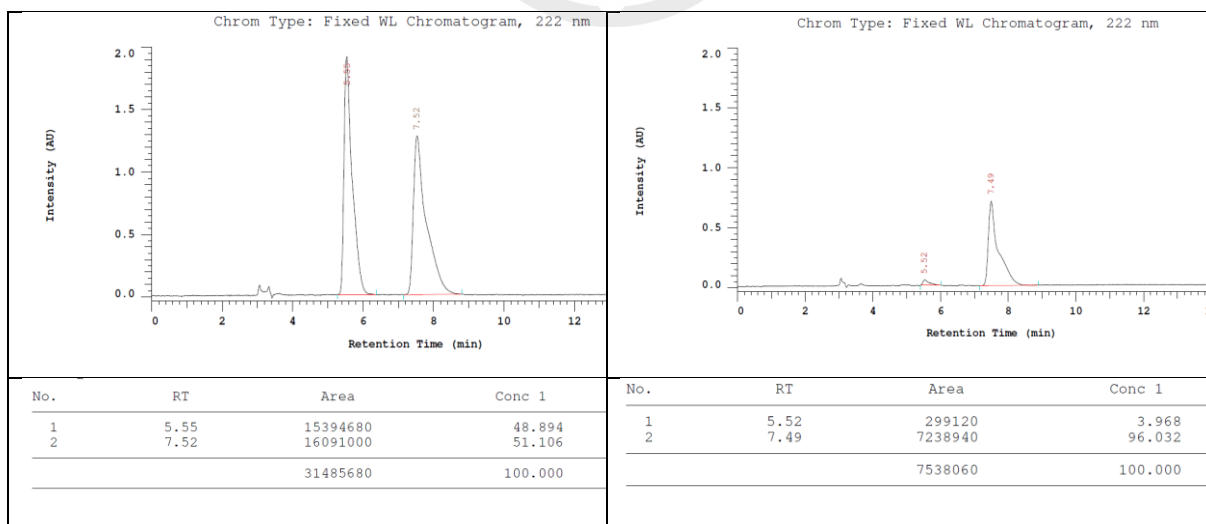
Isolated as a transparent oil, 92% ee. The ee was determined on CHIRALPAK ASH column with hexane/2-propanol = 90:10, flow rate = 1.0 mL/ min, wavelength = 222 nm. Retention time: 5.52 min [(*R*)-enantiomer], 7.49 min [(*S*)-enantiomer]. $[\alpha]_D^{28} = +44.5$ (c 1.00, CHCl₃).

¹H NMR (CDCl₃, 400 MHz): 7.20 (t, *J* = 7.8 Hz, 1H), 6.76–6.72 (m, 3H), 4.02 (q, *J* = 7.0 Hz, 2H), 3.56–3.44 (m, 2H), 3.37 (m, 2H), 3.31–3.26 (m, 1H), 3.23–3.17 (m, 1H), 2.84 (sep, *J* = 5.2 Hz, 1H), 1.99–1.76 (m, 5H), 1.41 (t, *J* = 7.0 Hz, 3H), 1.51 (t, *J* = 7.0 Hz, 3H)

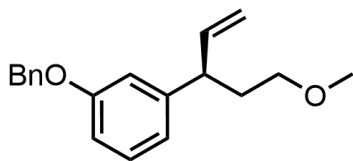
¹³C NMR (CDCl₃, 400 MHz): 159.1, 146.2, 129.4, 119.9, 114.1, 111.9, 68.4, 66.1, 63.2, 60.9, 39.5, 39.1, 36.5, 15.1, 14.8

FTIR (KBr, neat) $\tilde{\nu}$ 3408, 2930, 2878, 1584, 1448, 1392, 1256, 1159, 1050, 956, 878, 769, 701 cm⁻¹

HRMS (ESI-TOF) *m/z*: [M+H]⁺ Calcd for C₁₅H₂₃O 2235.1698; Found 235.1690



(R)-1-(benzyloxy)-3-(5-methoxypent-1-en-3-yl)benzene (94dm)



Isolated as a transparent oil: 33% yield after 12 h, 75% ee,

The ee was determined on CHIRALPAK OJ-H column with hexane/2-propanol = 150:1, flow rate = 1.0 mL / min,

wavelength = 220 nm. Retention time:

14.45 min [(S)-enantiomer], 15.71 min [(R)-enantiomer]

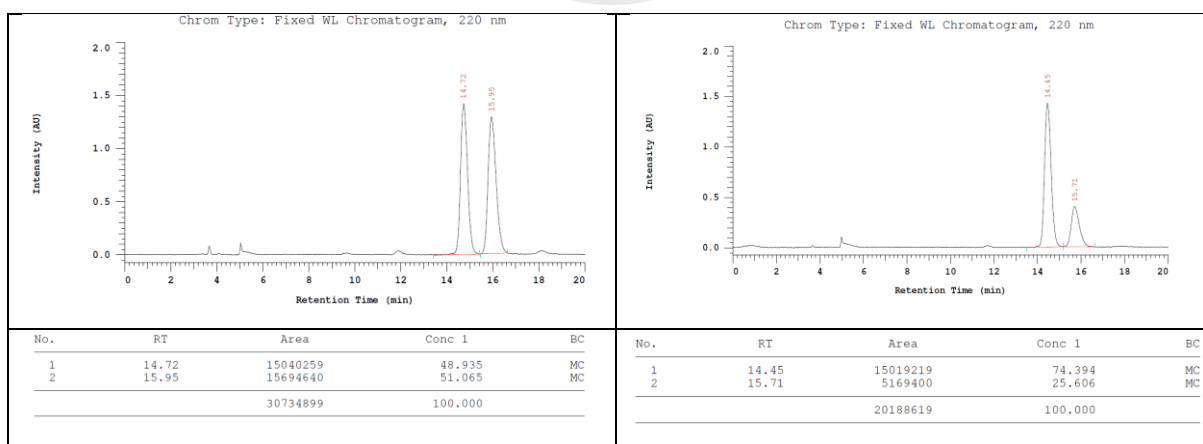
$[\alpha]_D^{28} = +23.5$ (c 1.00, CHCl₃).

¹H NMR (CDCl₃, 400 MHz): δ 7.44–7.30 (m, 5H), 7.22 (td, $J = 7.7, 0.6$ Hz, 1H), 6.83–6.80 (m, 3H), 5.95 (ddd, $J = 17.3, 10.0, 7.4$ Hz, 1H), 5.08–5.02, (m, 4H), 3.41 (q, $J = 7.6$ Hz, 1H), 3.37–3.24 (m, 5H), 1.97 (dq, $J = 13.8, 6.9$ Hz, 1H), 1.94 (ddt, $J = 14.2, 7.6, 6.6$ Hz, 1H)

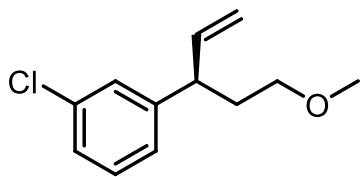
¹³C NMR (CDCl₃, 100 MHz): δ 159.0, 145.5, 141.5, 137.1, 129.4, 128.5, 127.9, 127.5, 120.3, 114.5, 114.4, 112.4, 70.4, 70.0, 58.5, 46.1, 34.9

FTIR (KBr, neat) $\tilde{\nu}$ 3033, 2925, 2872, 1583, 1452, 1383, 1260, 1157, 1117, 915, 875, 778, 736, 698 cm⁻¹

HRMS (ESI-TOF) m/z : [M+H]⁺ Calcd for C₁₉H₂₃O₂ 283.1698; Found 283.1701



(R)-1-chloro-3-(5-methoxypent-1-en-3-yl)benzene (94fm)



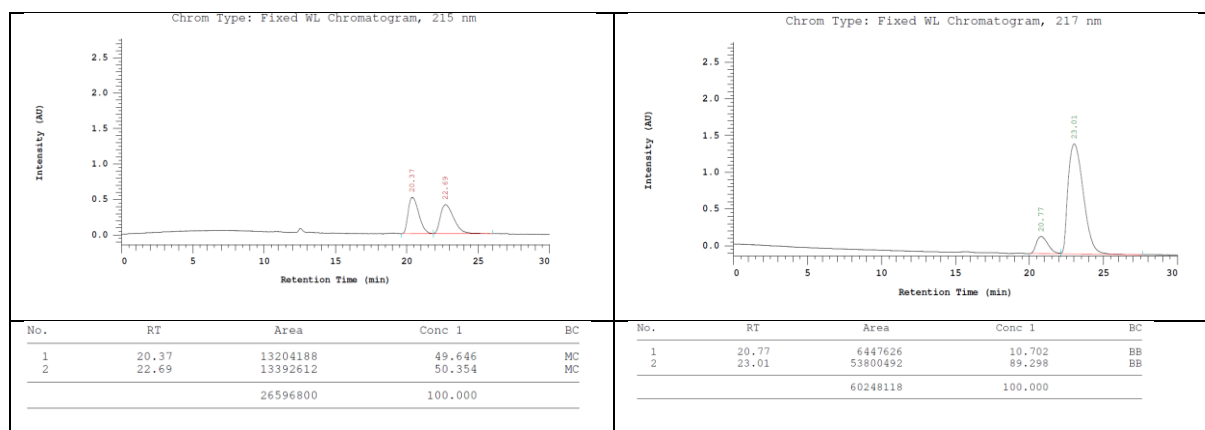
Isolated as a transparent oil: 45% yield after 12 h, 79% ee. The ee was determined on CHIRALPAK ASH column with hexane, flow rate = 0.3 mL / min, wavelength = 217 nm. Retention time: 20.77 min [(R)-enantiomer], 23.01 min [(S)-enantiomer]
 $[\alpha]_D^{28} = +31.1$ (c 1.00, CHCl₃).

¹H NMR (CDCl₃, 400 MHz): δ 7.25–7.16 (m, 3H), 7.08 (dt, $J = 7.4, 1.4$ Hz, 1H), 5.91 (ddd, $J = 17.4, 9.4, 7.5$ Hz, 1H), 5.07 (dt, $J = 10.2, 1.4$ Hz, 1H), 5.06 (dt, $J = 16.2, 1.4$ Hz, 1H), 3.44 (q, $J = 7.1$ Hz, 1H), 3.33 (dt, $J = 9.5, 6.3$ Hz, 1H), 3.29 (s, 3H), 3.26 (dt, $J = 9.4, 6.6$ Hz, 1H), 1.97 (dq, $J = 13.8, 6.8$ Hz, 1H), 1.92 (ddt, $J = 13.9, 7.7, 6.2$ Hz, 1H)

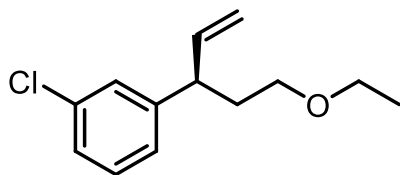
¹³C NMR (CDCl₃, 100 MHz): δ 145.9, 140.9, 134.3, 129.7, 127.8, 126.5, 125.9, 114.9, 70.1, 58.5, 45.7, 34.9

FTIR (KBr, neat) $\tilde{\nu}$ 2925, 2872, 2361, 2341, 1595, 1573, 1476, 1194, 1110, 999, 918, 784, 694 cm⁻¹

HRMS (ESI-TOF) m/z : [M+H]⁺ Calcd for C₁₂H₁₆OCl 211.0890; Found 211.0895



***(R)*-1-chloro-3-(5-ethoxypent-1-en-3-yl)benzene (94fe)**



Isolated as a transparent oil: 45% yield after 12 h, 90% ee. The ee was determined on CHIRALPAK ASH column with hexane/2-propanol = 150:1, flow rate = 0.5mL/ min, wavelength = 217 nm. Retention time: 9.2 min [(*R*)-enantiomer], 11.04 min [(*S*)-enantiomer]

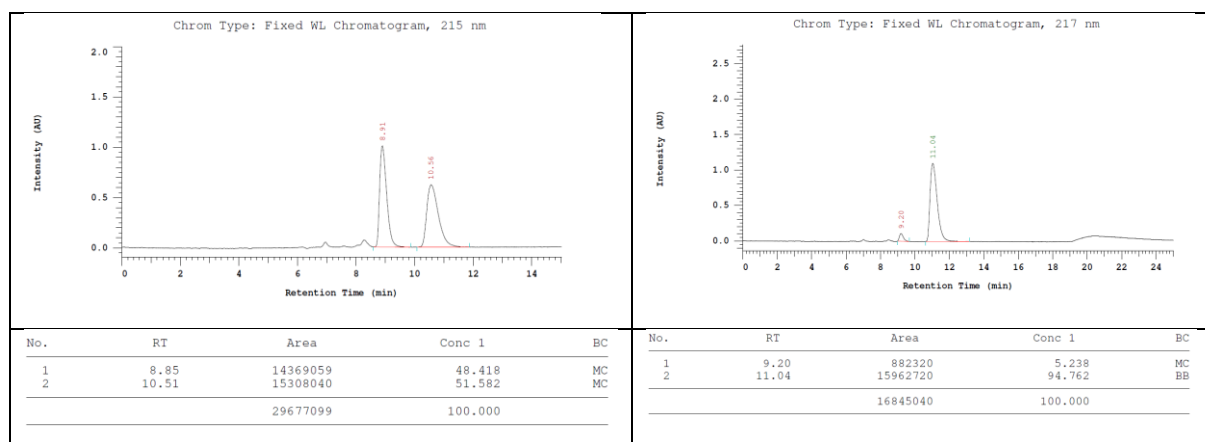
$$[\alpha]_D^{28} = +27.9 \text{ (c 1.00, CHCl}_3\text{)}.$$

¹H NMR (CDCl₃, 400 MHz): δ 7.25–7.16 (m, 3H), 7.08 (dt, *J* = 7.3, 1.5 Hz, 1H), 5.91 (ddd, *J* = 17.4, 9.8, 7.4, 1H), 5.07 (dt, *J* = 11.0, 1.2 Hz, 1H), 5.06 (dt, *J* = 16.2, 1.5 Hz, 1H), 3.48–3.39 (m, 3H), 3.37 (dt, *J* = 9.4, 6.4 Hz, 1H), 3.29 (dt, *J* = 9.4, 6.7 Hz, 1H), 1.99 (dq, *J* = 13.8, 6.8 Hz, 1H), 1.92 (ddt, *J* = 14.1, 7.5, 6.4, 1H), 1.18 (t, *J* = 7.0 Hz, 3H)

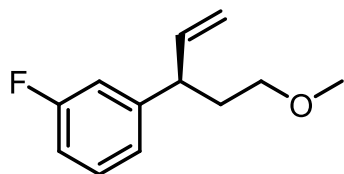
¹³C NMR (CDCl₃, 100 MHz): δ 146.0, 141.0, 134.2, 129.7, 127.9, 126.4, 125.9, 114.9, 67.9, 66.2, 45.8, 34.9, 15.2

FTIR (KBr, neat) $\tilde{\nu}$ cm⁻¹ 3081, 2976, 2932, 2867, 2801, 2606, 2363, 2342, 1638, 1596, 1573 cm⁻¹

HRMS (ESI-TOF) *m/z*: [M+H]⁺ Calcd for C₁₃H₁₈OCl 225.1046; Found 225.1048



***(R)*-1-fluoro-3-(5-methoxypent-1-en-3-yl)benzene**



Isolated as a transparent oil: 17% yield after 12 h, The ee

undetermined

¹H NMR (CDCl₃, 400 MHz): δ 7.28–7.23 (m, 1H), 6.99–6.97 (m, 1H), 6.92–6.87 (m, 2H), 5.92 (ddd, *J* = 17.5, 10.0, 7.5 Hz, 1H), 5.07 (dt, *J* = 11.52, 1.4 Hz, 1H), 5.06 (dt, *J* = 15.8, 1.3 Hz, 1H), 3.46 (q, *J* = 7.1 Hz, 1H), 3.37–3.23 (m, 5H), 1.99 (dq, *J* = 13.8, 6.7 Hz, 1H), 1.92 (ddt, *J* = 6.4, 7.7, 13.9 Hz, 1H)

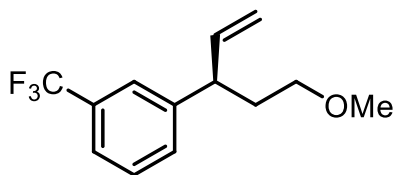
¹³C NMR (CDCl₃, 100 MHz): δ 163.0 (d, *J*_{CF} = 244.0 Hz), 146.5 (d, *J*_{CF} = 6.8 Hz), 141.0, 129.9 (d, *J*_{CF} = 8.24 Hz), 123.3 (d, *J*_{CF} = 2.45 Hz), 114.8, 114.5 (d, *J*_{CF} = 84.4 Hz), 113.1 (d, *J*_{CF} = 21.0 Hz), 70.2, 58.6, 45.8, 34.9

¹⁹F NMR (CDCl₃, 376 MHz): δ -114.27

FTIR (KBr, neat) $\tilde{\nu}$ 2925, 2872, 2363, 2344, 1588, 1573, 1479, 1190, 1105, 997, 915, 781, 692 cm⁻¹

HRMS (ESI-TOF) *m/z*: [M+H]⁺ Calcd for C₁₂H₁₆OF 195.1185; Found 195.1183

(R)-1-(5-methoxypent-1-en-3-yl)-3-(trifluoromethyl)benzene (94gm)



Isolated as a transparent oil: 85% yield after 12 h, 99% ee.

The ee was determined on CHIRALPAK ASH column with hexane, flow rate = 0.3 mL/min, wavelength = 217 nm.

Retention time: 17.17 min [(R)-enantiomer], 21.12 min [(S)-enantiomer]. $[\alpha]_D^{28} = +9.6$ (c 1.00, CHCl₃).

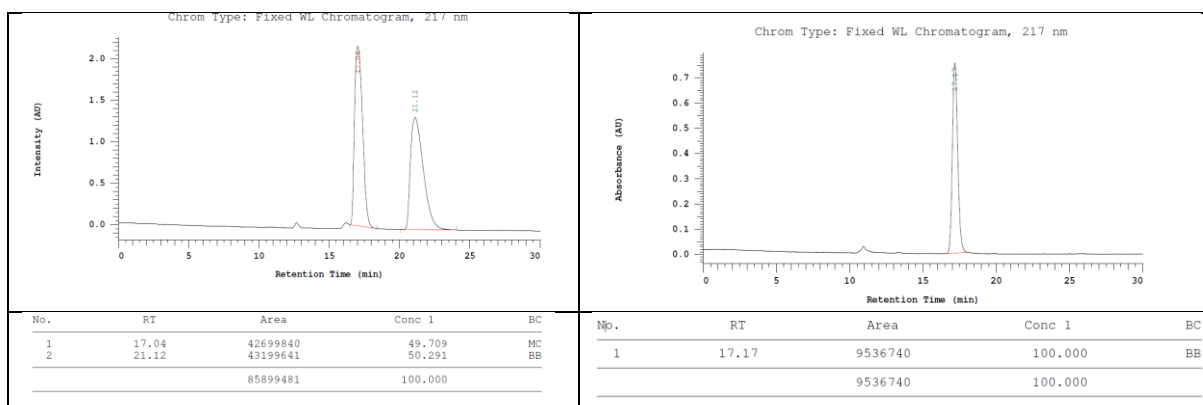
¹H NMR (CDCl₃, 400 MHz): δ 7.48–7.38 (m, 4H), 5.95 (ddd, $J = 17.9, 10.5, 7.5$ Hz, 1H), 5.09 (dt, $J = 18.3, 1.3$ Hz, 1H), 5.07 (dt, $J = 9.1, 1.2$ Hz, 1H), 3.55 (q, $J = 7.5$ Hz, 1H), 3.35 (dt, $J = 9.4, 6.2$ Hz, 1H), 3.29 (s, 1H), 3.25 (dt, $J = 9.4, 6.5$ Hz, 1H), 2.02 (dq, $J = 13.8, 6.7$ Hz, 1H), 1.92 (ddt, $J = 13.9, 7.7, 6.2$ Hz, 1H)

¹³C NMR (CDCl₃, 100 MHz): δ 144.8, 140.7, 131.1, 130.8 (q, $J_{CF} = 31.7$ Hz), 128.9, 124.5 (q, $J_{CF} = 3.7$ Hz), 124.2 (q, $J_{CF} = 270.7$ Hz), 123.2 (q, $J_{CF} = 3.7$ Hz), 115.2, 70.0, 58.5, 45.8, 35.0

¹⁹F NMR (CDCl₃, 376 MHz): δ -62.55

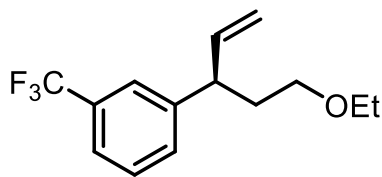
FTIR (KBr, neat) $\tilde{\nu}$ 2928, 2875, 2831, 2362, 2342, 1450, 1331, 1124, 1075, 919, 802, 773, 705, 657 cm⁻¹

HRMS (ESI-TOF) m/z : $[M+H]^+$ Calcd for C₁₃H₁₆OF₃ 245.1153; Found 245.1154





***(R)*-1-(5-ethoxypent-1-en-3-yl)-3-(trifluoromethyl)benzene (94ge)**



Isolated as a transparent oil: 88% yield after 12 h, 84% ee.

Enantiomeric excess was determined via derivatization.

$[\alpha]_D^{28} = +11.8$ (c 1.00, CHCl₃).

¹H NMR (CDCl₃, 400 MHz): δ 7.47–7.37 (m, 4H), 5.94 (ddd, $J = 17.3, 10.3, 7.4$ Hz, 1H), 5.09 (dt, $J = 9.7, 1.2$ Hz, 1H), 5.08 (dt, $J = 18.0, 1.2$ Hz, 1H), 3.56 (q, $J = 7.0$ Hz, 1H), 3.45–3.35, (m, 3H), 3.28 (dt, $J = 9.5, 6.6$ Hz, 1H), 2.03 (dq, $J = 13.8, 6.8$ Hz, 1H), 1.93 (ddt, $J = 13.8, 5.6, 6.2$, 1H), 1.18 (t, $J = 7.0$ Hz, 3H)

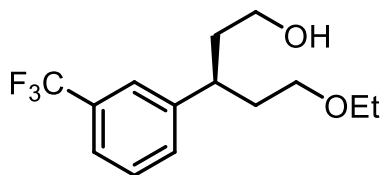
¹³C NMR (CDCl₃, 100 MHz): δ 144.9, 140.9, 131.3, 130.8, 128.8, 124.5 ($J_{CF} = 3.67$ Hz), 124.3 ($J_{CF} = 270.6$ Hz), 123.1 ($J_{CF} = 3.69$ Hz), 115.1, 67.8, 66.2, 45.9, 35.0, 15.1

¹⁹F NMR (CDCl₃, 376 MHz): δ -62.66

FTIR (KBr, neat) $\tilde{\nu}$ 2926, 2875, 2829, 2361, 2342, 1438, 1328, 1121, 1075, 923, 798, 772, 706, 654 cm⁻¹

HRMS (ESI-TOF) m/z : $[M+H]^+$ Calcd for C₁₄H₁₈OF₃ 259.1310; Found 259.1300

(S)-5-ethoxy-3-(3-(trifluoromethyl)phenyl)pentan-1-ol



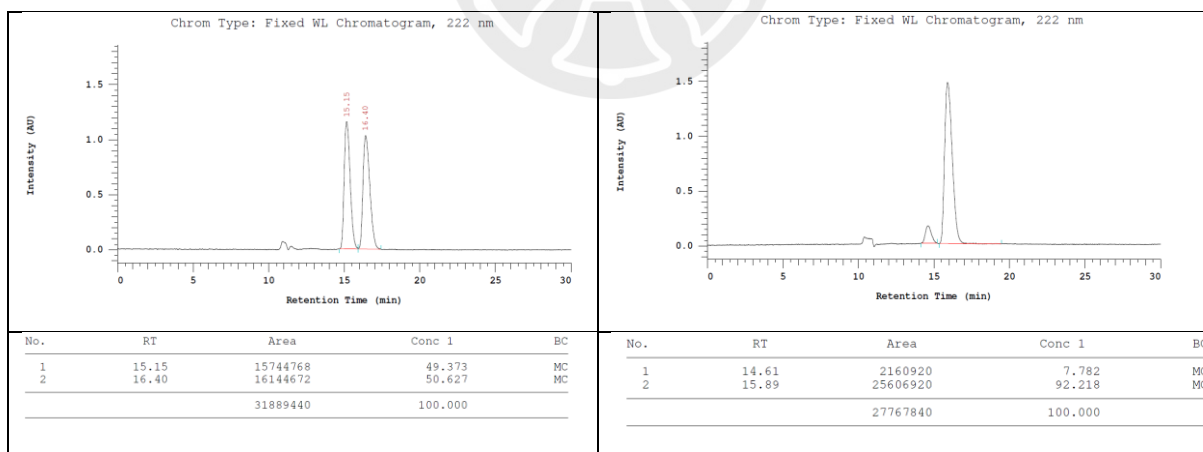
Isolated as a transparent oil, 84% ee. The ee was determined on CHIRALPAK ASH column with hexane/2-propanol = 90:10, flow rate = 0.3 mL/min, wavelength = 222 nm. Retention time: 14.61 min [(*R*)-enantiomer], 15.89 min [(*S*)-enantiomer]. $[\alpha]_D^{28} = +40.5$ (c 1.00, CHCl₃).

¹H NMR (CDCl₃, 400 MHz): 7.48–7.37 (m, 4H), 3.56 (dt, *J* = 10.3, 6.3, 1H), 3.47 (dt, *J* = 10.5, 6.9, 1H), 3.42–3.27 (m, 3H), 3.15 (ddd, *J* = 9.2, 8.1, 6.1 Hz, 1H), 3.02 (sep, *J* = 5.3 Hz, 1H), 2.07–1.93 (m, 2H), 1.90–1.76 (m, 2H), 1.15 (t, *J* = 7.0 Hz)

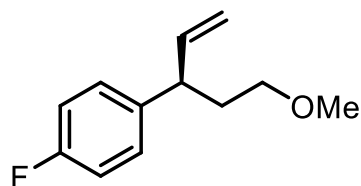
¹⁹F NMR (CDCl₃, 376 MHz): δ -62.54

FTIR (KBr, neat) $\tilde{\nu}$ 3384, 2934, 2871, 2347, 1450, 1328, 1125, 917, 898, 804, 773, 728, 705, 659 cm⁻¹

HRMS (ESI-TOF) *m/z*: [M+H]⁺ Calcd for C₁₄H₂₀O₂F₃ 277.1415; Found 277.1414



(R)-1-fluoro-4-(5-methoxypent-1-en-3-yl)benzene (94hm)



Isolated as a transparent oil: 88% yield after 12 h, 85% ee.

Enantiomeric excess was determined via derivatization.

$[\alpha]_D^{28} = +13.8$ (c 1.00, CHCl₃).

¹H NMR (CDCl₃, 400 MHz): δ 7.16 (dd, $J = 8.6, 5.5$ Hz, 2H), 6.99 (dd, $J = 8.7, 8.7$ Hz, 1H), 5.92 (ddd, $J = 7.4, 11.0, 16.5$ Hz, 1H), 5.05 (dt, $J = 9.8, 1.3$, 1H), 5.04 (dt, $J = 16.7, 1.4$, 1H), 3.45 (q, $J = 7.5$ Hz, 1H), 3.33 (dt, $J = 9.4, 6.3$ Hz, 1H), 3.29 (s, 3H), 3.25 (dt, $J = 9.4, 6.6$ Hz, 1H), 1.99 (dq, $J = 13.7, 6.8$ Hz, 1H), 1.88 (ddt, $J = 13.8, 7.9, 6.4$ Hz, 1H)

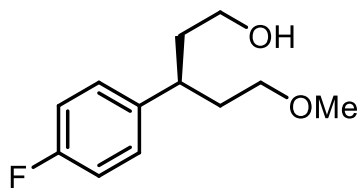
¹³C NMR (CDCl₃, 100 MHz): δ 161.4 (d, $J_{CF}=242.2$ Hz), 141.6, 139.4 (d, $J_{CF}=2.84$ Hz), 129.0 (d, $J_{CF}=7.8$ Hz), 115.2 (d, $J_{CF}=21.0$ Hz), 114.4, 70.3, 58.5, 45.2, 35.1

¹⁹F NMR (CDCl₃, 376 MHz): δ -117.09

FTIR (KBr, neat) $\tilde{\nu}$ 2930, 2874, 2830, 2811, 2357, 2331, 1637, 1603, 1510, 1455, 1222, 1159, 1118, 999, 917, 833, 656, 533 cm⁻¹

HRMS (ESI-TOF) m/z : $[M+H]^+$ Calcd for C₁₂H₁₆OF 195.1185; Found 195.1177

(S)-3-(4-fluorophenyl)-5-methoxypentan-1-ol (95hm)



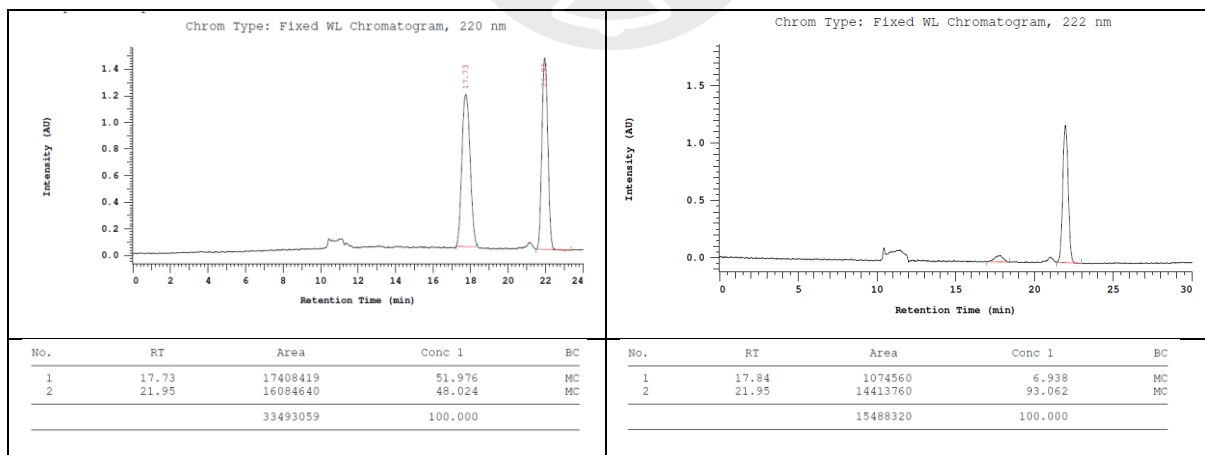
Isolated as a transparent oil, 86% ee, The ee was determined on CHIRALPAK OJH column with hexane/2-propanol = 90:10, flow rate = 0.3mL/ min, wavelength = 222nm
Retention time: 17.84 min [(R)-enantiomer], 21.95 min [(S)-enantiomer]. $[\alpha]_D^{28} = +18.2$ (c 0.2 CHCl₃).

¹H NMR (CDCl₃, 400 MHz): δ 7.14 (dd, $J = 8.7, 5.5$ Hz, 2H), 6.99 (t, $J = 8.7$ Hz, 2H), 3.57–3.43 (m, 2H), 3.27–3.22 (m, 1H), 3.25 (s, 1H), 3.17–3.11 (m, 1H), 2.89 (tt, $J = 4.9$ Hz), 2.00–1.89 (m, 2H), 1.85–1.72 (m, 2H)

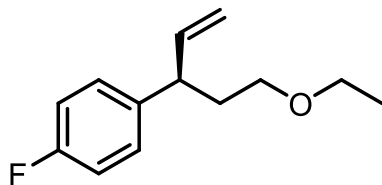
¹³C NMR (CDCl₃, 100 MHz): δ 161.4 (d, $J_{CF}=242.5$ Hz), 141.0 (d, $J_{CF}=3.12$ Hz), 128.9 (d, $J_{CF}=7.7$ Hz), 115.3 (d, $J_{CF}=21.0$ Hz), 70.4, 60.8, 58.5, 39.5, 38.1, 36.7

¹⁹F NMR (CDCl₃, 376 MHz): δ -116.93

FTIR (KBr, neat) $\tilde{\nu}$ 3404, 2932, 2885, 1581, 1448, 1389, 1279, 1147, 1112, 1044, 963, 874. 702, 601 cm⁻¹



(R)-1-(5-ethoxypent-1-en-3-yl)-4-fluorobenzene (94he)



Isolated as a transparent oil: 81% yield after 12h, 91% ee,

The ee was determined on CHIRALPAK OJH column with hexane/2-propanol = 1000:1, flow rate = 0.7mL/ min, wavelength = 217nm. Retention time: 7.01 min [(R)-enantiomer], 7.52 min [(S)-enantiomer]. $[\alpha]_D^{28} = +7.0$ (c 1.00, CHCl₃).

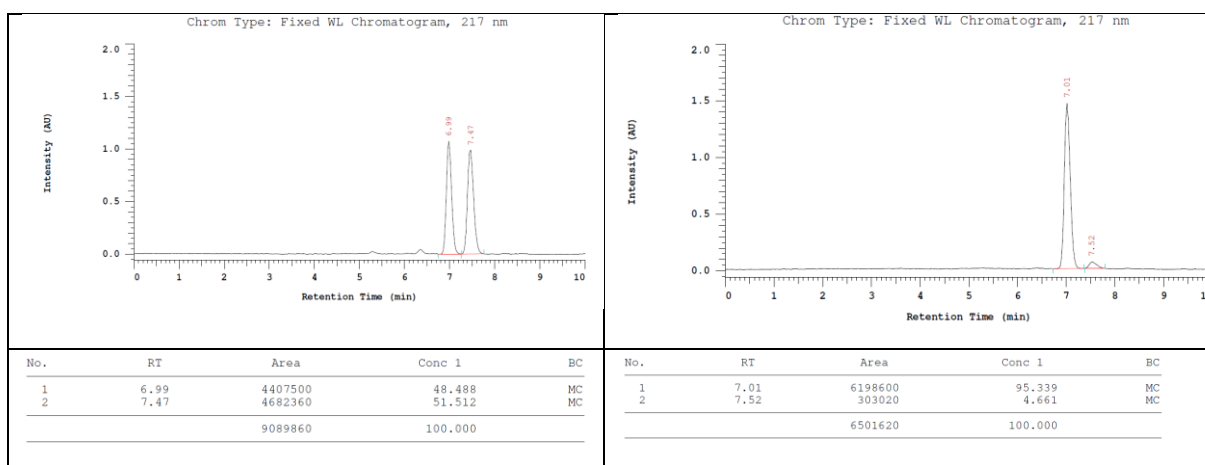
¹H NMR (CDCl₃, 400 MHz): δ 7.14 (dd, $J = 8.7, 5.5$ Hz, 2H), 6.98 (dd, $J = 8.7$ Hz, 1H), 5.92 (ddd, $J = 17.4, 9.8, 7.3$ Hz, 1H), 5.04 (dt, $J = 11.0, 1.3$ Hz, 1H), 5.03 (dt, $J = 16.1, 1.2$ Hz, 1H), 3.48–3.39 (m, 3H), 3.36 (dt, $J = 9.4, 6.4$ Hz, 1H), 3.29 (dt, $J = 9.4, 6.7$ Hz, 1H), 2.00 (dq, $J = 13.8, 6.9$ Hz, 1H), 1.89 (ddt, $J = 13.8, 7.7, 6.3$ Hz, 1H), 1.18 (t, $J = 7.0$ Hz, 3H)

¹³C NMR (CDCl₃, 100 MHz): δ 161.4 (d, $J_{CF} = 242.6$ Hz), 141.6, 139.4 (d, $J_{CF} = 2.84$ Hz), 129.0 (d, $J_{CF} = 7.8$ Hz), 115.1 (d, $J_{CF} = 21.0$ Hz), 114.3, 68.0, 66.1, 45.2, 35.1, 15.2

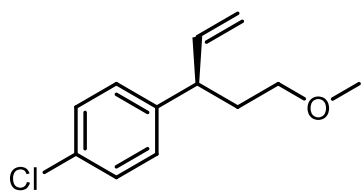
¹⁹F NMR (CDCl₃, 376 MHz): δ -117.11

HRMS (ESI-TOF) m/z : $[M+H]^+$ Calcd for C₁₃H₁₈OF 209.1342 ; Found 209.1343

FTIR (KBr, neat) $\tilde{\nu}$ cm⁻¹ 2977, 2933, 2867, 2364, 2342, 1638, 1510, 1226, 1124, 1016, 918cm⁻¹



(R)-1-chloro-4-(5-methoxypent-1-en-3-yl)benzene (94im)



Isolated as a transparent oil: 63% yield after 6 h, 92% ee.

Enantiomeric excess was determined via derivatization.

$[\alpha]_D^{28} = +15.4$ (c 1.00, CHCl₃).

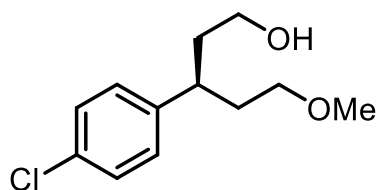
¹H NMR (CDCl₃, 400 MHz): δ 7.27 (d, $J = 8.4$ Hz, 2H), 7.13 (d, $J = 8.4$ Hz, 2H), 5.91 (ddd, $J = 16.6, 10.7, 7.4$ Hz, 1H), 5.05 (dt, $J = 9.4, 1.1$ Hz, 1H), 5.04 (dt, $J = 17.2, 1.5$ Hz, 1H), 3.44 (q, $J = 7.5$ Hz, 1H), 3.33 (dt, $J = 9.4, 6.5$ Hz, 1H), 3.29 (s, 1H), 3.25 (dt, $J = 9.4, 6.6$ Hz, 1H), 1.99 (dq, $J = 13.7, 6.8$ Hz, 1H), 1.88 (ddt, $J = 13.8, 7.8, 6.2$ Hz, 1H)

¹³C NMR (CDCl₃, 100 MHz): δ 142.3, 141.2, 132.0, 129.0, 128.6, 114.7, 70.2, 58.5, 45.4, 35.0

FTIR (KBr, neat) $\tilde{\nu}$ 3081, 2980, 2925, 2873, 2829, 1896, 1638, 1492, 1459, 1408, 1220, 1182, 1014, 918, 825, 769, 725, 637, 519 cm⁻¹

HRMS (ESI-TOF) m/z : $[M+H]^+$ Calcd for C₁₂H₁₆OCl 211.0890; Found 211.0887

***(S)*-3-(4-chlorophenyl)-5-methoxypentan-1-ol (95im)**



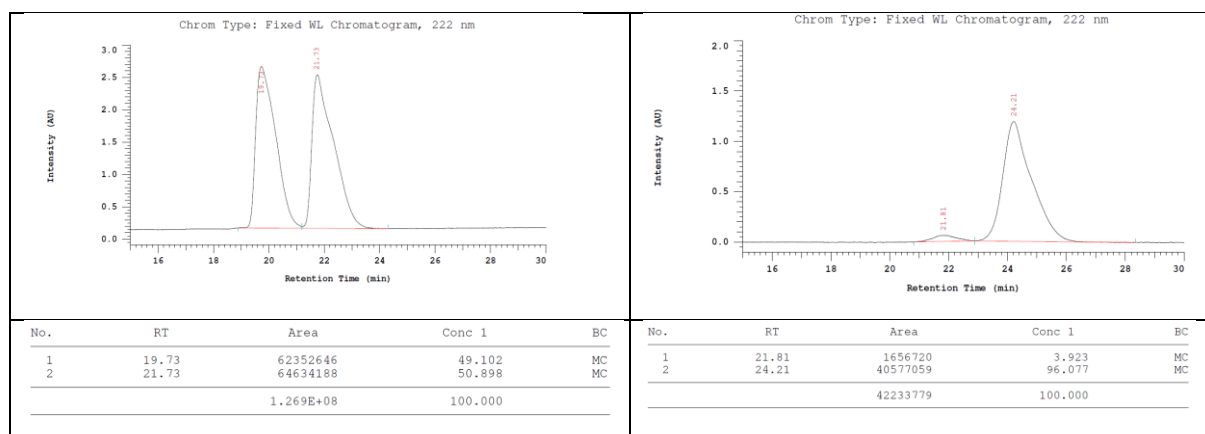
92% ee, The ee was determined on CHIRALPAK ASH column with hexane/2-propanol = 90:10 , flow rate = 0.3mL/min, wavelength = 222nm. Retention time: 21.8 min [(*R*)-enantiomer], 24.2 min [(*S*)-enantiomer]. $[\alpha]_D^{25} = +19.7$ (c 1.00, CHCl₃).

¹H NMR (CDCl₃, 400 MHz): δ 7.27 (d, J = 8.3 Hz, 2H), 7.12 (d, J = 8.4 Hz, 2H), 3.54 (ddd, J = 10.6, 5.6, 5.6 Hz, 1H), 3.45 (ddd, J = 10.6, 6.6, 6.6 Hz, 1H), 3.27–3.22(m, 1H), 3.25 (s, 3H), 3.13 (ddd, J = 8.0, 6.2, 6.2, 1H), 2.89 (tt, J = 5.1 Hz, 1H), 2.01–1.89 (m, 2H), 1.84–1.71 (m, 2H)

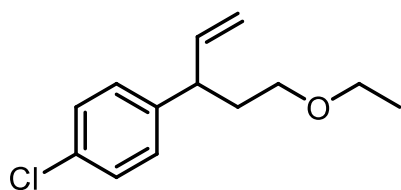
¹³C NMR (CDCl₃, 400 MHz): 143.0, 131.9, 129.0, 128.6, 70.4, 60.8, 58.5, 39.3, 38.3, 36.5

FTIR (KBr, neat) $\tilde{\nu}$ 3406, 2930, 2881, 1580, 1452, 1388, 1289, 1150, 1114, 1052, 960, 872. 705, 603 cm⁻¹

HRMS (ESI-TOF) m/z : [M+H]⁺ Calcd for C₁₂H₁₈O₂Cl 229.0995; Found 229.1001



(R)-1-chloro-4-(5-ethoxypent-1-en-3-yl)benzene (94ie)



Isolated as a transparent oil: 16% yield after 12 h, 93% ee,

The ee was determined on CHIRALPAK OJH column with hexane/2-propanol = 1000:1, flow rate = 0.7mL/min, wavelength = 217nm. Retention time: 7.07 min [(R)-enantiomer], 7.60 min [(S)-enantiomer].

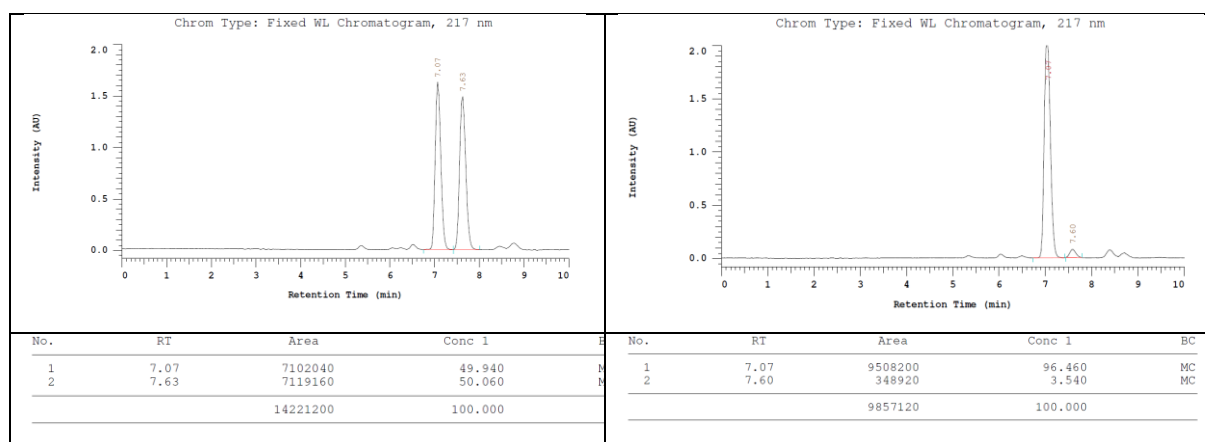
$[\alpha]_D^{28} = +7.6$ (c 1.00, CHCl₃).

¹H NMR (CDCl₃, 400 MHz): δ 7.27 (d, J = 8.4 Hz, 2H), 7.13 (d, J = 8.4 Hz, 2H), 5.90 (ddd, J = 16.4, 10.9, 7.3 Hz, 1H), 5.04 (dt, J = 17.8, 1.4 Hz, 1H), 5.04 (dt, J = 9.5, 1.3 Hz, 1H), 3.48–3.39 (m, 3H), 3.36 (dt, J = 9.5, 6.4 Hz, 1H), 3.28 (dt, J = 9.4, 6.7 Hz, 1H), 2.00 (dq, J = 13.7, 6.9 Hz, 1H) 1.89 (ddt, J = 13.8, 7.7, 6.4 Hz, 1H), 1.18 (t, J = 7.0 Hz, 3H)

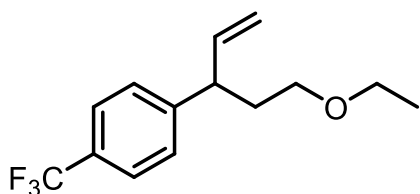
¹³C NMR (CDCl₃, 100 MHz): δ 142.3, 141.4, 131.9, 129.1, 128.6, 114.6, 68.0, 66.2, 45.4, 35.0, 15.2

HRMS (ESI-TOF) m/z : $[M+H]^+$ Calcd for C₁₃H₁₈OCl 225.1046; Found 225.1058

FTIR (KBr, neat) $\tilde{\nu}$ cm⁻¹ 3081, 2976, 2932, 2866, 2342, 1895, 1638, 1492, 1378, 1118, 724 cm⁻¹



(R)-1-(5-ethoxypent-1-en-3-yl)-4-(trifluoromethyl)benzene (94jm)



Isolated as a transparent oil: 65% yield after 12 h, 91% ee,

The ee was determined on CHIRALPAK ADH column with hexane/2-propanol = 1500:1, flow rate = 0.5mL/ min, wavelength = 215nm. Retention time: 13.25 min [(S)-enantiomer], 14.64 min [(R)-enantiomer]. $[\alpha]_D^{28} = +5.0$ (c 0.7, CHCl₃).

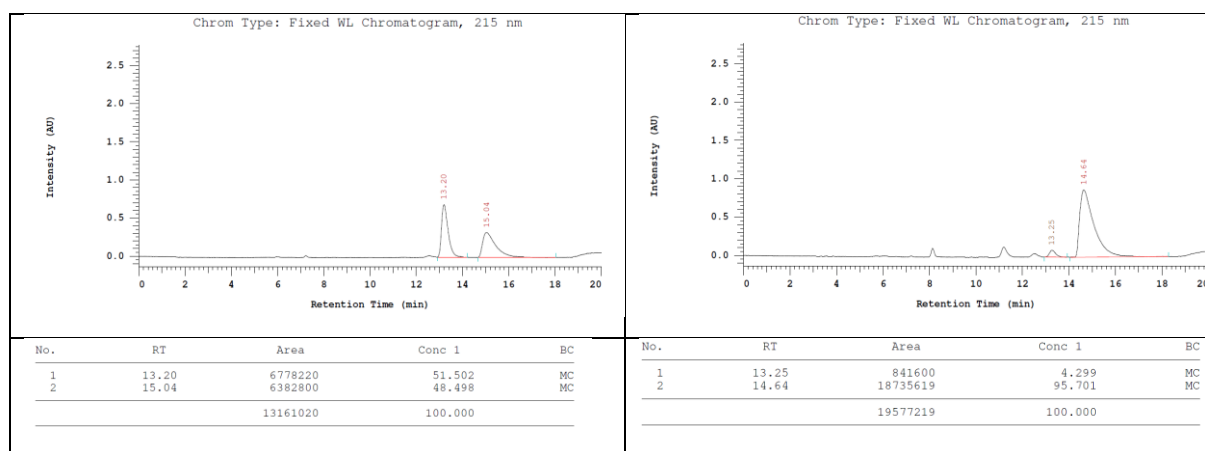
¹H NMR (CDCl₃, 400 MHz): δ 7.55 (d, $J = 8.2$ Hz, 2H), 7.31 (d, $J = 8.2$ Hz, 2H), 5.93 (ddd, $J = 16.6, 10.8, 7.4$ Hz, 1H), 5.07, (dt, $J = 17.0, 1.1$, 1H), 5.06, (dt, $J = 7.6, 1.3$, 1H), 3.6 (q, $J = 7.5$ Hz, 1H), 3.45–3.35 (m, 3H), 3.29 (dt, $J = 9.5, 6.6$, 1H), 2.04 (dq, $J = 13.8, 6.9$, 1H), 1.93 (ddt, $J = 13.8, 7.7, 6.3$, 1H), 2.08–1.90 (m, 2H), 1.18 (t, $J = 7.0$ Hz, 3H)

¹³C NMR (CDCl₃, 100 MHz): δ 148.0, 140.8, 128.6 (q, $J_{CF} = 32.2$ Hz), 128.1, 125.4 (q, $J_{CF} = 3.64$ Hz), 124.3 (q, $J_{CF} = 270.1$ Hz), 115.1, 67.9, 66.2, 45.9, 35.0, 15.2

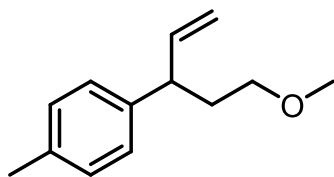
¹⁹F NMR (CDCl₃, 376 MHz): δ -62.37

FTIR (KBr, neat) $\tilde{\nu}$ 2979, 2937, 2869, 2803, 1619, 1417, 1320, 1166, 1126, 1069, 1019, 920, 839, 685, 608, 515 cm⁻¹

HRMS (ESI-TOF) m/z : $[M+H]^+$ Calcd for C₁₄H₁₈OF₃ 259.1310; Found 259.1310



(R)-1-(5-methoxypent-1-en-3-yl)-4-methylbenzene (94km)



Isolated as a transparent oil: 88% yield after 6 h, 88% ee,

The ee was determined on CHIRALPAK IB column with

hexane, flow rate = 1mL/ min, wavelength = 215nm

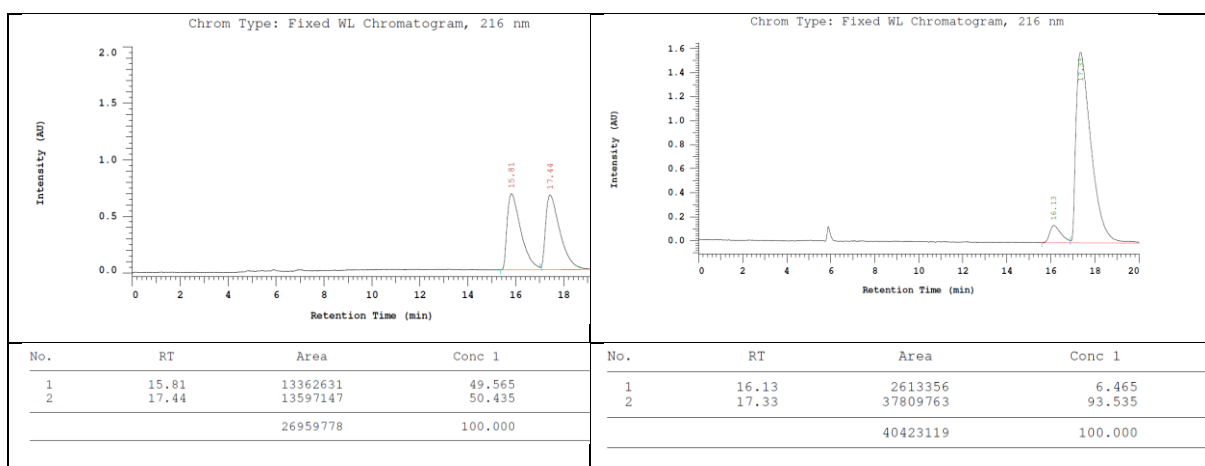
$[\alpha]_D^{28} = +18.2$ (c 1.00, CHCl₃).

¹H NMR (CDCl₃, 600 MHz): δ 7.12–7.08 (m, 4H), 5.94 (ddd, $J = 17.2, 10.3, 7.6$ Hz, 1H), 5.04 (dt, $J = 16.9, 1.5$ Hz, 1H), 5.02 (dt, $J = 9.5, 1.3$ Hz, 1H), 3.40 (q, $J = 7.5$ Hz, 1H), 3.33 (dt, $J = 9.4, 6.5$ Hz, 1H), 3.29 (s, 3H), 3.28 (dt, $J = 9.4, 6.7$ Hz, 1H), 3.32 (s, 3H), 1.98 (dq, $J = 13.9, 6.9$ Hz, 1H), 1.92 (ddt, $J = 13.9, 7.5, 6.4$ Hz, 1H)

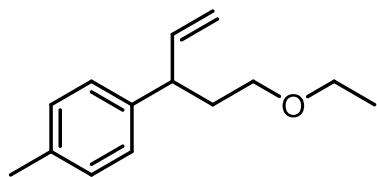
¹³C NMR (CDCl₃, 100 MHz): δ 142.0, 140.7, 135.7, 129.2, 127.5, 114.0, 70.5, 58.5, 45.6, 35.0, 21.0,

FTIR (KBr, neat) $\tilde{\nu}$ 2925, 2872, 2809, 2328, 1723, 1638, 1513, 1460, 1386, 1268, 1190, 1120, 999, 914, 815, 733, 657, 527 cm⁻¹

HRMS (ESI-TOF) m/z : $[M+H]^+$ Calcd for C₁₃H₁₉O 191.1436; Found 191.1432



(R)-1-(5-ethoxypent-1-en-3-yl)-4-methylbenzene (94ke)



Isolated as a transparent oil: 71% yield after 6 h, 93% ee.

The ee was determined on CHIRALPAK OJH column with hexane/2-propanol = 1000:1, flow rate = 1mL/ min, wavelength = 215nm. Retention time: 6.56 min [(R)-enantiomer], 7.55 min [(S)-enantiomer].

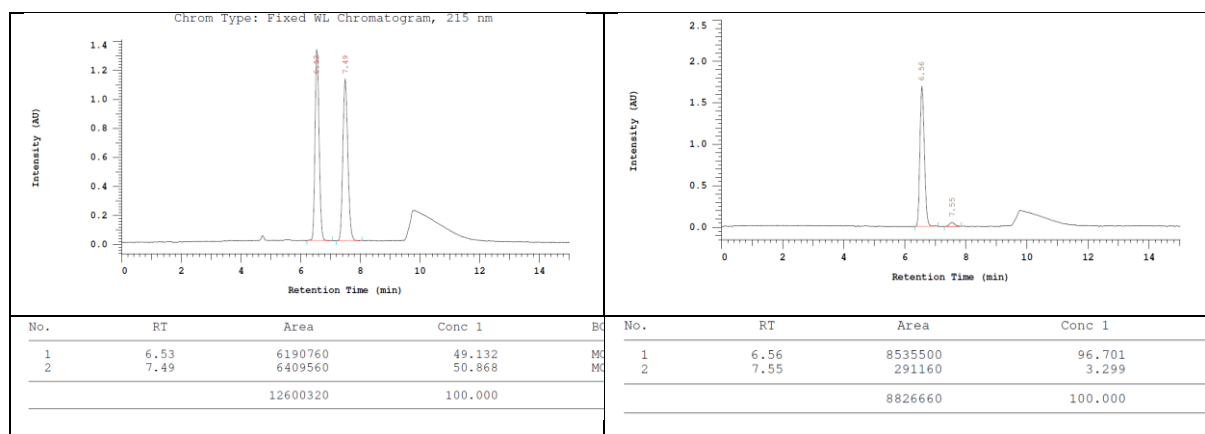
$[\alpha]_D^{28} = +4.2$ (c 1.00, CHCl₃).

¹H NMR (CDCl₃, 600 MHz): δ 7.1 (m, 4H), 5.94 (ddd, $J = 17.4, 10.2, 7.5$ Hz, 1H), 5.03 (dt, $J = 18.5, 1.4$ Hz, 1H), 5.01 (dt, $J = 11.5, 1.2$ Hz, 1H), 3.44–3.39 (m, 3H), 3.36 (dt, $J = 9.4, 6.6$ Hz, 1H), 3.31 (dt, $J = 9.5, 6.8$ Hz, 1H), 2.31 (s, 3H), 1.99 (dq, $J = 13.8, 7.0$, 1H), 1.93 (ddt, $J = 14.4, 7.0, 1$ Hz), 1.18 (t, $J = 7.0$ Hz, 3H)

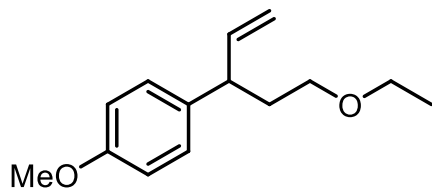
¹³C NMR (CDCl₃, 100 MHz): δ 142.1, 140.8, 135.7, 129.1, 127.5, 113.9, 68.3, 66.1, 45.7, 35.0, 21.0, 15.2

FTIR (KBr, neat) $\tilde{\nu}$ 2976, 2930, 2362, 2341, 1638, 1513, 1356, 1124, 1021, 815, 657, 543 cm⁻¹

HRMS (ESI-TOF) m/z : $[M+H]^+$ Calcd for C₁₄H₂₁O 205.1592; Found 205.1601



(R)-1-(5-ethoxypent-1-en-3-yl)-4-methoxybenzene (94le)



Isolated as a transparent oil: 90% yield after 6 h, 97% ee.

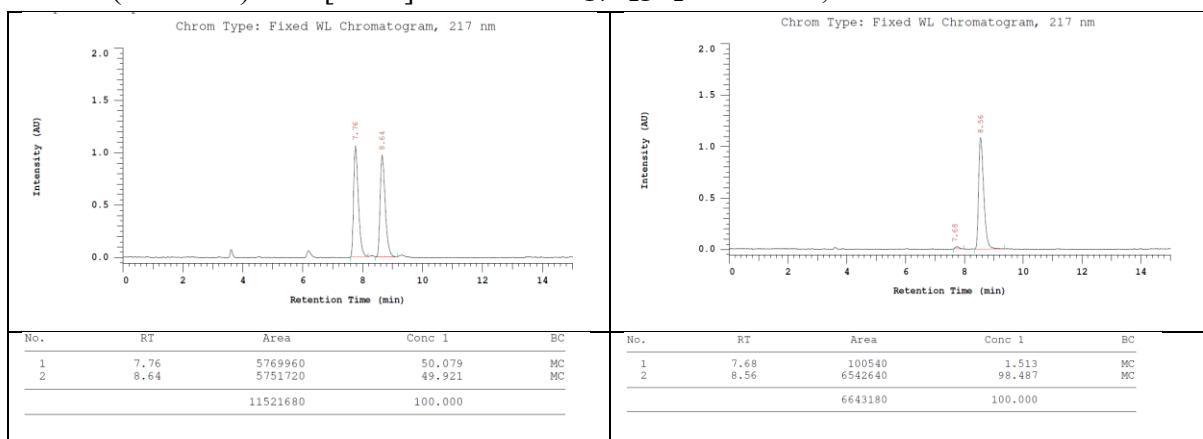
The ee was determined on CHIRALPAK IB column with hexane/2-propanol = 1000:1, flow rate = 1 mL/min, wavelength = 215 nm. Retention time: 7.68 min [(S)-enantiomer], 8.56 min [(R)-enantiomer]. $[\alpha]_D^{28} = +7.7$ (c 1.00, CHCl₃).

¹H NMR (CDCl₃, 400 MHz): δ 7.11 (d, J = 8.6 Hz, 2H), 6.84 (d, J = 8.7 Hz, 2H), 5.93 (ddd, J = 17.3, 10.3, 7.4 Hz, 1H), 5.02 (dt, J = 17.3, 1.4, 1H), 5.01 (dt, J = 9.3, 1.4, 1H), 3.79 (s, 1H), 3.42 (q, J = 7.0 Hz, 1H), 3.41 (q, J = 7.0 Hz, 1H), 3.36 (dt, J = 13.8, 6.5 Hz, 1H), 3.33–3.27 (dt, J = 9.3, 6.8 Hz, 1H), 1.99 (dq, J = 13.7, 6.9 Hz, 1H), 1.92 (ddt, J = 14.2, 7.2, 6.6 Hz, 1H), 1.18 (t, J = 7.0 Hz, 3H)

¹³C NMR (CDCl₃, 100 MHz): δ 158.0, 142.2, 135.9, 128.5, 113.9, 68.3, 66.1, 55.2, 45.2, 35.1, 15.2

FTIR (KBr, neat) $\tilde{\nu}$ 2975, 2934, 2363, 2340, 1612, 1584, 1511, 1249, 1038, 830, 658 cm⁻¹

HRMS (ESI-TOF) m/z : $[M+H]^+$ Calcd for C₁₄H₂₁O₂ 221.1542; Found 221.1548



第八章 參考文獻

1. Oguma, K.; Miura, M.; Satoh, T.; Nomura, M. *J. Am. Chem. Soc.* **2000**, *122*, 10464–10465.
2. Heck, R. F. J. *Organomet. Chem.* **1972**, *37*, 389–396
3. Hayashi, T.; Inoue, K.; Taniguchi, N.; Ogasawara, M. *J. Am. Chem. Soc.* **2001**, *123*, 40, 9918–9919
4. Ming, J.; and Hayashi, T. *Org. Lett.* **2016**, *18*, 24, 6452–6455
5. Shintani, R.; Yashio, K.; Nakamura, T.; Okamoto, K.; Shimada, T.; Hayashi, T. *J. Am. Chem. Soc.* **2006**, *128*, 2772–2773.
6. Miura, T.; Sasaki, T.; Nakazawa, H.; Murakami, M. *J. Am. Chem. Soc.* **2005**, *127*, 5, 1390–1391
7. Keilitz, J.; Newman, S.; Lautens, M. *Org. Lett.* **2013**, *15*, 1148–1151.
8. Selmani, A.; Darses, S. *Org. Lett.* **2020**, *22*, 2681–2686
9. Sasaki, K.; Nishimura, T.; Shintani, S.; Kantchev, E.; Hayashi, T. *Chem. Sci.*, **2012**, *3*, 1278
10. Partridge, B.; Callingham, M.; Lewis, W.; Lam, H. *Angew. Chem.* **2017**, *129*, 7333–7338
11. Igawa, H.; Murakami, M. *Chem. Commun.* **2002**, 390–391.
12. Miura, T.; Shimada, M.; Murakami, M. *J. Am. Chem. Soc.* **2005**, *127*, 1094–1095
13. Muto, K.; Kumagai, T.; Kakiuchi, F.; Kochi, T. *Angew. Chem.* **2021**, *133*, 24705–24709
14. Griesbeck, A.; Bondock, S.; Cygon, P. *J. Am. Chem. Soc.* **2003**, *125*, 30, 9016–9017
15. Kozaka, T.; Uno, I.; Kitamura, Y.; Miwa, D.; Ogawa, K.; Shiba, K. *Bioorganic and Medicinal Chemistry*. **2012**, *20*, 16, 4936–4941
16. Huang, R.; Franke, P.; Nicolaus, N.; Lautens, M. *Tetrahedron*. **2013**, *69*, 22, 4395–4402
17. Tanaka, T.; Koga, Y.; Honda, Y.; Tsuruta, A.; Matsunaga, N.; Koyanagi, S.; Ohdo, S.; Yazaki, R.; Ohshima, T. *Nature Synthesis*. **2020**, *1*, 824–830
18. Biberger, T.; Makai, S.; Lian, Z.; Morandi, B. *Angew. Chem.* **2018**, *130*, 23, 7057–7061

附錄一 X-RAY 單晶數據與 ORTEP 解析數據



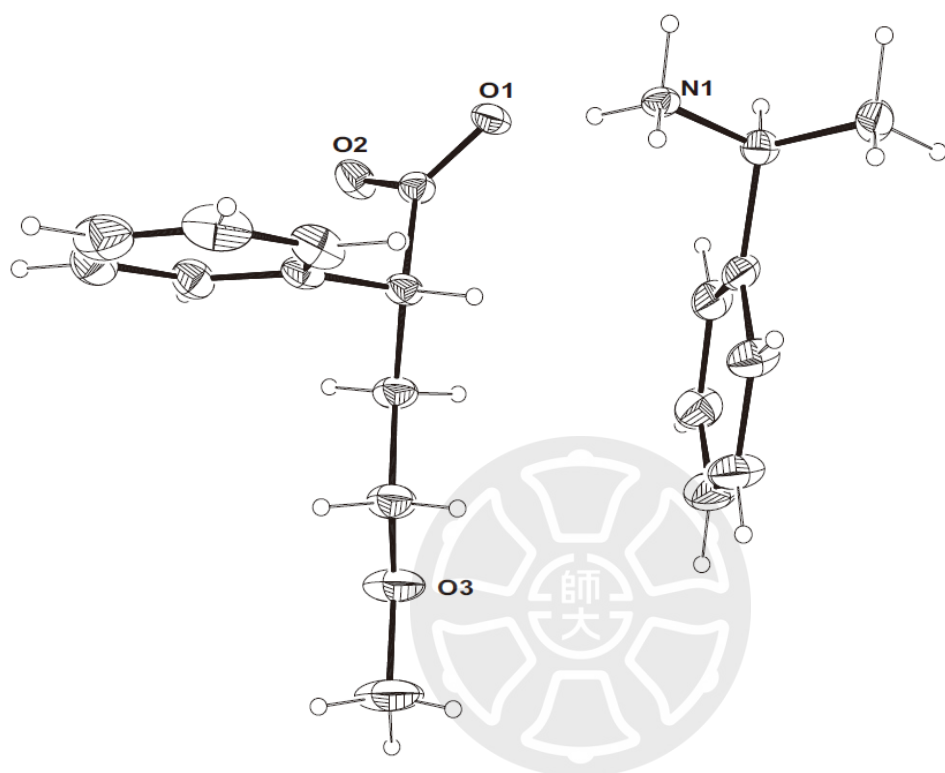
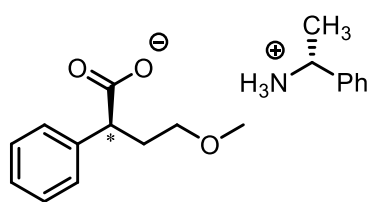


Table 1. Crystal data and structure refinement for d24494.

Identification code	d24494	
Empirical formula	C ₁₉ H ₂₅ N O ₃	
Formula weight	315.40	
Temperature	200(2) K	
Wavelength	0.71073 Å	
Crystal system	Monoclinic	
Space group	C 2	
Unit cell dimensions	a = 19.085(3) Å	$\alpha = 90^\circ$.
	b = 6.2276(14) Å	$\beta = 106.576(4)^\circ$.
	c = 16.273(3) Å	$\gamma = 90^\circ$.
Volume	1853.7(7) Å ³	
Z	4	
Density (calculated)	1.130 Mg/m ³	
Absorption coefficient	0.076 mm ⁻¹	
F(000)	680	
Crystal size	0.79 x 0.05 x 0.01 mm ³	
Theta range for data collection	2.24 to 25.05°.	
Index ranges	-22 ≤ h ≤ 19, -7 ≤ k ≤ 7, -19 ≤ l ≤ 19	
Reflections collected	10328	
Independent reflections	3279 [R(int) = 0.1279]	
Completeness to theta = 25.05°	99.9 %	
Absorption correction	multi-scan	
Max. and min. transmission	0.9992 and 0.9426	
Refinement method	Full-matrix least-squares on F ²	
Data / restraints / parameters	3279 / 1 / 211	
Goodness-of-fit on F ²	0.958	
Final R indices [I > 2σ(I)]	R1 = 0.0637, wR2 = 0.1211	
R indices (all data)	R1 = 0.1506, wR2 = 0.1540	
Absolute structure parameter	2(2)	
Largest diff. peak and hole	0.172 and -0.206 e.Å ⁻³	

Table 2. Atomic coordinates ($\times 10^4$) and equivalent isotropic displacement parameters ($\text{\AA}^2 \times 10^3$) for d24494. $U(\text{eq})$ is defined as one third of the trace of the orthogonalized U^{ij} tensor.

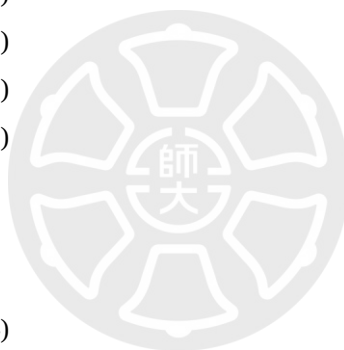
	x	y	z	$U(\text{eq})$
C(1)	7423(2)	2369(8)	3331(3)	45(1)
C(2)	7387(2)	3710(7)	2532(2)	47(1)
C(3)	6593(2)	4150(7)	2050(2)	48(1)
C(4)	6150(2)	2554(8)	1578(2)	56(1)
C(5)	5427(3)	2927(11)	1138(3)	76(2)
C(6)	5137(3)	4943(12)	1176(4)	87(2)
C(7)	5558(4)	6535(11)	1649(4)	85(2)
C(8)	6281(3)	6163(8)	2078(3)	68(1)
C(9)	7820(2)	2630(8)	1987(2)	60(1)
C(10)	7857(2)	3965(10)	1225(3)	70(2)
C(11)	8389(3)	4006(13)	80(3)	120(2)
C(12)	8958(2)	9563(8)	5337(3)	66(1)
C(13)	8710(2)	7440(8)	4867(2)	48(1)
C(14)	9029(2)	7027(7)	4122(3)	51(1)
C(15)	9009(2)	8578(9)	3508(3)	70(1)
C(16)	9306(3)	8183(10)	2837(3)	81(2)
C(17)	9631(3)	6255(11)	2802(4)	89(2)
C(18)	9659(3)	4659(9)	3399(3)	76(2)
C(19)	9345(2)	5042(8)	4064(3)	60(1)
N(1)	7893(1)	7446(5)	4541(2)	40(1)
O(1)	7568(1)	3339(4)	4041(2)	51(1)
O(2)	7310(2)	397(5)	3246(2)	61(1)
O(3)	8323(2)	2900(7)	819(2)	94(1)

Table 3. Bond lengths [Å] and angles [°] for d24494.

C(1)-O(2)	1.248(5)
C(1)-O(1)	1.263(4)
C(1)-C(2)	1.530(5)
C(2)-C(3)	1.519(5)
C(2)-C(9)	1.530(5)
C(2)-H(2)	1.0000
C(3)-C(4)	1.386(6)
C(3)-C(8)	1.394(6)
C(4)-C(5)	1.381(6)
C(4)-H(4)	0.9500
C(5)-C(6)	1.381(8)
C(5)-H(5)	0.9500
C(6)-C(7)	1.367(8)
C(6)-H(6)	0.9500
C(7)-C(8)	1.377(7)
C(7)-H(7)	0.9500
C(8)-H(8)	0.9500
C(9)-C(10)	1.511(5)
C(9)-H(9A)	0.9900
C(9)-H(9AB)	0.9900
C(10)-O(3)	1.414(5)
C(10)-H(10A)	0.9900
C(10)-H(10B)	0.9900
C(11)-O(3)	1.423(5)
C(11)-H(11A)	0.9800
C(11)-H(11B)	0.9800
C(11)-H(11C)	0.9800
C(12)-C(13)	1.533(6)
C(12)-H(12A)	0.9800
C(12)-H(12B)	0.9800
C(12)-H(12C)	0.9800
C(13)-N(1)	1.498(4)
C(13)-C(14)	1.524(5)
C(13)-H(13)	1.0000
C(14)-C(15)	1.382(6)
C(14)-C(19)	1.391(6)

C(15)-C(16)	1.390(6)
C(15)-H(15)	0.9500
C(16)-C(17)	1.359(8)
C(16)-H(16)	0.9500
C(17)-C(18)	1.380(7)
C(17)-H(17)	0.9500
C(18)-C(19)	1.398(6)
C(18)-H(18)	0.9500
C(19)-H(19)	0.9500
N(1)-H(1A)	0.9100
N(1)-H(1B)	0.9100
N(1)-H(1C)	0.9100

O(2)-C(1)-O(1)	123.9(4)
O(2)-C(1)-C(2)	118.6(4)
O(1)-C(1)-C(2)	117.5(4)
C(3)-C(2)-C(1)	109.5(3)
C(3)-C(2)-C(9)	113.8(3)
C(1)-C(2)-C(9)	110.6(3)
C(3)-C(2)-H(2)	107.6
C(1)-C(2)-H(2)	107.6
C(9)-C(2)-H(2)	107.6
C(4)-C(3)-C(8)	117.7(4)
C(4)-C(3)-C(2)	121.2(4)
C(8)-C(3)-C(2)	121.2(4)
C(5)-C(4)-C(3)	121.9(5)
C(5)-C(4)-H(4)	119.1
C(3)-C(4)-H(4)	119.1
C(6)-C(5)-C(4)	118.9(6)
C(6)-C(5)-H(5)	120.5
C(4)-C(5)-H(5)	120.5
C(7)-C(6)-C(5)	120.4(6)
C(7)-C(6)-H(6)	119.8
C(5)-C(6)-H(6)	119.8
C(6)-C(7)-C(8)	120.4(6)
C(6)-C(7)-H(7)	119.8
C(8)-C(7)-H(7)	119.8
C(7)-C(8)-C(3)	120.7(5)



C(7)-C(8)-H(8)	119.7
C(3)-C(8)-H(8)	119.7
C(10)-C(9)-C(2)	113.1(4)
C(10)-C(9)-H(9A)	108.9
C(2)-C(9)-H(9A)	108.9
C(10)-C(9)-H(9AB)	108.9
C(2)-C(9)-H(9AB)	108.9
H(9A)-C(9)-H(9AB)	107.8
O(3)-C(10)-C(9)	107.9(4)
O(3)-C(10)-H(10A)	110.1
C(9)-C(10)-H(10A)	110.1
O(3)-C(10)-H(10B)	110.1
C(9)-C(10)-H(10B)	110.1
H(10A)-C(10)-H(10B)	108.4
O(3)-C(11)-H(11A)	109.5
O(3)-C(11)-H(11B)	109.5
H(11A)-C(11)-H(11B)	109.5
O(3)-C(11)-H(11C)	109.5
H(11A)-C(11)-H(11C)	109.5
H(11B)-C(11)-H(11C)	109.5
C(13)-C(12)-H(12A)	109.5
C(13)-C(12)-H(12B)	109.5
H(12A)-C(12)-H(12B)	109.5
C(13)-C(12)-H(12C)	109.5
H(12A)-C(12)-H(12C)	109.5
H(12B)-C(12)-H(12C)	109.5
N(1)-C(13)-C(14)	109.3(3)
N(1)-C(13)-C(12)	108.4(3)
C(14)-C(13)-C(12)	114.0(4)
N(1)-C(13)-H(13)	108.3
C(14)-C(13)-H(13)	108.3
C(12)-C(13)-H(13)	108.3
C(15)-C(14)-C(19)	119.6(4)
C(15)-C(14)-C(13)	121.4(4)
C(19)-C(14)-C(13)	118.9(4)
C(14)-C(15)-C(16)	120.7(5)
C(14)-C(15)-H(15)	119.6
C(16)-C(15)-H(15)	119.6



C(17)-C(16)-C(15)	118.8(5)
C(17)-C(16)-H(16)	120.6
C(15)-C(16)-H(16)	120.6
C(16)-C(17)-C(18)	122.3(5)
C(16)-C(17)-H(17)	118.8
C(18)-C(17)-H(17)	118.8
C(17)-C(18)-C(19)	118.8(5)
C(17)-C(18)-H(18)	120.6
C(19)-C(18)-H(18)	120.6
C(14)-C(19)-C(18)	119.7(5)
C(14)-C(19)-H(19)	120.2
C(18)-C(19)-H(19)	120.2
C(13)-N(1)-H(1A)	109.5
C(13)-N(1)-H(1B)	109.5
H(1A)-N(1)-H(1B)	109.5
C(13)-N(1)-H(1C)	109.5
H(1A)-N(1)-H(1C)	109.5
H(1B)-N(1)-H(1C)	109.5
C(10)-O(3)-C(11)	112.8(4)

Symmetry transformations used to generate equivalent atoms:

Table 4. Anisotropic displacement parameters ($\text{\AA}^2 \times 10^3$) for d24494. The anisotropic displacement factor exponent takes the form: $-2\pi^2 [h^2 a^{*2} U^{11} + \dots + 2 h k a^* b^* U^{12}]$

	U^{11}	U^{22}	U^{33}	U^{23}	U^{13}	U^{12}
C(1)	52(2)	43(3)	40(2)	5(3)	17(2)	-1(2)
C(2)	68(3)	41(3)	36(2)	5(2)	20(2)	-9(2)
C(3)	72(3)	38(3)	38(2)	9(2)	23(2)	1(3)
C(4)	70(3)	50(3)	47(2)	5(3)	15(2)	3(3)
C(5)	74(4)	97(5)	55(3)	10(3)	14(3)	2(4)
C(6)	82(4)	112(6)	69(4)	39(4)	27(3)	25(4)
C(7)	115(5)	71(4)	82(4)	23(4)	50(4)	48(4)
C(8)	106(4)	47(3)	54(3)	3(3)	28(3)	10(3)
C(9)	68(3)	71(4)	46(2)	18(3)	24(2)	3(3)
C(10)	73(3)	92(4)	52(3)	20(3)	27(2)	6(3)
C(11)	124(5)	175(7)	81(4)	52(5)	66(3)	15(5)
C(12)	53(3)	76(4)	74(3)	-24(3)	25(2)	-16(3)
C(13)	51(2)	50(3)	46(2)	0(2)	19(2)	0(2)
C(14)	49(2)	49(3)	63(3)	-5(3)	28(2)	-7(2)
C(15)	78(3)	67(4)	81(3)	5(3)	46(3)	5(3)
C(16)	105(4)	77(4)	84(4)	3(3)	65(3)	-2(3)
C(17)	102(4)	91(5)	100(4)	-19(4)	70(3)	-6(4)
C(18)	87(4)	60(4)	99(4)	-18(3)	55(3)	0(3)
C(19)	65(3)	48(4)	76(3)	-7(3)	32(3)	-3(3)
N(1)	55(2)	32(2)	40(2)	4(2)	24(2)	-3(2)
O(1)	79(2)	44(2)	37(2)	-4(2)	28(1)	-11(2)
O(2)	96(2)	43(2)	42(2)	5(2)	14(2)	-12(2)
O(3)	95(2)	133(4)	70(2)	43(2)	48(2)	30(2)

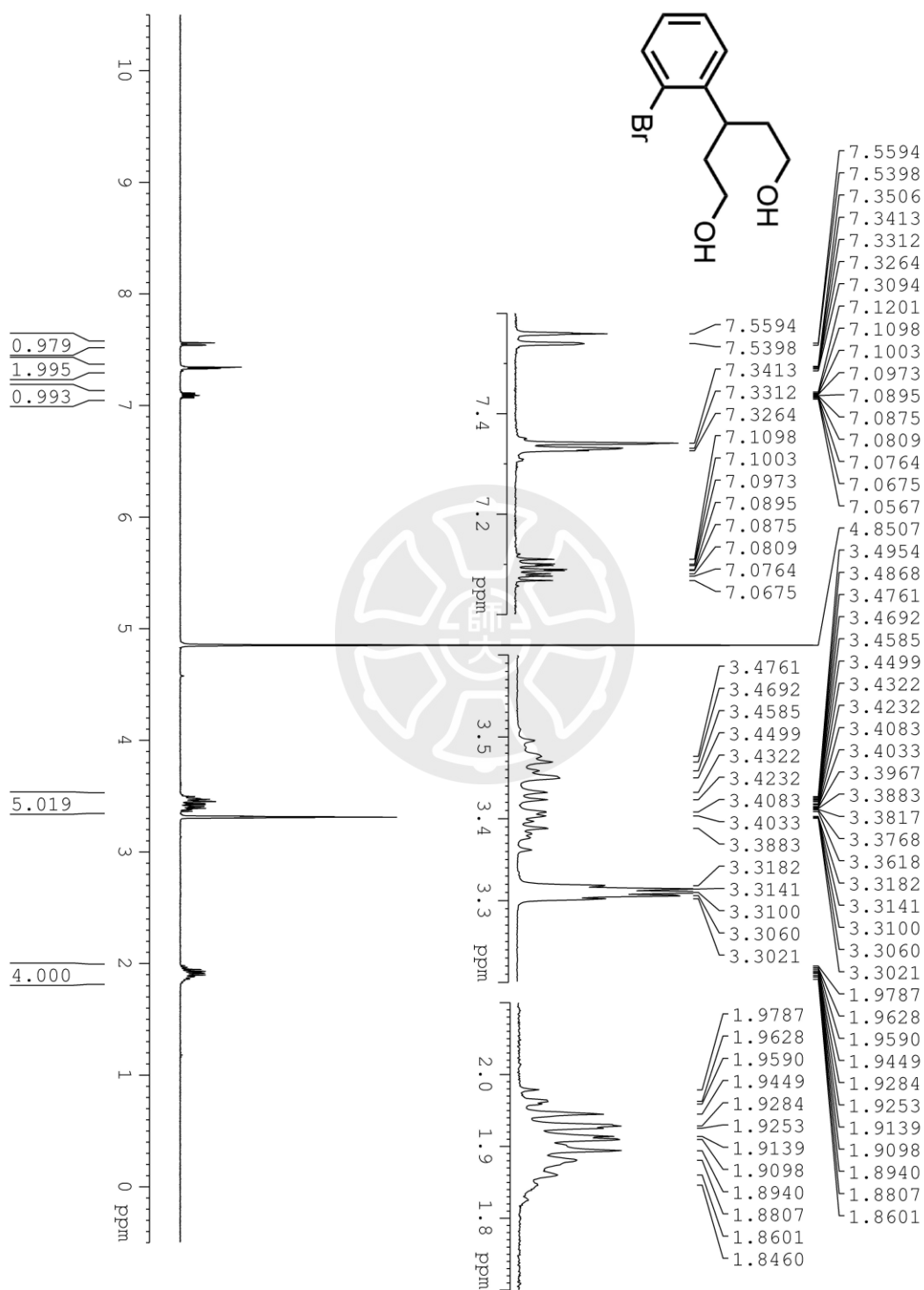
Table 5. Hydrogen coordinates ($\times 10^4$) and isotropic displacement parameters ($\text{\AA}^2 \times 10^3$) for d24494.

	x	y	z	U(eq)
H(2)	7625	5122	2729	57
H(4)	6350	1164	1558	67
H(5)	5134	1815	814	91
H(6)	4642	5225	873	104
H(7)	5351	7909	1681	102
H(8)	6571	7289	2397	81
H(9A)	8324	2345	2350	72
H(9AB)	7591	1230	1780	72
H(10A)	7363	4128	820	84
H(10B)	8051	5411	1416	84
H(11A)	8586	5448	243	179
H(11B)	7907	4121	-341	179
H(11C)	8721	3212	-172	179
H(12A)	9493	9603	5539	99
H(12B)	8760	9675	5829	99
H(12C)	8780	10765	4945	99
H(13)	8863	6239	5288	58
H(15)	8789	9930	3546	84
H(16)	9283	9241	2409	97
H(17)	9846	5998	2352	107
H(18)	9888	3324	3359	92
H(19)	9349	3953	4473	72
H(1A)	7701	7619	4989	60
H(1B)	7736	6178	4274	60
H(1C)	7744	8546	4163	60

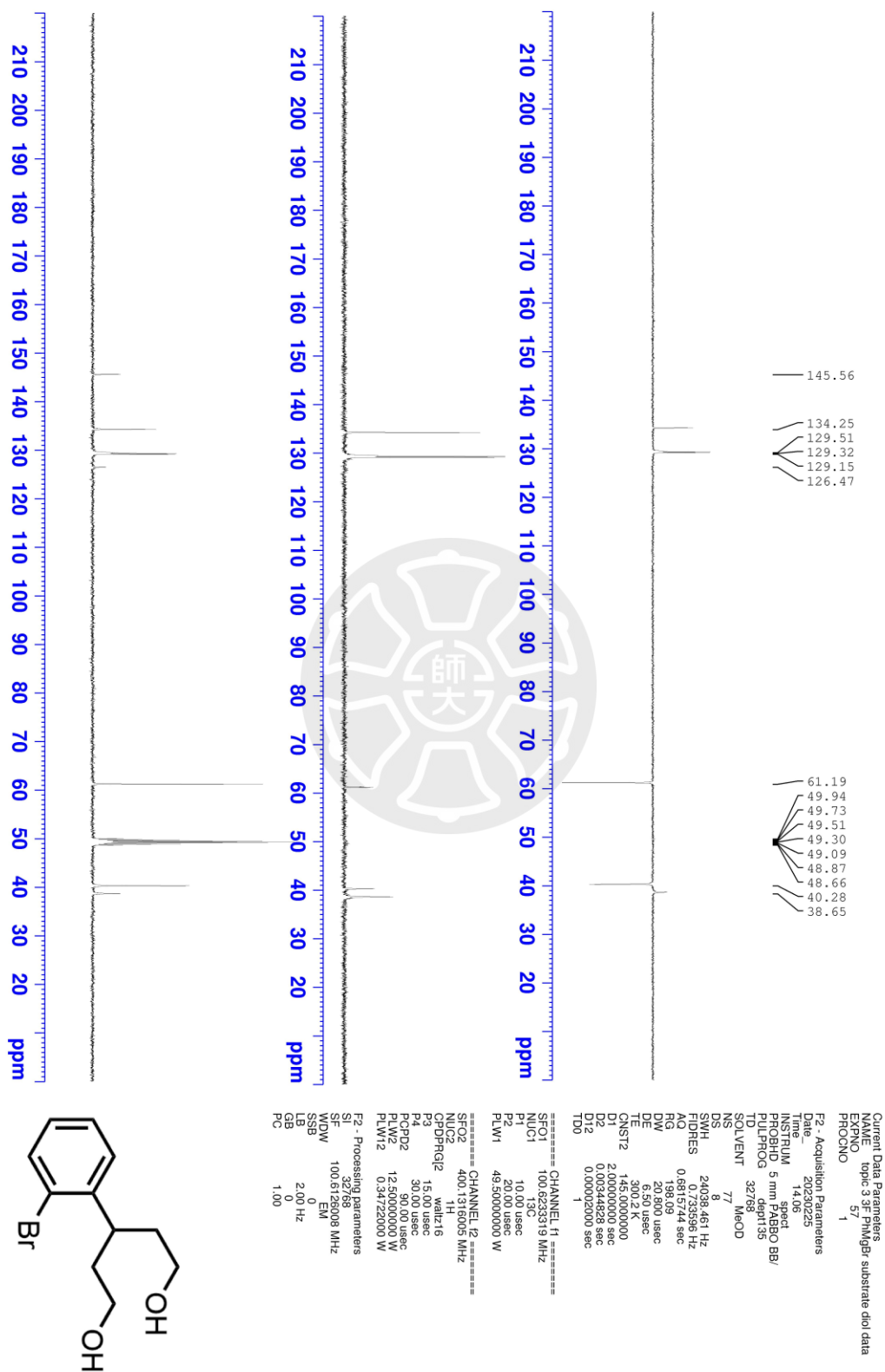
附錄二 核磁共振光譜



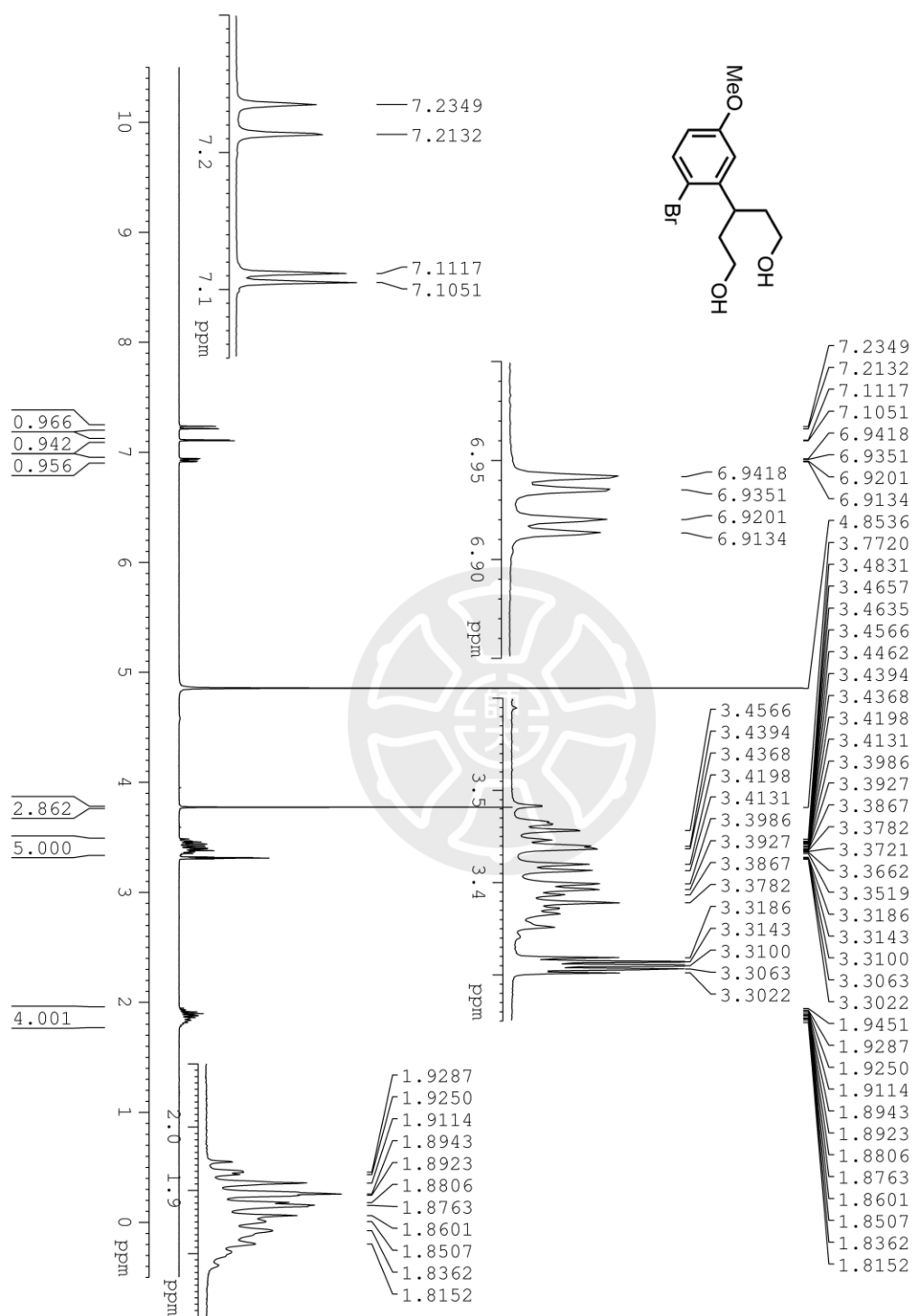
1. ^1H NMR of 3-(2-bromophenyl)pentane-1,5-diol (91a)



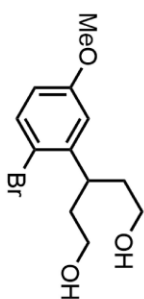
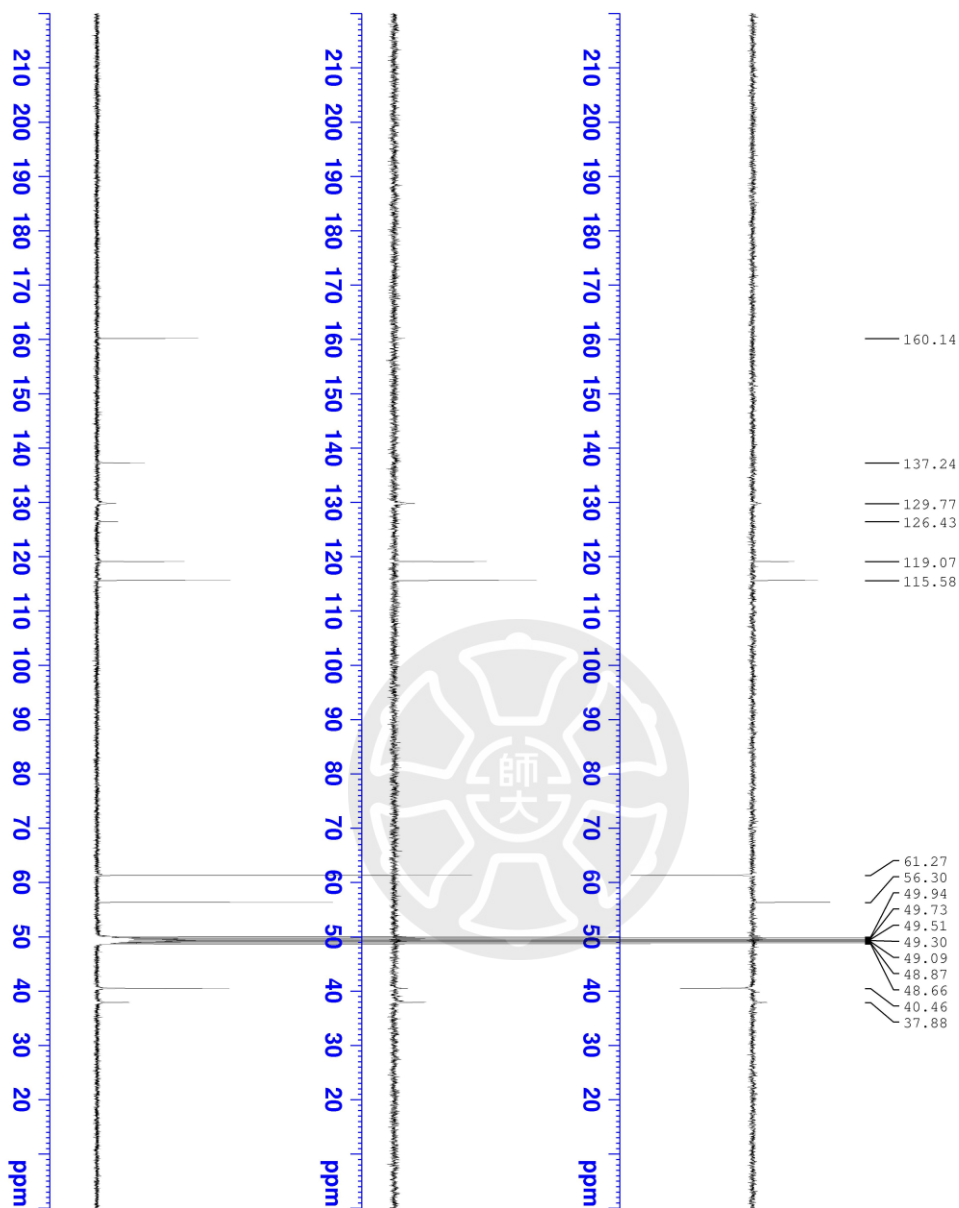
2. ^{13}C NMR of 3-(2-bromophenyl)pentane-1,5-diol (91a)



3. ^1H NMR of 3-(2-bromo-5-methoxyphenyl)pentane-1,5-diol (91b)

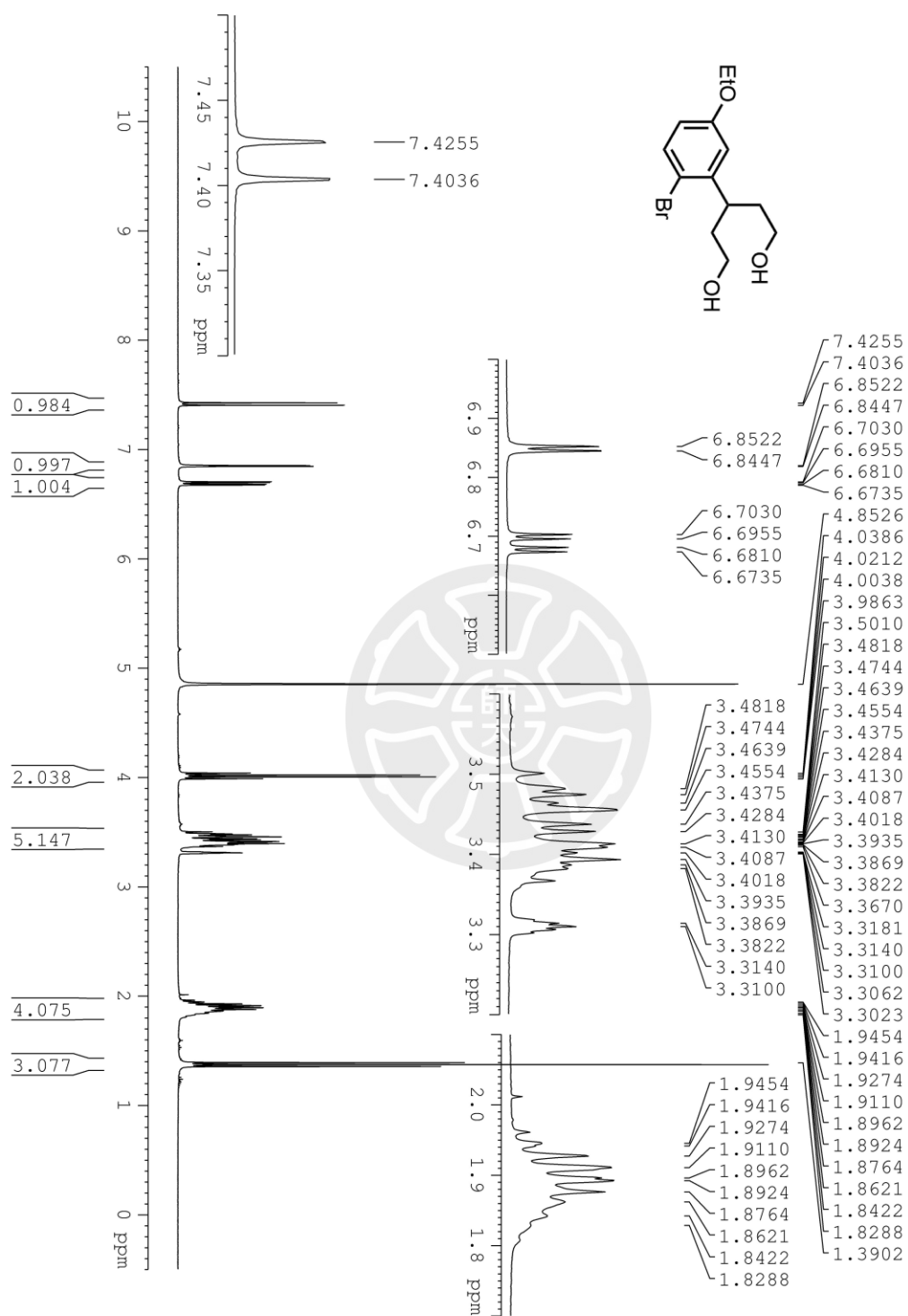


4. ^{13}C NMR of 3-(2-bromo-5-methoxyphenyl)pentane-1,5-diol (91b)

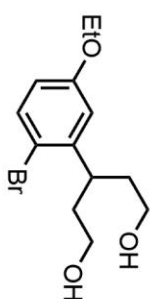
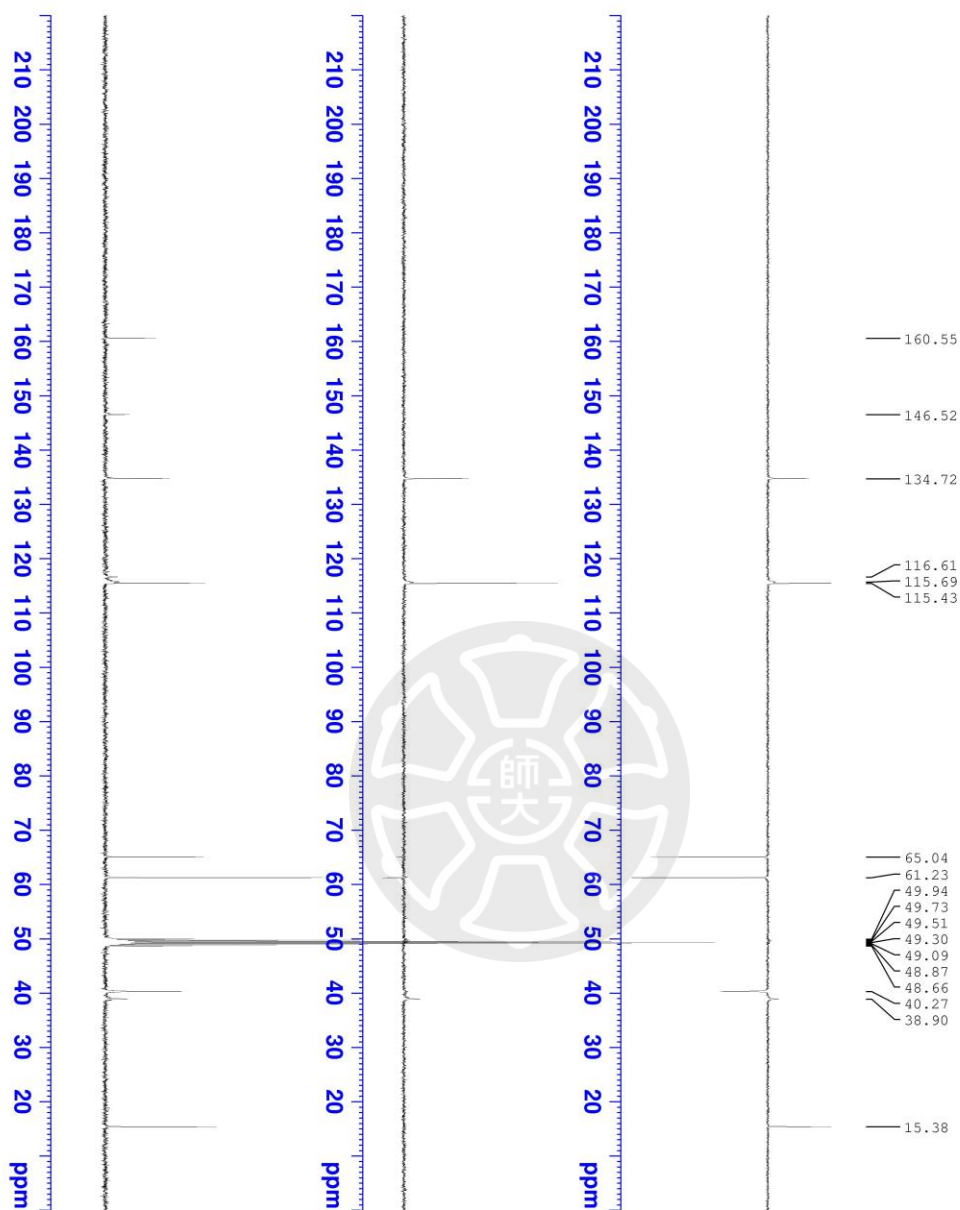


Current Data Parameters
 NAME: topic 3 3F PMagBr substrate diol data
 EXPNO: 87
 PROCNO: 1
 F2 - Acquisition Parameters
 Date_ : 20200611
 Time : 21:41
 INSTRUM : spect
 PROBHD : 5 mm PABO BB/
 PULPROG : zgpg30
 TD : 65536
 SOLVENT : MeOD
 NS : 420
 DS : 8
 SSF : 2403.461 Hz
 FIDRES : 0.733596 Hz
 AQ : 0.8815744 sec
 RG : 198.09
 DW : 20.800 usec
 TE : 300.2 K
 DE : 6.50 usec
 T2 : 228.41
 CNST2 : 145.0000000
 D1 : 2.00000000 sec
 D2 : 0.00344828 sec
 D12 : 0.00002000 sec
 TDO : 1
 ===== CHANNEL f1 =====
 SFO1 : 100.623319 MHz
 NUC1 : ^{13}C
 P1 : 10.00 usec
 PL1 : 20.10 usec
 PLW1 : 49.50000000 W
 ===== CHANNEL f2 =====
 SFO2 : 400.1316005 MHz
 NUC2 : ^1H
 CPDPRG2 : waltz16
 P3 : 15.00 usec
 P4 : 30.00 usec
 PCPD2 : 12.50000000 W
 PL12 : 0.34722000 W
 F2 - Processing parameters
 SI : 32768
 SF : 100.6125071 MHz
 WDW : EM
 SSB : 0
 LB : 2.00 Hz
 GB : 0
 PC : 1.00

5. ^1H NMR of 3-(2-bromo-5-ethoxyphenyl)pentane-1,5-diol (91c)

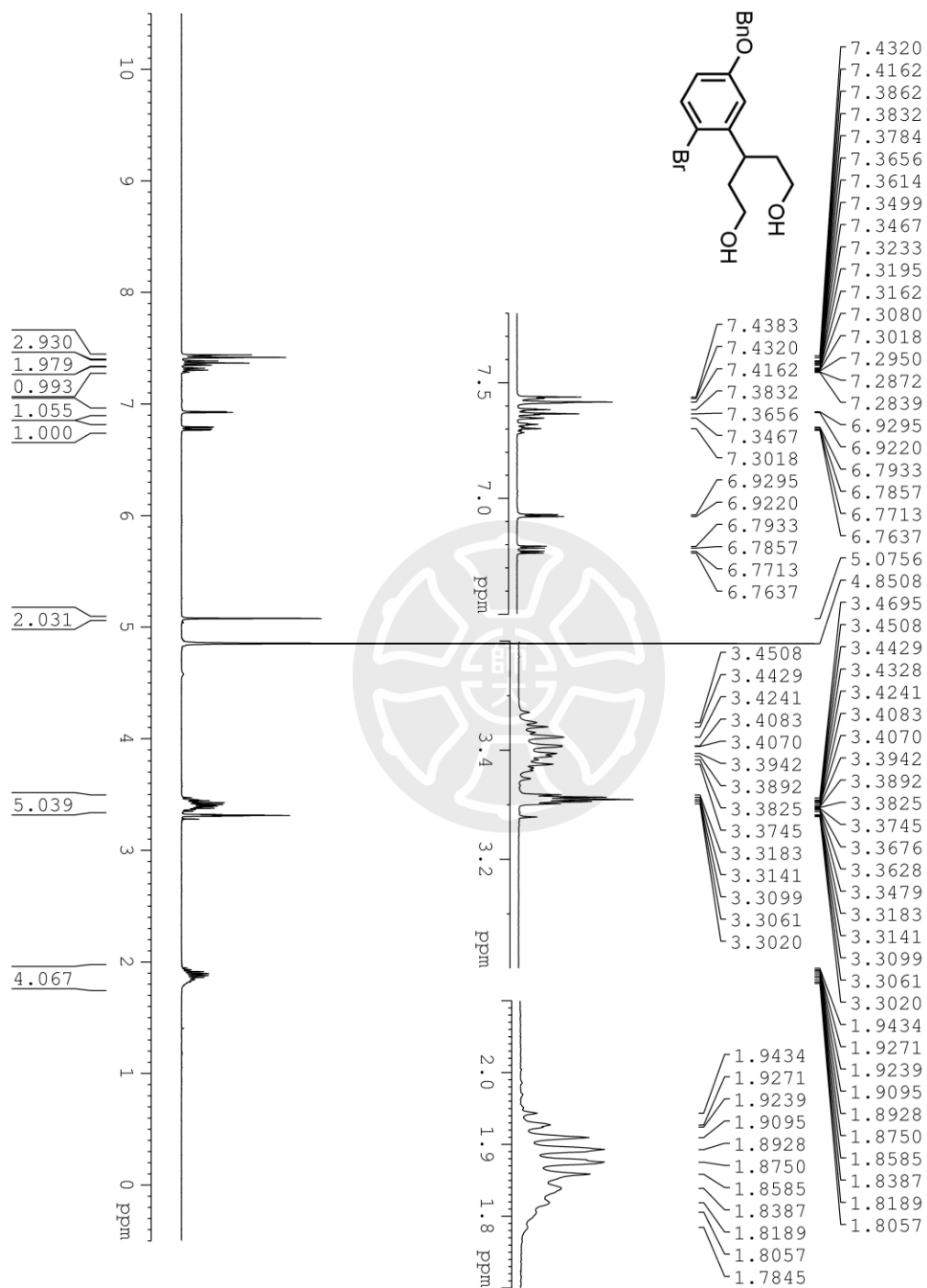


6. ^{13}C NMR of 3-(2-bromo-5-ethoxyphenyl)pentane-1,5-diol (91c)

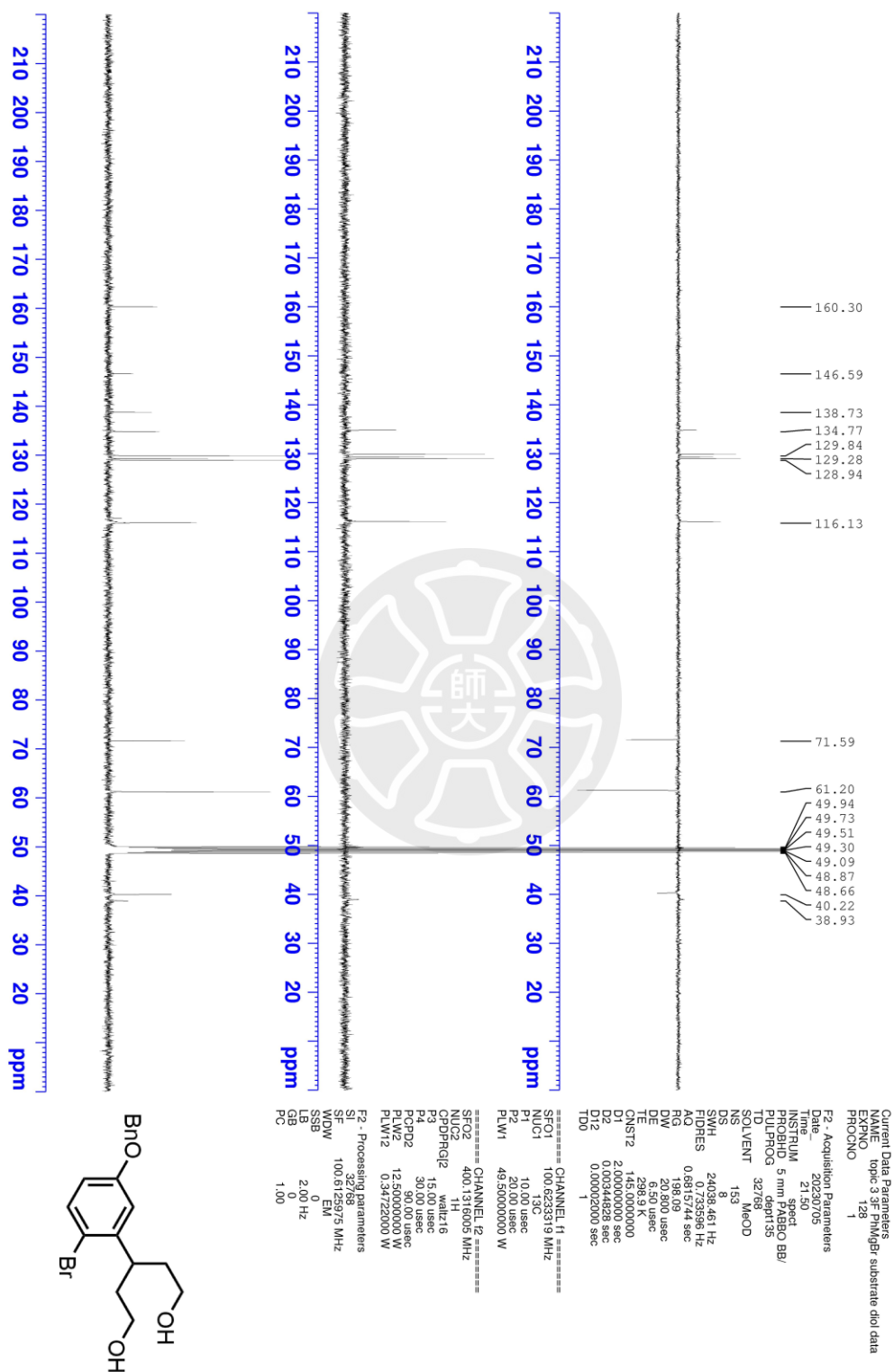


Current Data Parameters
NAME: topic 3 F1 PMAGBr substrate dci data
EXPNO: 91
PROCNO: 1
F2 - Acquisition Parameters
Date_ : 20200611
Time : 22:07
INSTRUM : spect
PROBHD : 5 mm PABO BB/
PULPROG : zgpg30
TD : 65536
SOLVENT : MeOD
NS : 203
DS : 8
SS : 2403.461 Hz
FIDRES : 0.733595 Hz
AQ : 0.8815744 sec
RG : 198.09
DW : 20.800 usec
DE : 6.50 usec
TE : 298.15
CNST2 : 145.0000000
D1 : 2.00000000 sec
D2 : 0.00344828 sec
D3 : 0.00002000 sec
TD0 : 1
===== CHANNEL f1 =====
SFO1 : 100.6233319 MHz
NUC1 : ^{13}C
P1 : 10.00 usec
PL1 : 20.10 usec
PLW1 : 49.50000000 W
===== CHANNEL f2 =====
SFO2 : 400.1316005 MHz
NUC2 : ^1H
CPCPRG2 : waltz16
P3 : 15.00 usec
P4 : 30.00 usec
PCPD2 : 12.50000000 W
PL12 : 0.34722000 W
F2 - Processing parameters
SI : 32768
SF : 100.6125992 MHz
WDW : EM
SSB : 0
LB : 2.00 Hz
GB : 0
PC : 1.00

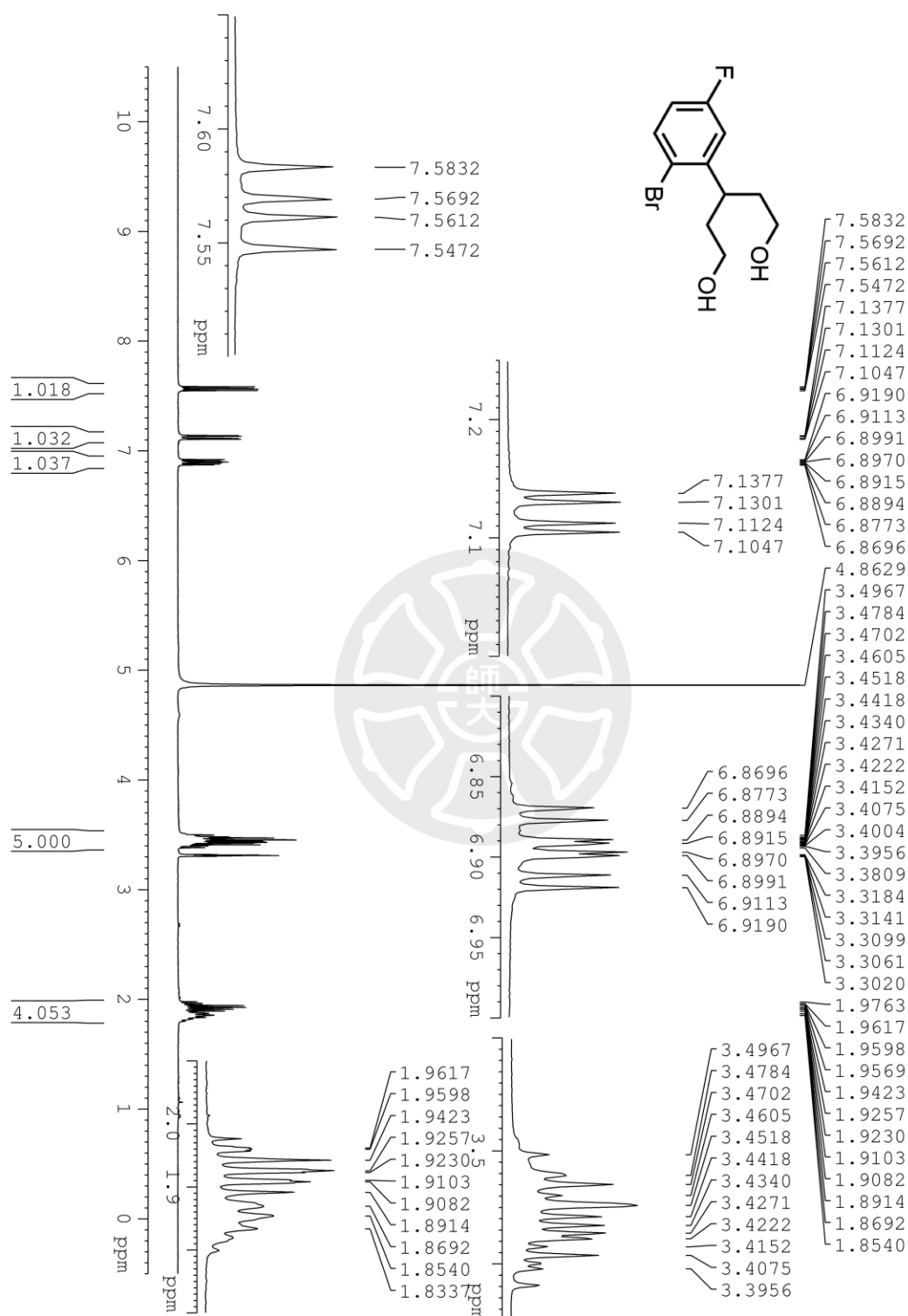
7. ^1H NMR of 3-(5-(benzyloxy)-2-bromophenyl)pentane-1,5-diol (91d)



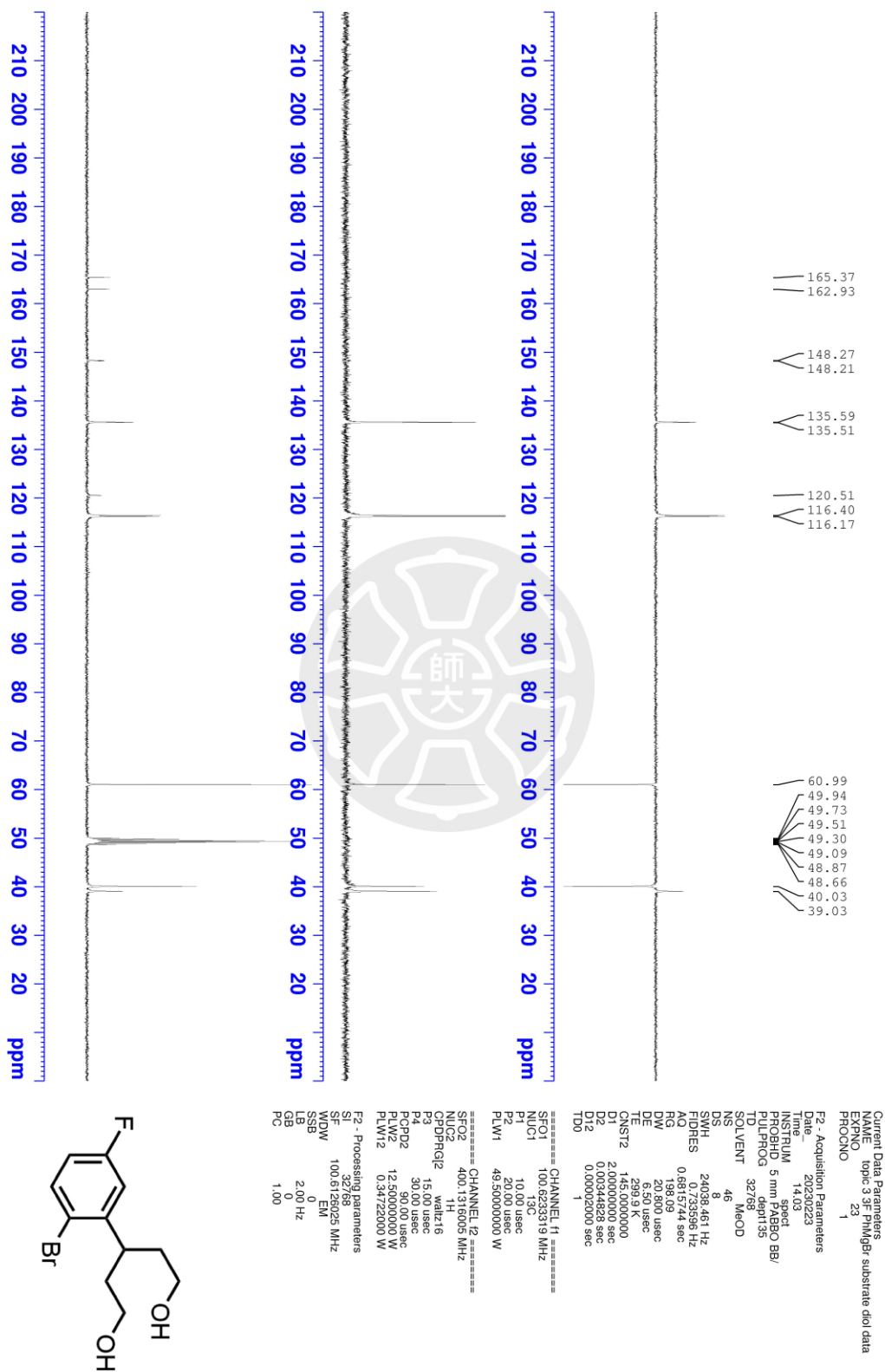
8. ^{13}C NMR of 3-(5-(benzyloxy)-2-bromophenyl)pentane-1,5-diol (91d)



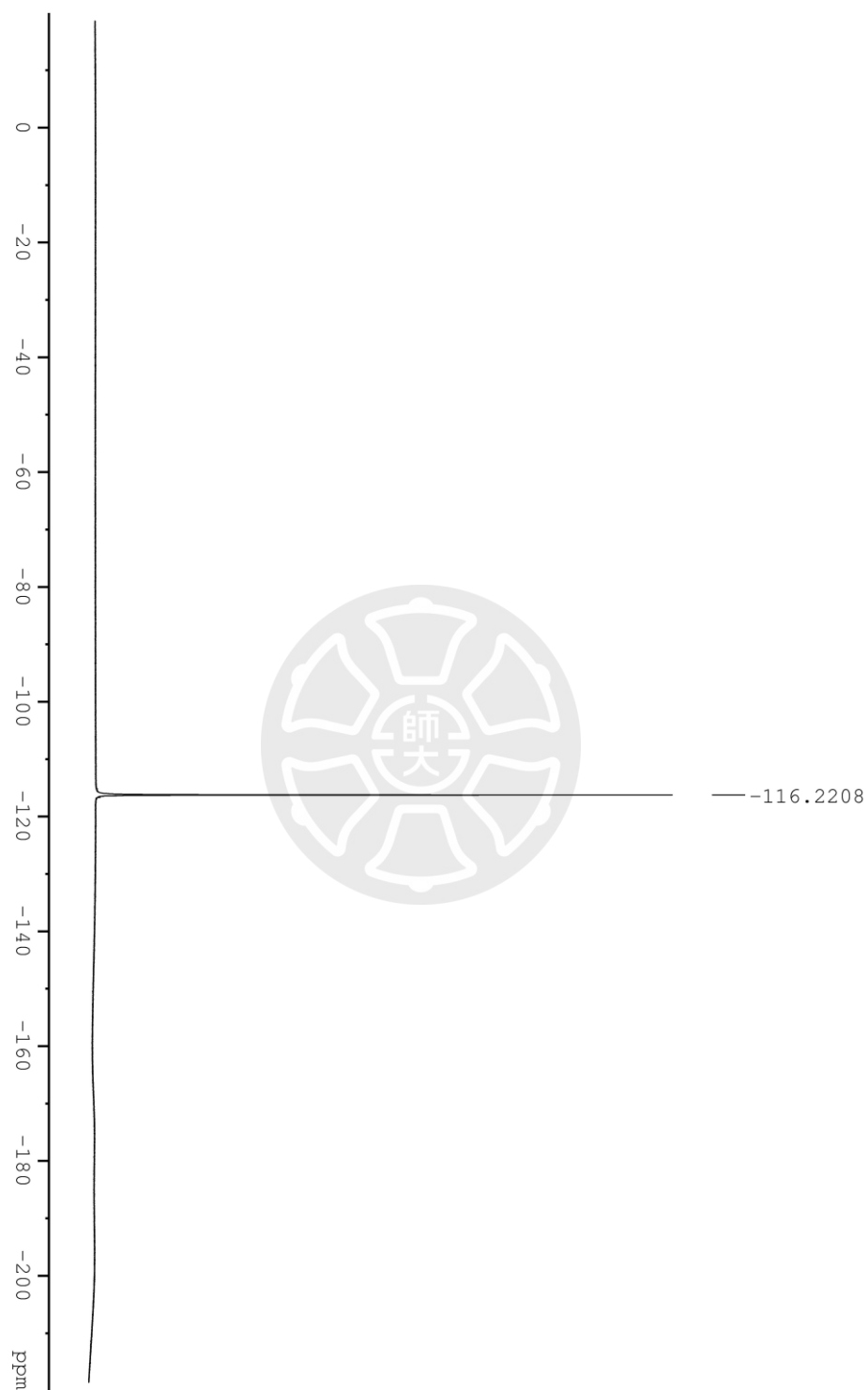
9. ^1H NMR of 3-(2-bromo-5-fluorophenyl)pentane-1,5-diol (91e)



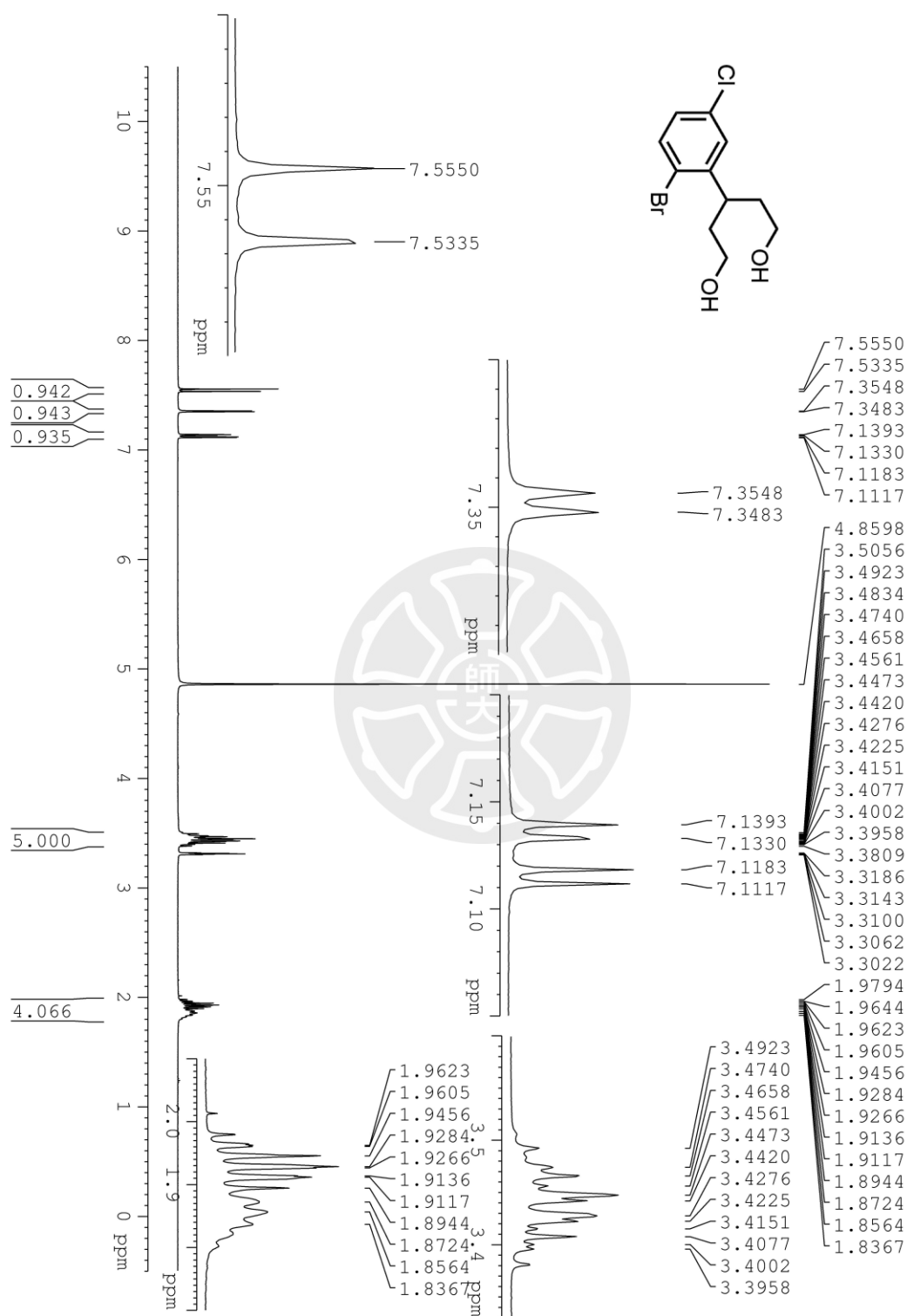
10. ^{13}C NMR of 3-(2-bromo-5-fluorophenyl)pentane-1,5-diol (91e)



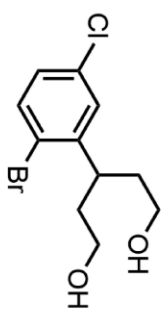
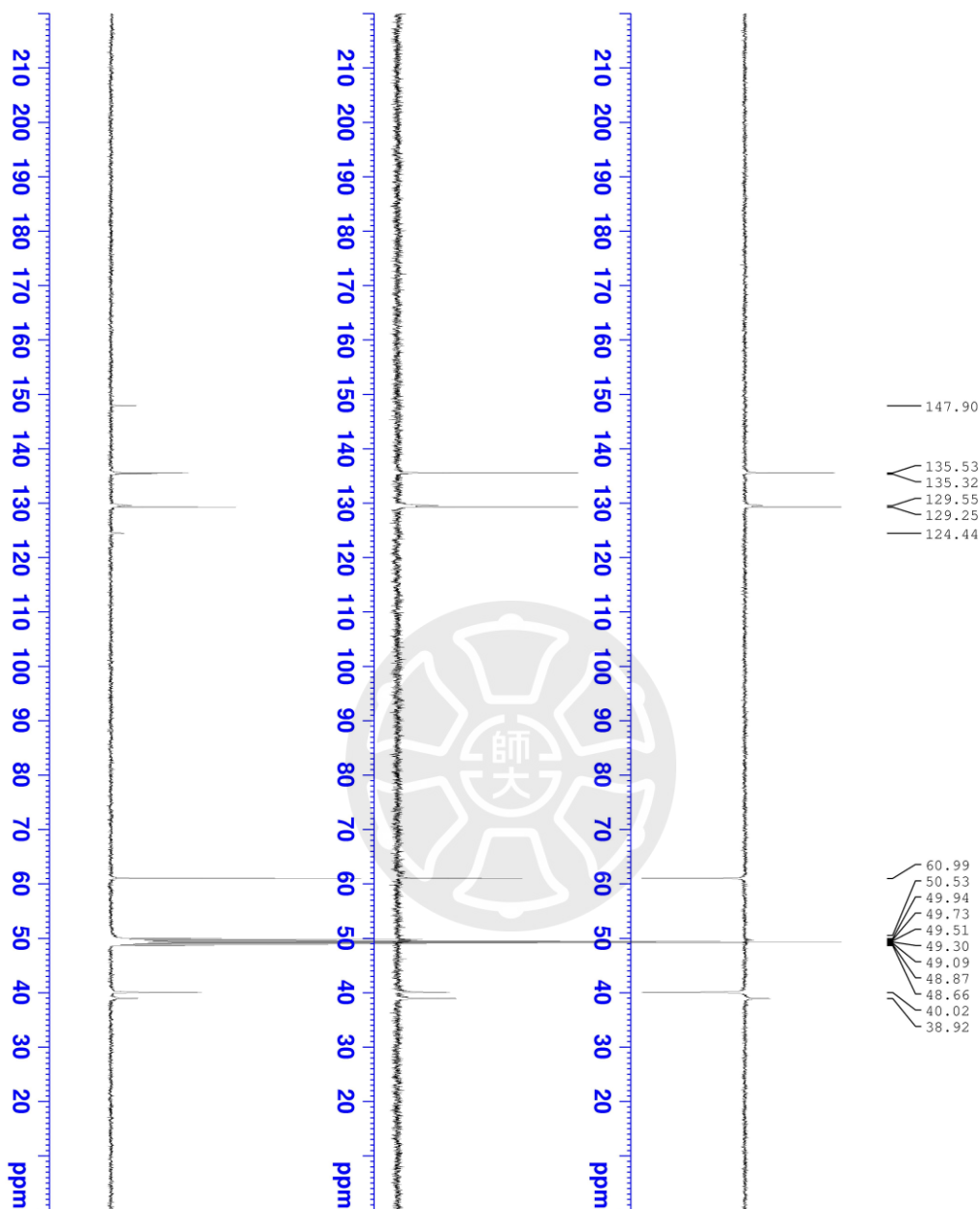
11 ^{19}F NMR of 3-(2-bromo-5-fluorophenyl)pentane-1,5-diol (91e)



12. ^1H NMR of 3-(2-bromo-5-chlorophenyl)pentane-1,5-diol (91f)

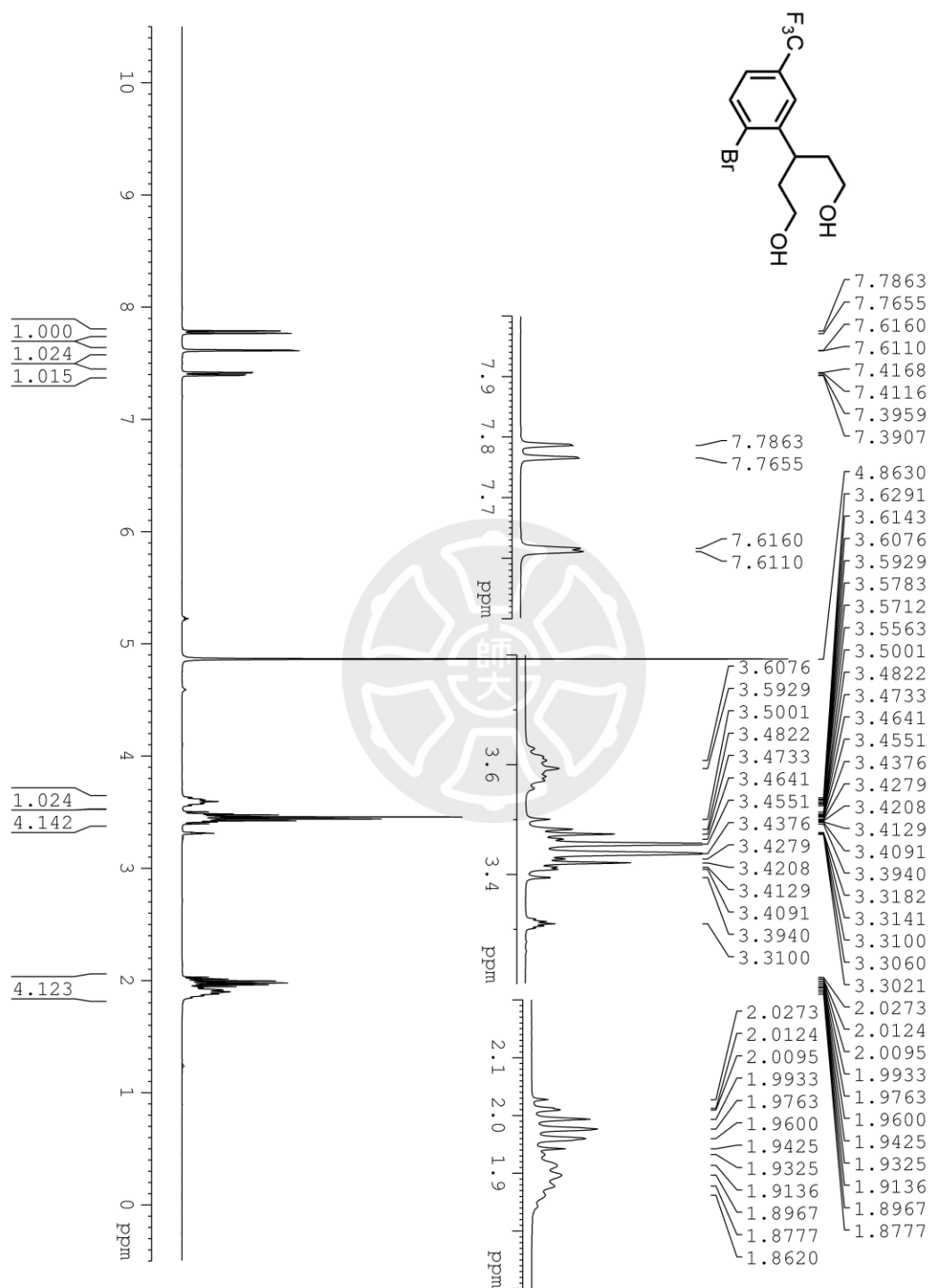


13. ¹³C NMR of 3-(2-bromo-5-chlorophenyl)pentane-1,5-diol (91f)

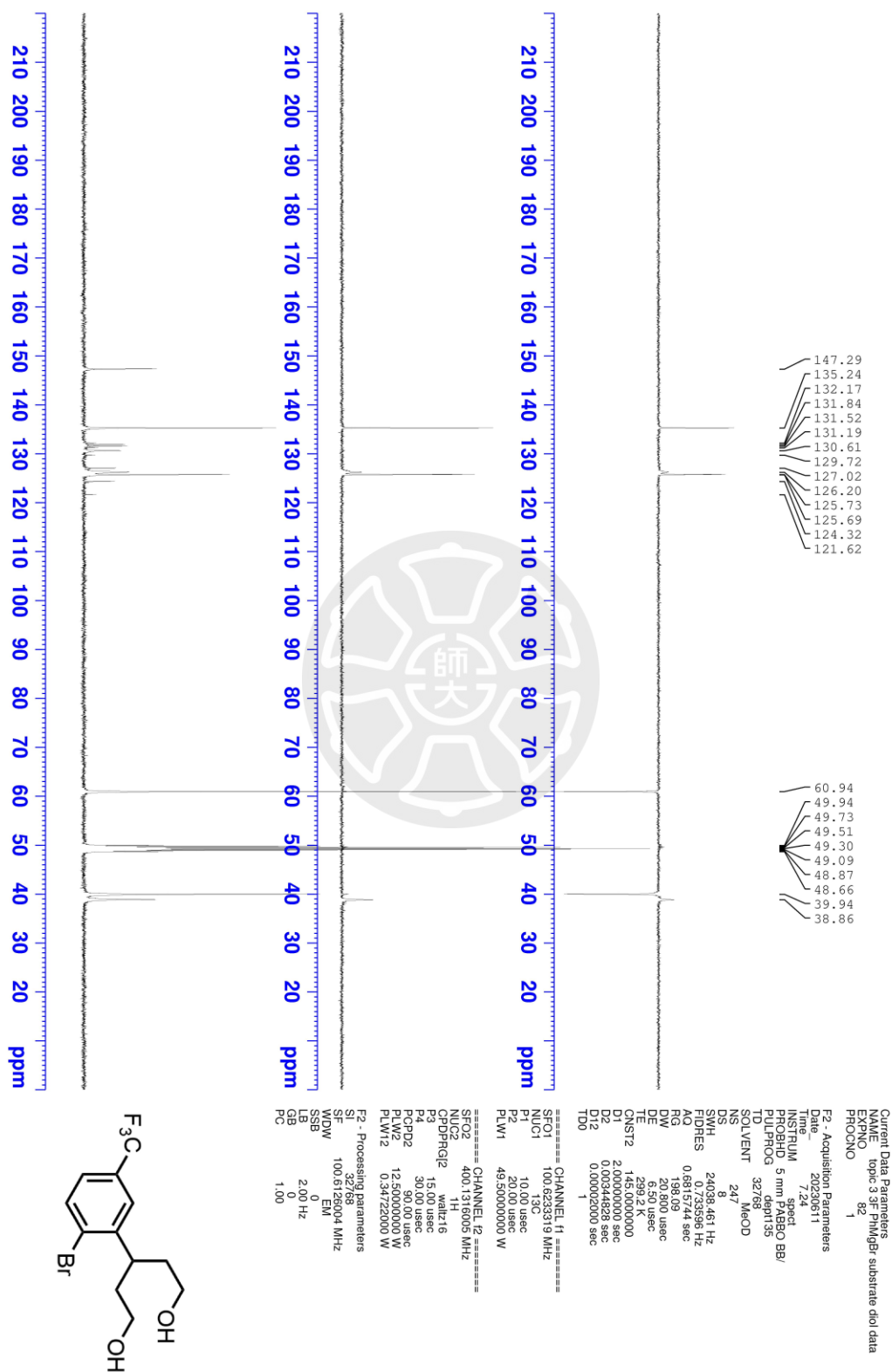


Current Data Parameters
NAME topic 3 3f P1MqBr substrate diol data
EXPNO 63
PROCNO 1
F2 - Acquisition Parameters
Date_ 20230407
Time 13:37
INSTRUM spect
PROBHD 5 mm PABBO BB/
TULPROG 32/16pp1 3s
SOLVENT MeOD
NS 200
DS 8
SWH 24038.461 Hz
FIDRES 0.733595 Hz
AQ 0.68174 sec
RG 158.09
DW 20.800 usec
DE 6.50 usec
TE 298.3 K
CNST2 145.000000
D1 2.0000000 sec
D2 0.00344828 sec
D12 0.0000200 sec
TD0 1
===== CHANNEL f1 =====
NUC1 100.625319 MHz
NUC1 13C
P1 10.00 usec
P2 20.00 usec
PLW1 49.50000000 W
===== CHANNEL f2 =====
SFO2 400.136065 MHz
NUC2 1H
CPDPRG2 waltz16
P3 15.00 usec
P4 30.00 usec
PCPD2 80.00 usec
PLW2 12.50000000 W
PLW12 0.34722000 W
F2 - Processing parameters
SI 32768
SF 100.6125989 MHz
FNUW 0
EM 0
SSB 0
LB 2.00 Hz
GB 0
PC 1.00

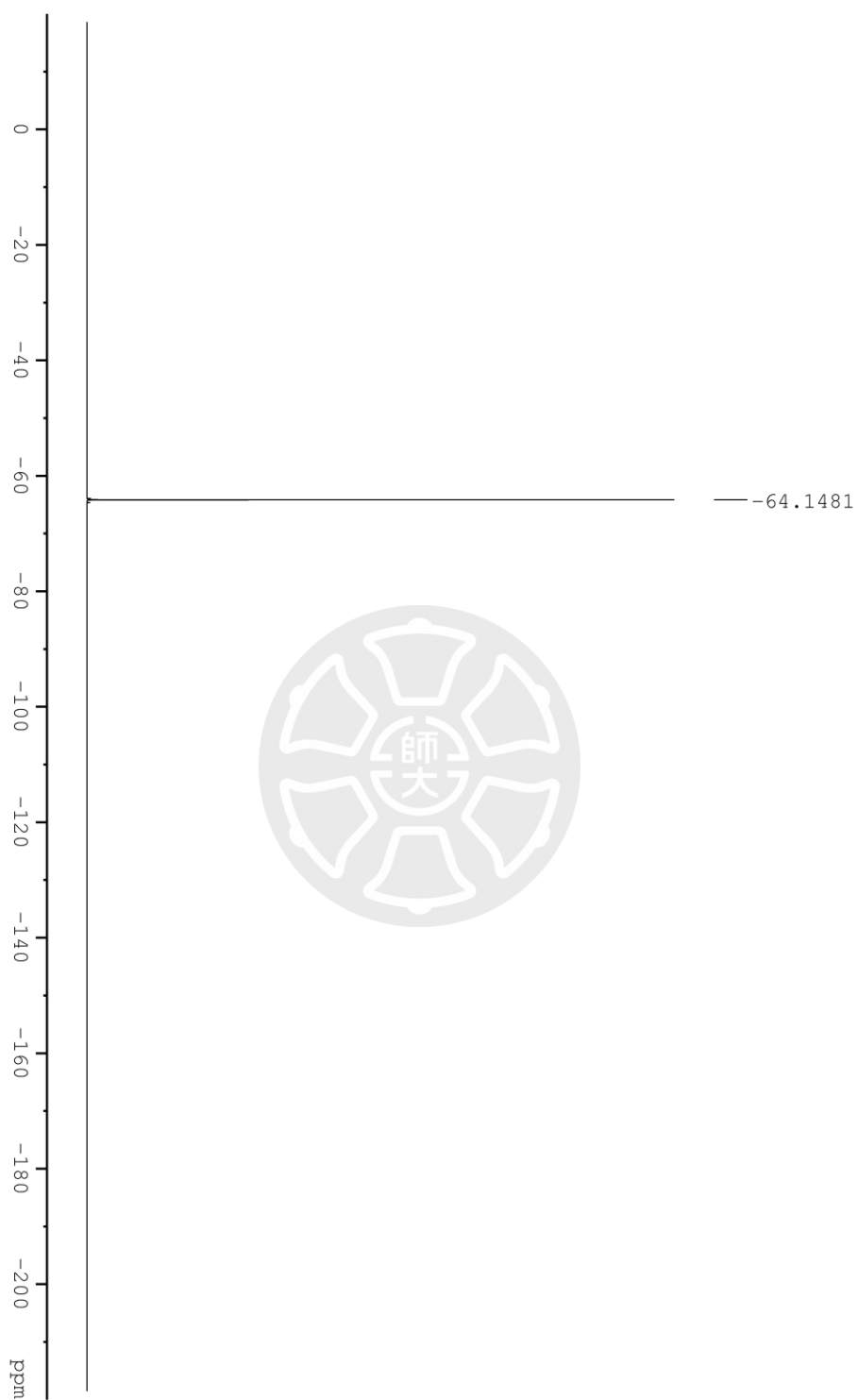
14. ^1H NMR of 3-(2-bromo-5-(trifluoromethyl)phenyl)pentane-1,5-diol (91g)



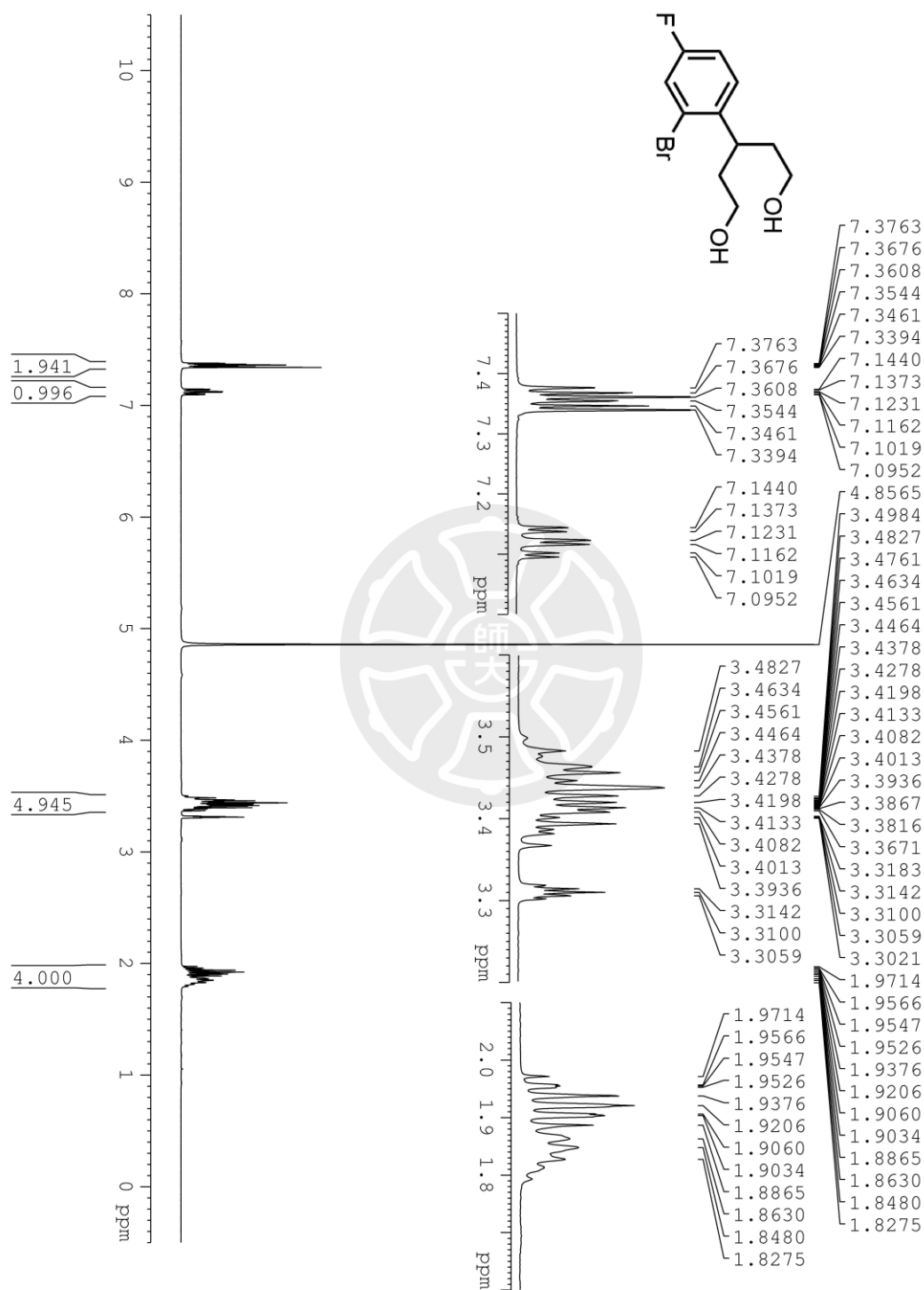
15. ^{13}C NMR of 3-(2-bromo-5-(trifluoromethyl)phenyl)pentane-1,5-diol (91g)



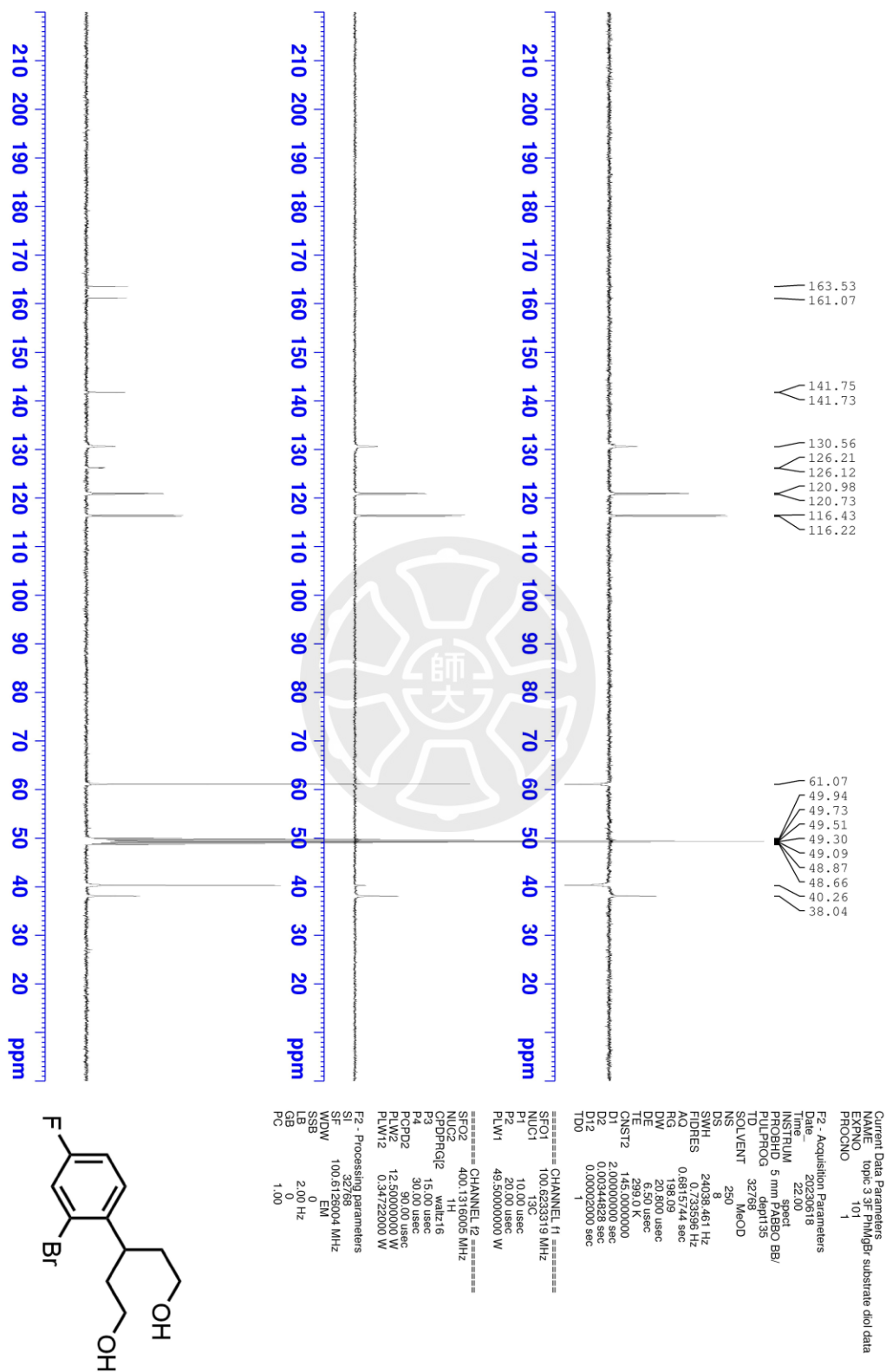
16. ^{19}F NMR of 3-(2-bromo-5-(trifluoromethyl)phenyl)pentane-1,5-diol (91g)



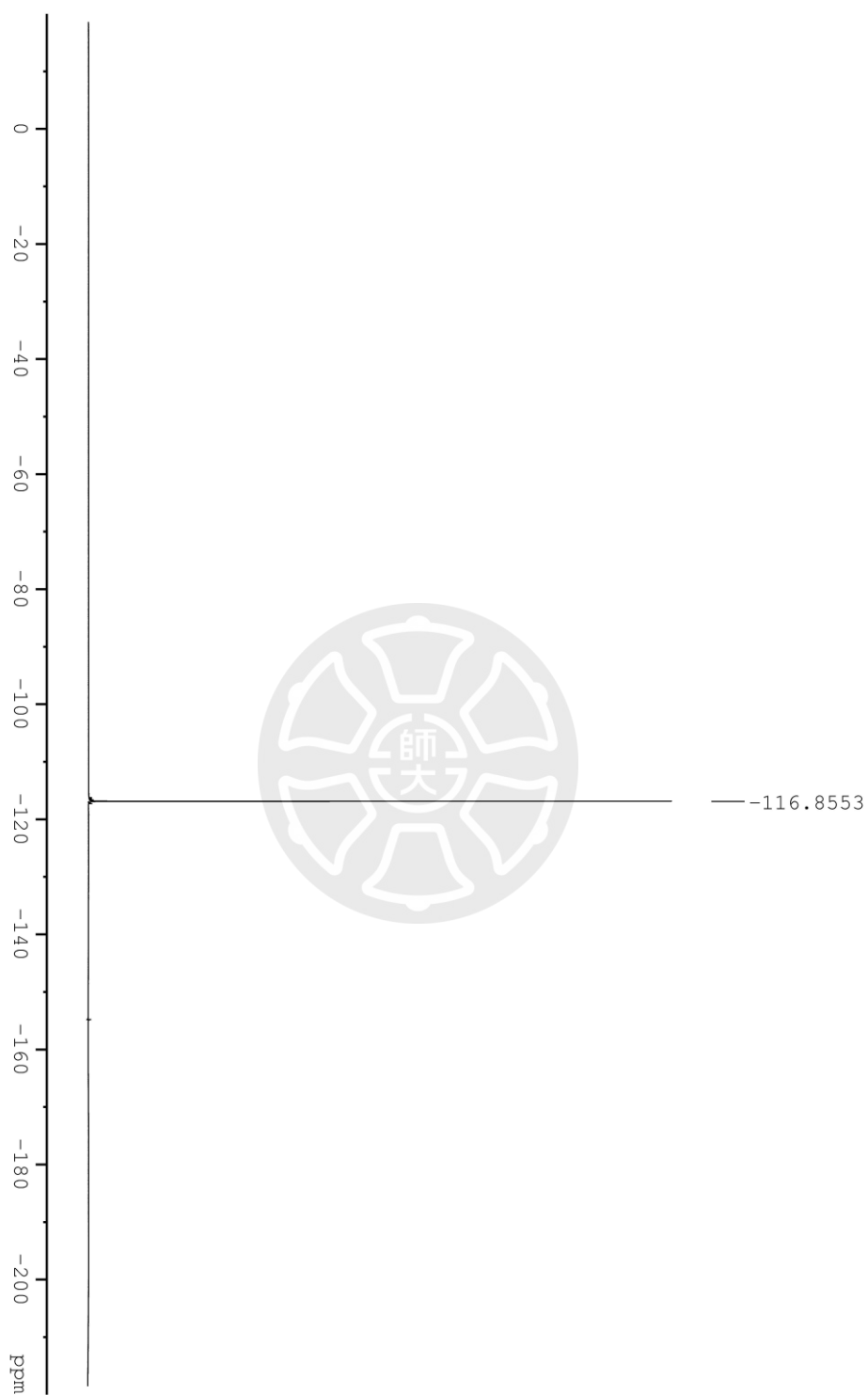
17. ^1H NMR of 3-(2-bromo-4-fluorophenyl)pentane-1,5-diol (91h)



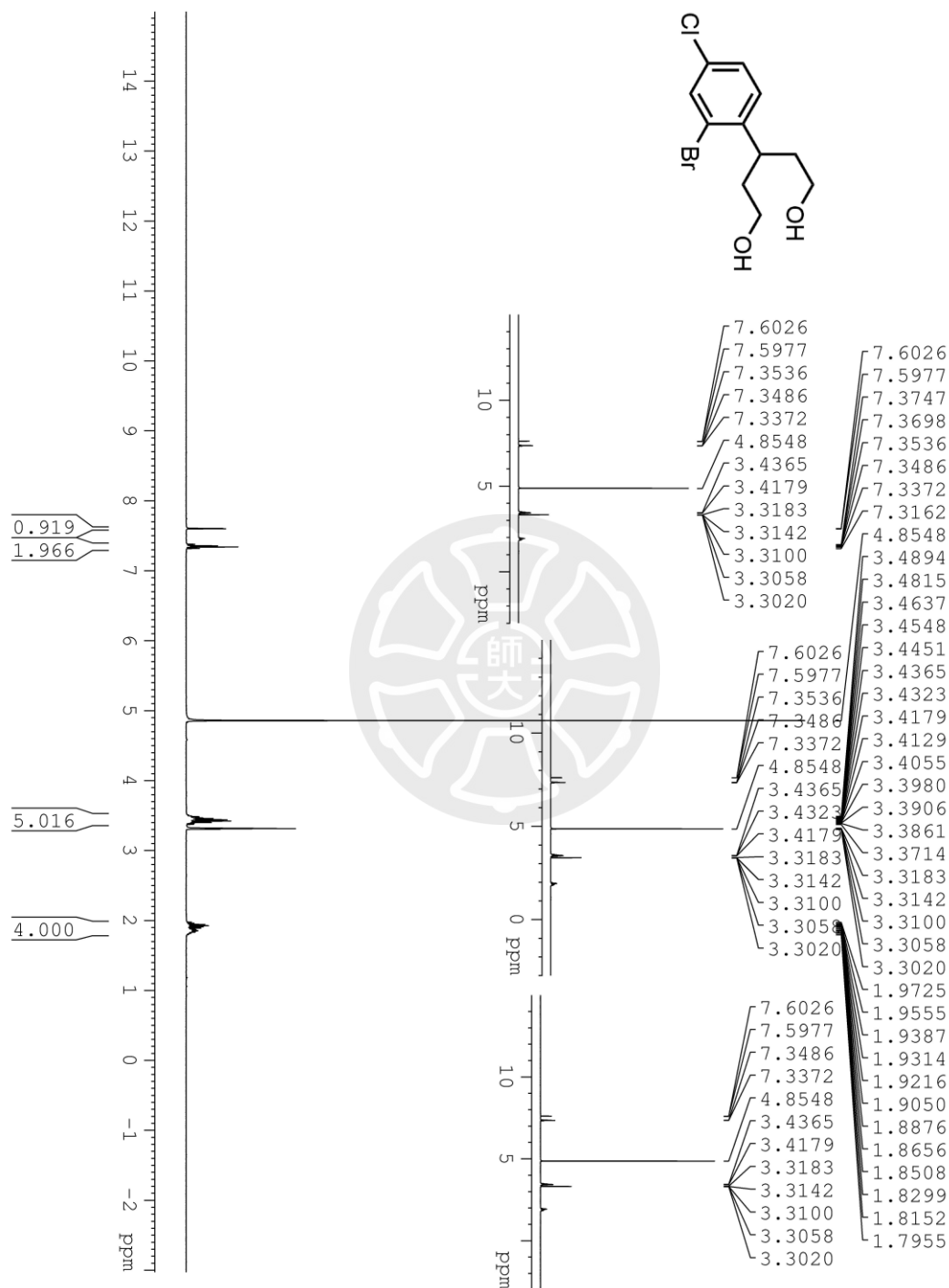
18. ^{13}C NMR of 3-(2-bromo-4-fluorophenyl)pentane-1,5-diol (91h)



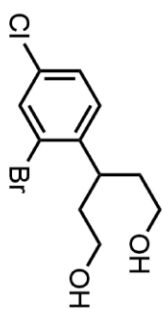
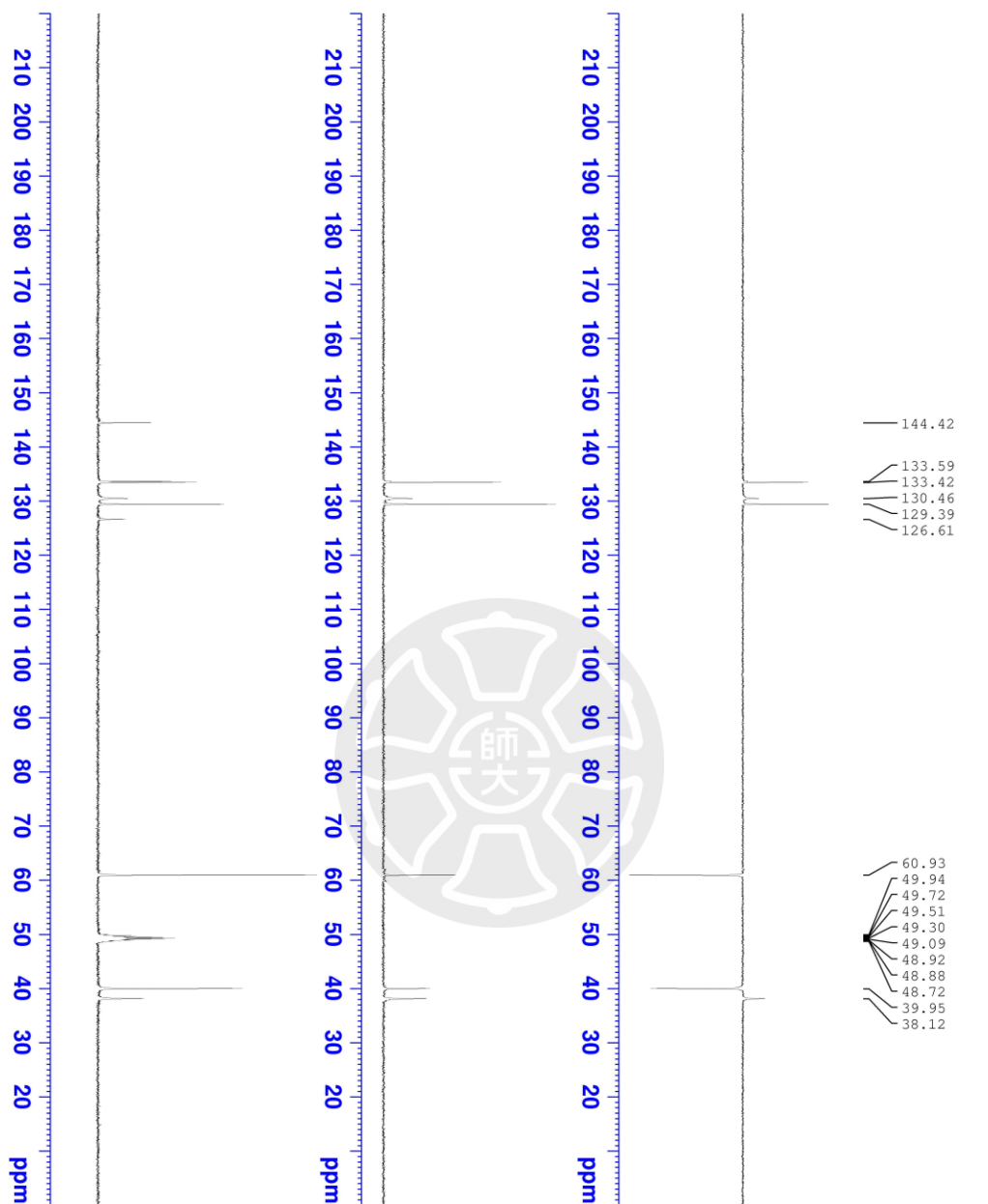
19. ^{19}F NMR of 3-(2-bromo-4-fluorophenyl)pentane-1,5-diol (91h)



20. ^1H NMR of 3-(2-bromo-4-chlorophenyl)pentane-1,5-diol (91i)

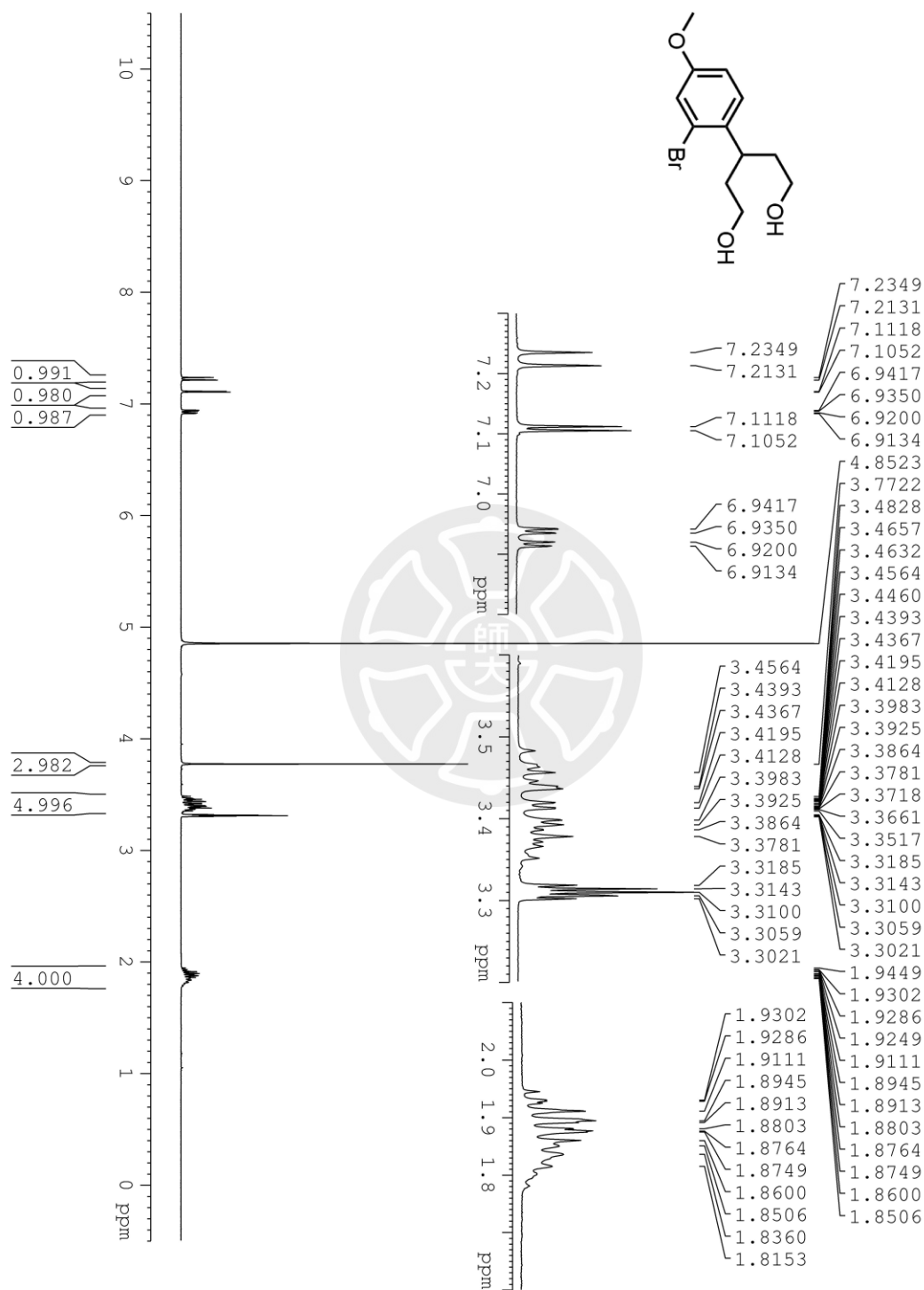


21. ^{13}C NMR of 3-(2-bromo-4-chlorophenyl)pentane-1,5-diol (91i)

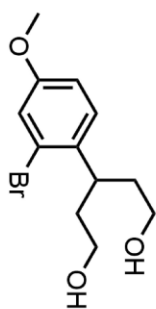
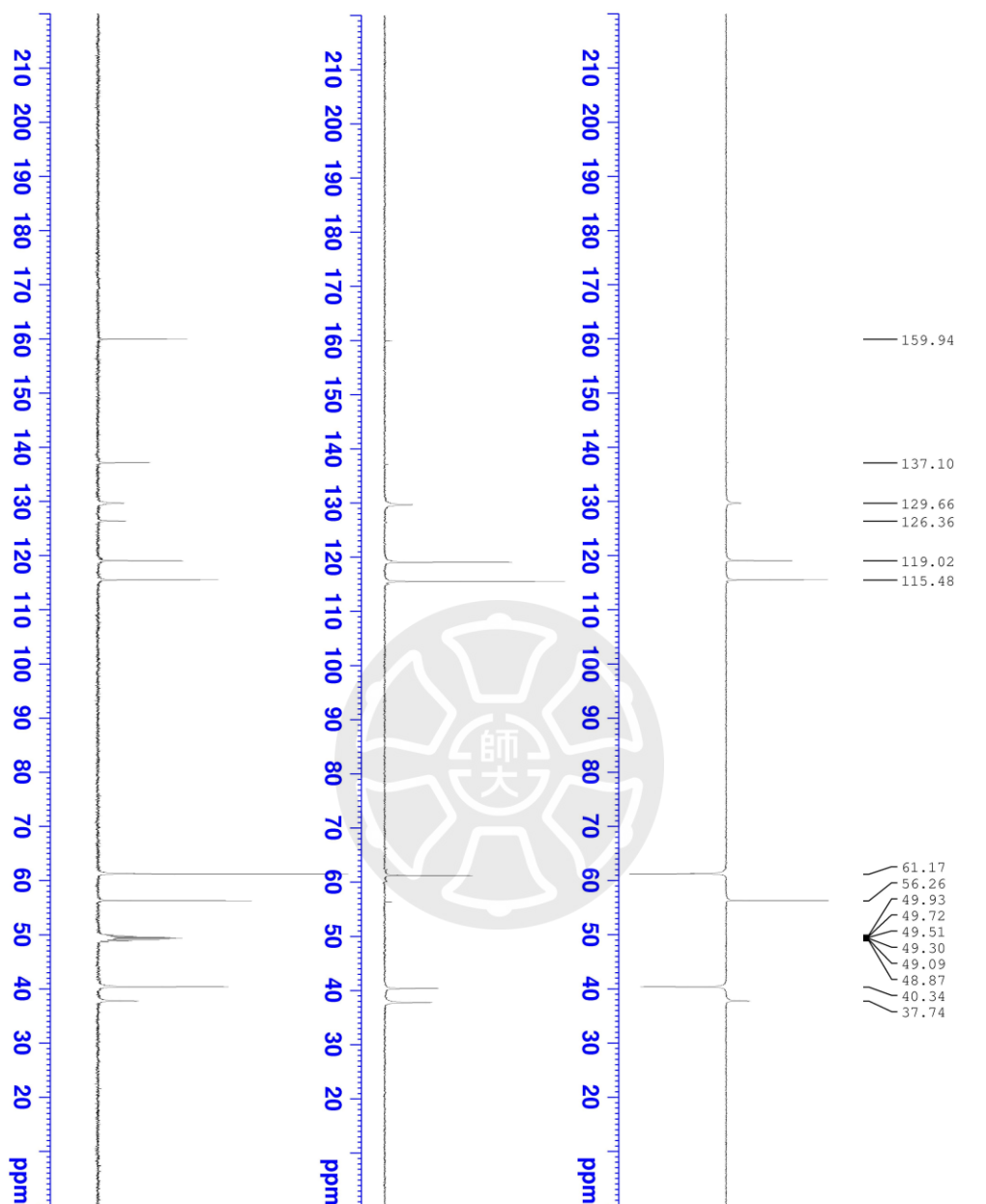


Current Data Parameters
NAME: topic 3 3F P1MqBr substrate diol data
EXPNO: 26
PROCNO: 1
F2 - Acquisition Parameters
Date_: 20230223
Time: 21.43
INSTRUM: spect
PROBHD: 5 mm PABBO BB/
TULPHOG: 3276pp1 3s
SOLVENT: MeOD
NS: 33
DS: 8
SWH: 24038.461 Hz
FIDRES: 0.733595 Hz
AQ: 0.68374 sec
RG: 198.09
DW: 20.800 usec
DE: 6.50 usec
TE: 299.5 K
CNST2: 145.000000
D1: 2.4000000 sec
D2: 0.00344828 sec
D12: 0.0000200 sec
TD0: 1
===== CHANNEL f1 =====
NUC1: 100.625319 MHz
NUC1: 13C
P1: 10.00 usec
P2: 20.00 usec
PLW1: 49.50000000 W
===== CHANNEL f2 =====
SFO2: 400.1315605 MHz
NUC2: 1H
CPDPRG2: waltz16
P3: 15.00 usec
P4: 30.00 usec
PCPD2: 80.00 usec
PLW2: 12.50000000 W
PLW12: 0.34722000 W
F2 - Processing parameters
SI: 32768
SF: 100.6126172 MHz
V1: 0
SSB: 0
LB: 2.00 Hz
GB: 0
PC: 1.00

22. ^1H NMR of 3-(2-bromo-4-methoxyphenyl)pentane-1,5-diol (911)

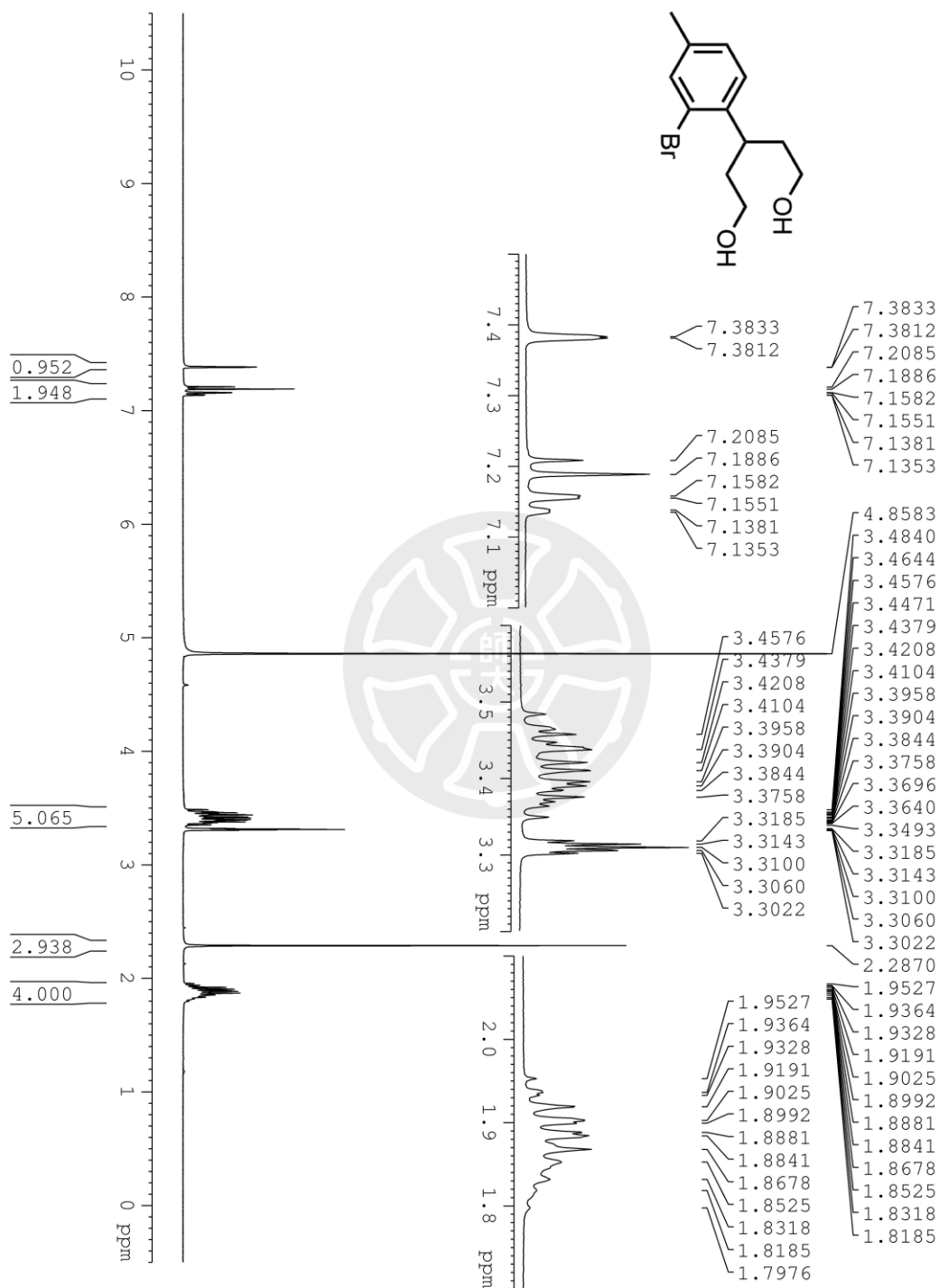


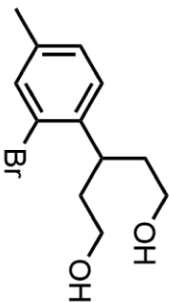
23. ^{13}C NMR of 3-(2-bromo-4-methoxyphenyl)pentane-1,5-diol (911)



Current Data Parameters
NAME: topic 3 3F P1MqBr substrate diol data
EXPNO: 39
PROCNO: 1
F2 - Acquisition Parameters
Date_ Time: 20230225 7:33
INSTRUM: spect
PROBHD: 5 mm PABBO BB/
TULPHOG: 327.680135
SOLVENT: MeOD
NS: 130
DS: 8
SWH: 24038.461 Hz
FIDRES: 0.733596 Hz
AQ: 0.68574 sec
RG: 198.09
DW: 20.800 usec
DE: 6.50 usec
TE: 299.8 K
CNST2: 145.000000
D1: 2.0000000 sec
D2: 0.00344828 sec
D12: 0.0000200 sec
TD0: 1
===== CHANNEL f1 =====
NUC1: 100.625319 MHz
P1: 10.00 usec
P2: 20.00 usec
PLW1: 49.50000000 W
===== CHANNEL f2 =====
SFO2: 400.1315005 MHz
NUC2: 1H
CPDPRG2: waltz16
P3: 15.00 usec
P4: 30.00 usec
PCPD2: 80.00 usec
PLW2: 12.50000000 W
PLW12: 0.34722000 W
F2 - Processing parameters
SI: 32768
SF: 100.6126138 MHz
V1: 0
SSB: 0
LB: 2.00 Hz
GB: 0
PC: 1.00

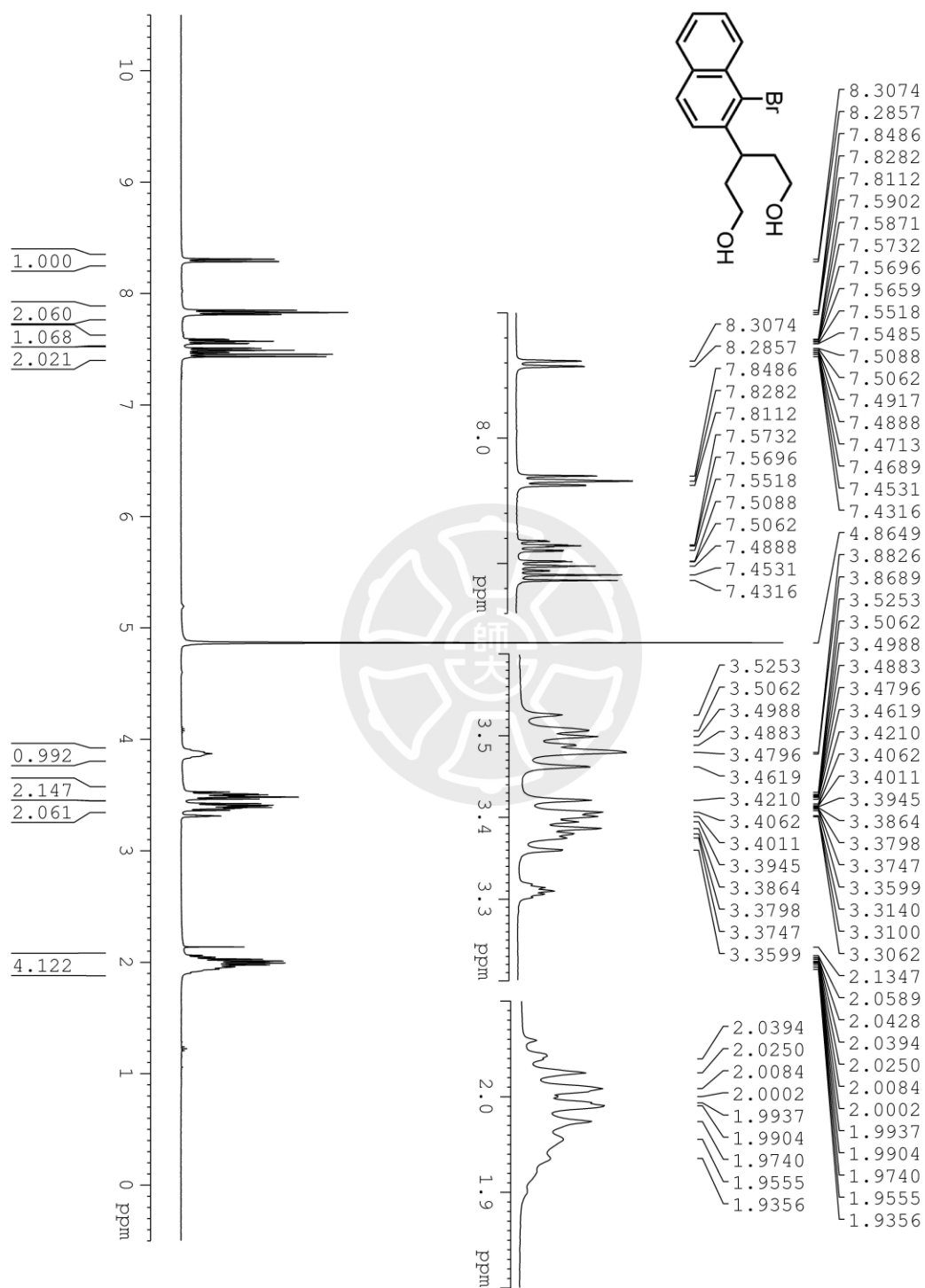
24. ^1H NMR of 3-(2-bromo-4-methylphenyl)pentane-1,5-diol (91k)



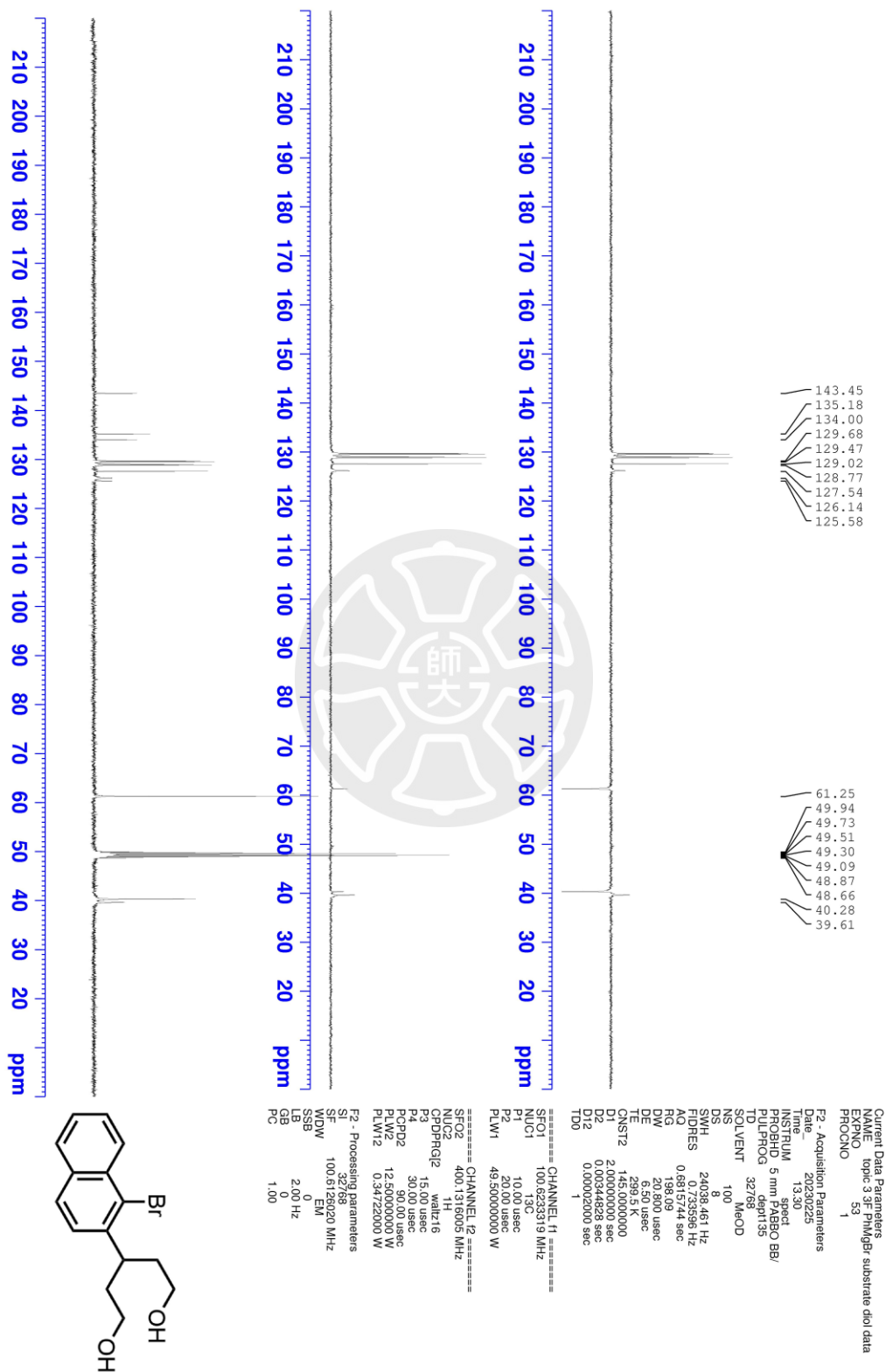


132

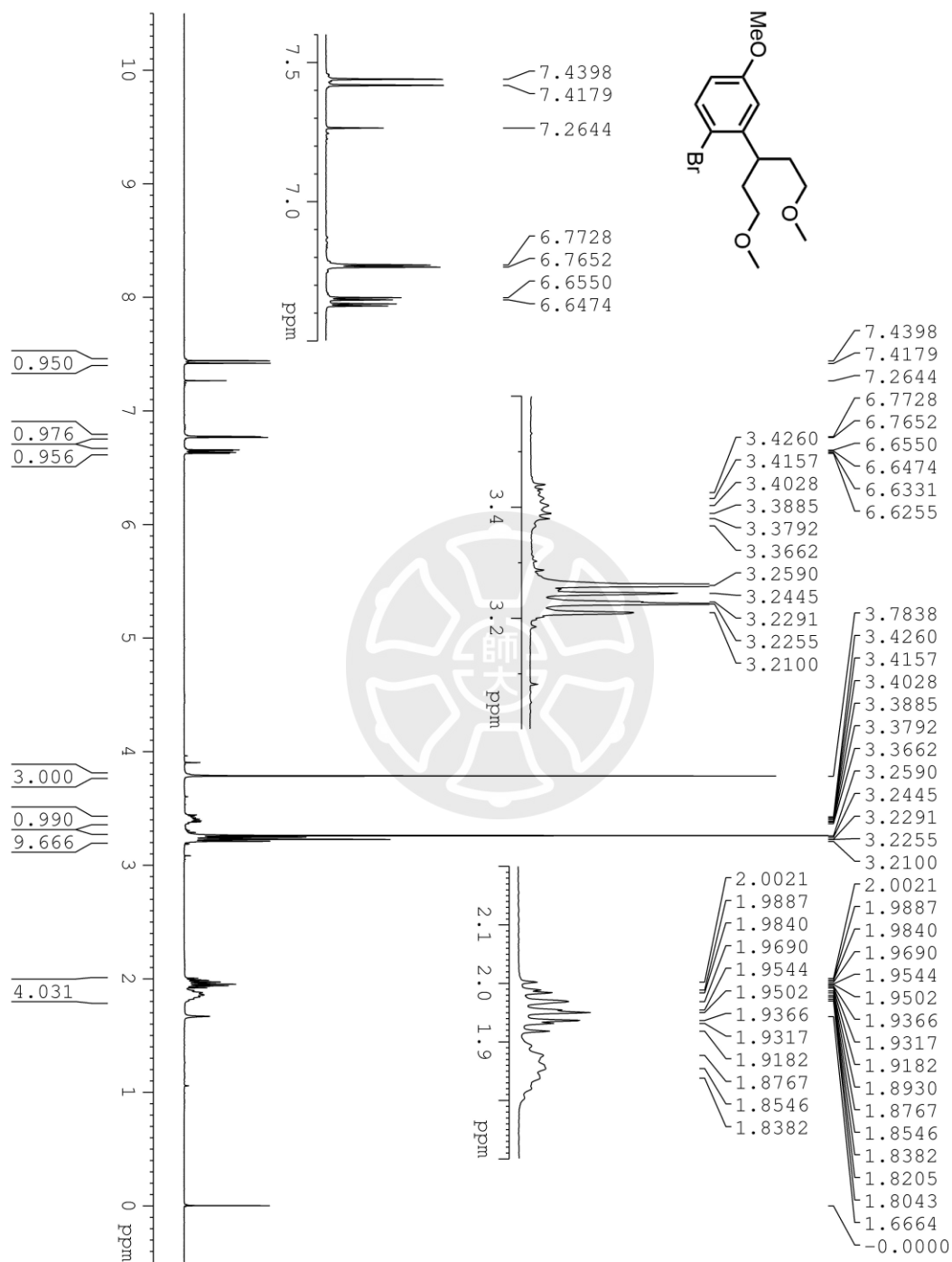
26. ^1H NMR of 3-(1-bromonaphthalen-2-yl)pentane-1,5-diol (91m)



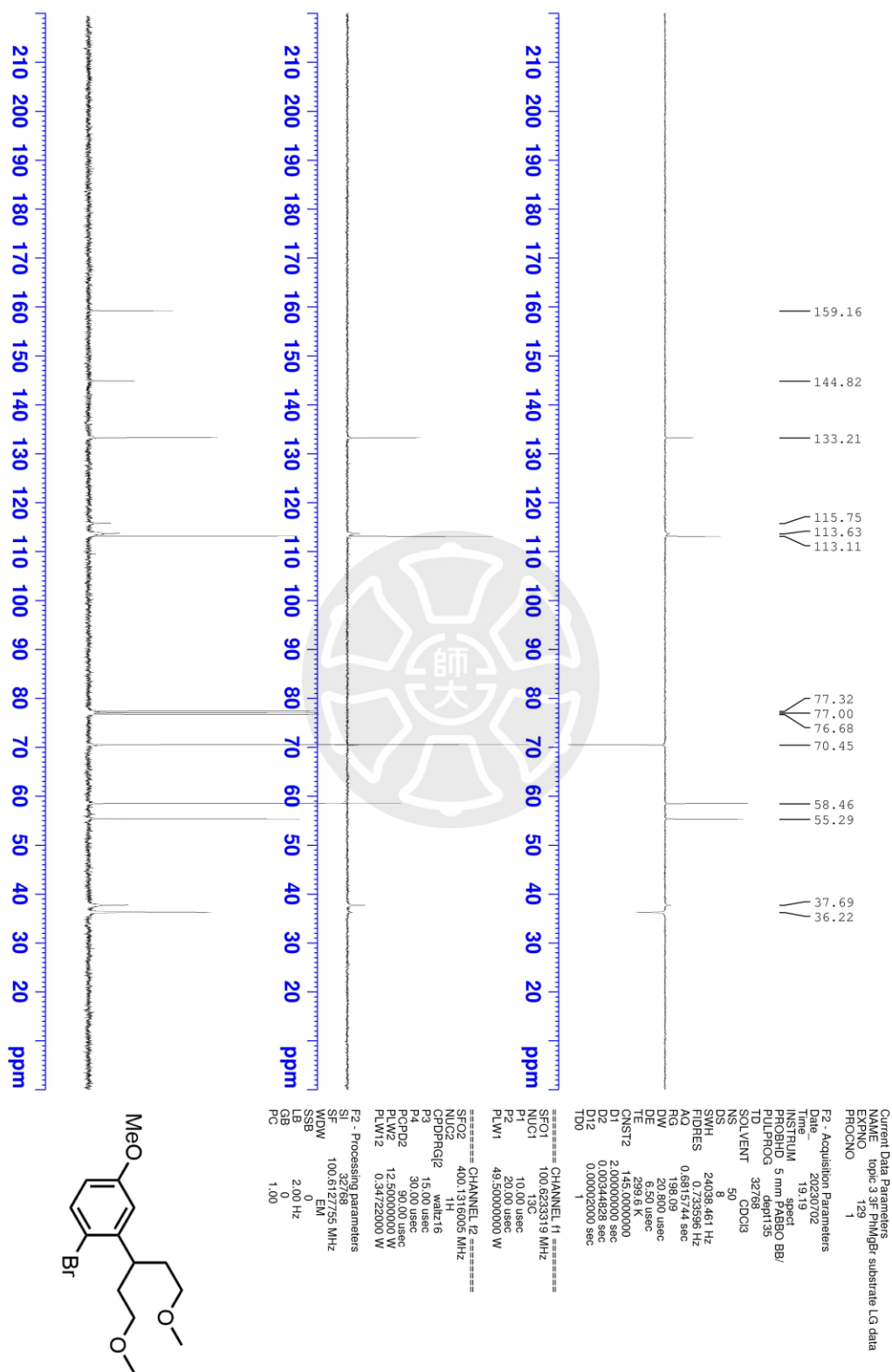
27. ^{13}C NMR of 3-(1-bromonaphthalen-2-yl)pentane-1,5-diol (91m)



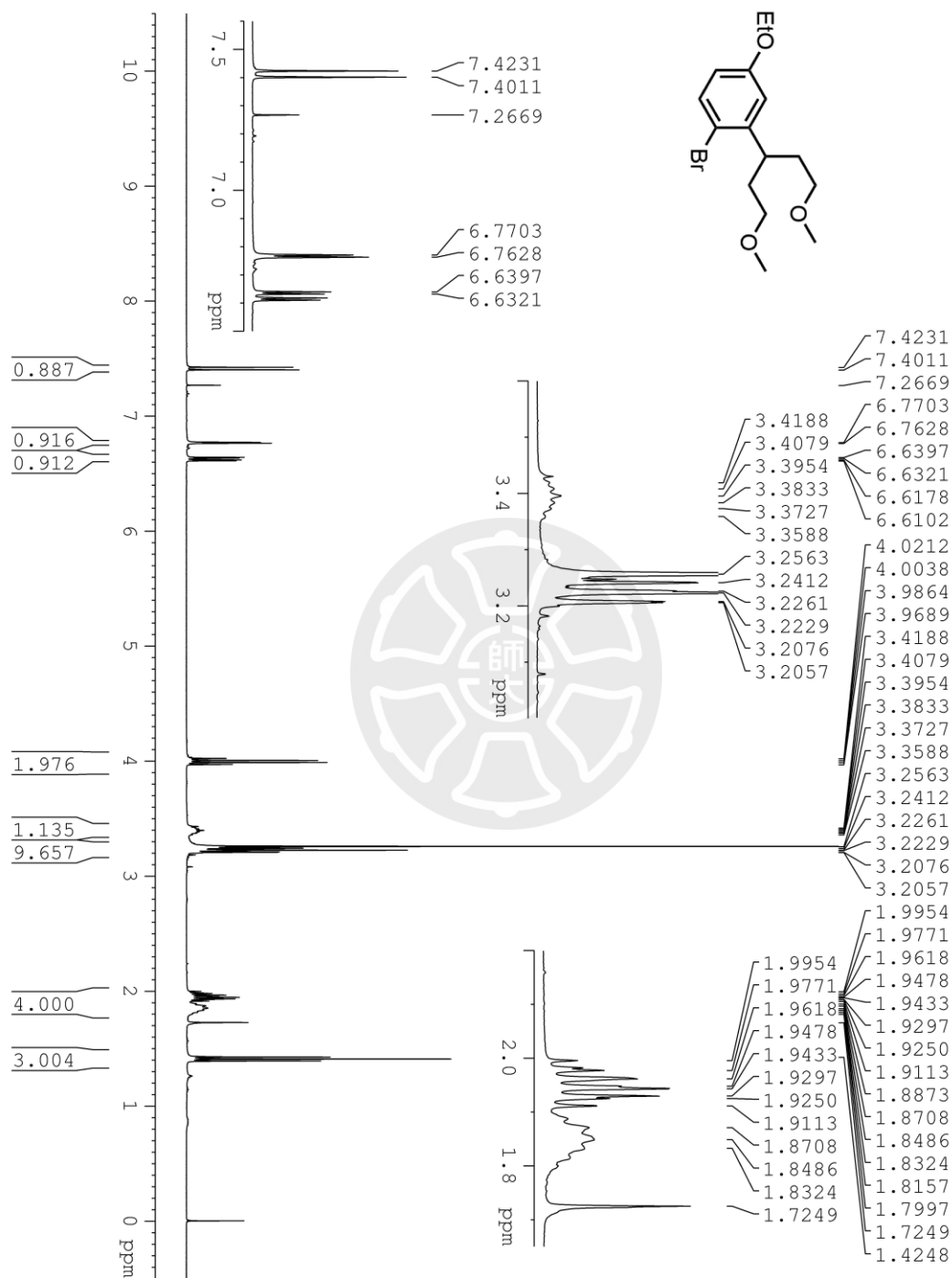
28. ^1H NMR of 1-bromo-2-(1,5-dimethoxypentan-3-yl)-4-methoxybenzene (92bm)



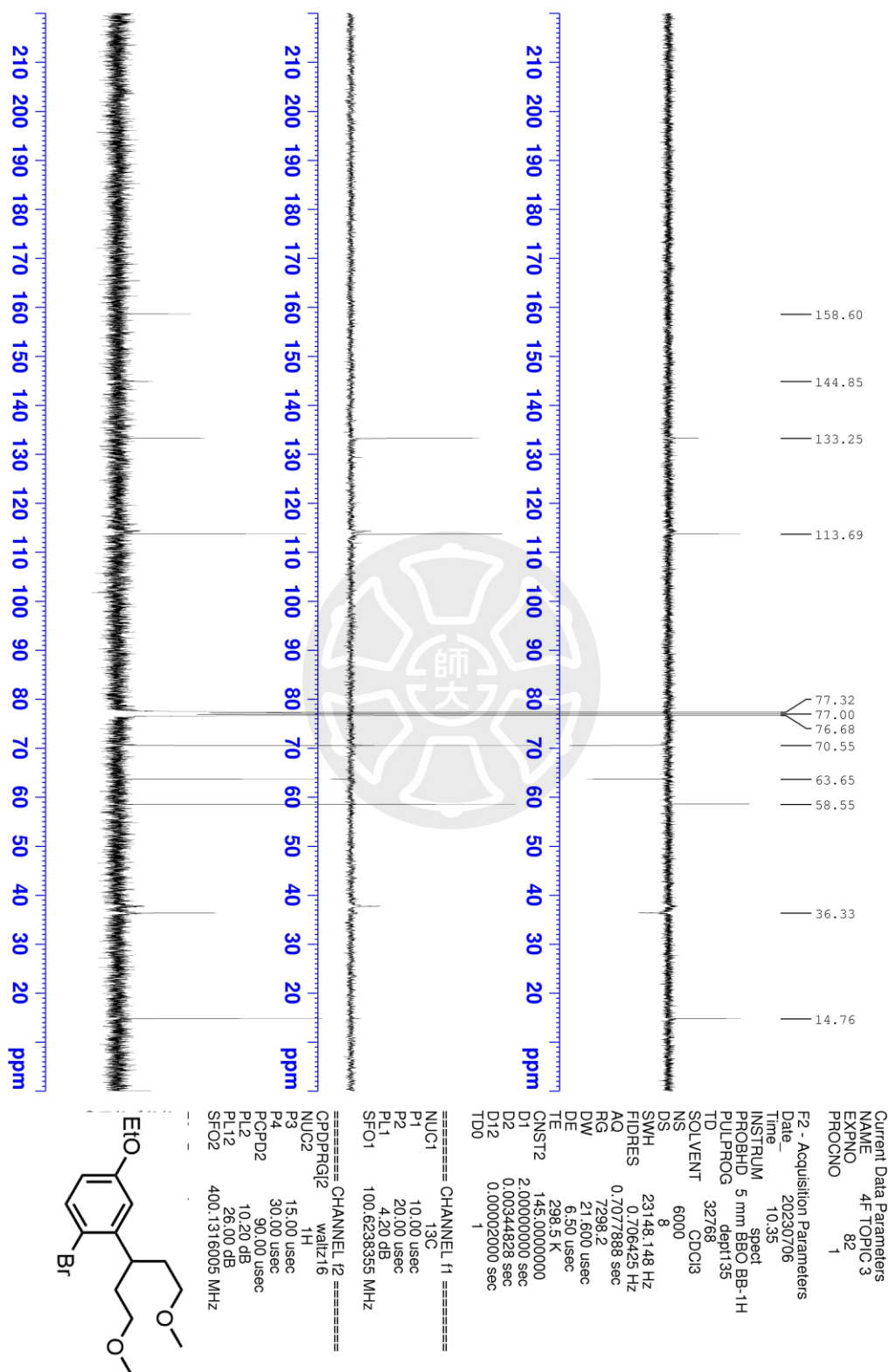
29. ^{13}C NMR of 1-bromo-2-(1,5-dimethoxypentan-3-yl)-4-methoxybenzene (92bm)



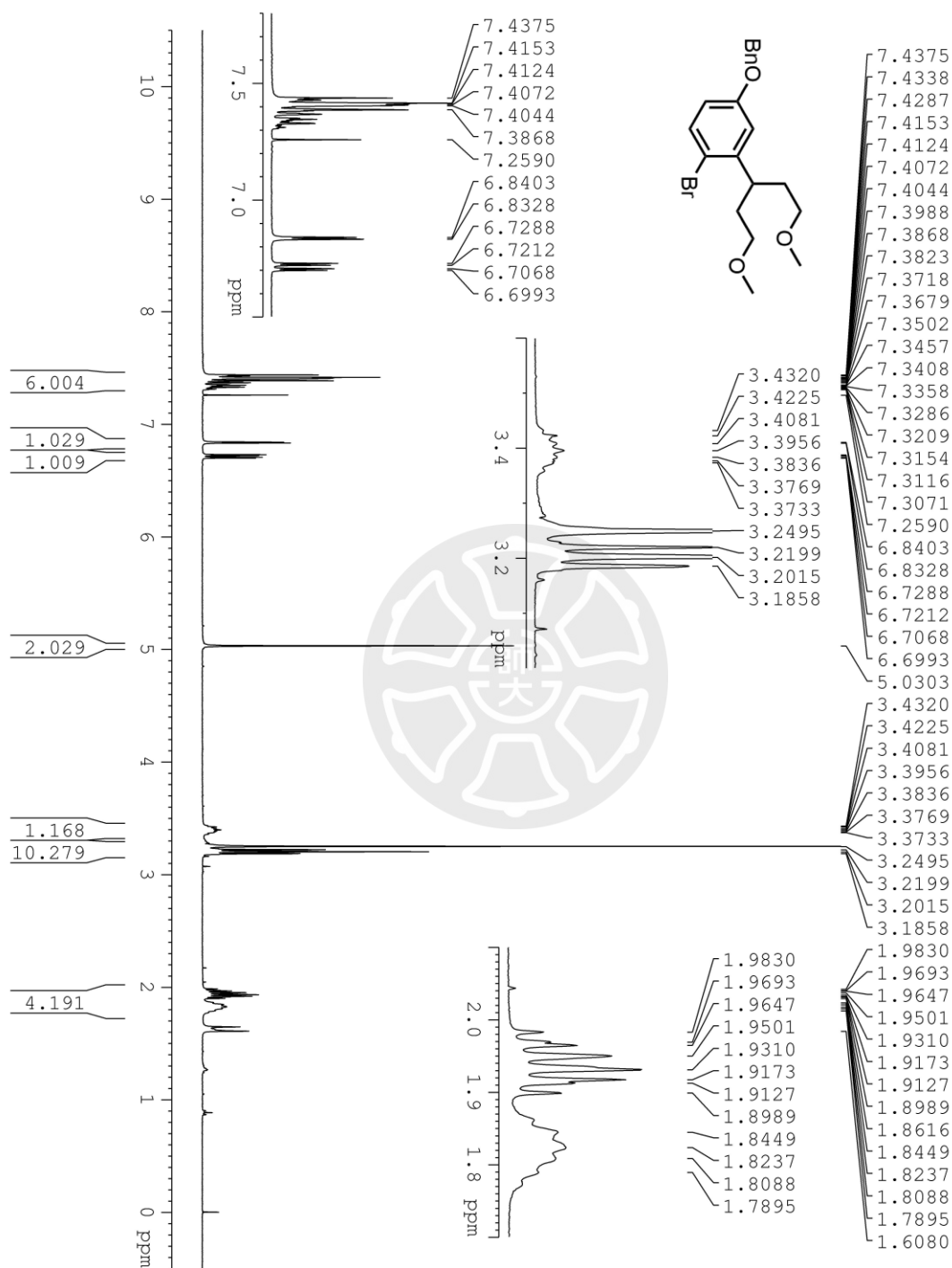
30. ^1H NMR of 1-bromo-2-(1,5-diethoxypentan-3-yl)-4-ethoxybenzene (92cm)



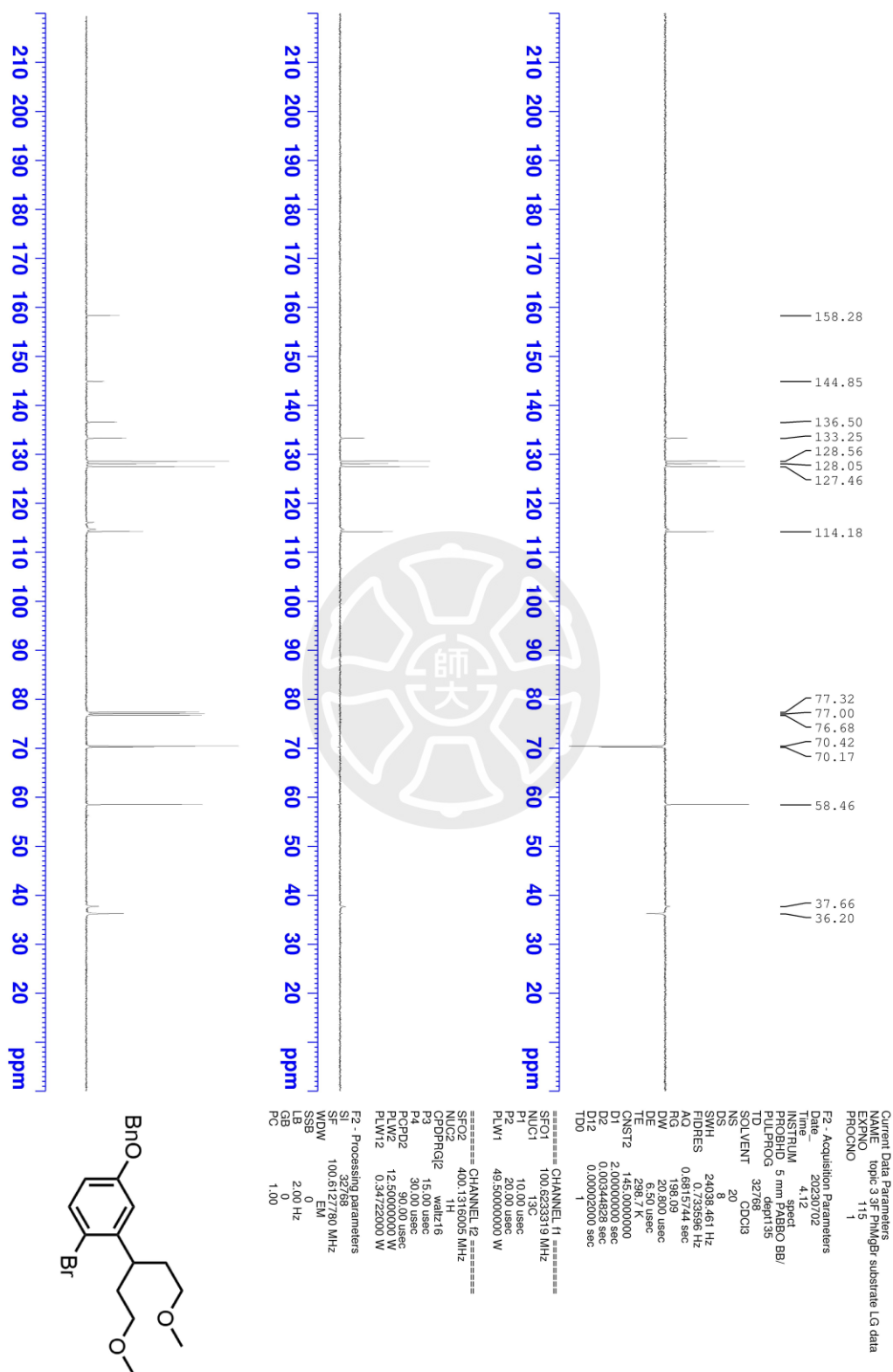
31. ^{13}C NMR of 1-bromo-2-(1,5-diethoxypentan-3-yl)-4-ethoxybenzene (92cm)



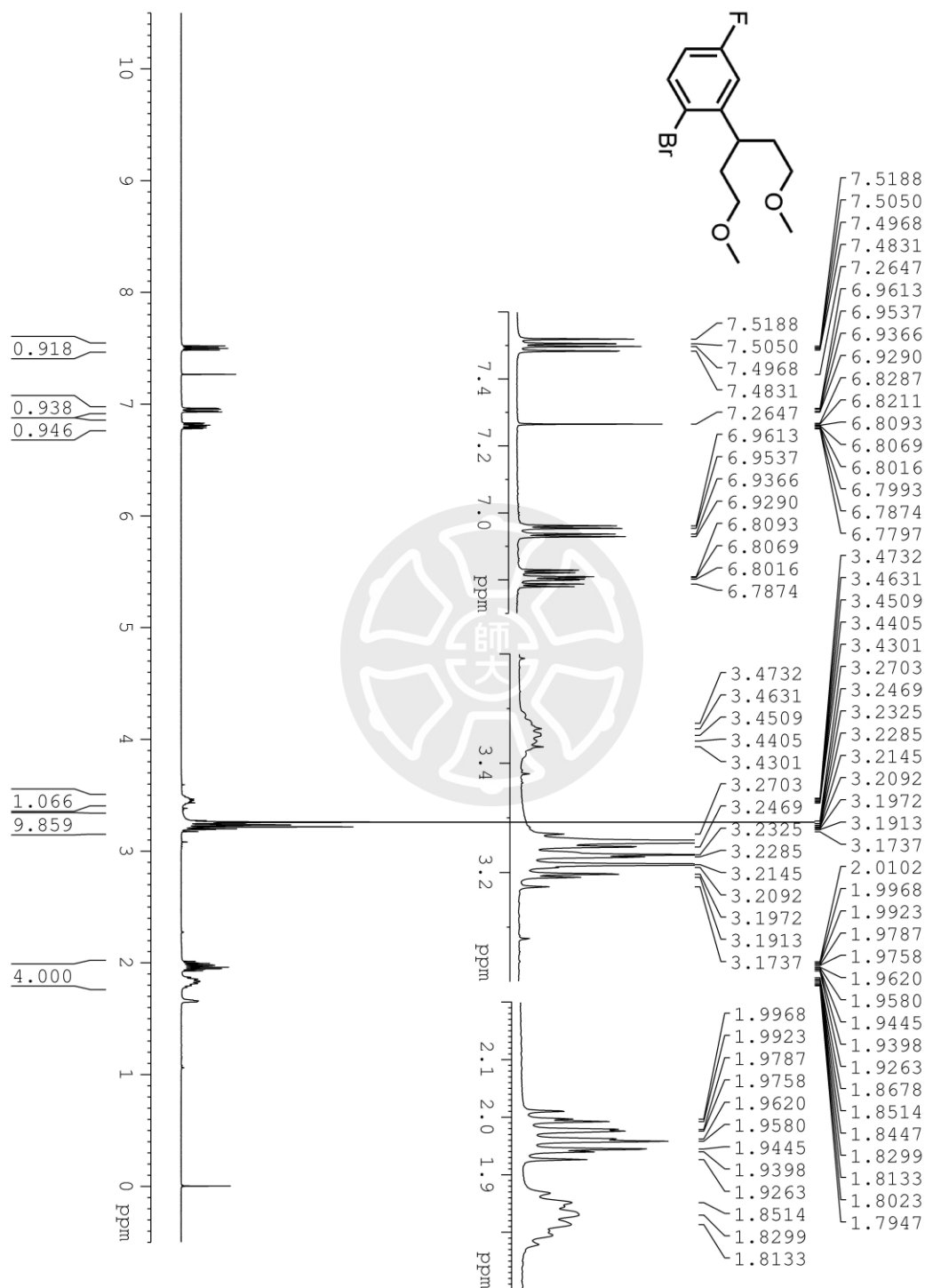
32. ^1H NMR of 4-(benzyloxy)-1-bromo-2-(1,5-dimethoxypentan-3-yl)benzene (92dm)



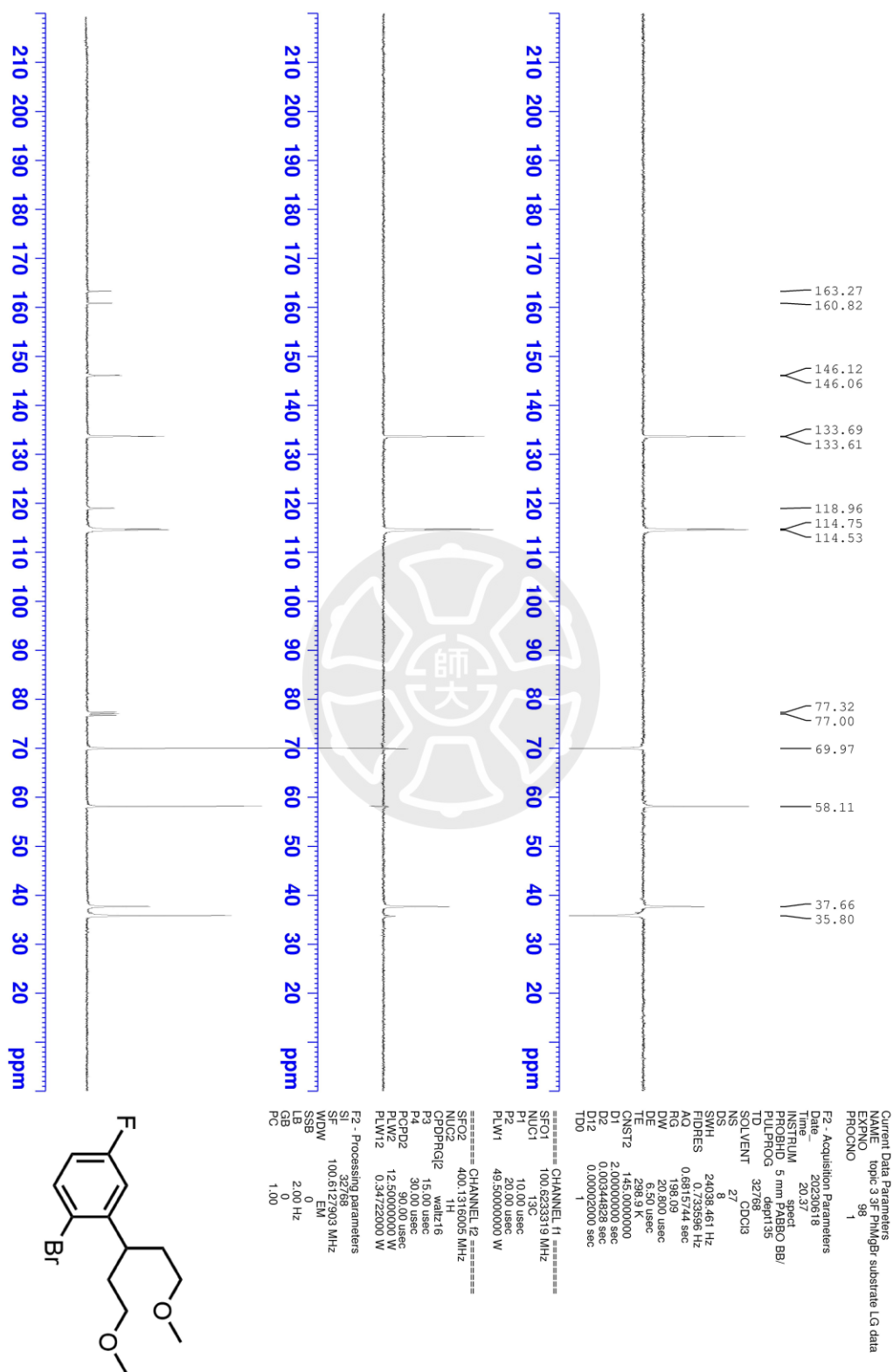
33. ^{13}C NMR of 4-(benzyloxy)-1-bromo-2-(1,5-dimethoxypentan-3-yl)benzene (92dm)



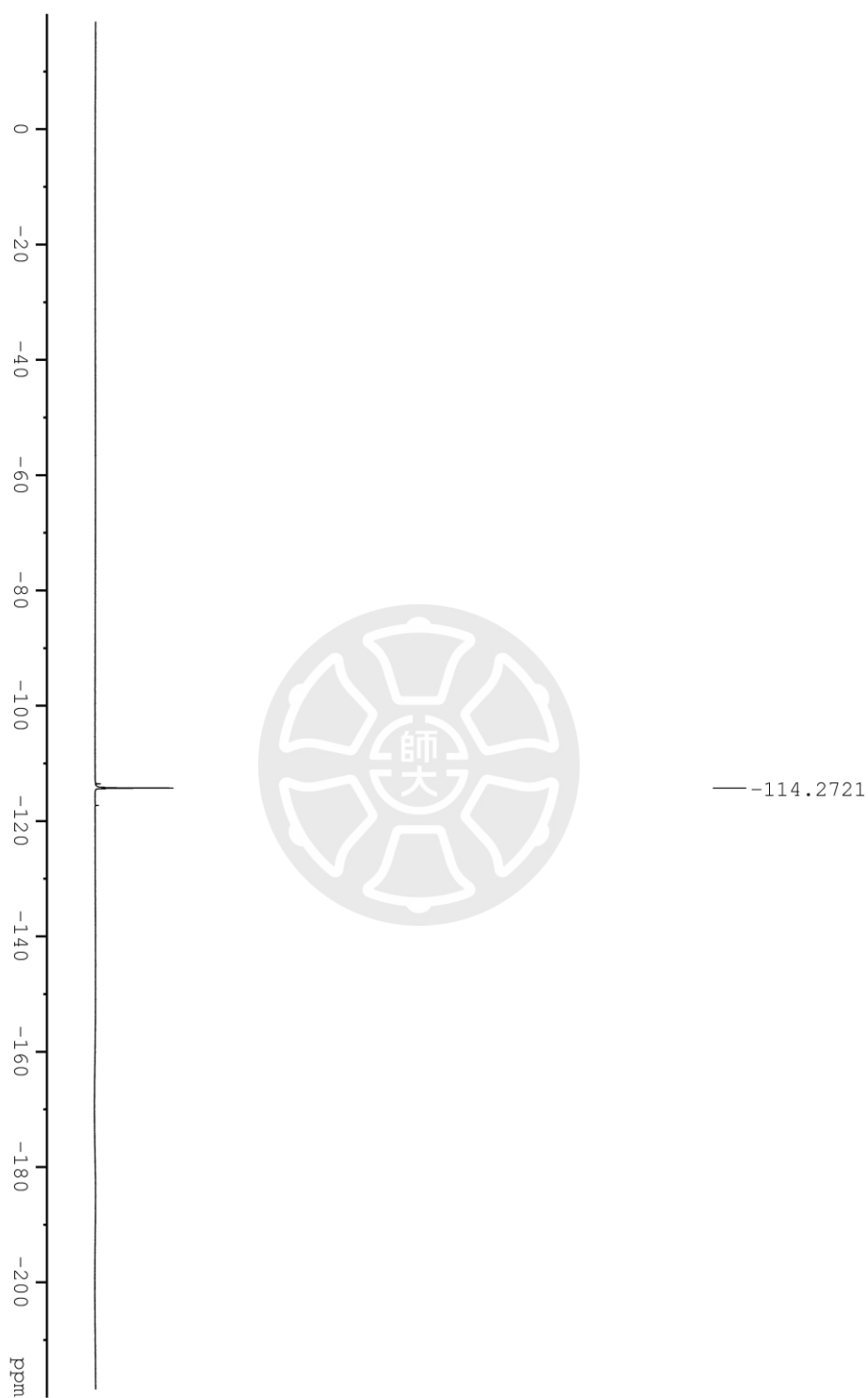
34. ^1H NMR of 1-bromo-2-(1,5-dimethoxypentan-3-yl)-4-fluorobenzene (92em)



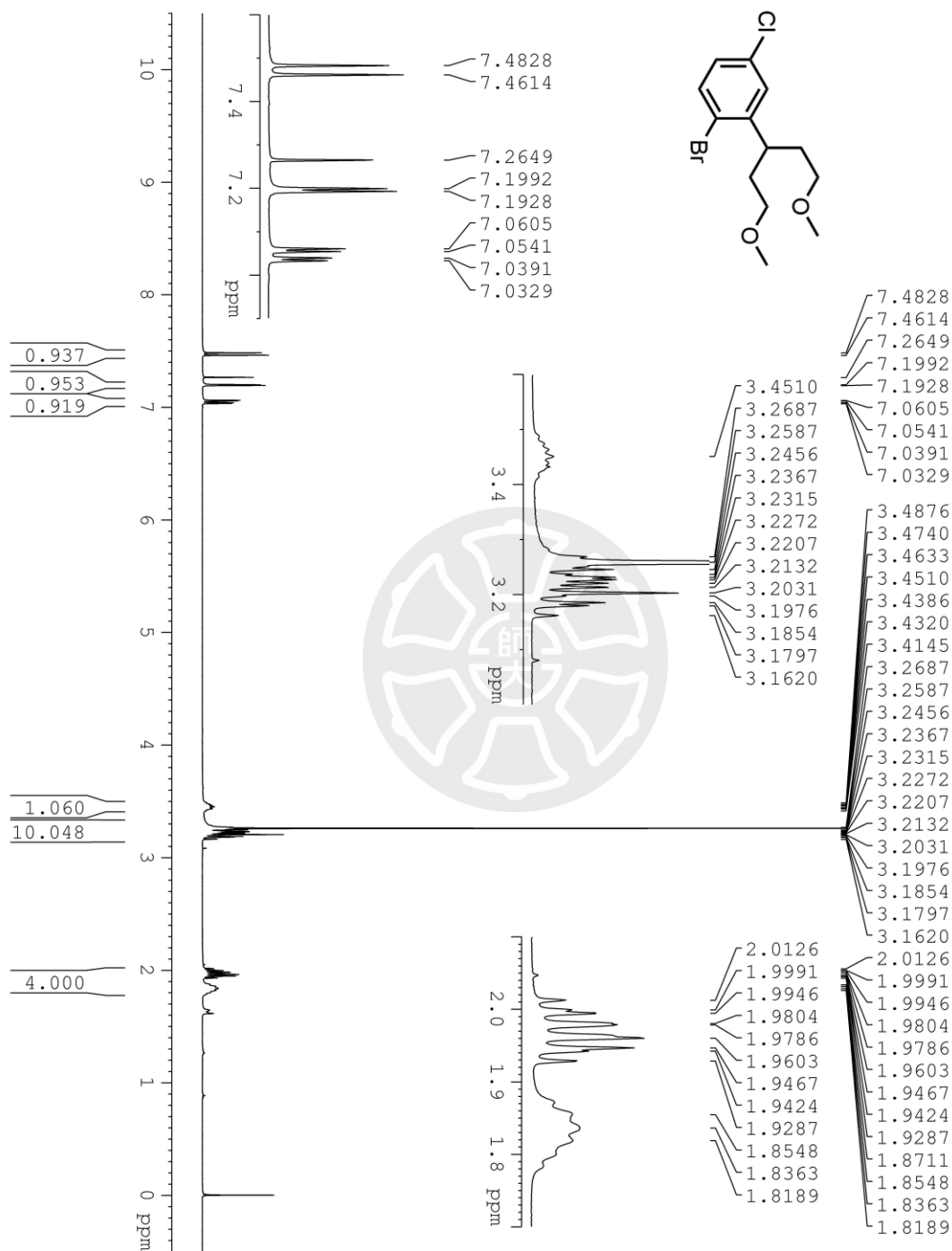
35. ^{13}C NMR of 1-bromo-2-(1,5-dimethoxypentan-3-yl)-4-fluorobenzene (92em)



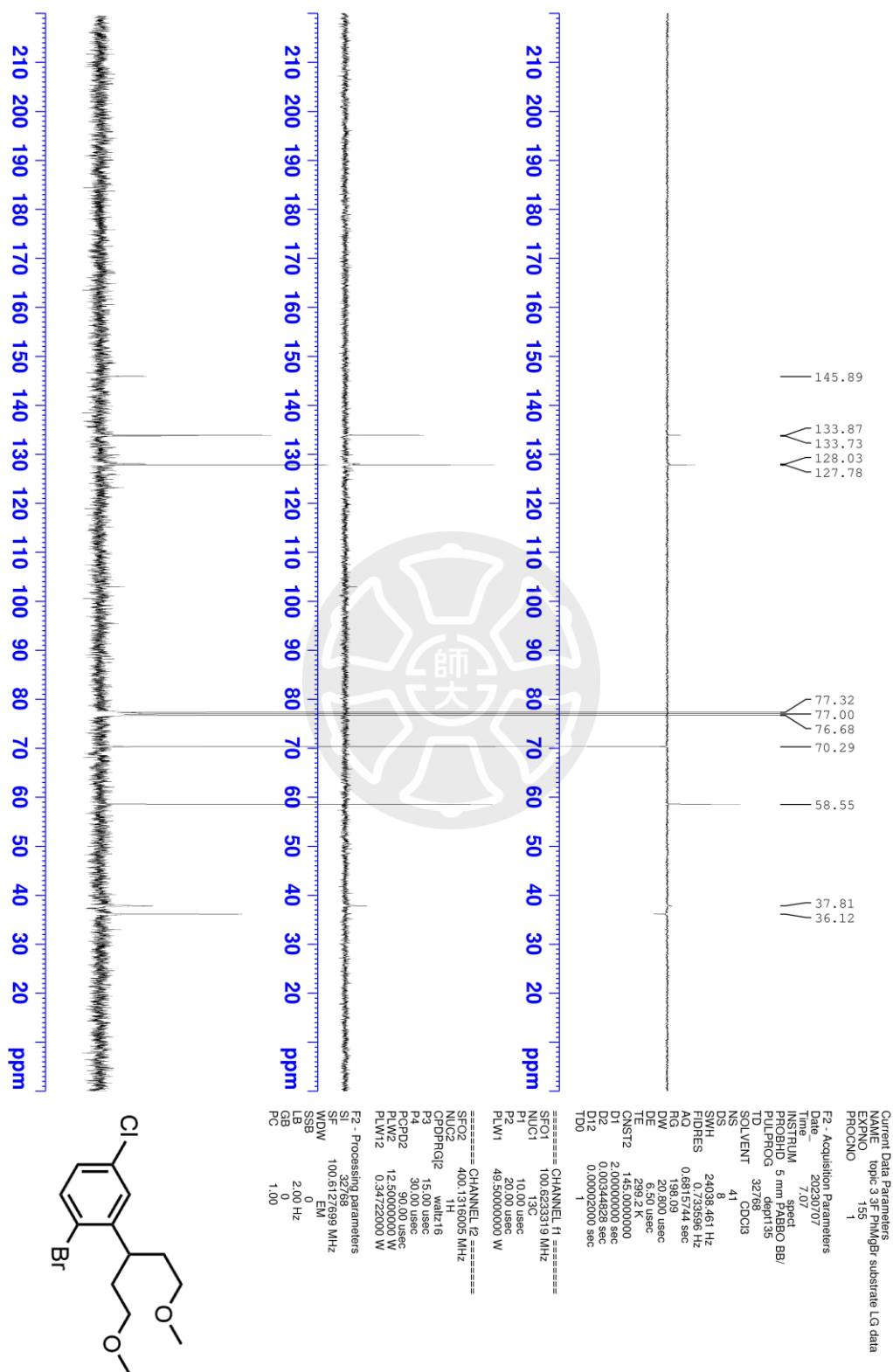
36. ^{19}F NMR of *1-bromo-2-(1,5-dimethoxypentan-3-yl)-4-fluorobenzene* (92em)



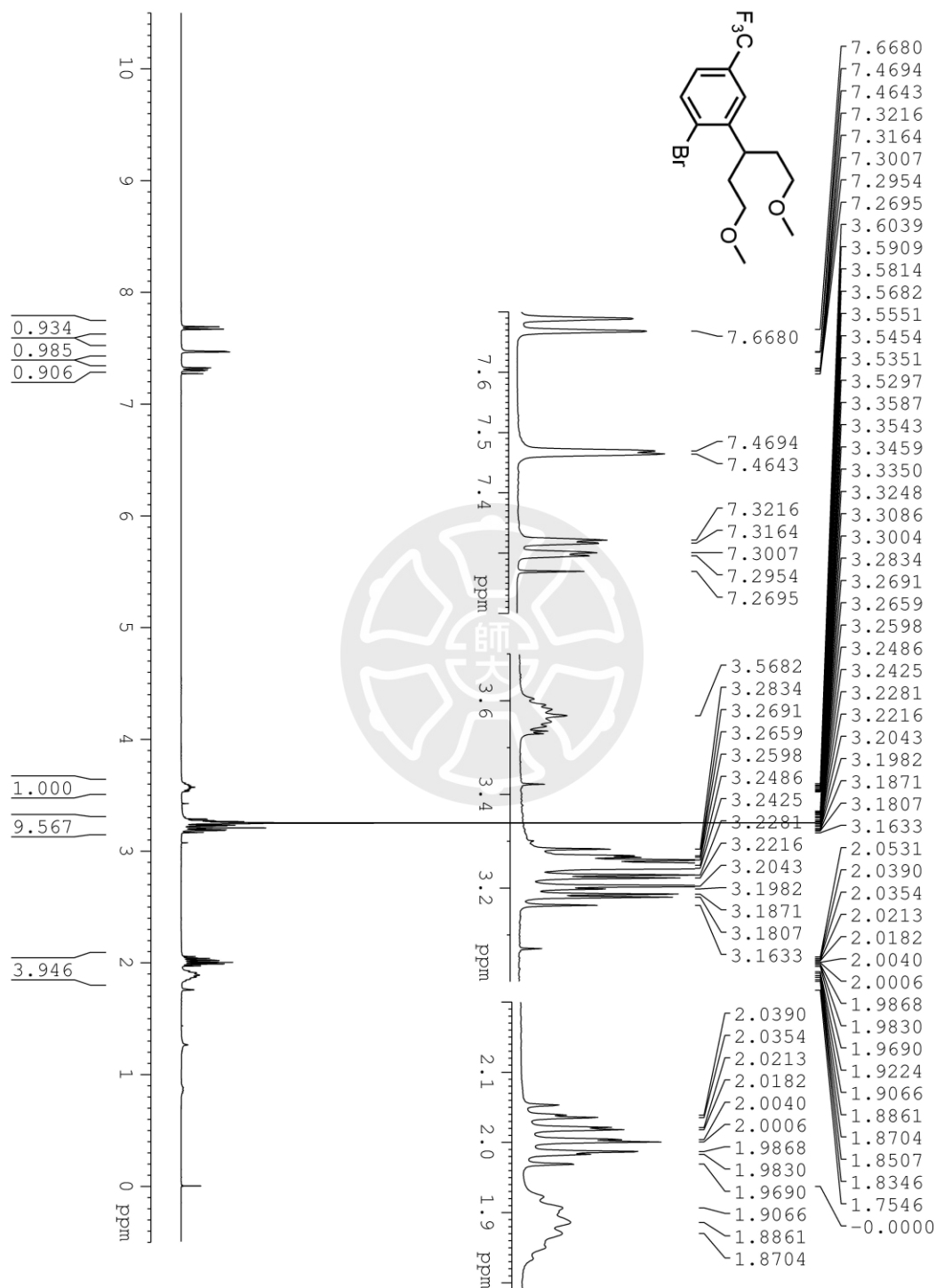
37. ^1H NMR of 1-bromo-2-(1,5-dimethoxypentan-3-yl)-4-chlorobenzene (92fm)



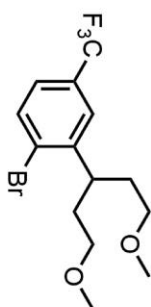
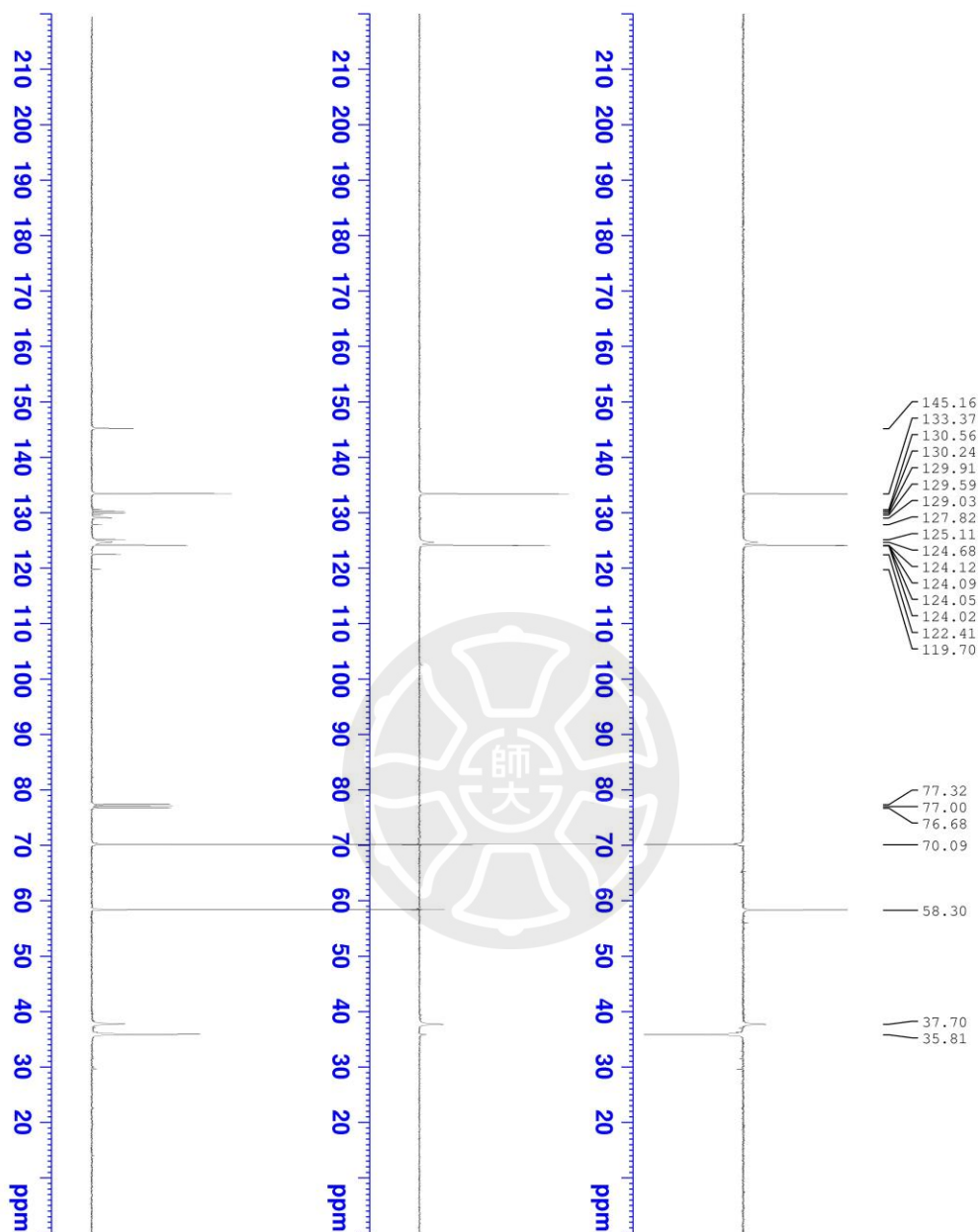
38. ^{13}C NMR of 1-bromo-2-(1,5-dimethoxypentan-3-yl)-4-chlorobenzene (92fm)



39. ^1H NMR of 1-bromo-2-(1,5-dimethoxypentan-3-yl)-4-(trifluoromethyl)benzene (92gm)

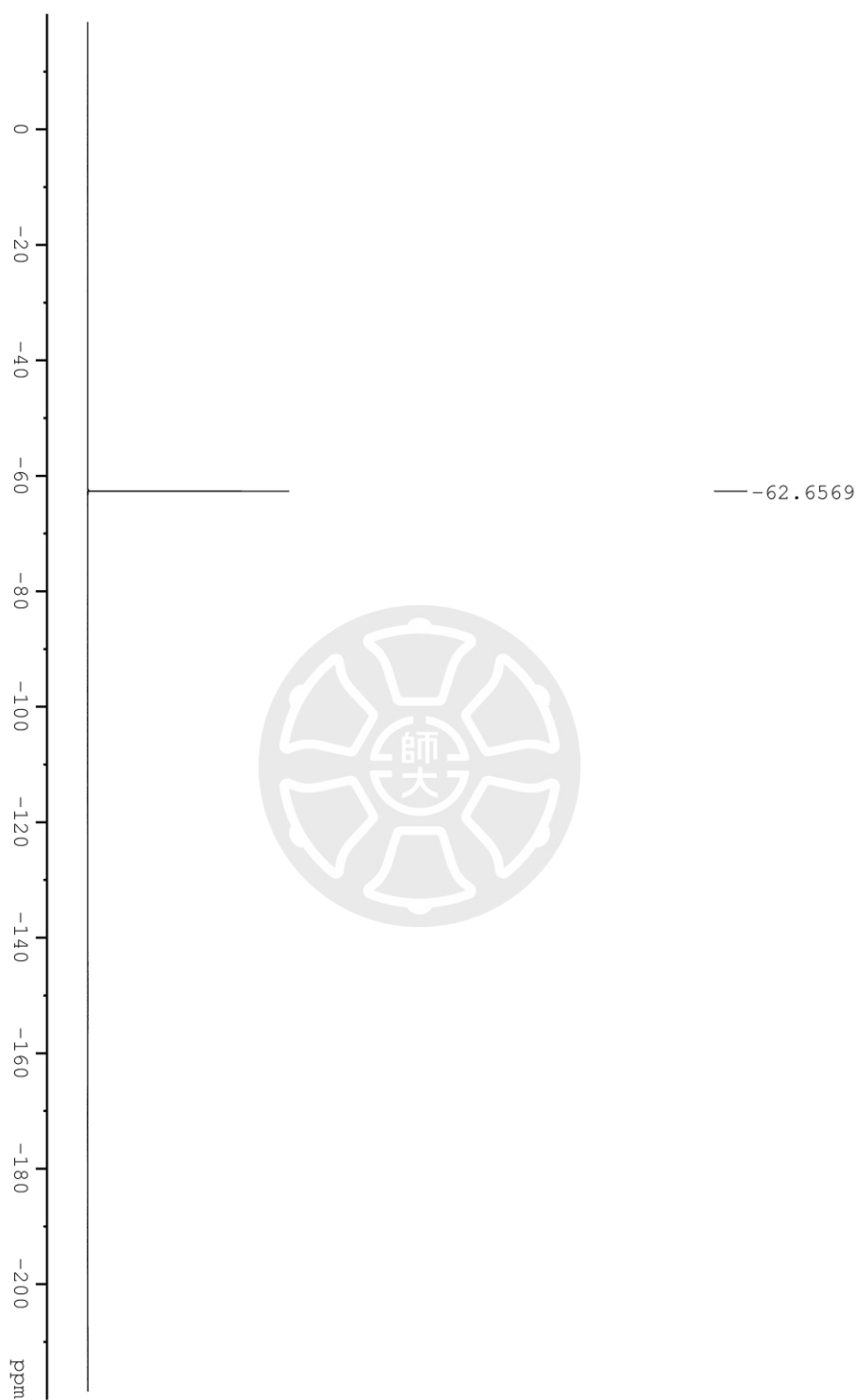


40. ^{13}C NMR of 1-bromo-2-(1,5-dimethoxypentan-3-yl)-4-(trifluoromethyl)benzene (92gm)

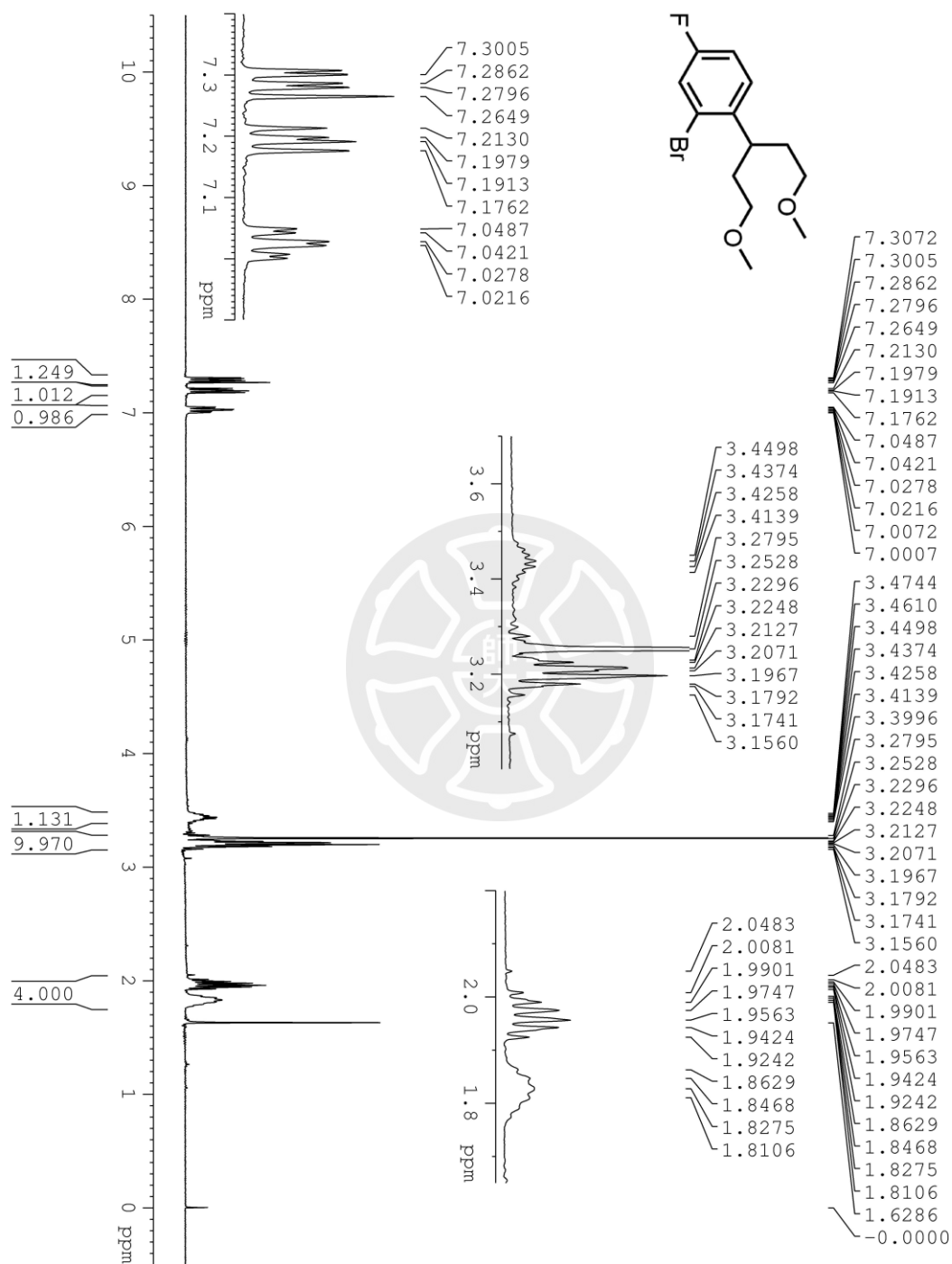


Current Data Parameters
 NAME: topic 3 3F P1MqBr substrate LQ data
 EXPNO: 61
 PROCNO: 1
 F2 - Acquisition Parameters
 Date_: 20230520
 Time: 1.56
 INSTRU: spect
 PROBHD: 5 mm PABO BB/
 PULPROG: zgpg30
 SOLVENT: CDCl3
 NS: 77
 DS: 8
 SWH: 24038.461 Hz
 FIDRES: 0.733596 Hz
 AQ: 0.8815744 sec
 RG: 1280
 DW: 20.500 usec
 DE: 6.50 usec
 TE: 299.6 K
 CNST2: 145.0000000
 D1: 2.00000000 sec
 D2: 0.0004628 sec
 D3: 0.0004200 sec
 TD0: 1
 ===== CHANNEL f1 =====
 SFO1: 100.623319 MHz
 NUCl: 13C
 P2: 10.035
 PLW1: 20.00 usec
 PLW1: 49.50000000 W
 ===== CHANNEL f2 =====
 SFO2: 400.1316005 MHz
 NUCl: 1H
 P3: 15.00 usec
 P4: 30.00 usec
 PCPD2: 90.00 usec
 PLW2: 12.50000000 W
 PLW2: 0.34722000 W
 F2 - Processing parameters
 SF: 100.6127758 MHz
 WDW: EM
 SSB: 0
 LB: 2.00 Hz
 GB: 0
 PC: 1.00

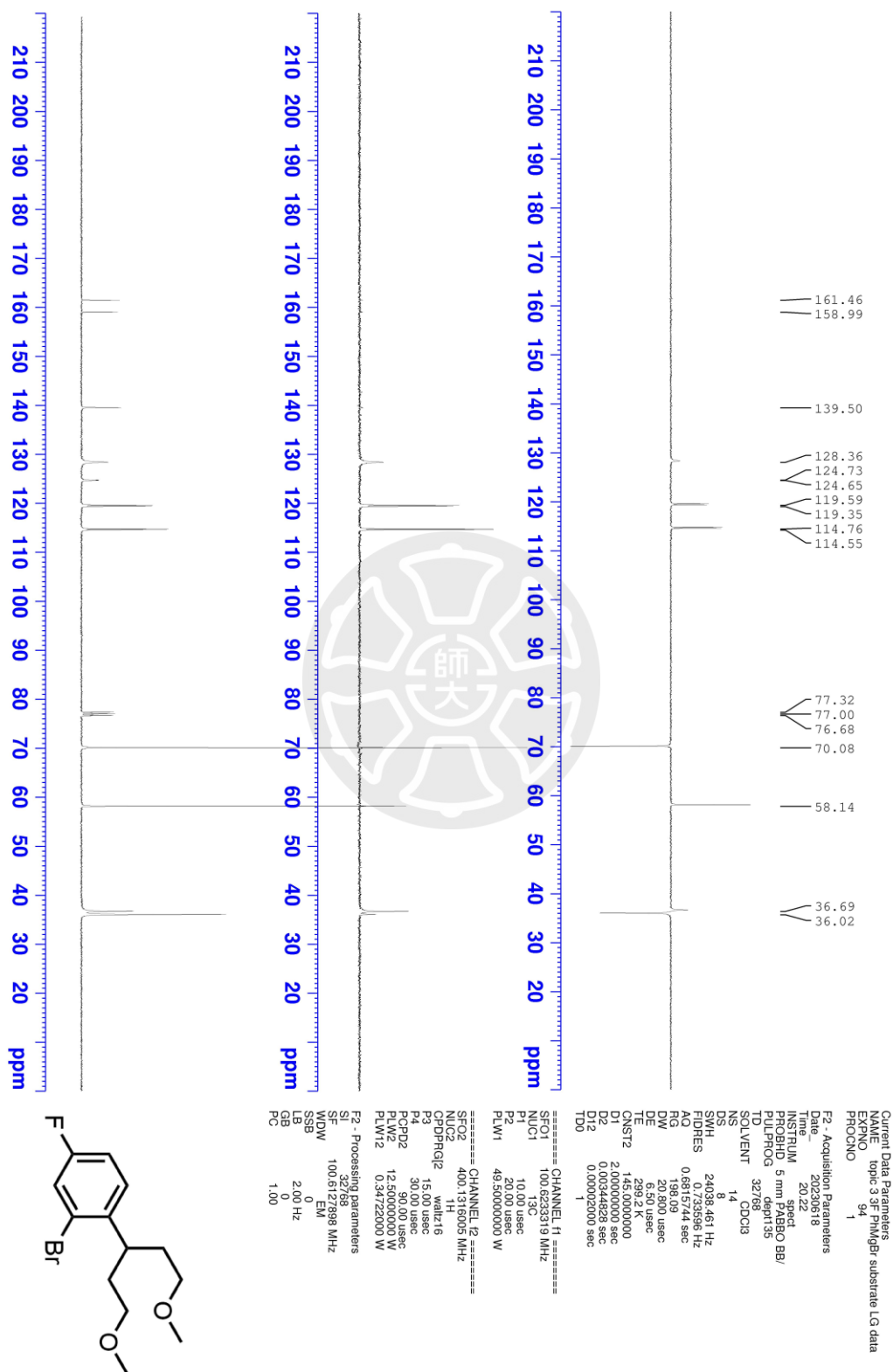
41. ^{19}F NMR of 1-bromo-2-(1,5-dimethoxypentan-3-yl)-4-(trifluoromethyl)benzene (92gm)



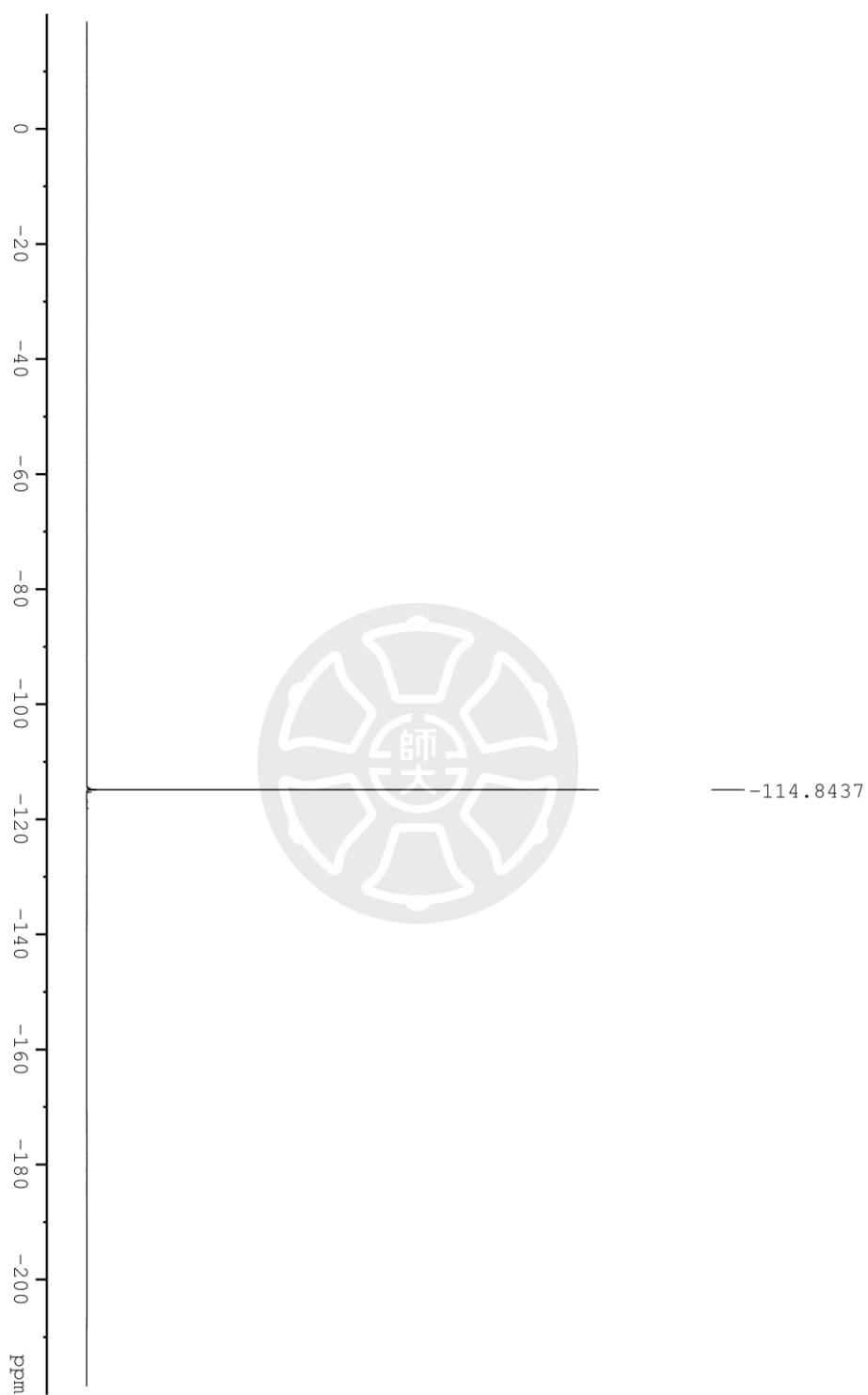
42. ¹H NMR of 2-bromo-1-(1,5-dimethoxypentan-3-yl)-4-fluorobenzene(92hm)



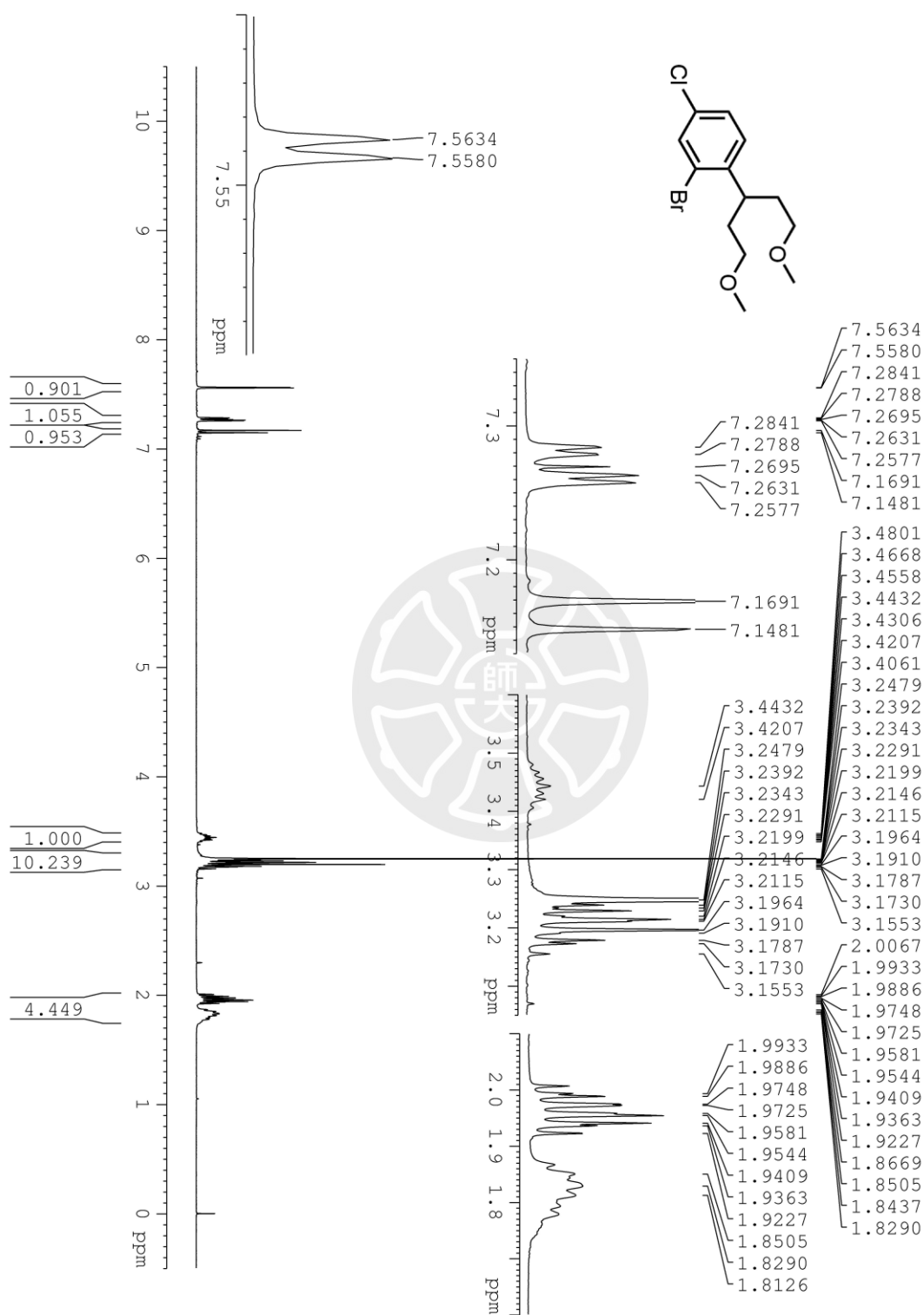
43. ^{13}C NMR of 2-bromo-1-(1,5-dimethoxypentan-3-yl)-4-fluorobenzene(92hm)



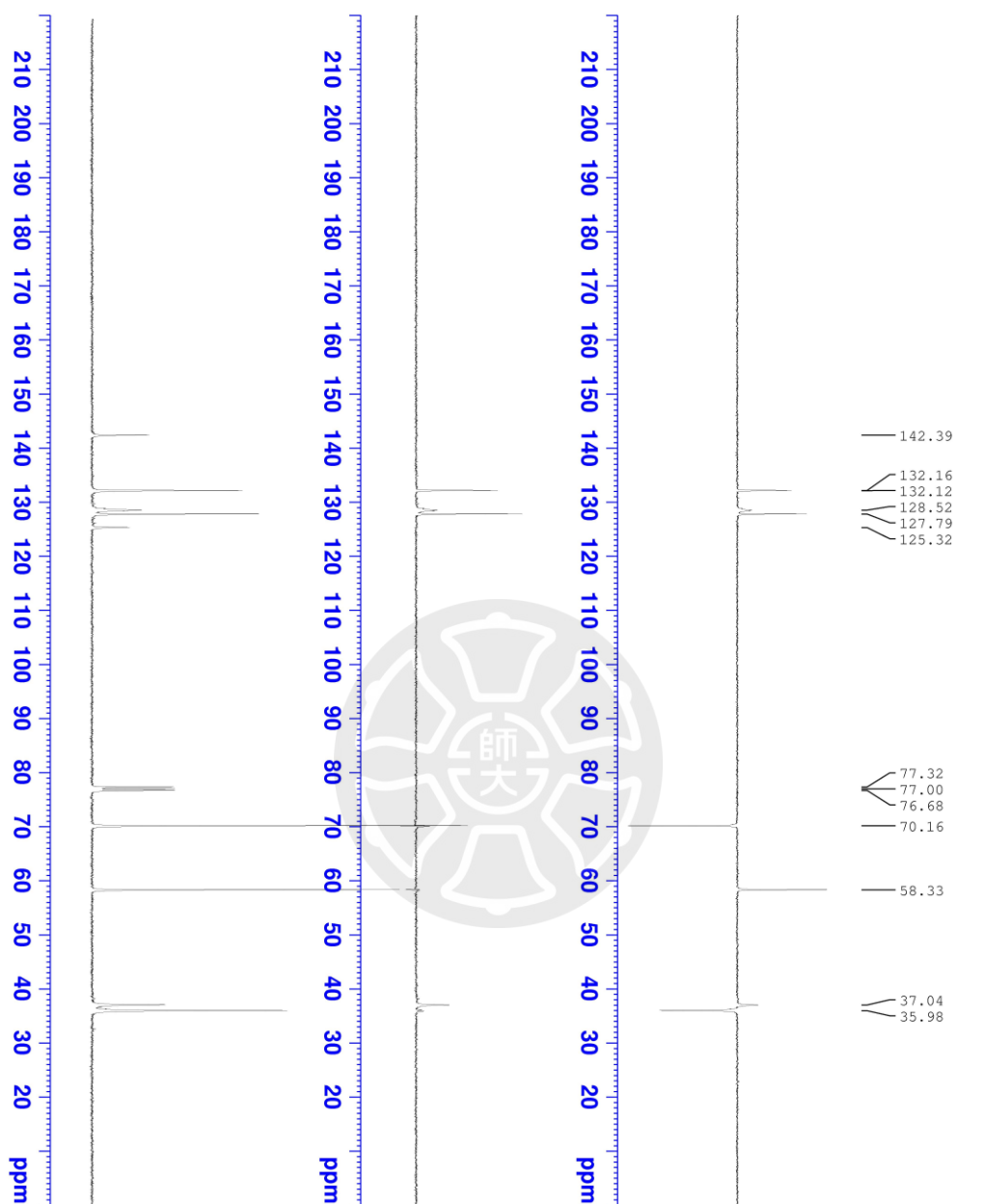
44. ^{19}F NMR of 2-bromo-1-(1,5-dimethoxypentan-3-yl)-4-fluorobenzene (92hm)



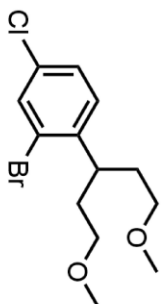
45. ¹H NMR of 2-bromo-4-chloro-1-(1,5-dimethoxypentan-3-yl)benzene (92im)



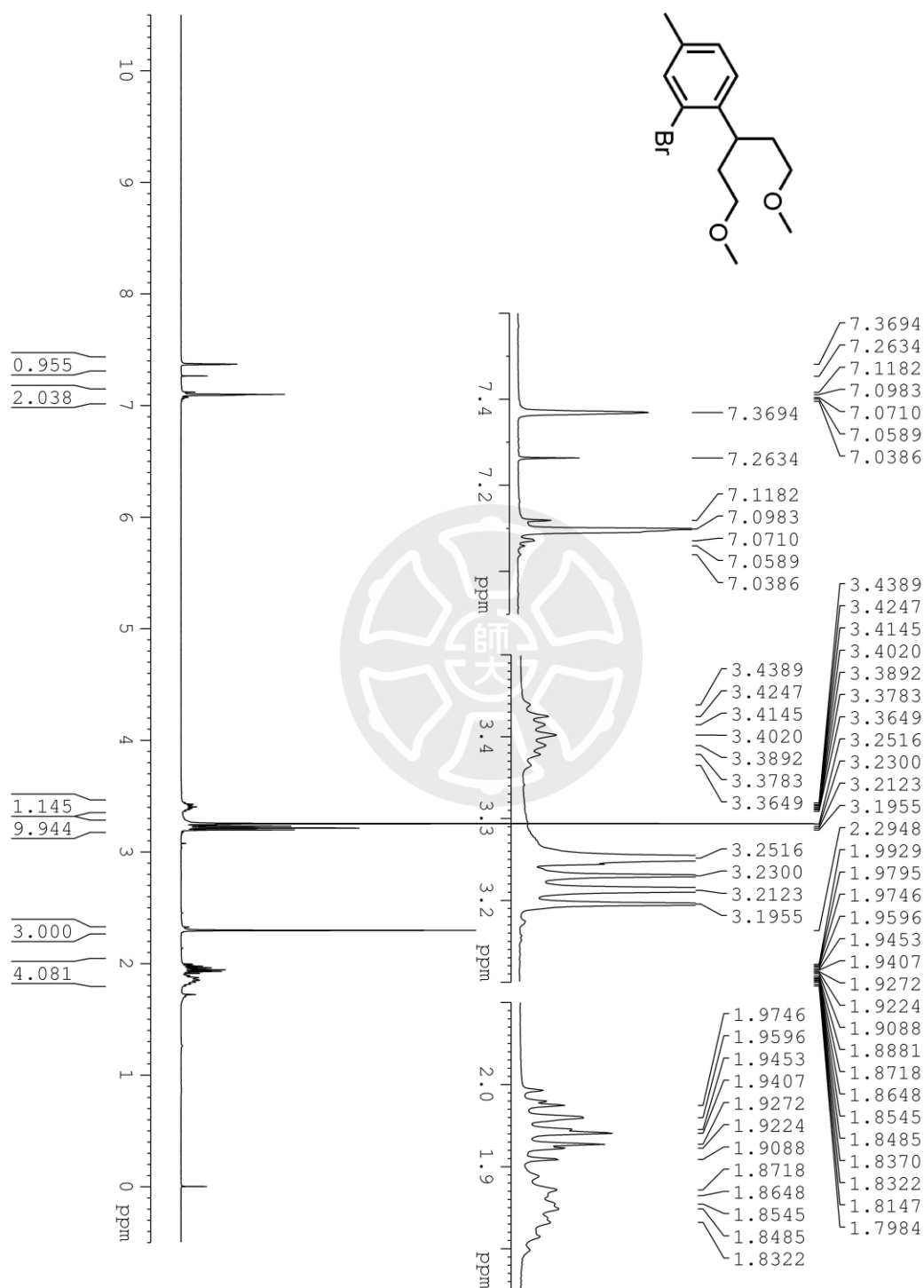
46. ^{13}C NMR of 2-bromo-4-chloro-1-(1,5-dimethoxypentan-3-yl)benzene (92im)



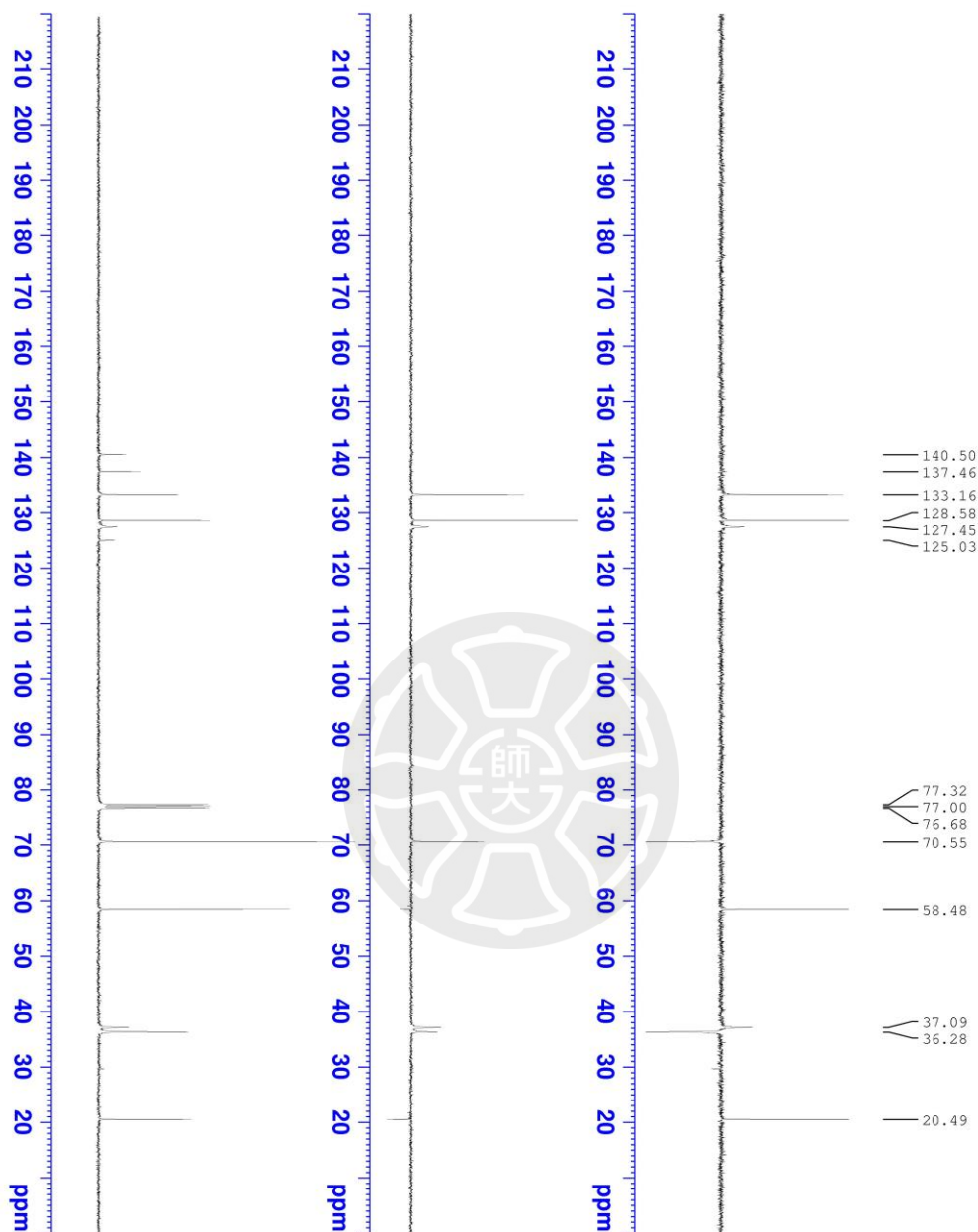
Current Data Parameters
 NAME: topic 3 3F P1MqBr substrate LQ data
 EXPNO: 106
 PROCNO: 1
 F2 - Acquisition Parameters
 Date_: 20230618
 Time: 23.31
 INSTRUM: spect
 PROBHD: 5 mm PABBO BB/
 PULPROG: zgpg30
 SOLVENT: DMSO-d6
 NS: 38
 DS: 8
 SWH: 24038.461 Hz
 FIDRES: 0.733596 Hz
 AQ: 0.881574 sec
 RG: 128
 DW: 20.800 usec
 DE: 6.50 usec
 TE: 298.9 K
 CNST2: 145.0000000
 D1: 2.0000000 sec
 D2: 0.0004628 sec
 D3: 0.0004200 sec
 TDO: 1
 ===== CHANNEL f1 =====
 SFO1: 100.6233319 MHz
 NUC1: ^{13}C
 P1: 10.00 usec
 PLW1: 49.50000000 W
 ===== CHANNEL f2 =====
 SFO2: 400.1316005 MHz
 NUC2: ^1H
 P2: 15.00 usec
 PLW2: 12.50000000 W
 P3: 30.00 usec
 P4: 90.00 usec
 PLW4: 0.3472000 W
 F2 - Processing parameters
 SI: 32768
 SF: 100.6127849 MHz
 WDW: EM
 SSB: 0
 LB: 2.00 Hz
 GB: 0
 PC: 1.00



47. ^1H NMR of 2-bromo-1-(1,5-dimethoxypentan-3-yl)-4-methylbenzene (92km)



48. ¹³C NMR of 2-bromo-1-(1,5-dimethoxypentan-3-yl)-4-methylbenzene (92km)

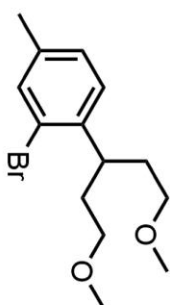


```
Current Data Parameters
NAME      topic 3 3F PnMgBr substrate Lg data
EXPNO     46
PROCNO    1
```

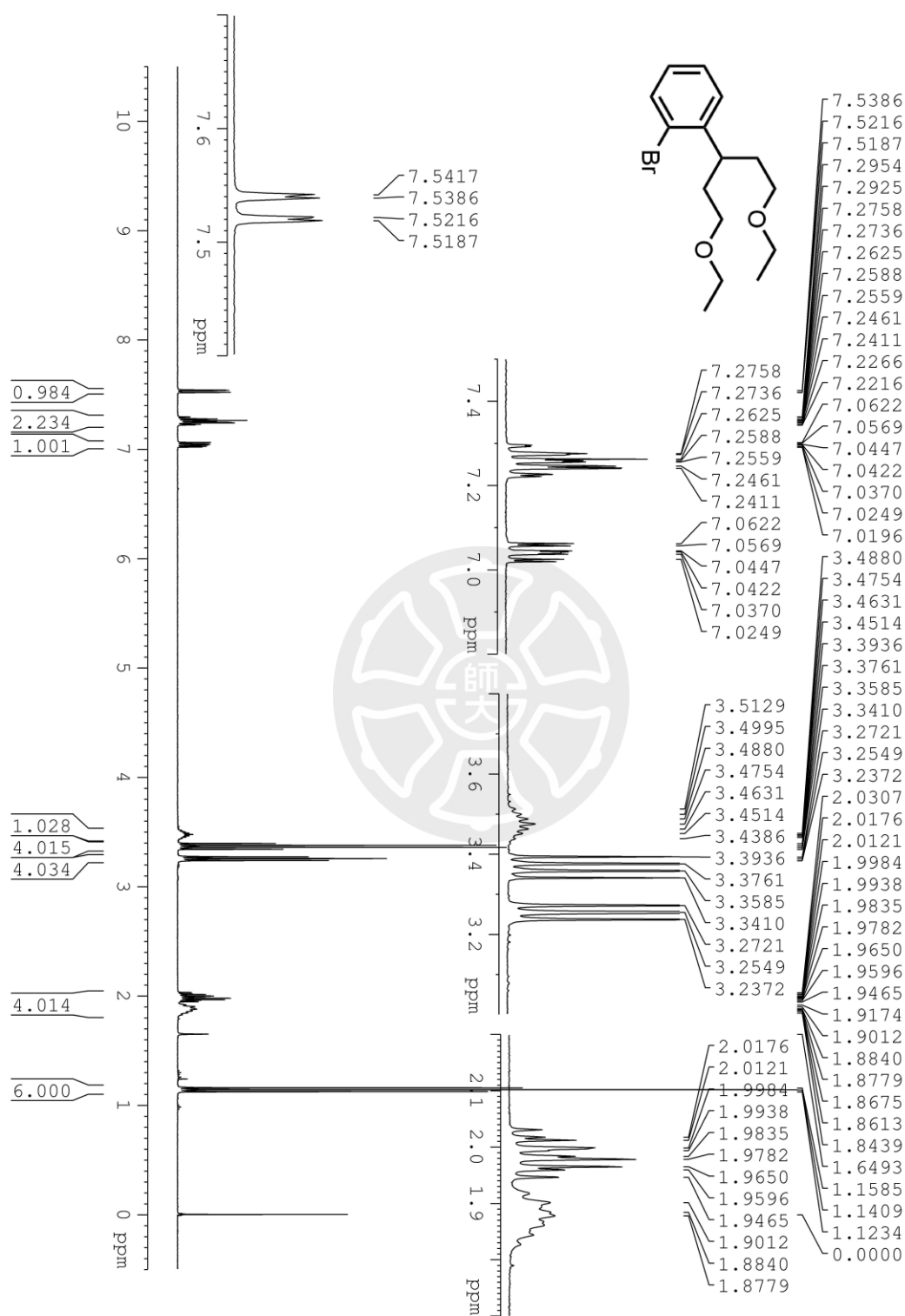
F2 Acquisition Parameters	
Date_	20230407
Time	11:27
INSTRUM	spect
PROBHD	5 mm PABBO BE
PULPROG	dept135
TD	32/68
NS	CDCl3
DS	8
SWH	24038.461 Hz
FDRES	0.735396 Hz
AQ	0.6815744 sec
RG	198.09
DW	20.800 usec
DE	6.50 usec
TE	298.3 K
CNSTR1	145.000000
D1	2.0000000 sec
D2	0.00344828 sec
TD0	0.00002000 sec
	1

```
===== CHANNEL #1 =====
SFO1      100.6233319 MHz
NUC1      13C
P1         10.00 usec
P2         20.00 usec
PLW1      49.50000000 W
```

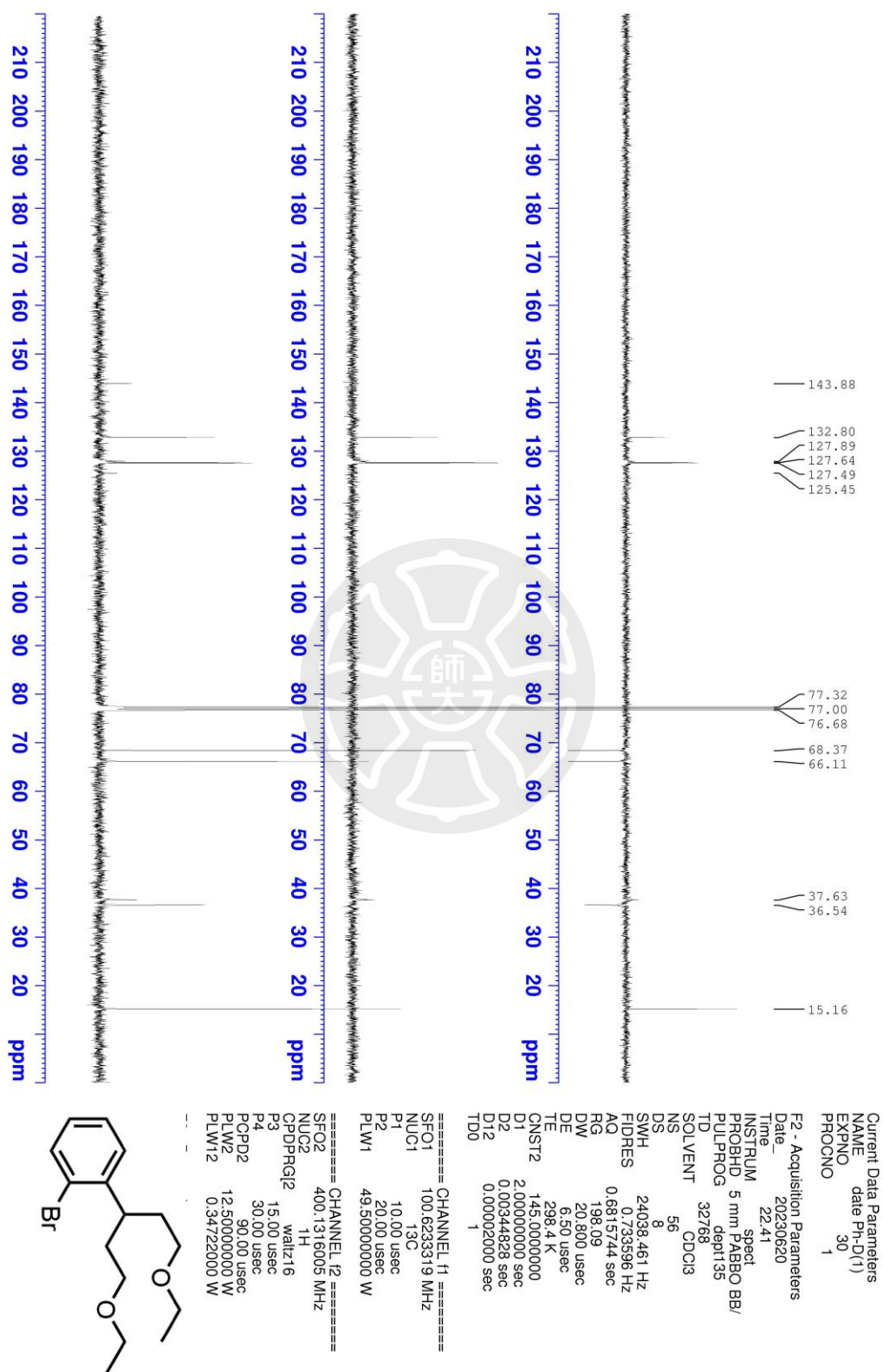
SSFO2	CHANNEL 12
NIC2	400.1316005 MHz
P3	16
CPDPFQI2	wh1t16
P3	15.00 usec
P4	30.00 usec
PCPD2	90.00 usec
PLW2	12.50000000 W
PLW12	0.34722000 W
F2 - Processing parameters	
SF	32168
SF	100.612742 MHz
WDW	EM
SSB	0
LB	2.00 Hz
CB	0
PC	1.00



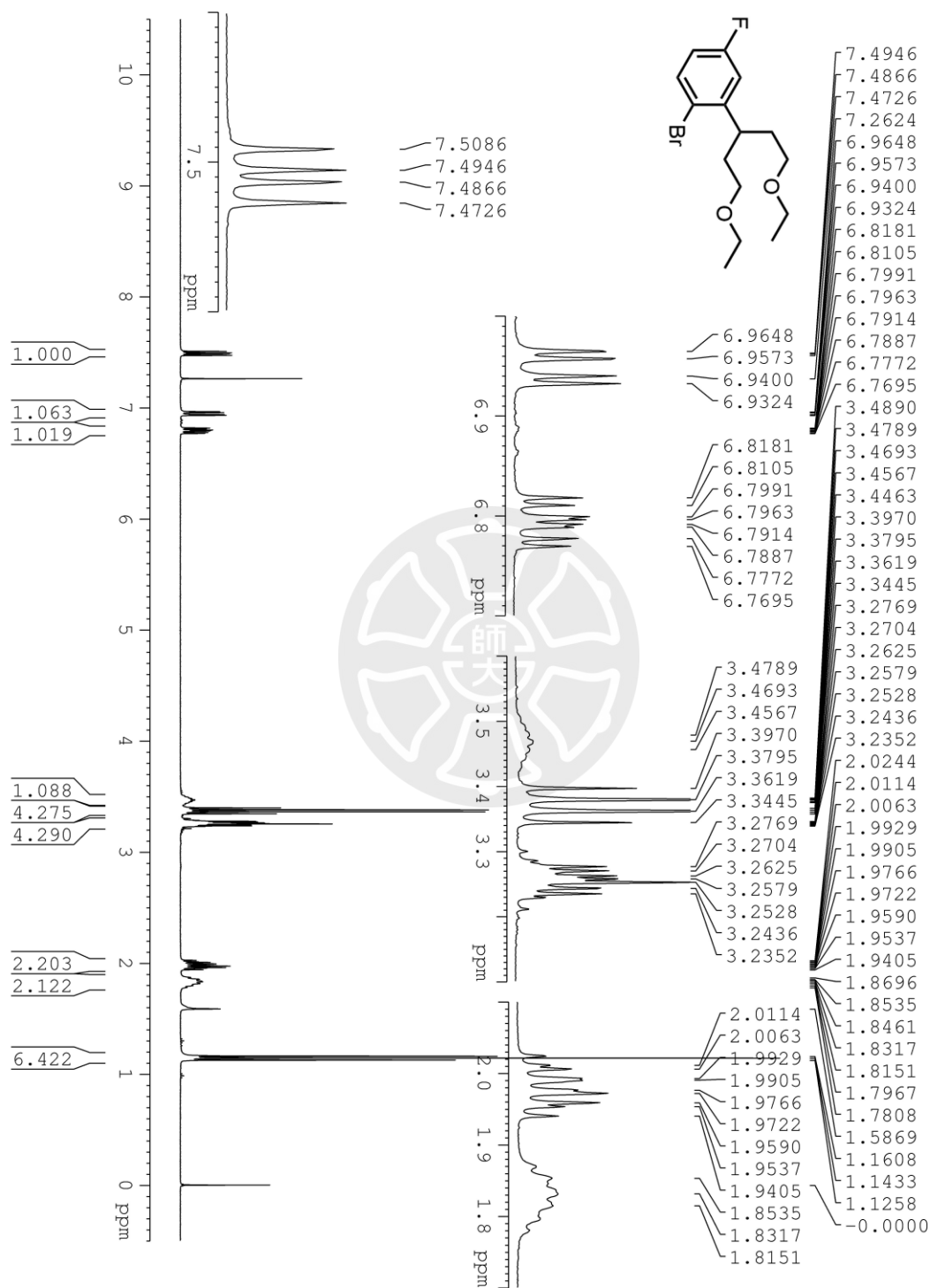
49. ^1H NMR of 1-bromo-2-(1,5-diethoxypentan-3-yl)benzene (92ae)



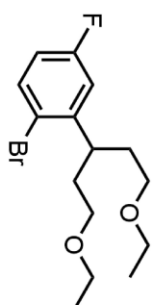
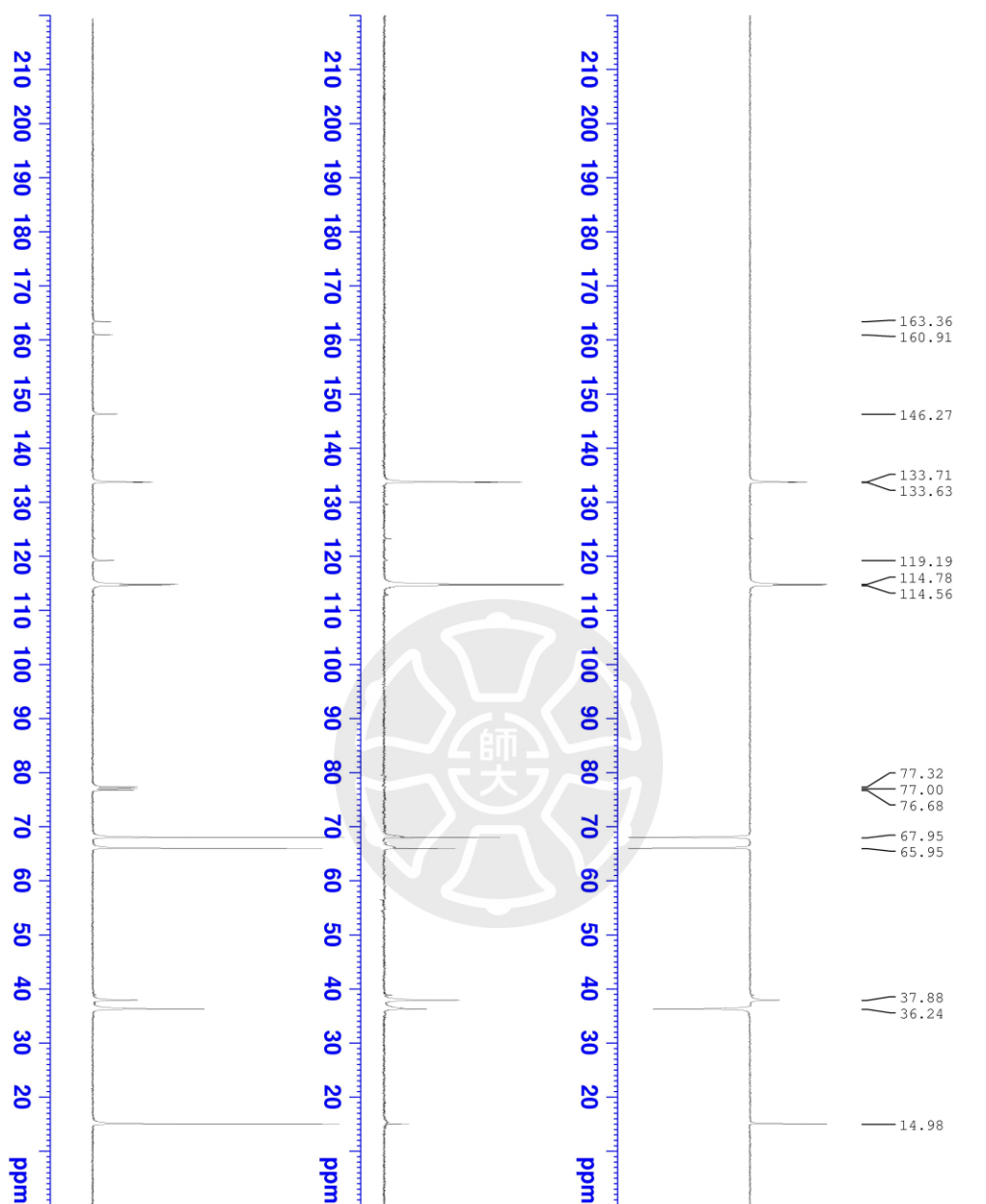
50. ^{13}C NMR of 1-bromo-2-(1,5-diethoxypentan-3-yl)benzene (92ae)



51. ¹H NMR of 1-bromo-2-(1,5-diethoxypentan-3-yl)-4-fluorobenzene (92ee)

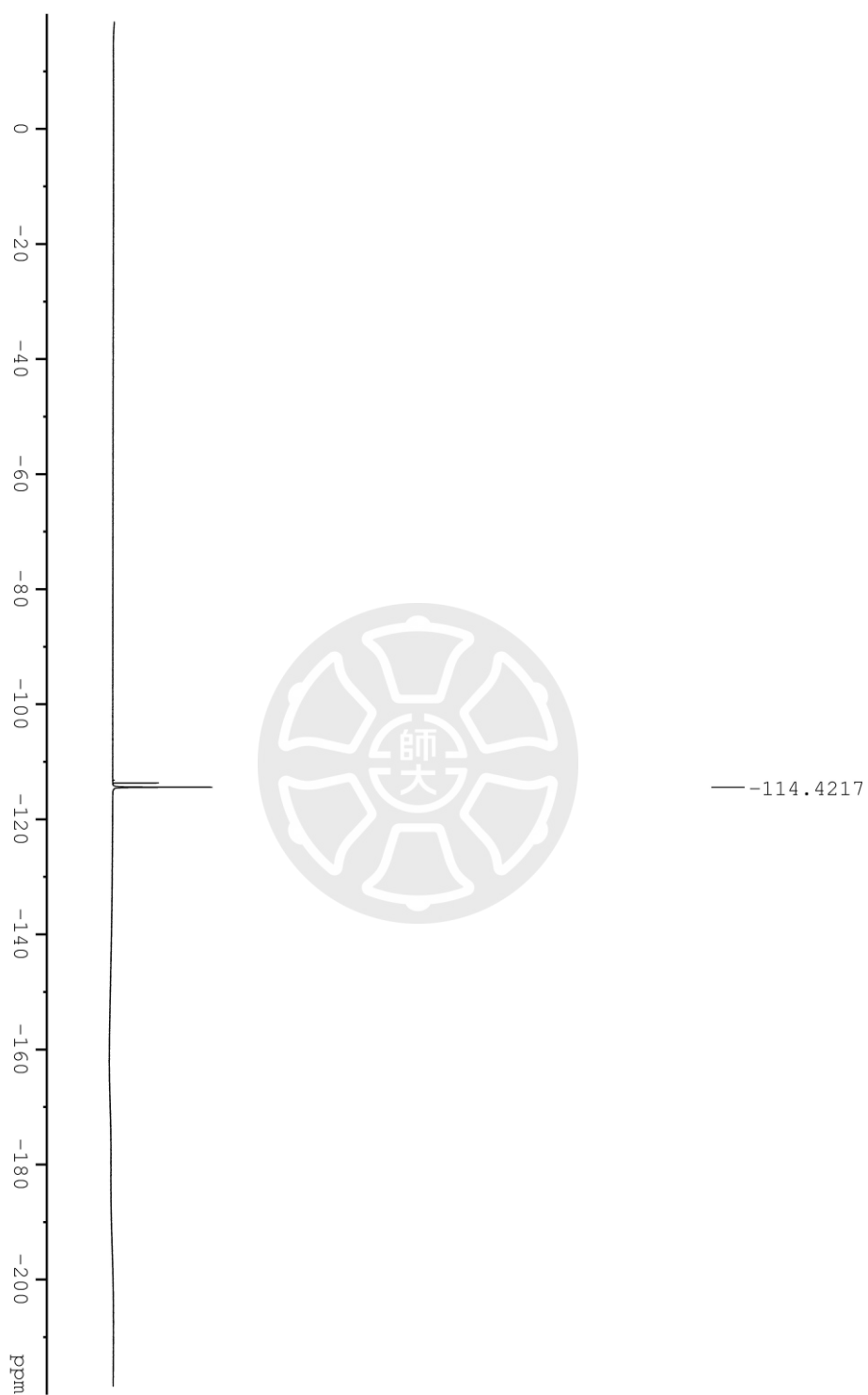


52. ^{13}C NMR of 1-bromo-2-(1,5-diethoxyypentan-3-yl)-4-fluorobenzene (92ee)

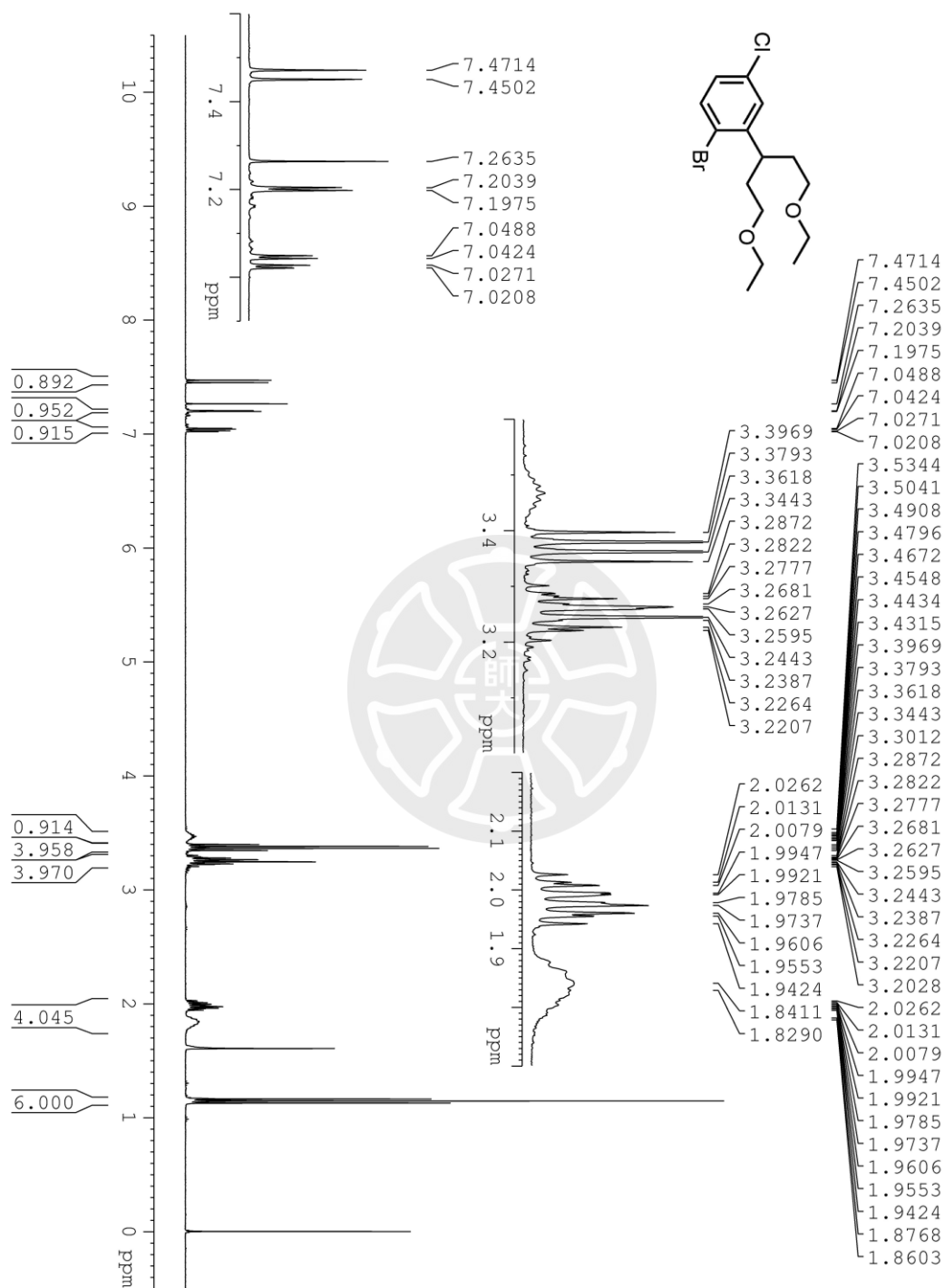


Current Data Parameters
NAME: topic 3 3F P1MqBr substrate LQ data
EXPNO: 22
PROCNO: 1
F2 - Acquisition Parameters
Date_ : 20230107
Time : 8.45
INSTRUM : spect
PROBHD : 5 mm PABBO BB/
PULPROG : zgpg30
SOLVENT : DMSO-d6
NS : 139
DS : 8
SWH : 24038.461 Hz
FIDRES : 0.733596 Hz
AQ : 0.861574 sec
RG : 327.5
DWM : 20.500 usec
DE : 6.50 usec
TE : 300.0 K
CNST2 : 145.0000000
D1 : 2.00000000 sec
D2 : 0.0004628 sec
D3 : 0.0004200 sec
TD0 : 1
===== CHANNEL f1 =====
SFO1 : 100.6233319 MHz
NUC1 : ^{13}C
P1 : 10.130 usec
PLW1 : 49.50000000 W
===== CHANNEL f2 =====
SFO2 : 400.1316005 MHz
NUC2 : ^1H
P2 : 15.00 usec
PLW2 : 12.50000000 W
F2 - Processing parameters
SF : 100.6127816 MHz
WDW : EM
SSB : 0
LB : 2.00 Hz
GB : 0
PC : 1.00

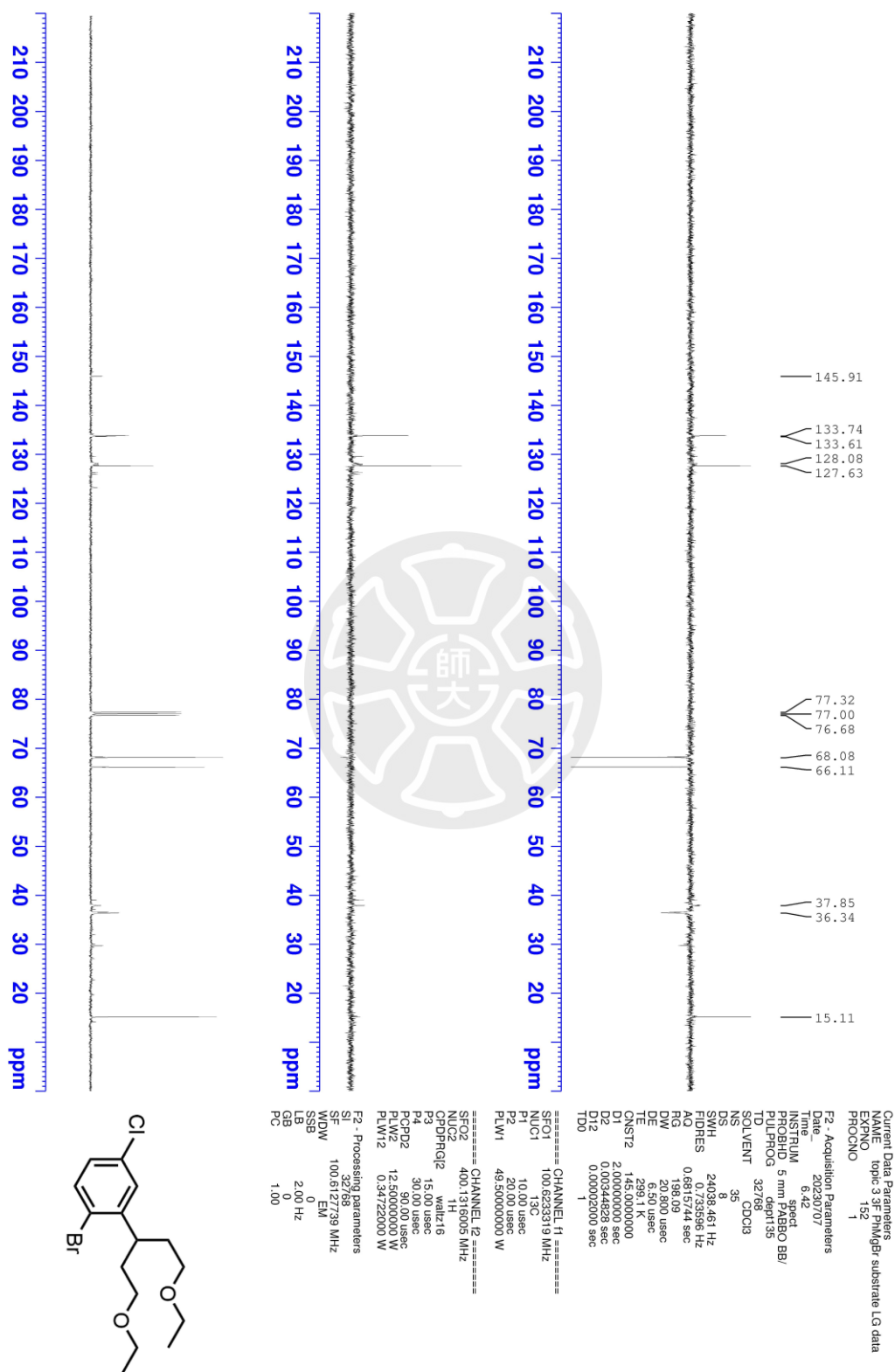
53. ^{19}F NMR of 1-bromo-2-(1,5-diethoxypentan-3-yl)-4-fluorobenzene (92ee)



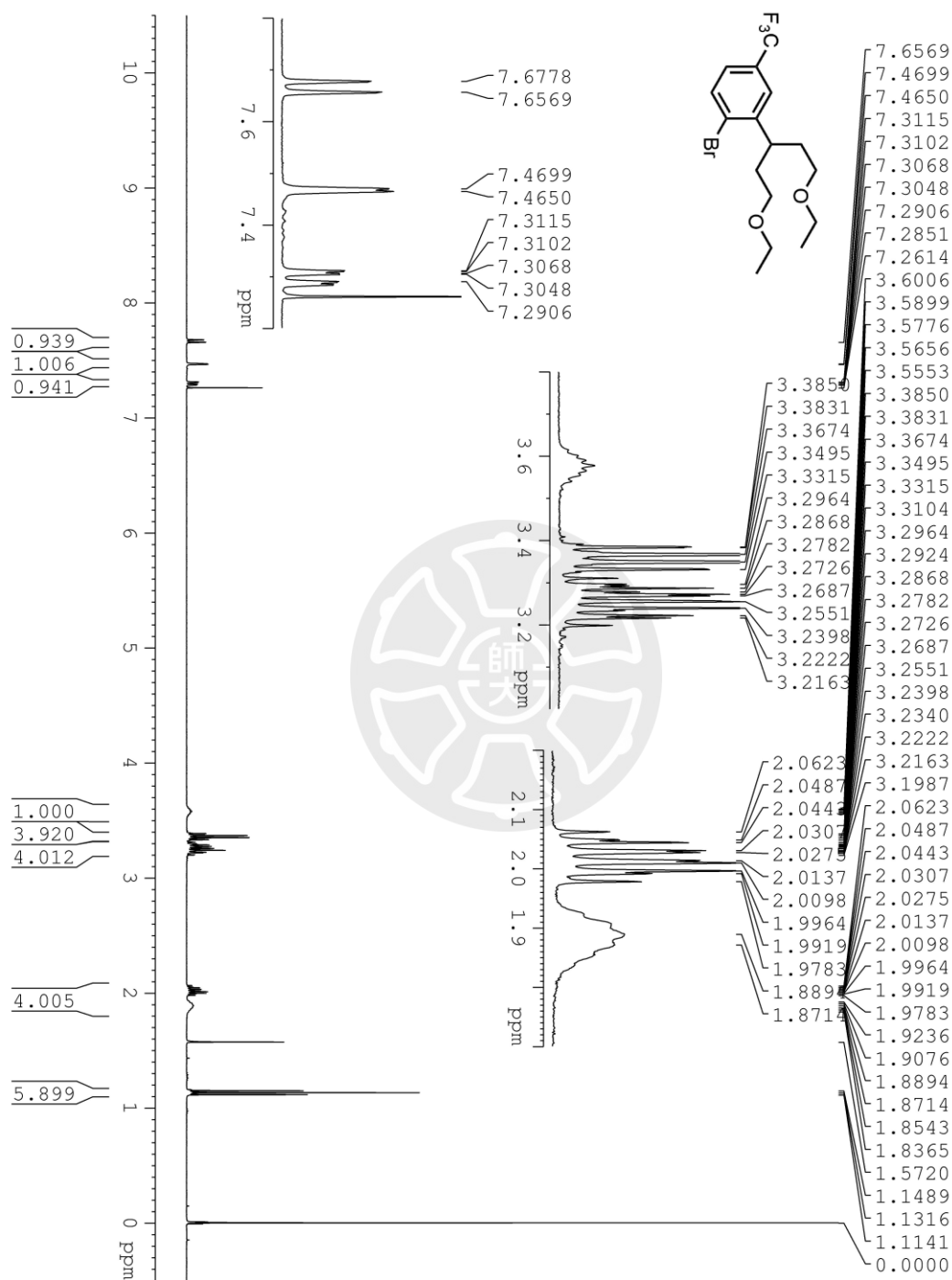
54. ^1H NMR of 2-bromo-4-chloro-1-(1,5-diethoxy-pentan-3-yl)benzene (92ie)



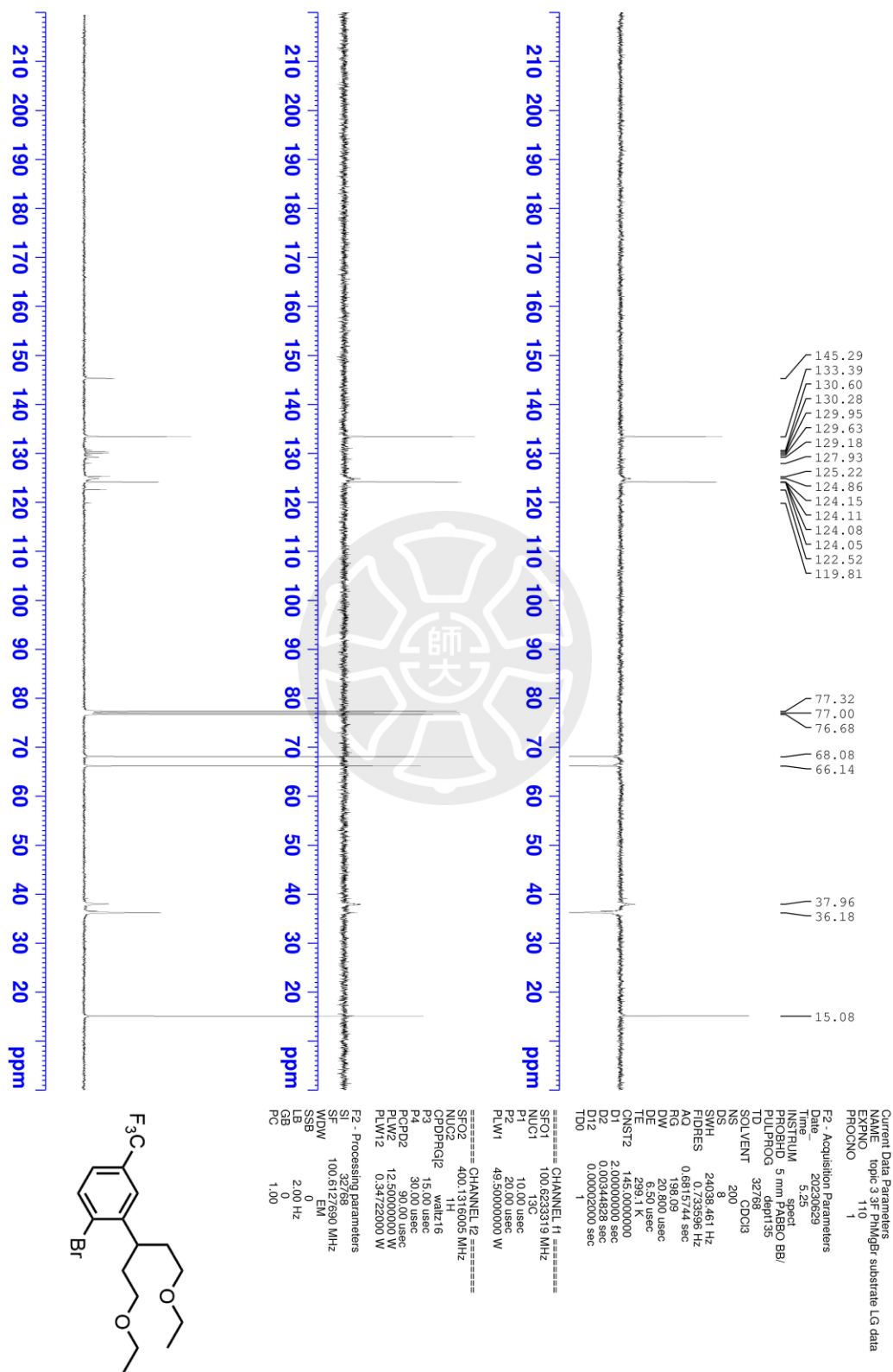
55. ^{13}C NMR of 2-bromo-4-chloro-1-(1,5-diethoxypentan-3-yl)benzene (92ie)



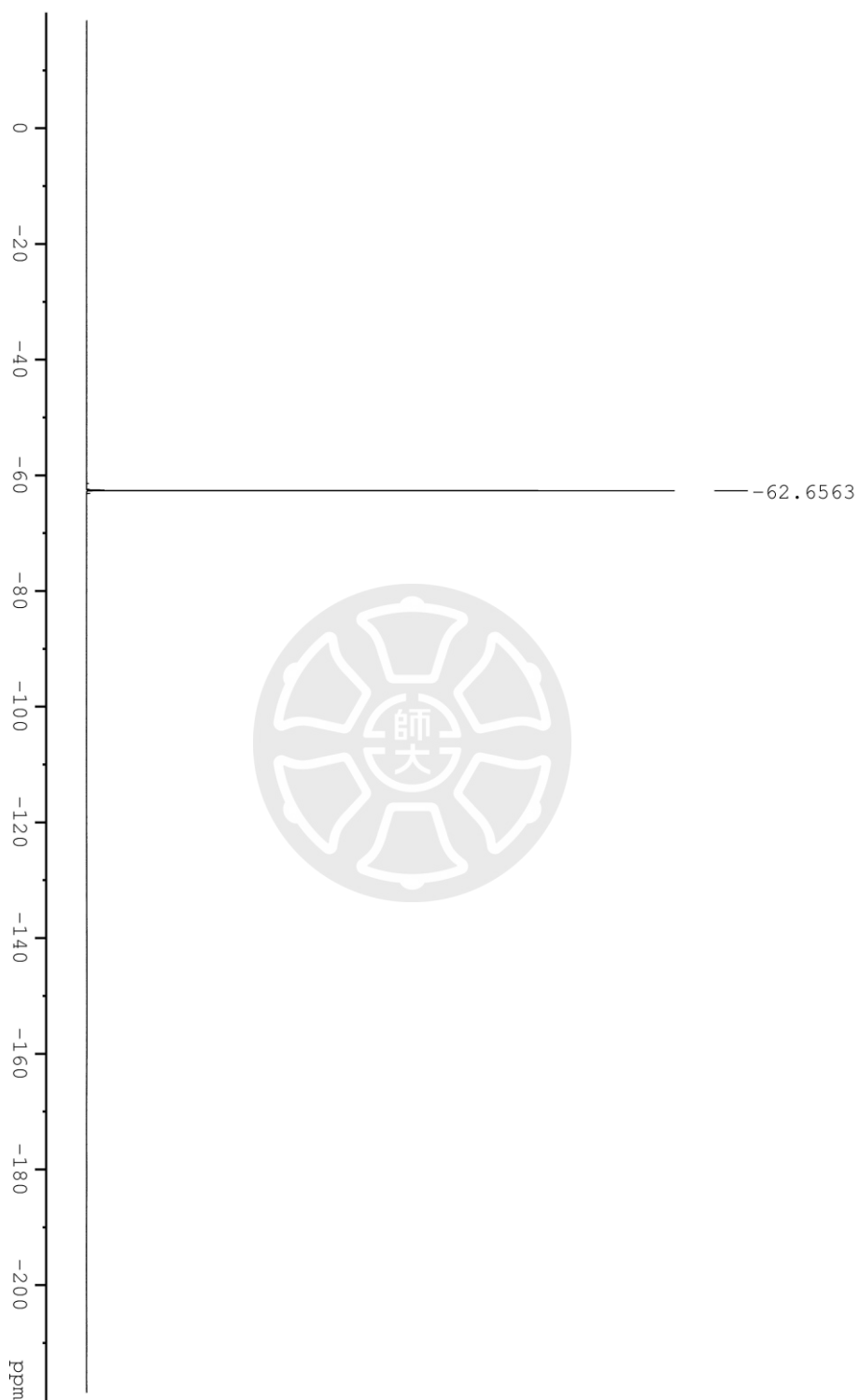
56. ^1H NMR of 1-bromo-2-(1,5-diethoxypentan-3-yl)-4-(trifluoromethyl)benzene (92ge)



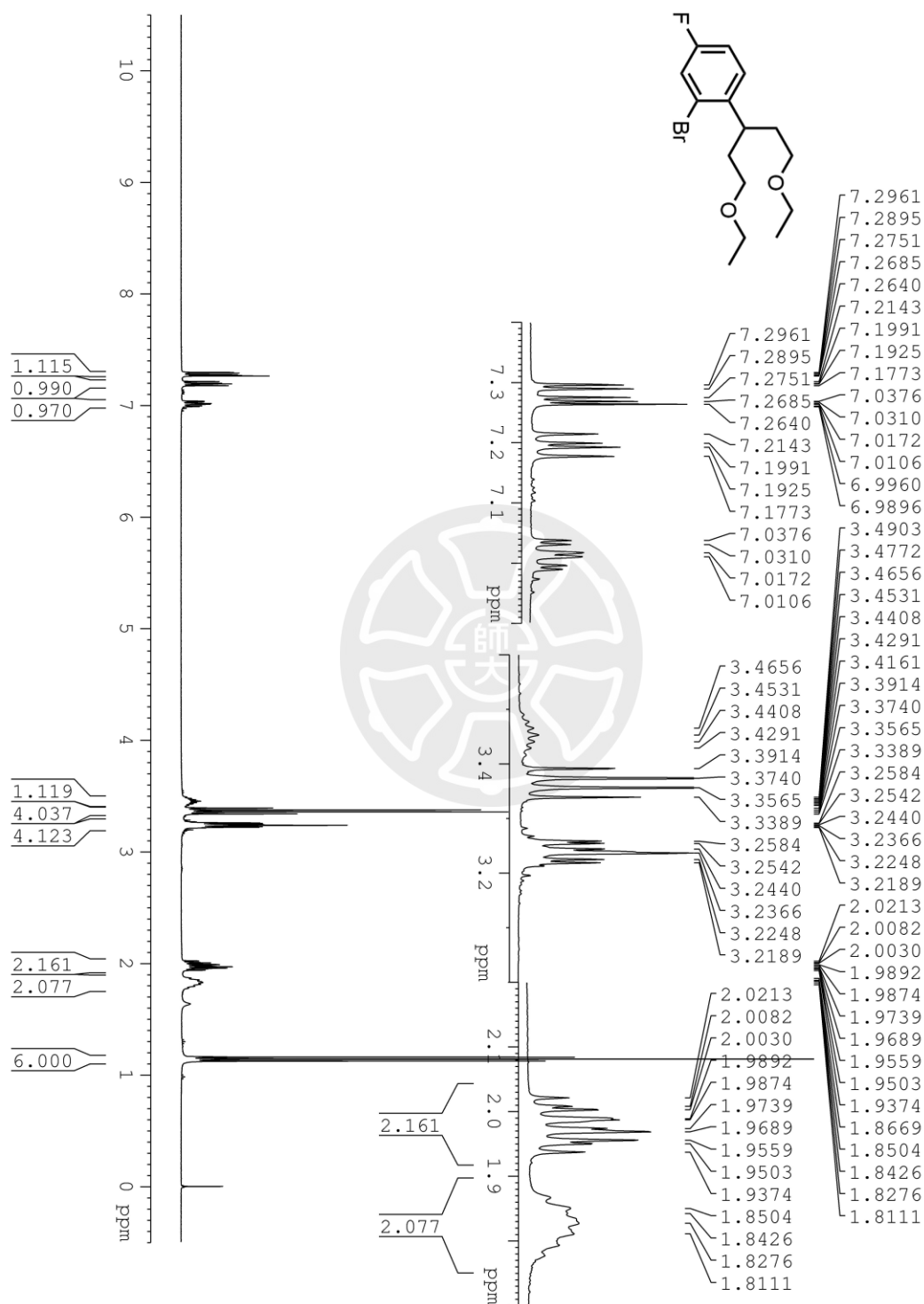
57. ^{13}C NMR of 1-bromo-2-(1,5-diethoxy-pentan-3-yl)-4-(trifluoromethyl)benzene (92ge)



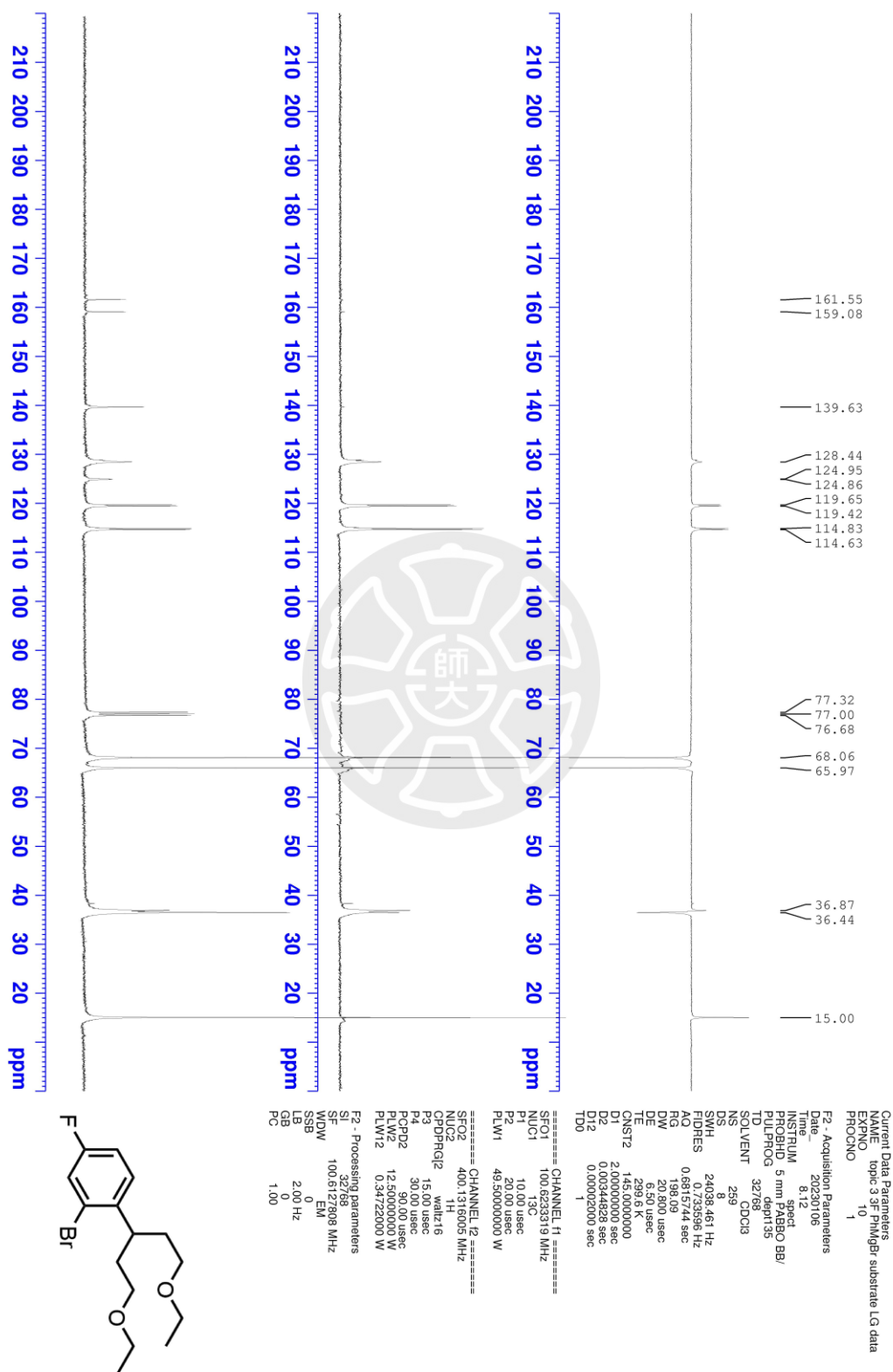
58. ^{19}F NMR of 1-bromo-2-(1,5-diethoxypentan-3-yl)-4-(trifluoromethyl)benzene (92ge)



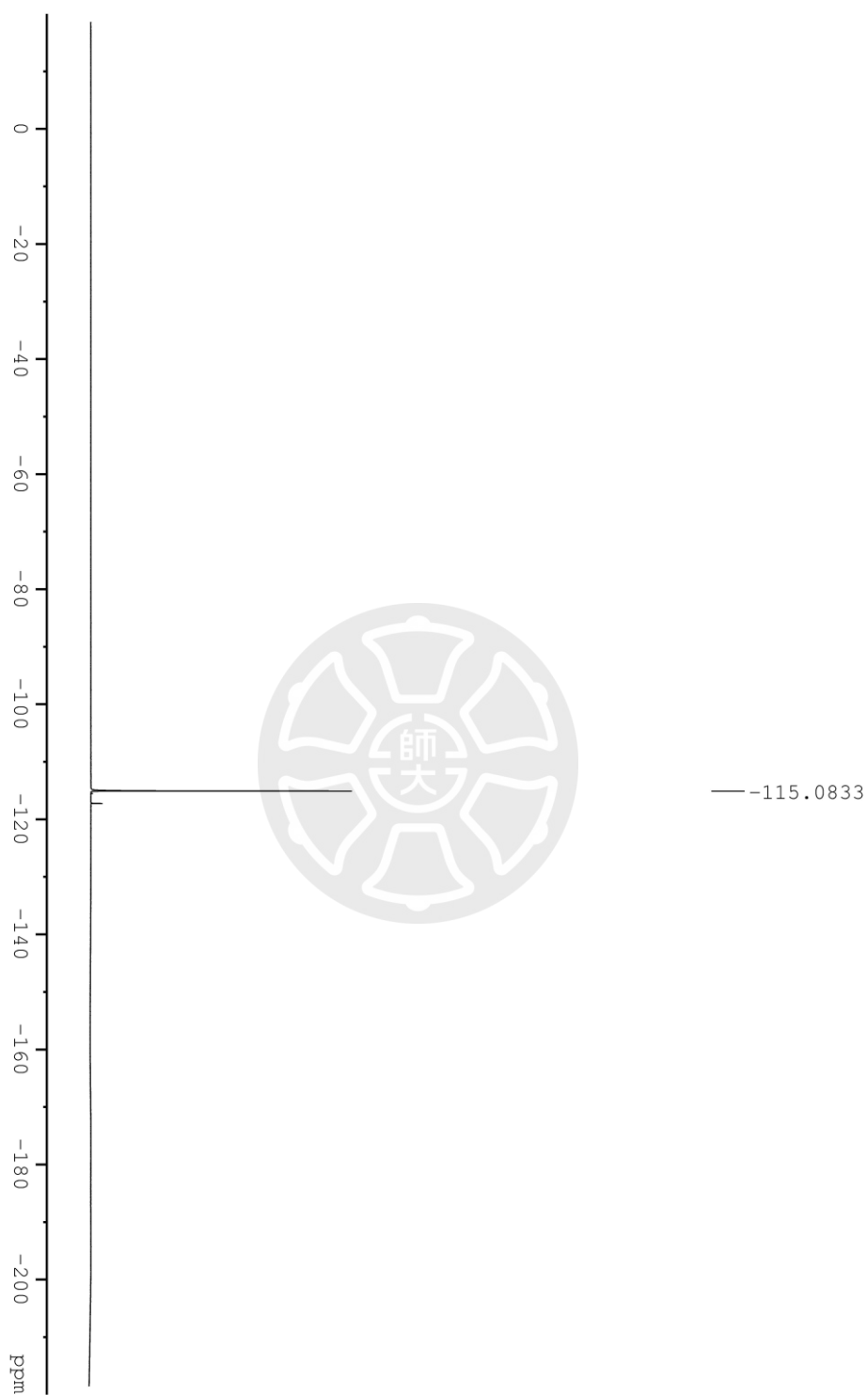
59. ¹H NMR of 2-bromo-1-(1,5-diethoxypentan-3-yl)-4-fluorobenzene (92he)



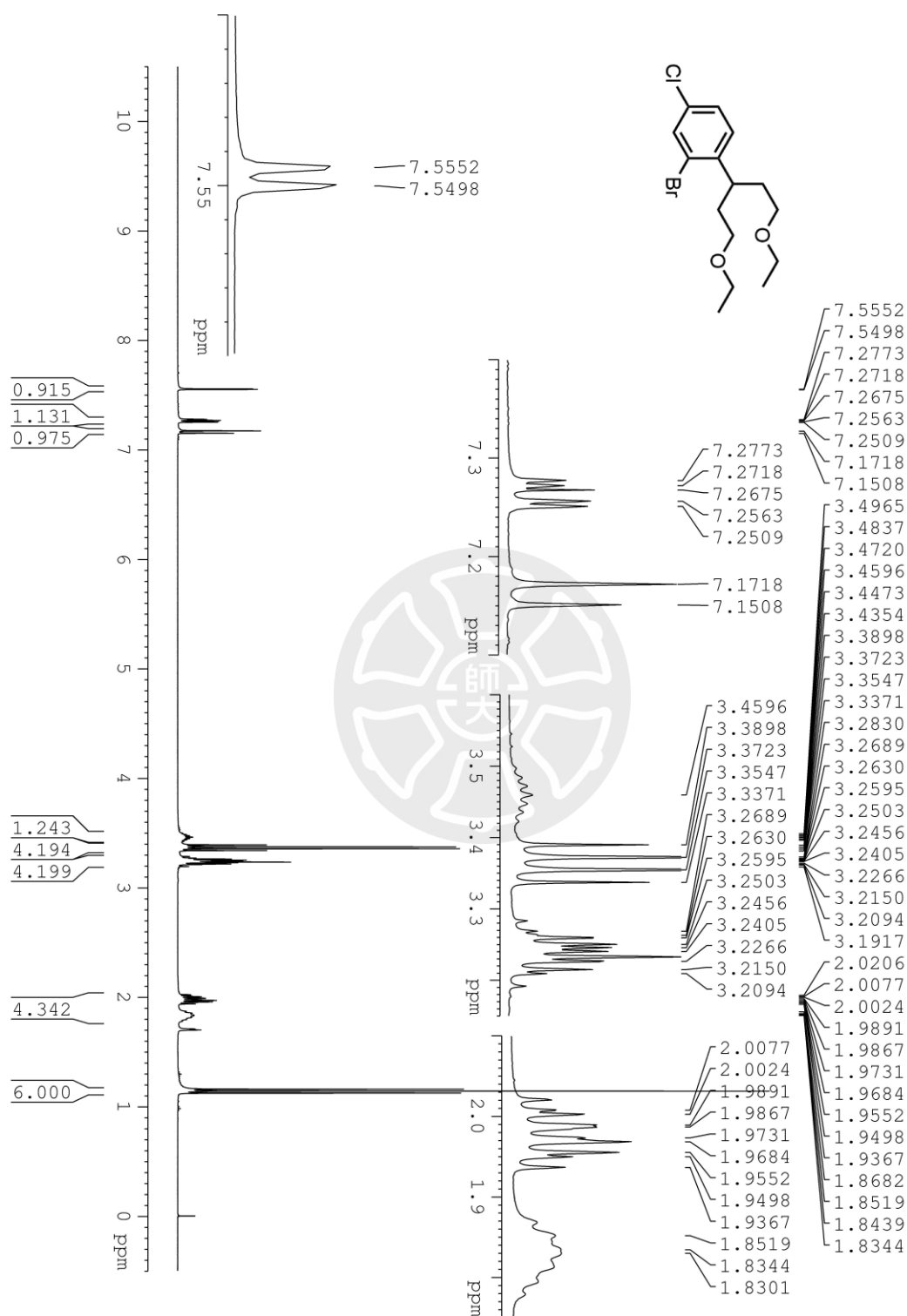
60. ^{13}C NMR of 2-bromo-1-(1,5-diethoxy-pentan-3-yl)-4-fluorobenzene (92he)



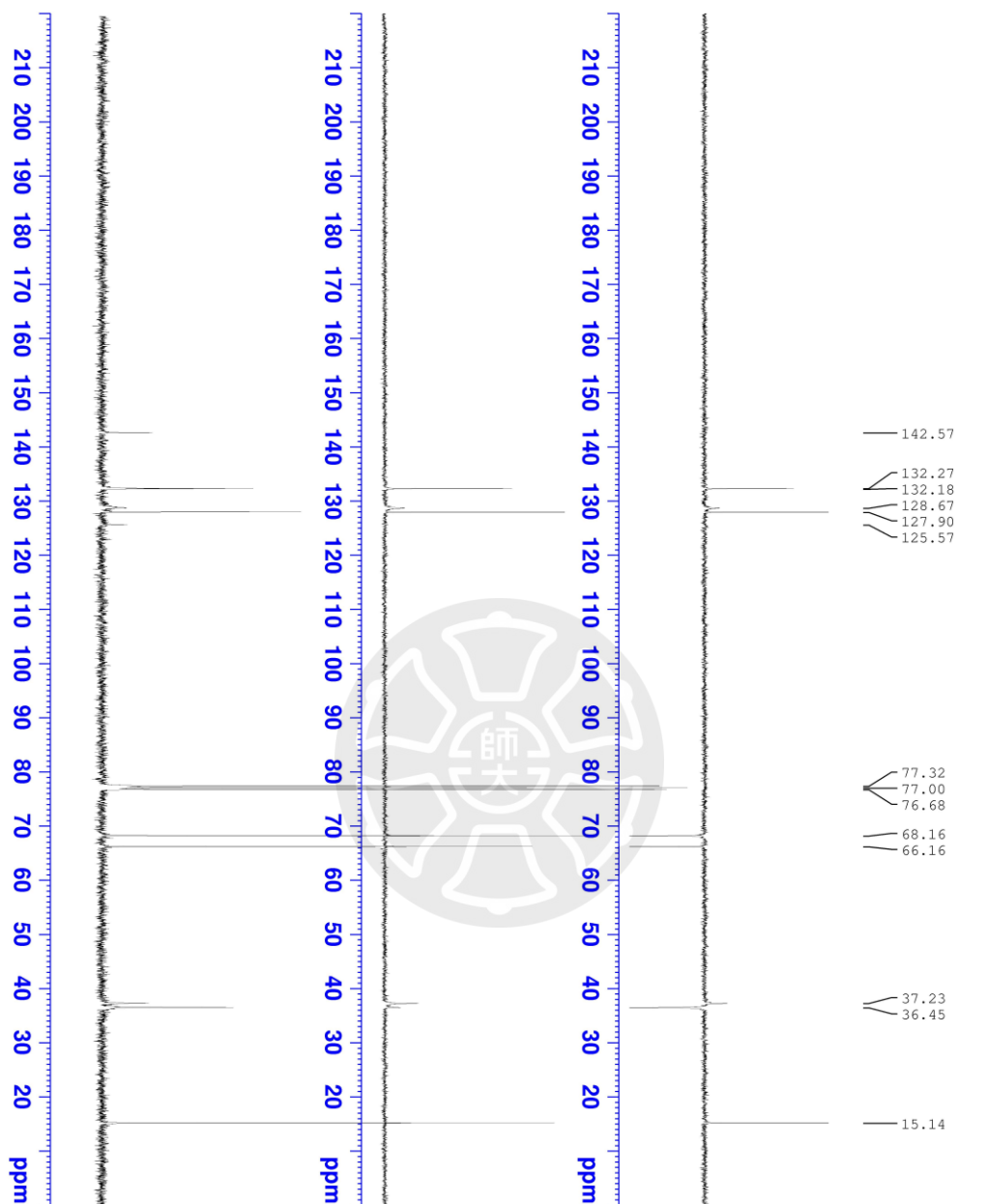
61. ^{19}F NMR of 2-bromo-1-(1,5-diethoxypentan-3-yl)-4-fluorobenzene (92he)



62. ^1H NMR of 2-bromo-4-chloro-1-(1,5-diethoxypentan-3-yl)benzene (92ie)

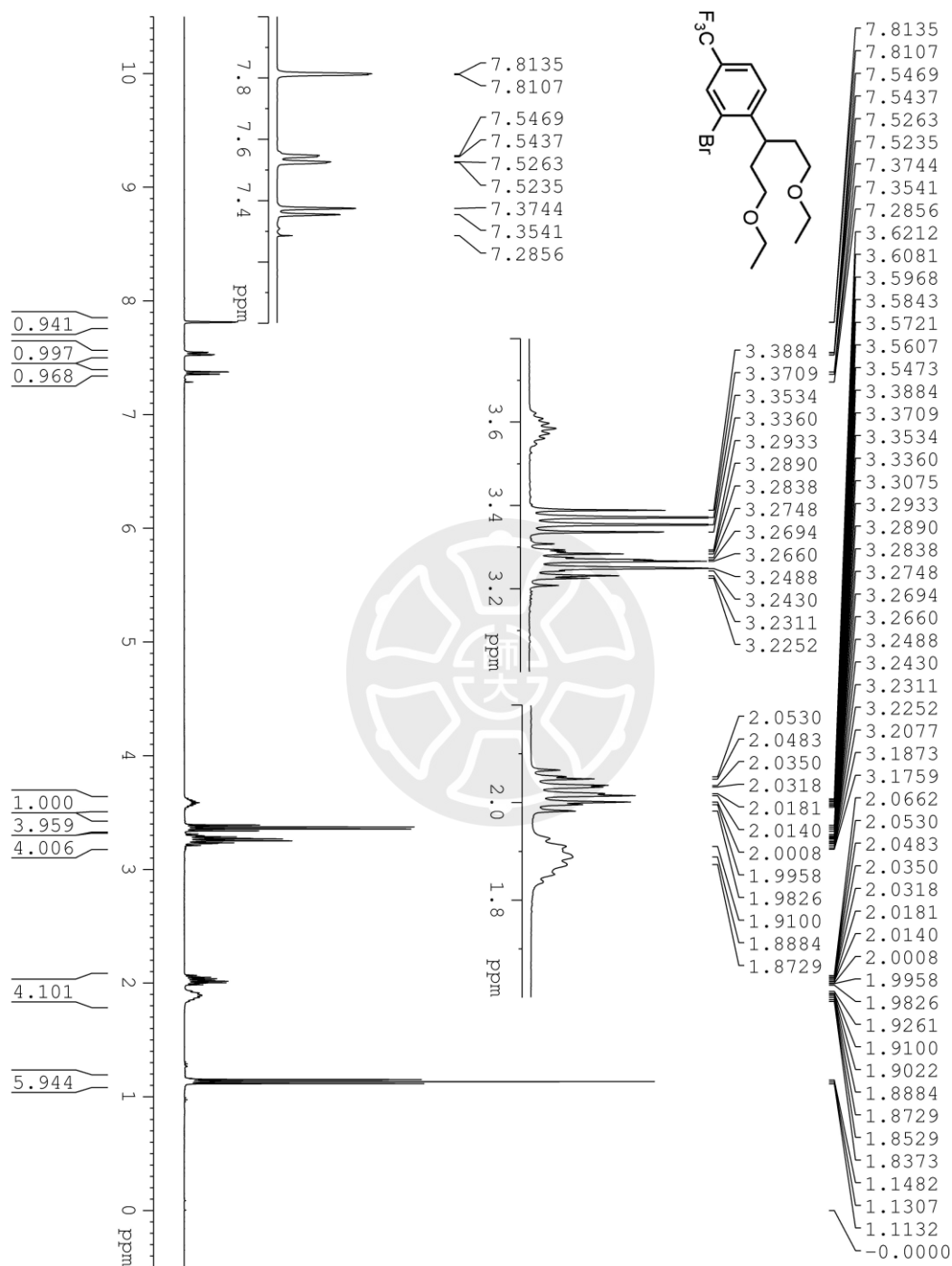


63. ^{13}C NMR of 2-bromo-4-chloro-1-(1,5-diethoxypentan-3-yl)benzene (92ie)

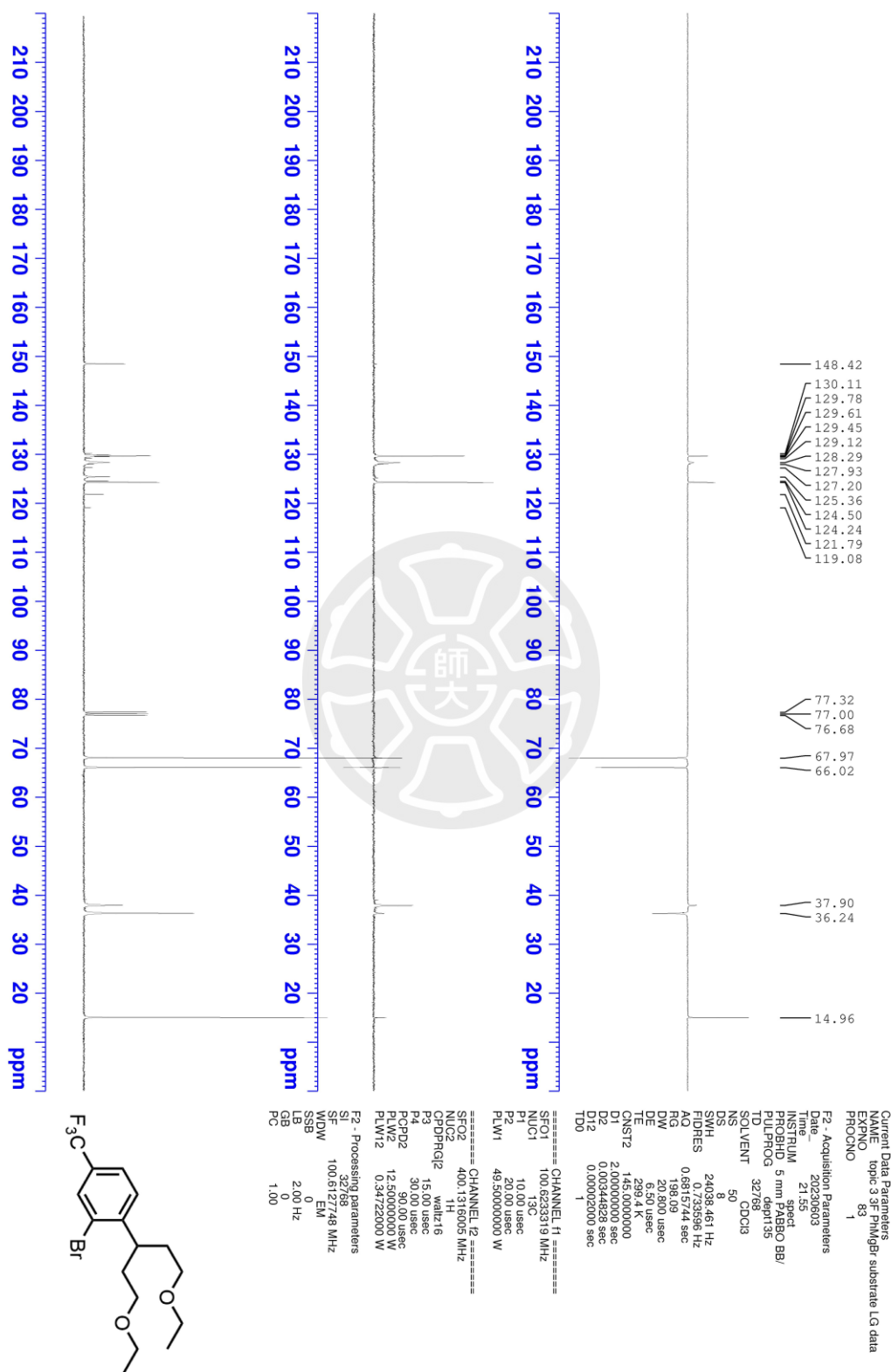


Current Data Parameters
 NAME topic 3 3F P1MqBr substrate LQ data
 EXPNO 6
 PROCNO 1
 F2 - Acquisition Parameters
 Date_ 20230105
 Time 9:09
 INSTRUM spect
 PROBD 5 mm PABBO BB/
 PULPROG 32/76
 SOLVENT 200
 NS 200
 DS 8
 SWH 24038.461 Hz
 FIDRES 0.733596 Hz
 AQ 0.861574 sec
 T8 128.32
 D1 20.500 usec
 DE 6.50 usec
 TE 299.5 K
 CNST2 145.0000000
 D1 2.0000000 sec
 D2 0.0004628 sec
 D3 0.0004200 sec
 TD6 1
 ===== CHANNEL f1 =====
 SFO1 100.6233319 MHz
 NUC1 13C
 P2 20.00 usec
 PLW1 49.50000000 W
 ===== CHANNEL f2 =====
 SFO2 400.1316005 MHz
 NUC2 1H
 P3 15.00 usec
 P4 30.00 usec
 PCPD2 90.00 usec
 PLW2 12.50000000 W
 PLW12 0.34722000 W
 F2 - Processing parameters
 SI 32768
 SF 100.6127714 MHz
 WDW EM
 SSB 0
 LB 2.00 Hz
 GB 0
 PC 1.00

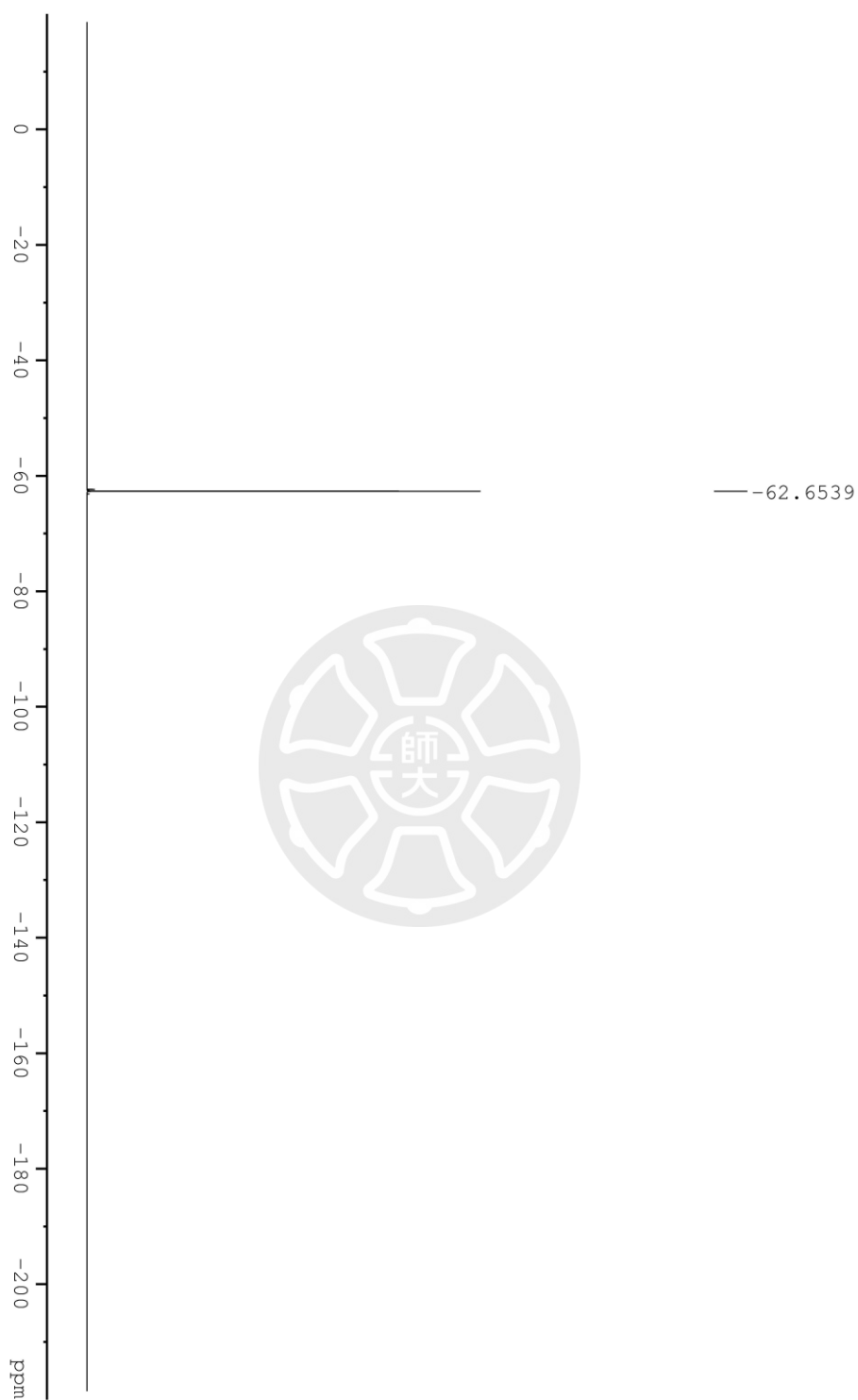
64. ^1H NMR of 2-bromo-1-(1,5-diethoxypentan-3-yl)-4-(trifluoromethyl)benzene (92je)



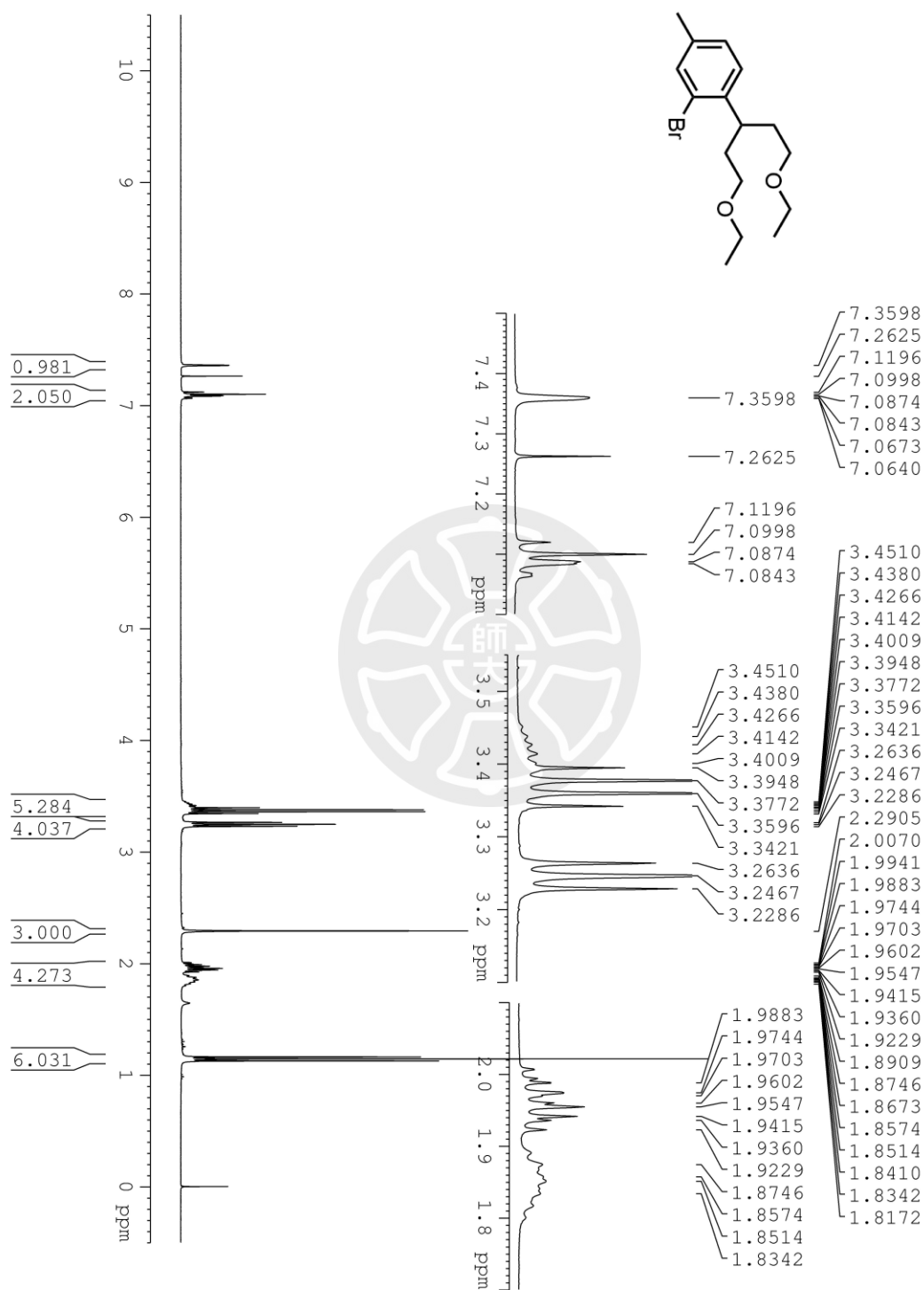
65. ^{13}C NMR of 2-bromo-1-(1,5-diethoxy-pentan-3-yl)-4-(trifluoromethyl)benzene (92je)



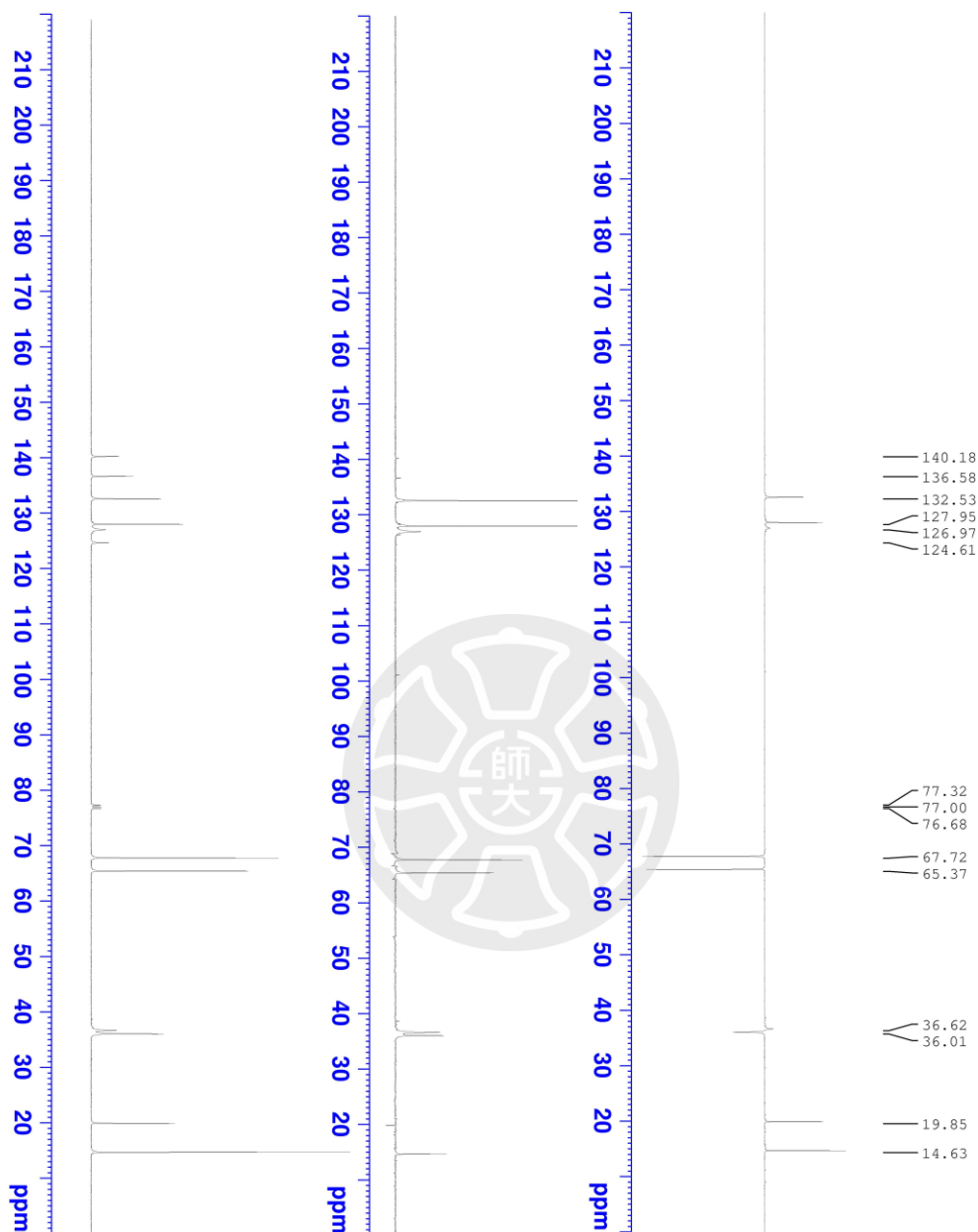
66. ^{19}F NMR of 2-bromo-1-(1,5-diethoxypentan-3-yl)-4-(trifluoromethyl)benzene (92je)



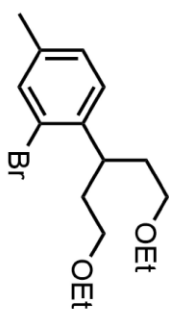
67. ^1H NMR of 2-bromo-1-(1,5-diethoxypentan-3-yl)-4-methylbenzene (92ke)



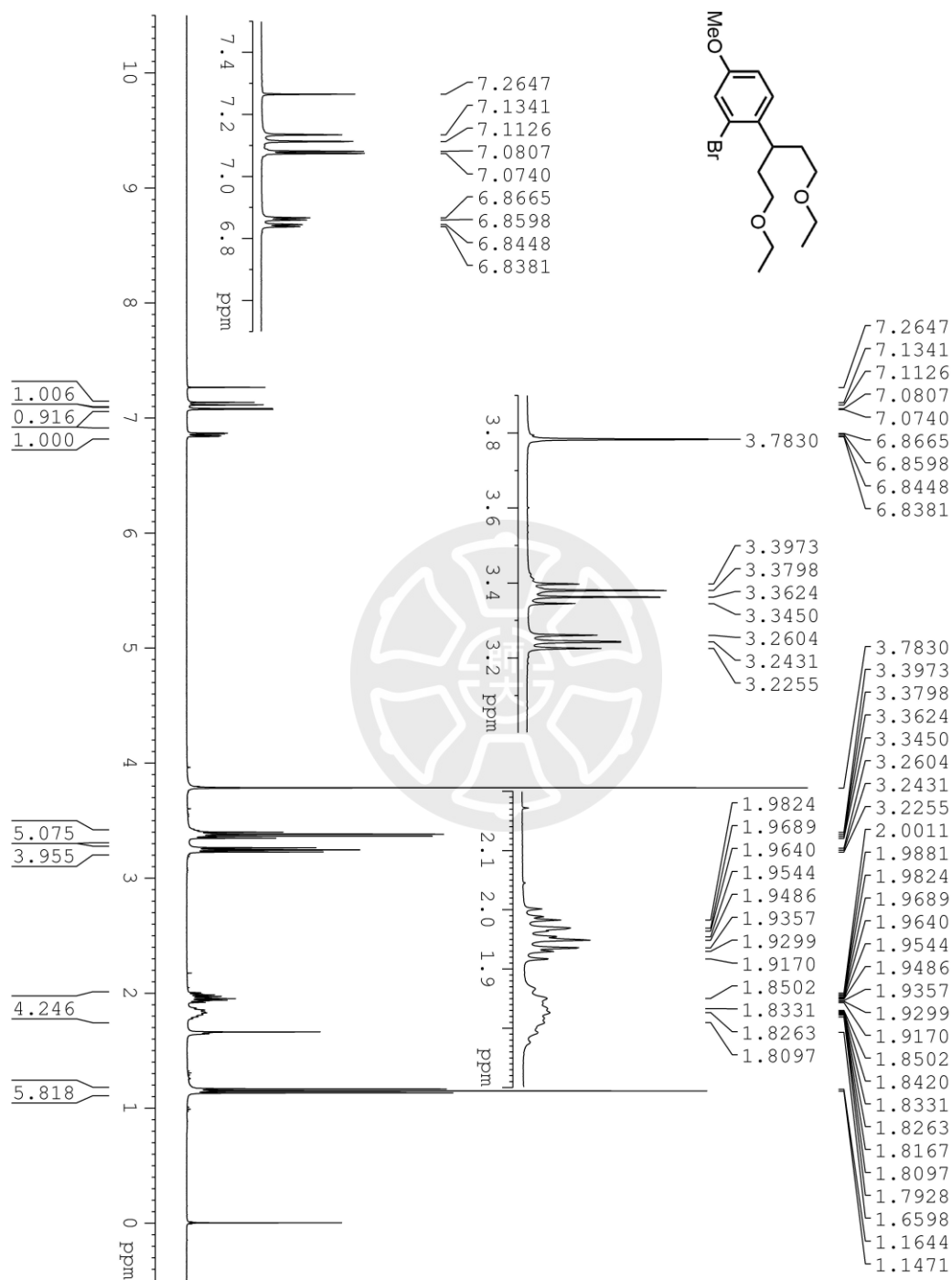
68. ^{13}C NMR of 2-bromo-1-(1,5-diethoxypentan-3-yl)-4-methylbenzene (92ke)



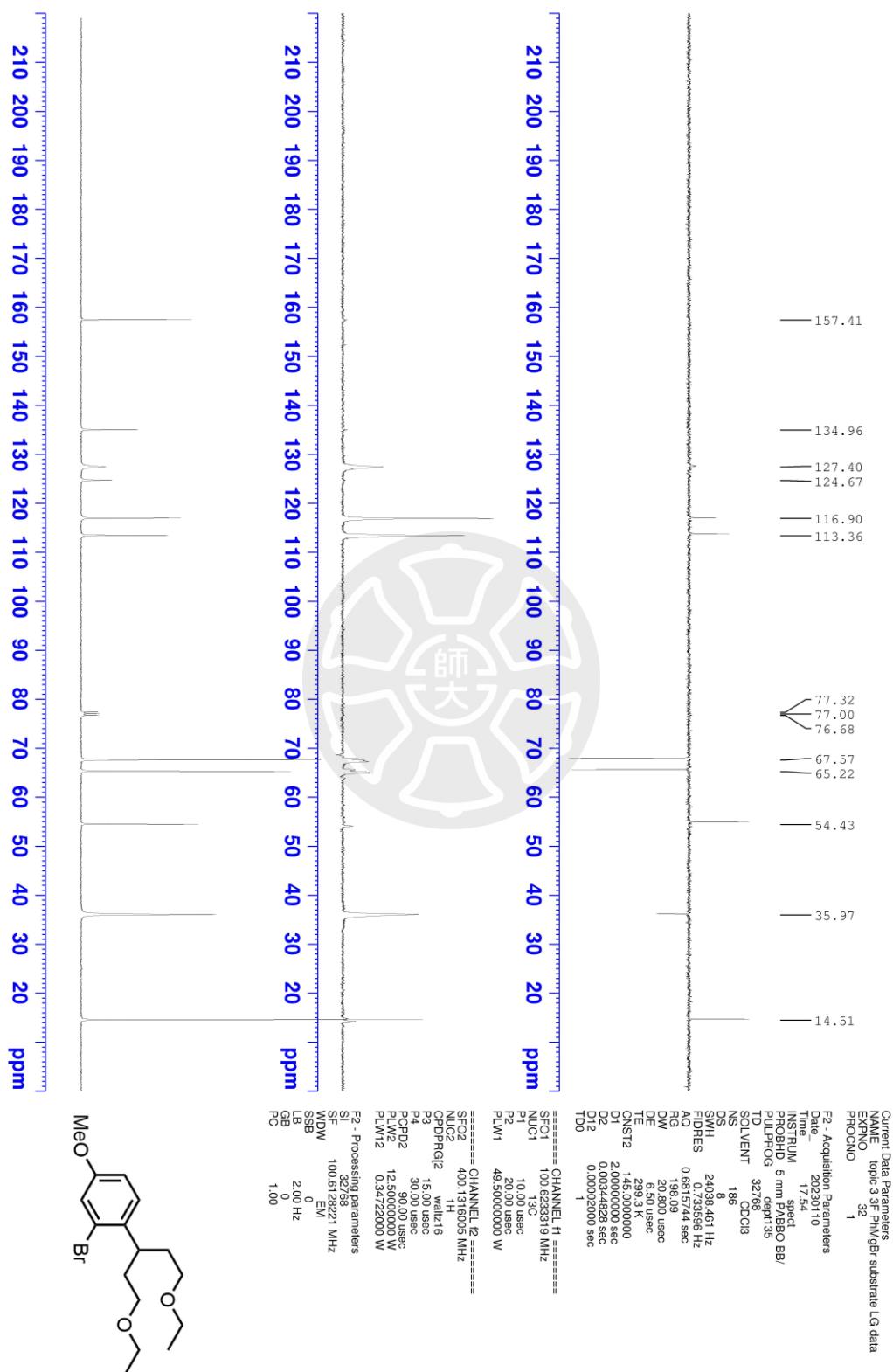
Current Data Parameters
NAME topic 3 3F P1MqBr substrate LQ data
EXPNO 18
PROCNO 1
F2 - Acquisition Parameters
Date_ 20230107
Time 8:15
INSTRUM spect
PROBHD 5 mm PABBO BB/
PULPROG zgpg30
SOLVENT CDCl3
NS 137
DS 8
SWH 24038.461 Hz
FIDRES 0.733596 Hz
AQ 0.861574 sec
RG 327.5
DWM 20.800 usec
DE 6.50 usec
TE 299.7 K
CNS12 145.0000000
D1 2.00000000 sec
D2 0.00046828 sec
D3 0.00042000 sec
TD0 1
===== CHANNEL f1 =====
SFO1 100.6233319 MHz
NUC1 13C
P1 10.136
PLW1 49.50000000 W
===== CHANNEL f2 =====
SFO2 400.1316005 MHz
NUC2 1H
P2 15.000 usec
PLW2 12.50000000 W
F2 - Processing parameters
SF 100.6128165 MHz
WDW EM
SSB 0
LB 2.00 Hz
GB 0
PC 1.00



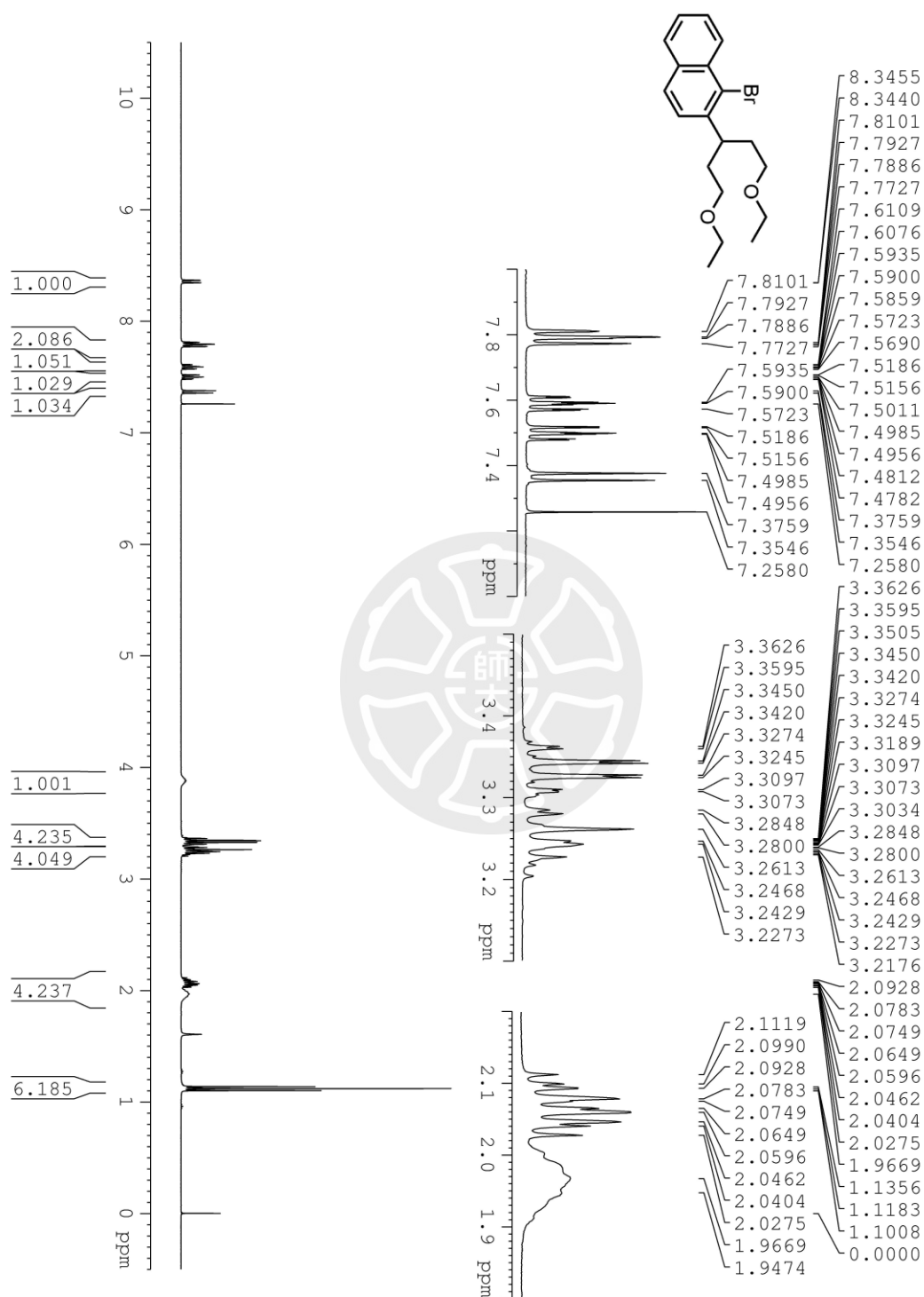
69. ^1H NMR of 2-bromo-1-(1,5-diethoxypentan-3-yl)-4-methoxybenzene (92le)



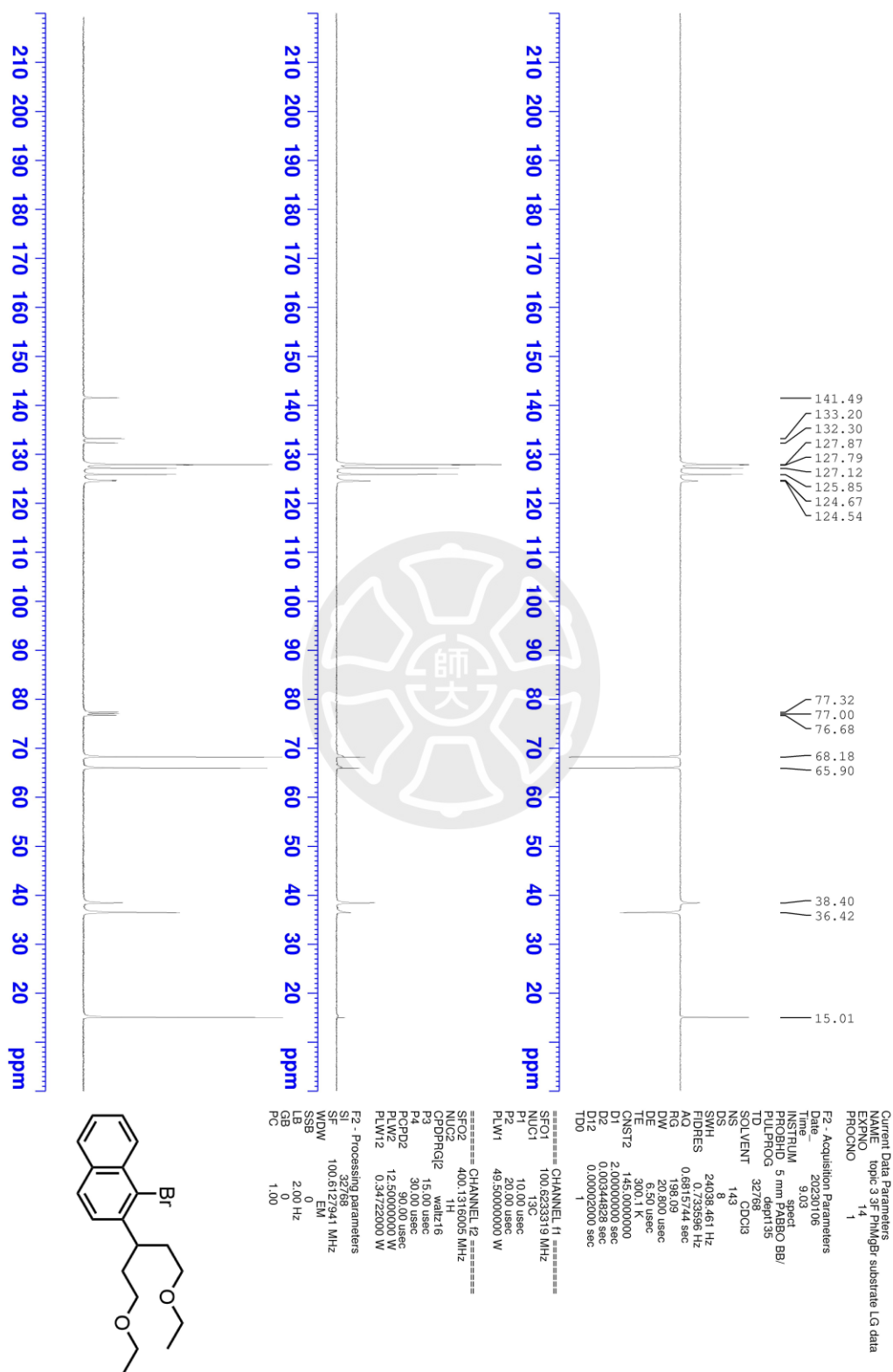
70. ^{13}C NMR of 2-bromo-1-(1,5-diethoxypentan-3-yl)-4-methoxybenzene (92le)



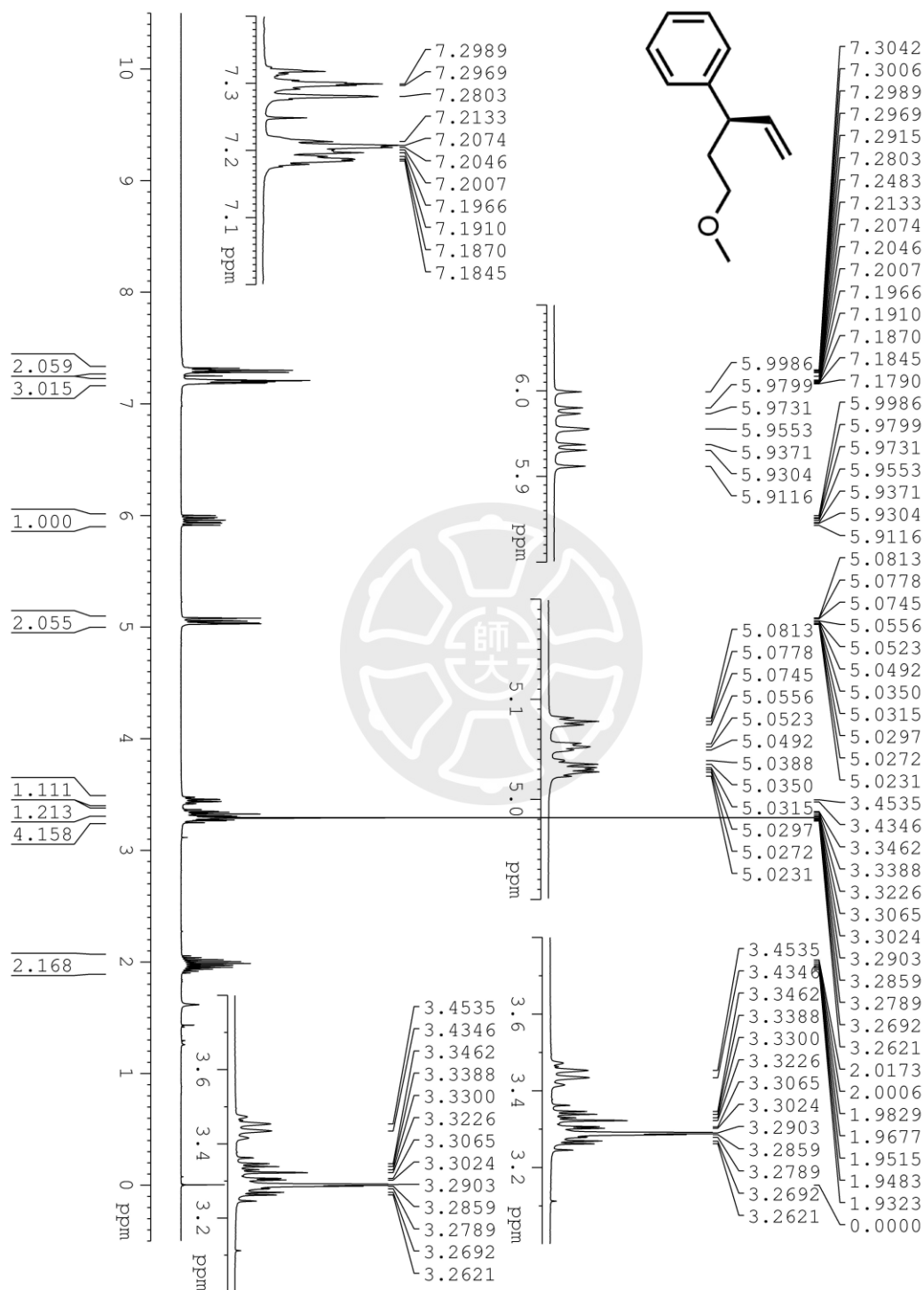
71. ^1H NMR of 1-bromo-2-(1,5-diethoxypentan-3-yl)naphthalene (92me)



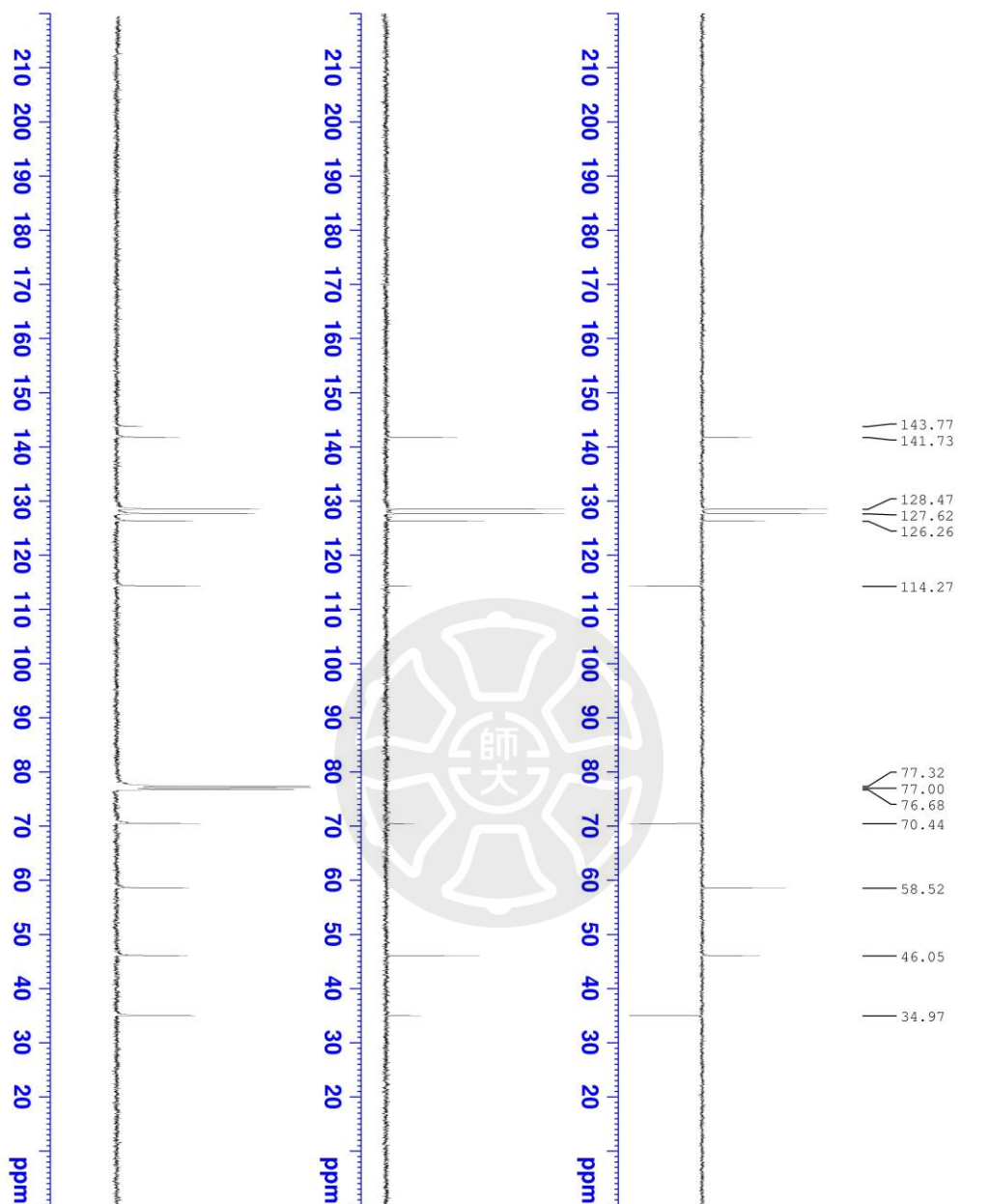
72. ^{13}C NMR of 1-bromo-2-(1,5-diethoxypentan-3-yl)naphthalene (92me)



73. ^1H NMR of (*R*)-(5-methoxypent-1-en-3-yl)benzene (94am)

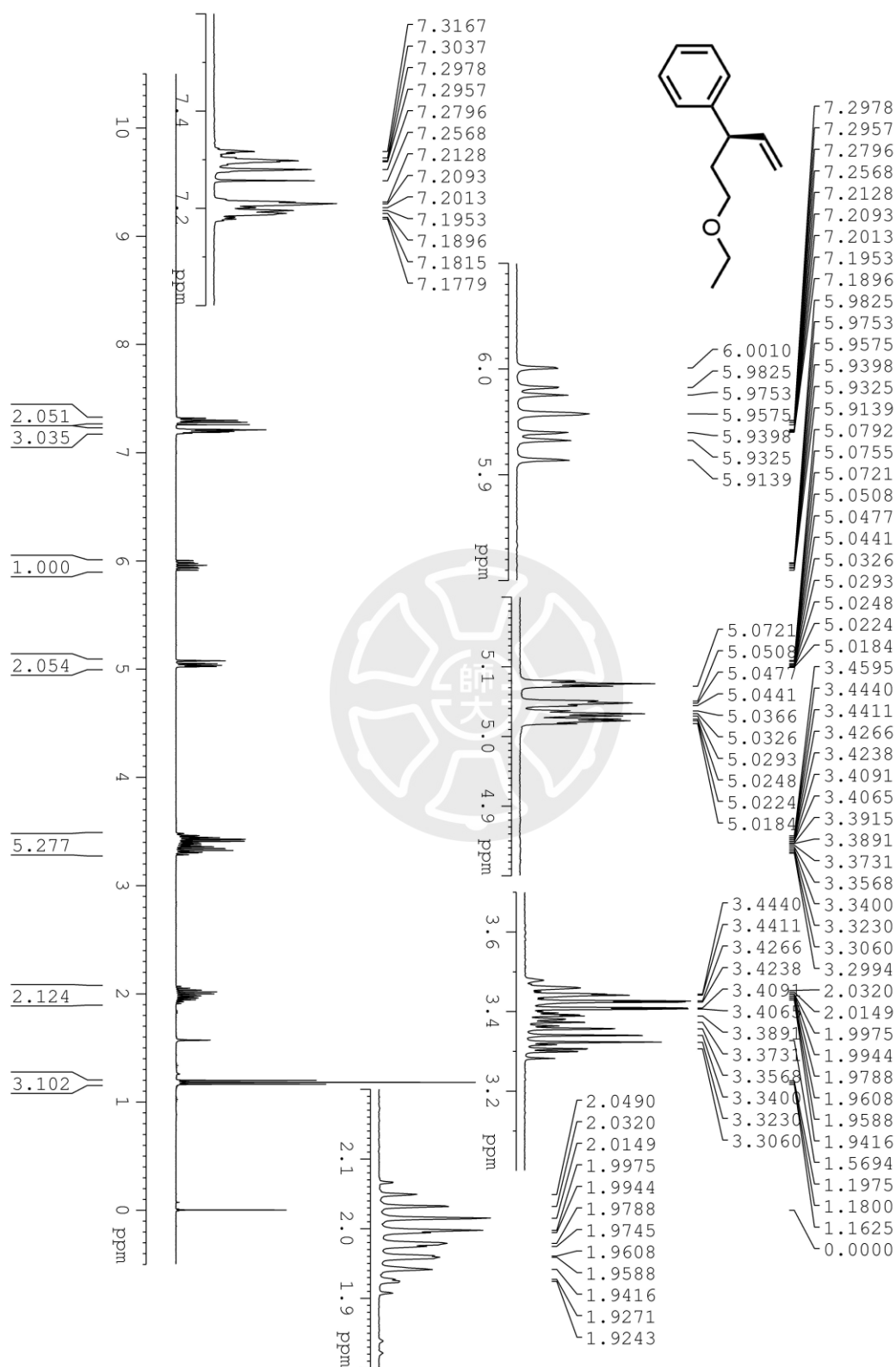


74. ^{13}C NMR of (*R*)-(*5-methoxypent-1-en-3-yl*)benzene (94am)

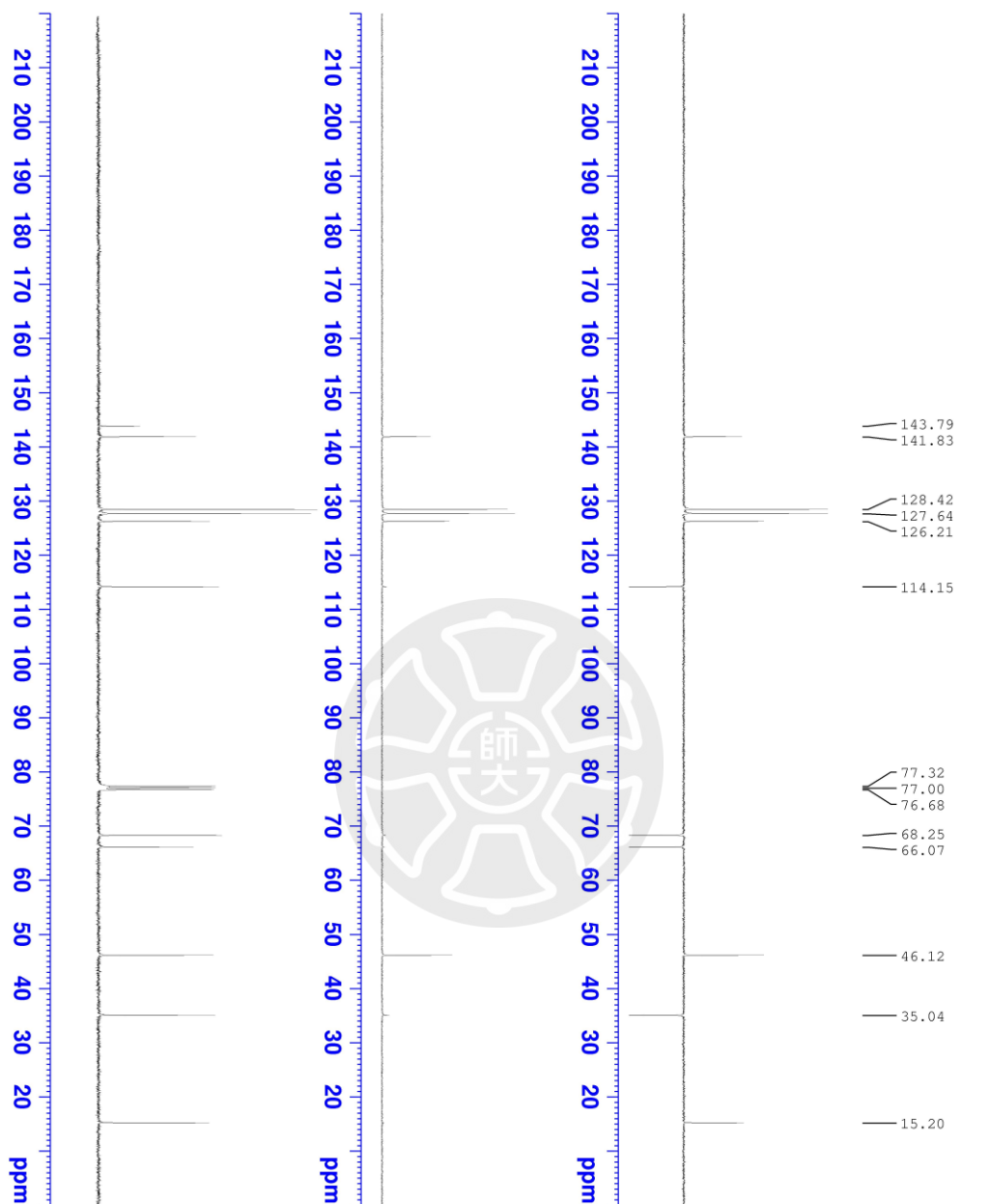


Current Data Parameters
NAME: topic 3-F: PhMagier substrate ene product data
EXPNO: 2
PROCNO: 1
F2 - Acquisition Parameters
Date_ 20230402
Time 14.35
INSTRUM spect
PROBHD 5 mm 1H/13C BBI
PULPROG zgpg30
TD 65536
SFO 125.760
AQ 0.0815744 sec
RG 188.09
DE 6.50 usec
TE 299.5 K
D1 2.00000000 sec
D2 0.00344828 sec
D3 0.00002000 sec
D4 1
D5 1
D6 1
D7 1
D8 1
D9 1
D10 1
D11 1
D12 1
D13 1
D14 1
D15 1
D16 1
D17 1
D18 1
D19 1
D20 1
D21 1
D22 1
D23 1
D24 1
D25 1
D26 1
D27 1
D28 1
D29 1
D30 1
D31 1
D32 1
D33 1
D34 1
D35 1
D36 1
D37 1
D38 1
D39 1
D40 1
D41 1
D42 1
D43 1
D44 1
D45 1
D46 1
D47 1
D48 1
D49 1
D50 1
D51 1
D52 1
D53 1
D54 1
D55 1
D56 1
D57 1
D58 1
D59 1
D60 1
D61 1
D62 1
D63 1
D64 1
D65 1
D66 1
D67 1
D68 1
D69 1
D70 1
D71 1
D72 1
D73 1
D74 1
D75 1
D76 1
D77 1
D78 1
D79 1
D80 1
D81 1
D82 1
D83 1
D84 1
D85 1
D86 1
D87 1
D88 1
D89 1
D90 1
D91 1
D92 1
D93 1
D94 1
D95 1
D96 1
D97 1
D98 1
D99 1
D100 1
D101 1
D102 1
D103 1
D104 1
D105 1
D106 1
D107 1
D108 1
D109 1
D110 1
D111 1
D112 1
D113 1
D114 1
D115 1
D116 1
D117 1
D118 1
D119 1
D120 1
D121 1
D122 1
D123 1
D124 1
D125 1
D126 1
D127 1
D128 1
D129 1
D130 1
D131 1
D132 1
D133 1
D134 1
D135 1
D136 1
D137 1
D138 1
D139 1
D140 1
D141 1
D142 1
D143 1
D144 1
D145 1
D146 1
D147 1
D148 1
D149 1
D150 1
D151 1
D152 1
D153 1
D154 1
D155 1
D156 1
D157 1
D158 1
D159 1
D160 1
D161 1
D162 1
D163 1
D164 1
D165 1
D166 1
D167 1
D168 1
D169 1
D170 1
D171 1
D172 1
D173 1
D174 1
D175 1
D176 1
D177 1
D178 1
D179 1
D180 1
D181 1
D182 1
D183 1
D184 1
D185 1
D186 1
D187 1
D188 1
D189 1
D190 1
D191 1
D192 1
D193 1
D194 1
D195 1
D196 1
D197 1
D198 1
D199 1
D200 1
D201 1
D202 1
D203 1
D204 1
D205 1
D206 1
D207 1
D208 1
D209 1
D210 1
D211 1
D212 1
D213 1
D214 1
D215 1
D216 1
D217 1
D218 1
D219 1
D220 1
D221 1
D222 1
D223 1
D224 1
D225 1
D226 1
D227 1
D228 1
D229 1
D230 1
D231 1
D232 1
D233 1
D234 1
D235 1
D236 1
D237 1
D238 1
D239 1
D240 1
D241 1
D242 1
D243 1
D244 1
D245 1
D246 1
D247 1
D248 1
D249 1
D250 1
D251 1
D252 1
D253 1
D254 1
D255 1
D256 1
D257 1
D258 1
D259 1
D260 1
D261 1
D262 1
D263 1
D264 1
D265 1
D266 1
D267 1
D268 1
D269 1
D270 1
D271 1
D272 1
D273 1
D274 1
D275 1
D276 1
D277 1
D278 1
D279 1
D280 1
D281 1
D282 1
D283 1
D284 1
D285 1
D286 1
D287 1
D288 1
D289 1
D290 1
D291 1
D292 1
D293 1
D294 1
D295 1
D296 1
D297 1
D298 1
D299 1
D300 1
D301 1
D302 1
D303 1
D304 1
D305 1
D306 1
D307 1
D308 1
D309 1
D310 1
D311 1
D312 1
D313 1
D314 1
D315 1
D316 1
D317 1
D318 1
D319 1
D320 1
D321 1
D322 1
D323 1
D324 1
D325 1
D326 1
D327 1
D328 1
D329 1
D330 1
D331 1
D332 1
D333 1
D334 1
D335 1
D336 1
D337 1
D338 1
D339 1
D340 1
D341 1
D342 1
D343 1
D344 1
D345 1
D346 1
D347 1
D348 1
D349 1
D350 1
D351 1
D352 1
D353 1
D354 1
D355 1
D356 1
D357 1
D358 1
D359 1
D360 1
D361 1
D362 1
D363 1
D364 1
D365 1
D366 1
D367 1
D368 1
D369 1
D370 1
D371 1
D372 1
D373 1
D374 1
D375 1
D376 1
D377 1
D378 1
D379 1
D380 1
D381 1
D382 1
D383 1
D384 1
D385 1
D386 1
D387 1
D388 1
D389 1
D390 1
D391 1
D392 1
D393 1
D394 1
D395 1
D396 1
D397 1
D398 1
D399 1
D400 1
D401 1
D402 1
D403 1
D404 1
D405 1
D406 1
D407 1
D408 1
D409 1
D410 1
D411 1
D412 1
D413 1
D414 1
D415 1
D416 1
D417 1
D418 1
D419 1
D420 1
D421 1
D422 1
D423 1
D424 1
D425 1
D426 1
D427 1
D428 1
D429 1
D430 1
D431 1
D432 1
D433 1
D434 1
D435 1
D436 1
D437 1
D438 1
D439 1
D440 1
D441 1
D442 1
D443 1
D444 1
D445 1
D446 1
D447 1
D448 1
D449 1
D450 1
D451 1
D452 1
D453 1
D454 1
D455 1
D456 1
D457 1
D458 1
D459 1
D460 1
D461 1
D462 1
D463 1
D464 1
D465 1
D466 1
D467 1
D468 1
D469 1
D470 1
D471 1
D472 1
D473 1
D474 1
D475 1
D476 1
D477 1
D478 1
D479 1
D480 1
D481 1
D482 1
D483 1
D484 1
D485 1
D486 1
D487 1
D488 1
D489 1
D490 1
D491 1
D492 1
D493 1
D494 1
D495 1
D496 1
D497 1
D498 1
D499 1
D500 1
D501 1
D502 1
D503 1
D504 1
D505 1
D506 1
D507 1
D508 1
D509 1
D510 1
D511 1
D512 1
D513 1
D514 1
D515 1
D516 1
D517 1
D518 1
D519 1
D520 1
D521 1
D522 1
D523 1
D524 1
D525 1
D526 1
D527 1
D528 1
D529 1
D530 1
D531 1
D532 1
D533 1
D534 1
D535 1
D536 1
D537 1
D538 1
D539 1
D540 1
D541 1
D542 1
D543 1
D544 1
D545 1
D546 1
D547 1
D548 1
D549 1
D550 1
D551 1
D552 1
D553 1
D554 1
D555 1
D556 1
D557 1
D558 1
D559 1
D560 1
D561 1
D562 1
D563 1
D564 1
D565 1
D566 1
D567 1
D568 1
D569 1
D570 1
D571 1
D572 1
D573 1
D574 1
D575 1
D576 1
D577 1
D578 1
D579 1
D580 1
D581 1
D582 1
D583 1
D584 1
D585 1
D586 1
D587 1
D588 1
D589 1
D590 1
D591 1
D592 1
D593 1
D594 1
D595 1
D596 1
D597 1
D598 1
D599 1
D600 1
D601 1
D602 1
D603 1
D604 1
D605 1
D606 1
D607 1
D608 1
D609 1
D610 1
D611 1
D612 1
D613 1
D614 1
D615 1
D616 1
D617 1
D618 1
D619 1
D620 1
D621 1
D622 1
D623 1
D624 1
D625 1
D626 1
D627 1
D628 1
D629 1
D630 1
D631 1
D632 1
D633 1
D634 1
D635 1
D636 1
D637 1
D638 1
D639 1
D640 1
D641 1
D642 1
D643 1
D644 1
D645 1
D646 1
D647 1
D648 1
D649 1
D650 1
D651 1
D652 1
D653 1
D654 1
D655 1
D656 1
D657 1
D658 1
D659 1
D660 1
D661 1
D662 1
D663 1
D664 1
D665 1
D666 1
D667 1
D668 1
D669 1
D670 1
D671 1
D672 1
D673 1
D674 1
D675 1
D676 1
D677 1
D678 1
D679 1
D680 1
D681 1
D682 1
D683 1
D684 1
D685 1
D686 1
D687 1
D688 1
D689 1
D690 1
D691 1
D692 1
D693 1
D694 1
D695 1
D696 1
D697 1
D698 1
D699 1
D700 1
D701 1
D702 1
D703 1
D704 1
D705 1
D706 1
D707 1
D708 1
D709 1
D710 1
D711 1
D712 1
D713 1
D714 1
D715 1
D716 1
D717 1
D718 1
D719 1
D720 1
D721 1
D722 1
D723 1
D724 1
D725 1
D726 1
D727 1
D728 1
D729 1
D730 1
D731 1
D732 1
D733 1
D734 1
D735 1
D736 1
D737 1
D738 1
D739 1
D740 1
D741 1
D742 1
D743 1
D744 1
D745 1
D746 1
D747 1
D748 1
D749 1
D750 1
D751 1
D752 1
D753 1
D754 1
D755 1
D756 1
D757 1
D758 1
D759 1
D760 1
D761 1
D762 1
D763 1
D764 1
D765 1
D766 1
D767 1
D768 1
D769 1
D770 1
D771 1
D772 1
D773 1
D774 1
D775 1
D776 1
D777 1
D778 1
D779 1
D780 1
D781 1
D782 1
D783 1
D784 1
D785 1
D786 1
D787 1
D788 1
D789 1
D790 1
D791 1
D792 1
D793 1
D794 1
D795 1
D796 1
D797 1
D798 1
D799 1
D800 1
D801 1
D802 1
D803 1
D804 1
D805 1
D806 1
D807 1
D808 1
D809 1
D810 1
D811 1
D812 1
D813 1
D814 1
D815 1
D816 1
D817 1
D818 1
D819 1
D820 1
D821 1
D822 1
D823 1
D824 1
D825 1
D826 1
D827 1
D828 1
D829 1
D830 1
D831 1
D832 1
D833 1
D834 1
D835 1
D836 1
D837 1
D838 1
D839 1
D840 1
D841 1
D842 1
D843 1
D844 1
D845 1
D846 1
D847 1
D848 1
D849 1
D850 1
D851 1
D852 1
D853 1
D854 1
D855 1
D856 1
D857 1
D858 1
D859 1
D860 1
D861 1
D862 1
D863 1
D864 1
D865 1
D866 1
D867 1
D868 1
D869 1
D870 1
D871 1
D872 1
D873 1
D874 1
D875 1
D876 1
D877 1
D878 1
D879 1
D880 1
D881 1
D882 1
D883 1
D884 1
D885 1
D886 1
D887 1
D888 1
D889 1
D890 1
D891 1
D892 1
D893 1
D894 1
D895 1
D896 1
D897 1
D898 1
D899 1
D900 1
D901 1
D902 1
D903 1
D904 1
D905 1
D906 1
D907 1
D908 1
D909 1
D910 1
D911 1
D912 1
D913 1
D914 1
D915 1
D916 1
D917 1
D918 1
D919 1
D920 1
D921 1
D922 1
D923 1
D924 1
D925 1
D926 1
D927 1
D928 1
D929 1
D930 1
D931 1
D932 1
D933 1
D934 1
D935 1
D936 1
D937 1
D938 1
D939 1
D940 1
D941 1
D942 1
D943 1
D944 1
D945 1
D946 1
D947 1
D948 1
D949 1
D950 1
D951 1
D952 1
D953 1
D954 1
D955 1
D956 1
D957 1
D958 1
D959 1
D960 1
D961 1
D962 1
D963 1
D964 1
D965 1
D966 1
D967 1
D968 1
D969 1
D970 1
D971 1
D972 1
D973 1
D974 1
D975 1
D976 1
D977 1
D978 1
D979 1
D980 1
D981 1
D982 1
D983 1
D984 1
D985 1
D986 1
D987 1
D988 1
D989 1
D990 1
D991 1
D992 1
D993 1
D994 1
D995 1
D996 1
D997 1
D998 1
D999 1
D1000 1
D1001 1
D1002 1
D1003 1
D1004 1
D1005 1
D1006 1
D1007 1
D1008 1
D1009 1
D1010 1
D1011 1
D1012 1
D1013 1
D1014 1
D1015 1
D1016 1
D1017 1
D1018 1
D1019 1
D1020 1
D1021 1
D1022 1
D1023 1
D1024 1
D1025 1
D1026 1
D1027 1
D1028 1
D1029 1
D1030 1
D1031 1
D1032 1
D1033 1
D1034 1
D1035 1
D1036 1
D1037 1
D1038 1
D1039 1
D1040 1
D1041 1
D1042 1
D1043 1
D1044 1
D1045 1
D1046 1
D1047 1
D1048 1
D1049 1
D1050 1
D1051 1
D1052 1
D1053 1
D1054 1
D1055 1
D1056 1
D1057 1
D1058 1
D1059 1
D1060 1
D1061 1
D1062 1
D1063 1
D1064 1
D1065 1
D1066 1
D1067 1
D1068 1
D1069 1
D1070 1
D1071 1
D1072 1
D1073 1
D1074 1
D1075 1
D1076 1
D1077 1
D1078 1
D1079 1
D1080 1
D1081 1
D1082 1
D1083 1
D1084 1
D1085 1
D1086 1
D1087 1
D1088 1
D1089 1
D1090 1
D1091 1
D1092 1
D1093 1
D1094 1
D1095 1
D1096 1
D1097 1
D1098 1
D1099 1
D1100 1
D1101 1
D1102 1
D1103 1
D1104 1
D1105 1
D1106 1
D1107 1
D1108 1
D1109 1
D1110 1
D1111 1
D1112 1
D1113 1
D1114 1
D1115 1
D1116 1
D1117 1
D1118 1
D1119 1
D1120 1
D1121 1
D1122 1
D1123 1
D1124 1
D1125 1
D1126 1
D1127 1
D1128 1
D1129 1
D1130 1
D1131 1
D1132 1
D1133 1
D1134 1
D1135 1
D1136 1
D1137 1
D1138 1
D1139 1
D1140 1
D1141 1
D1142 1
D1143 1
D1144 1
D1145 1
D1146 1
D1147 1
D1148 1
D1149 1
D1150 1
D1151 1
D1152 1
D1153 1
D1154 1
D1155 1
D1156 1
D1157 1
D1158 1
D1159 1
D1160 1
D1161 1
D1162 1
D1163 1
D1164 1
D1165 1
D1166 1
D1167 1
D1168 1
D1169 1
D1170 1
D1171 1
D1172 1
D1173 1
D1174 1
D1175 1
D1176 1
D1177 1
D1178 1
D1179 1
D1180 1
D1181 1
D1182 1
D1183 1
D1184 1
D1185 1
D1186 1
D1187 1
D1188 1
D1189 1
D1190 1
D1191 1
D1192 1
D1193 1
D1194 1
D1195 1
D1196 1
D1197 1
D1198 1
D1199 1
D1200 1
D1201 1
D1202 1
D1203 1
D1204 1
D1205 1
D1206 1
D1207 1
D1208 1
D1209 1
D1210 1
D1211 1
D1212 1
D1213 1
D1214 1
D1215 1
D1216 1
D1217 1
D1218 1
D1219 1
D1220 1
D1221 1
D1222 1
D1223 1
D1224 1
D1225 1
D1226 1
D1227 1
D1228 1
D1229 1
D1230 1
D1231 1
D1232 1
D1233 1
D1234 1
D1235 1
D1236 1
D1237 1
D1238 1
D1239 1
D1240 1
D1241 1
D1242 1
D1243 1
D1244 1
D1245 1
D1246 1
D1247 1
D1248 1
D1249 1
D1250 1
D1251 1
D1252 1
D1253 1
D1254 1
D1255 1
D1256 1
D1257 1
D1258 1
D1259 1
D1260 1
D1261 1
D1262 1
D1263 1
D1264 1
D1265 1
D1266 1
D1267 1
D1268 1
D1269 1
D1270 1
D1271 1
D1272 1
D1273 1
D1274 1
D1275 1
D1276 1
D1277 1
D1278 1
D1279 1
D1280 1
D1281 1
D1282 1
D1283 1
D1284 1
D1285 1
D1286 1
D1287 1
D1288

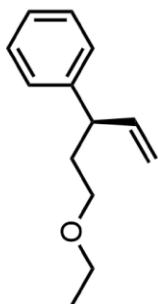
75. ¹H NMR of (R)-(5-ethoxypent-1-en-3-yl)benzene (94ae)



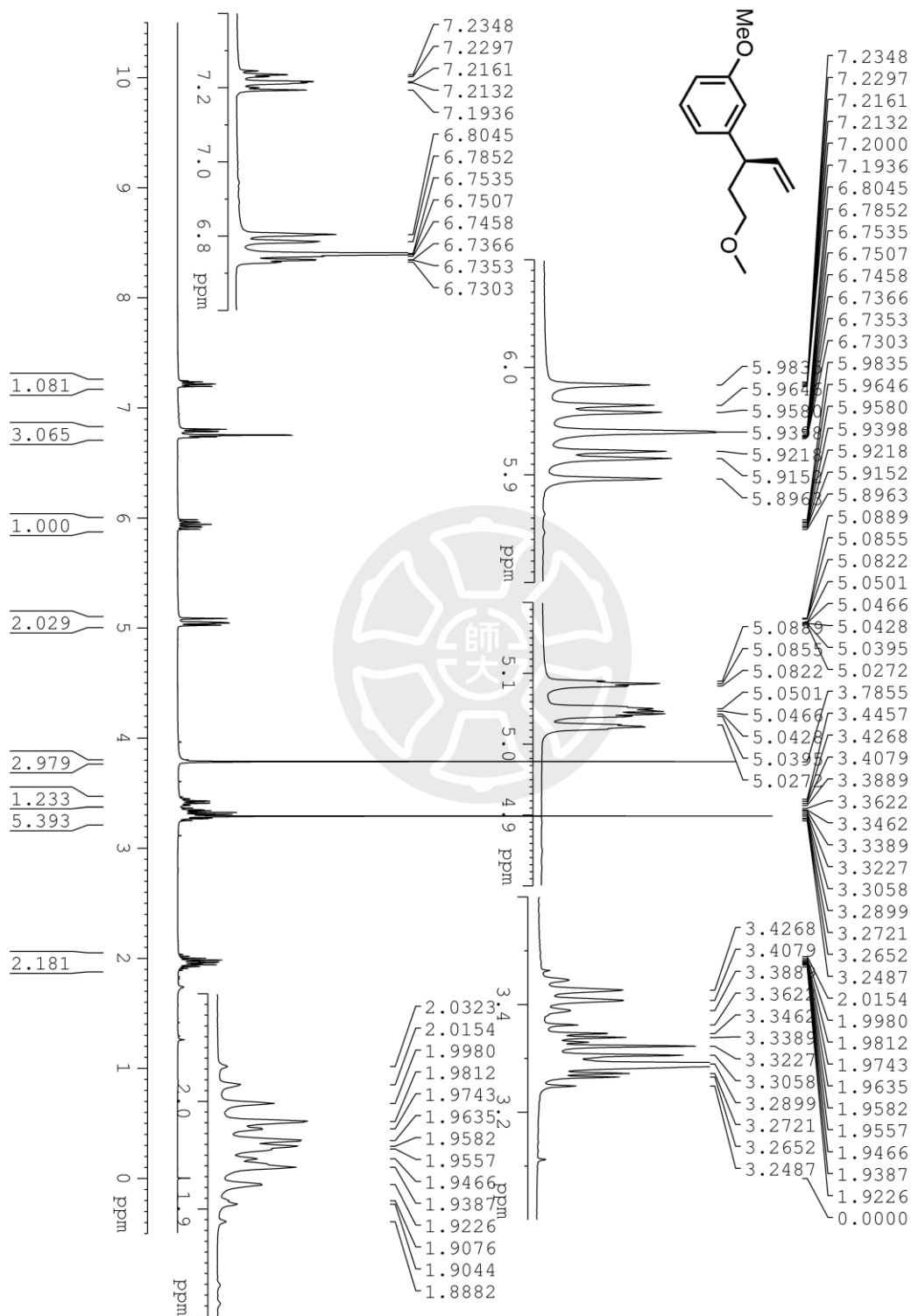
76. ^{13}C NMR of *(R)*-(5-ethoxypent-1-en-3-yl)benzene (94ae)



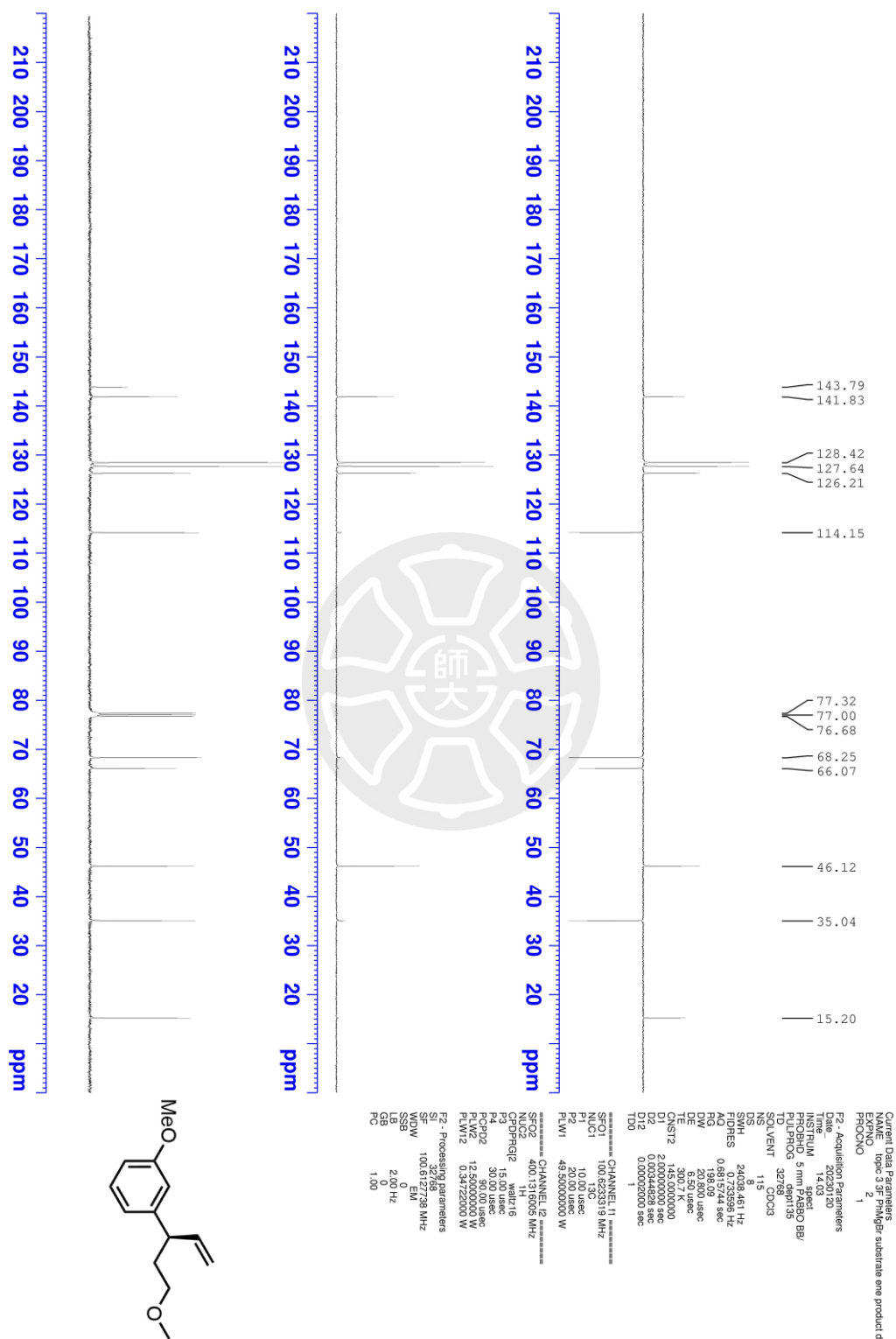
Current Data Parameters
NAME: topic 3 3F: Phlogifer substrate ene product data
EXPNO: 2
PROCNO: 1
F2 - Acquisition Parameters
Date_ 20230120
Time 14:03
INSTRUM spect
PROBHD 5 mm 1H/13C BBI
PULPROG zgpg30
TD 65536
SFO 125
AQ 0.0815744 sec
RG 188.09
DE 6.50 usec
TE 300.7 K
CNS12 145.000000
D1 2.00000000 sec
D2 0.00344828 sec
D12 0.00002000 sec
D10
===== CHANNEL f1 =====
NUC1 13C
P1 100.625319 MHz
PC 1.00
===== CHANNEL f2 =====
NUC2 1H
P2 400.1319005 MHz
PC 1.00
===== CHANNEL f3 =====
NUC3 1H
P3 400.1319005 MHz
PC 1.00
===== CHANNEL f4 =====
NUC4 1H
P4 400.1319005 MHz
PC 1.00
===== CHANNEL f5 =====
NUC5 1H
P5 400.1319005 MHz
PC 1.00
===== CHANNEL f6 =====
NUC6 1H
P6 400.1319005 MHz
PC 1.00
===== CHANNEL f7 =====
NUC7 1H
P7 400.1319005 MHz
PC 1.00
===== CHANNEL f8 =====
NUC8 1H
P8 400.1319005 MHz
PC 1.00
===== CHANNEL f9 =====
NUC9 1H
P9 400.1319005 MHz
PC 1.00
===== CHANNEL f10 =====
NUC10 1H
P10 400.1319005 MHz
PC 1.00
===== CHANNEL f11 =====
NUC11 1H
P11 400.1319005 MHz
PC 1.00
===== CHANNEL f12 =====
NUC12 1H
P12 400.1319005 MHz
PC 1.00
===== CHANNEL f13 =====
NUC13 1H
P13 400.1319005 MHz
PC 1.00
===== CHANNEL f14 =====
NUC14 1H
P14 400.1319005 MHz
PC 1.00
===== CHANNEL f15 =====
NUC15 1H
P15 400.1319005 MHz
PC 1.00
===== CHANNEL f16 =====
NUC16 1H
P16 400.1319005 MHz
PC 1.00
===== CHANNEL f17 =====
NUC17 1H
P17 400.1319005 MHz
PC 1.00
===== CHANNEL f18 =====
NUC18 1H
P18 400.1319005 MHz
PC 1.00
===== CHANNEL f19 =====
NUC19 1H
P19 400.1319005 MHz
PC 1.00
===== CHANNEL f20 =====
NUC20 1H
P20 400.1319005 MHz
PC 1.00
===== CHANNEL f21 =====
NUC21 1H
P21 400.1319005 MHz
PC 1.00
===== CHANNEL f22 =====
NUC22 1H
P22 400.1319005 MHz
PC 1.00
===== CHANNEL f23 =====
NUC23 1H
P23 400.1319005 MHz
PC 1.00
===== CHANNEL f24 =====
NUC24 1H
P24 400.1319005 MHz
PC 1.00
===== CHANNEL f25 =====
NUC25 1H
P25 400.1319005 MHz
PC 1.00
===== CHANNEL f26 =====
NUC26 1H
P26 400.1319005 MHz
PC 1.00
===== CHANNEL f27 =====
NUC27 1H
P27 400.1319005 MHz
PC 1.00
===== CHANNEL f28 =====
NUC28 1H
P28 400.1319005 MHz
PC 1.00
===== CHANNEL f29 =====
NUC29 1H
P29 400.1319005 MHz
PC 1.00
===== CHANNEL f30 =====
NUC30 1H
P30 400.1319005 MHz
PC 1.00
===== CHANNEL f31 =====
NUC31 1H
P31 400.1319005 MHz
PC 1.00
===== CHANNEL f32 =====
NUC32 1H
P32 400.1319005 MHz
PC 1.00
===== CHANNEL f33 =====
NUC33 1H
P33 400.1319005 MHz
PC 1.00
===== CHANNEL f34 =====
NUC34 1H
P34 400.1319005 MHz
PC 1.00
===== CHANNEL f35 =====
NUC35 1H
P35 400.1319005 MHz
PC 1.00
===== CHANNEL f36 =====
NUC36 1H
P36 400.1319005 MHz
PC 1.00
===== CHANNEL f37 =====
NUC37 1H
P37 400.1319005 MHz
PC 1.00
===== CHANNEL f38 =====
NUC38 1H
P38 400.1319005 MHz
PC 1.00
===== CHANNEL f39 =====
NUC39 1H
P39 400.1319005 MHz
PC 1.00
===== CHANNEL f40 =====
NUC40 1H
P40 400.1319005 MHz
PC 1.00
===== CHANNEL f41 =====
NUC41 1H
P41 400.1319005 MHz
PC 1.00
===== CHANNEL f42 =====
NUC42 1H
P42 400.1319005 MHz
PC 1.00
===== CHANNEL f43 =====
NUC43 1H
P43 400.1319005 MHz
PC 1.00
===== CHANNEL f44 =====
NUC44 1H
P44 400.1319005 MHz
PC 1.00
===== CHANNEL f45 =====
NUC45 1H
P45 400.1319005 MHz
PC 1.00
===== CHANNEL f46 =====
NUC46 1H
P46 400.1319005 MHz
PC 1.00
===== CHANNEL f47 =====
NUC47 1H
P47 400.1319005 MHz
PC 1.00
===== CHANNEL f48 =====
NUC48 1H
P48 400.1319005 MHz
PC 1.00
===== CHANNEL f49 =====
NUC49 1H
P49 400.1319005 MHz
PC 1.00
===== CHANNEL f50 =====
NUC50 1H
P50 400.1319005 MHz
PC 1.00
===== CHANNEL f51 =====
NUC51 1H
P51 400.1319005 MHz
PC 1.00
===== CHANNEL f52 =====
NUC52 1H
P52 400.1319005 MHz
PC 1.00
===== CHANNEL f53 =====
NUC53 1H
P53 400.1319005 MHz
PC 1.00
===== CHANNEL f54 =====
NUC54 1H
P54 400.1319005 MHz
PC 1.00
===== CHANNEL f55 =====
NUC55 1H
P55 400.1319005 MHz
PC 1.00
===== CHANNEL f56 =====
NUC56 1H
P56 400.1319005 MHz
PC 1.00
===== CHANNEL f57 =====
NUC57 1H
P57 400.1319005 MHz
PC 1.00
===== CHANNEL f58 =====
NUC58 1H
P58 400.1319005 MHz
PC 1.00
===== CHANNEL f59 =====
NUC59 1H
P59 400.1319005 MHz
PC 1.00
===== CHANNEL f60 =====
NUC60 1H
P60 400.1319005 MHz
PC 1.00
===== CHANNEL f61 =====
NUC61 1H
P61 400.1319005 MHz
PC 1.00
===== CHANNEL f62 =====
NUC62 1H
P62 400.1319005 MHz
PC 1.00
===== CHANNEL f63 =====
NUC63 1H
P63 400.1319005 MHz
PC 1.00
===== CHANNEL f64 =====
NUC64 1H
P64 400.1319005 MHz
PC 1.00
===== CHANNEL f65 =====
NUC65 1H
P65 400.1319005 MHz
PC 1.00
===== CHANNEL f66 =====
NUC66 1H
P66 400.1319005 MHz
PC 1.00
===== CHANNEL f67 =====
NUC67 1H
P67 400.1319005 MHz
PC 1.00
===== CHANNEL f68 =====
NUC68 1H
P68 400.1319005 MHz
PC 1.00
===== CHANNEL f69 =====
NUC69 1H
P69 400.1319005 MHz
PC 1.00
===== CHANNEL f70 =====
NUC70 1H
P70 400.1319005 MHz
PC 1.00
===== CHANNEL f71 =====
NUC71 1H
P71 400.1319005 MHz
PC 1.00
===== CHANNEL f72 =====
NUC72 1H
P72 400.1319005 MHz
PC 1.00
===== CHANNEL f73 =====
NUC73 1H
P73 400.1319005 MHz
PC 1.00
===== CHANNEL f74 =====
NUC74 1H
P74 400.1319005 MHz
PC 1.00
===== CHANNEL f75 =====
NUC75 1H
P75 400.1319005 MHz
PC 1.00
===== CHANNEL f76 =====
NUC76 1H
P76 400.1319005 MHz
PC 1.00
===== CHANNEL f77 =====
NUC77 1H
P77 400.1319005 MHz
PC 1.00
===== CHANNEL f78 =====
NUC78 1H
P78 400.1319005 MHz
PC 1.00
===== CHANNEL f79 =====
NUC79 1H
P79 400.1319005 MHz
PC 1.00
===== CHANNEL f80 =====
NUC80 1H
P80 400.1319005 MHz
PC 1.00
===== CHANNEL f81 =====
NUC81 1H
P81 400.1319005 MHz
PC 1.00
===== CHANNEL f82 =====
NUC82 1H
P82 400.1319005 MHz
PC 1.00
===== CHANNEL f83 =====
NUC83 1H
P83 400.1319005 MHz
PC 1.00
===== CHANNEL f84 =====
NUC84 1H
P84 400.1319005 MHz
PC 1.00
===== CHANNEL f85 =====
NUC85 1H
P85 400.1319005 MHz
PC 1.00
===== CHANNEL f86 =====
NUC86 1H
P86 400.1319005 MHz
PC 1.00
===== CHANNEL f87 =====
NUC87 1H
P87 400.1319005 MHz
PC 1.00
===== CHANNEL f88 =====
NUC88 1H
P88 400.1319005 MHz
PC 1.00
===== CHANNEL f89 =====
NUC89 1H
P89 400.1319005 MHz
PC 1.00
===== CHANNEL f90 =====
NUC90 1H
P90 400.1319005 MHz
PC 1.00
===== CHANNEL f91 =====
NUC91 1H
P91 400.1319005 MHz
PC 1.00
===== CHANNEL f92 =====
NUC92 1H
P92 400.1319005 MHz
PC 1.00
===== CHANNEL f93 =====
NUC93 1H
P93 400.1319005 MHz
PC 1.00
===== CHANNEL f94 =====
NUC94 1H
P94 400.1319005 MHz
PC 1.00
===== CHANNEL f95 =====
NUC95 1H
P95 400.1319005 MHz
PC 1.00
===== CHANNEL f96 =====
NUC96 1H
P96 400.1319005 MHz
PC 1.00
===== CHANNEL f97 =====
NUC97 1H
P97 400.1319005 MHz
PC 1.00
===== CHANNEL f98 =====
NUC98 1H
P98 400.1319005 MHz
PC 1.00
===== CHANNEL f99 =====
NUC99 1H
P99 400.1319005 MHz
PC 1.00
===== CHANNEL f100 =====
NUC100 1H
P100 400.1319005 MHz
PC 1.00



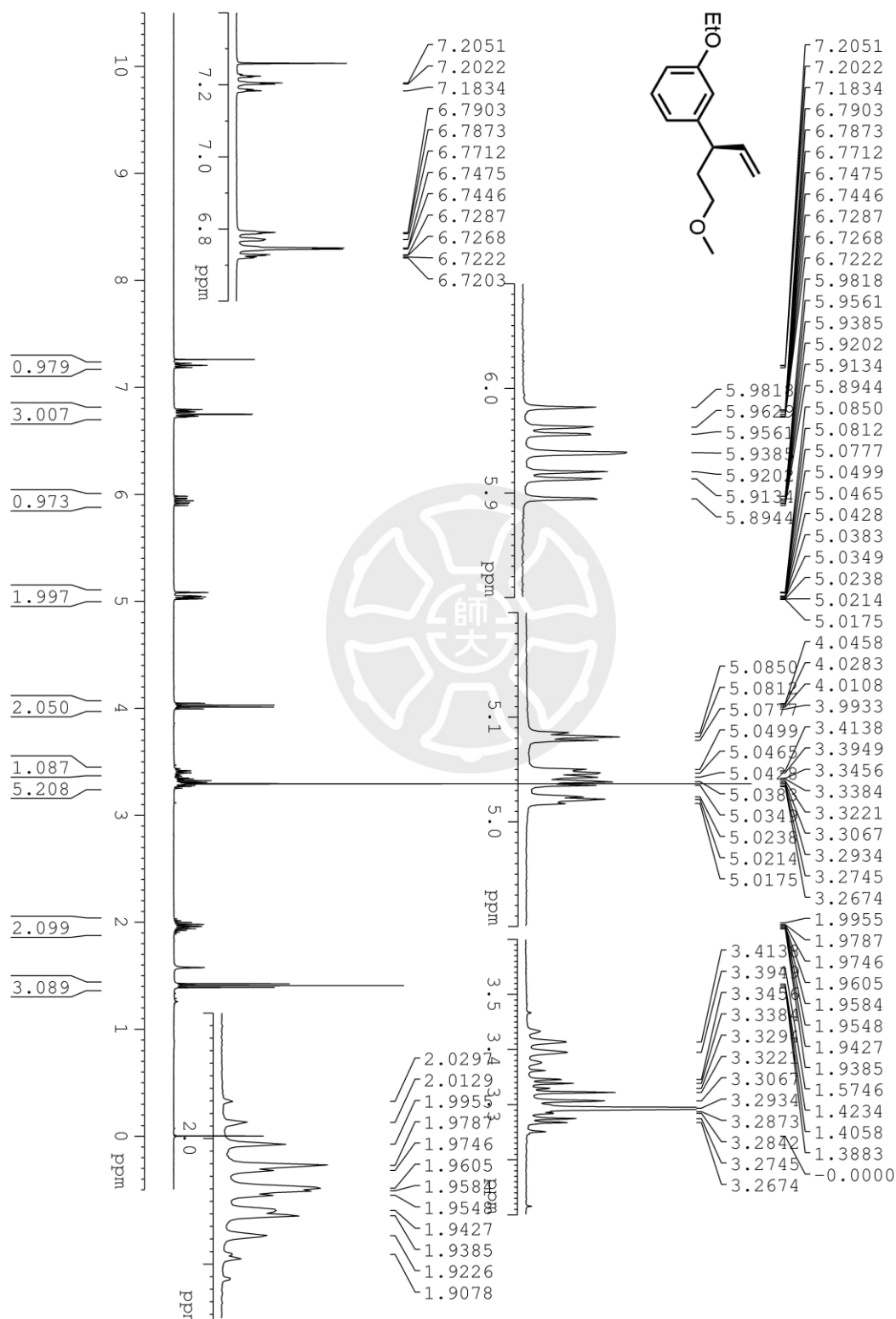
77. ^1H NMR of (*R*)-1-methoxy-3-(5-methoxypent-1-en-3-yl)benzene (94bm)

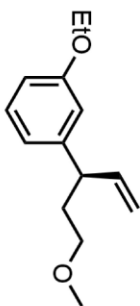
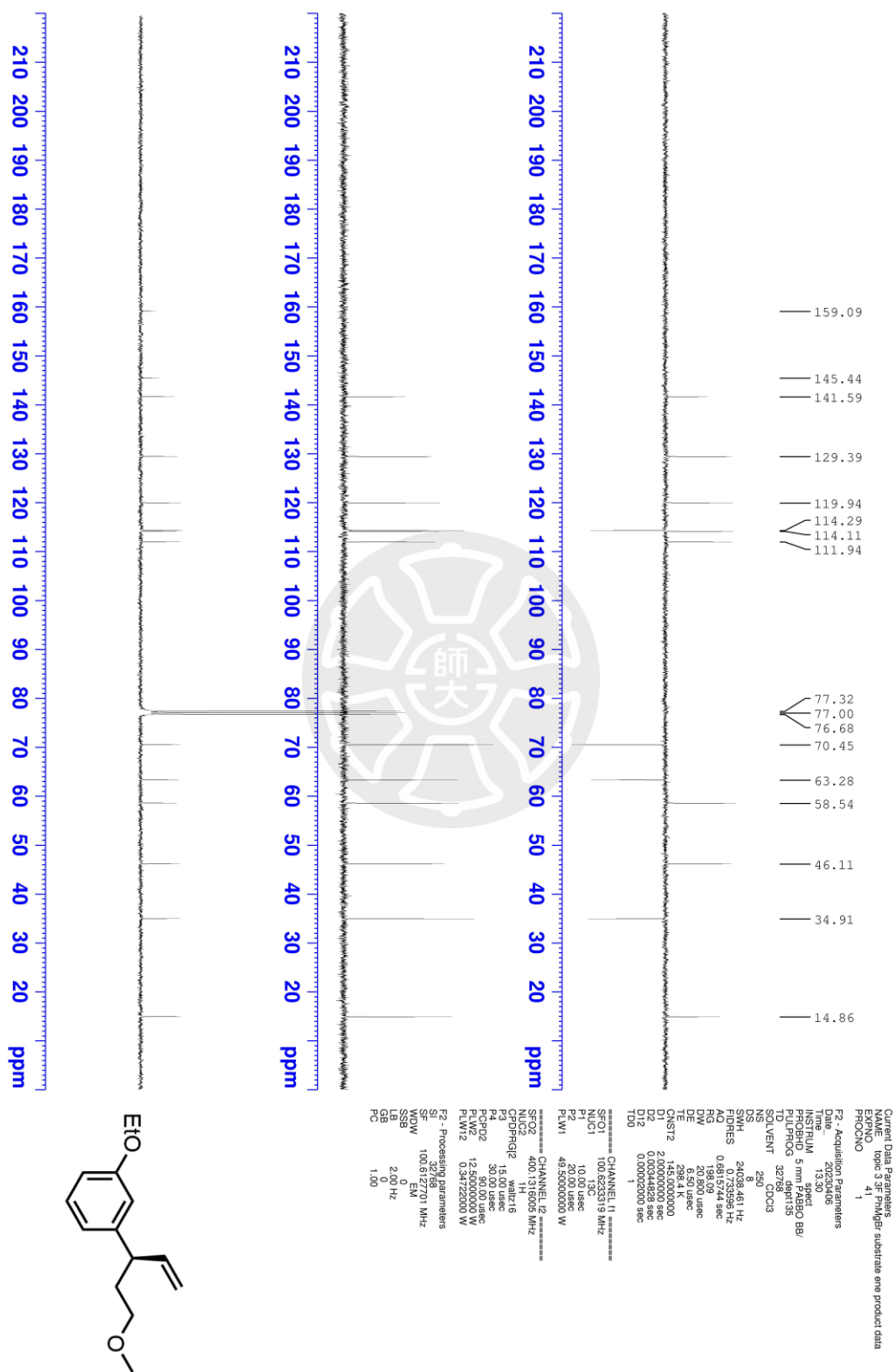


78. ¹³C NMR of (*R*)-1-methoxy-3-(5-methoxypent-1-en-3-yl)benzene (94bm)

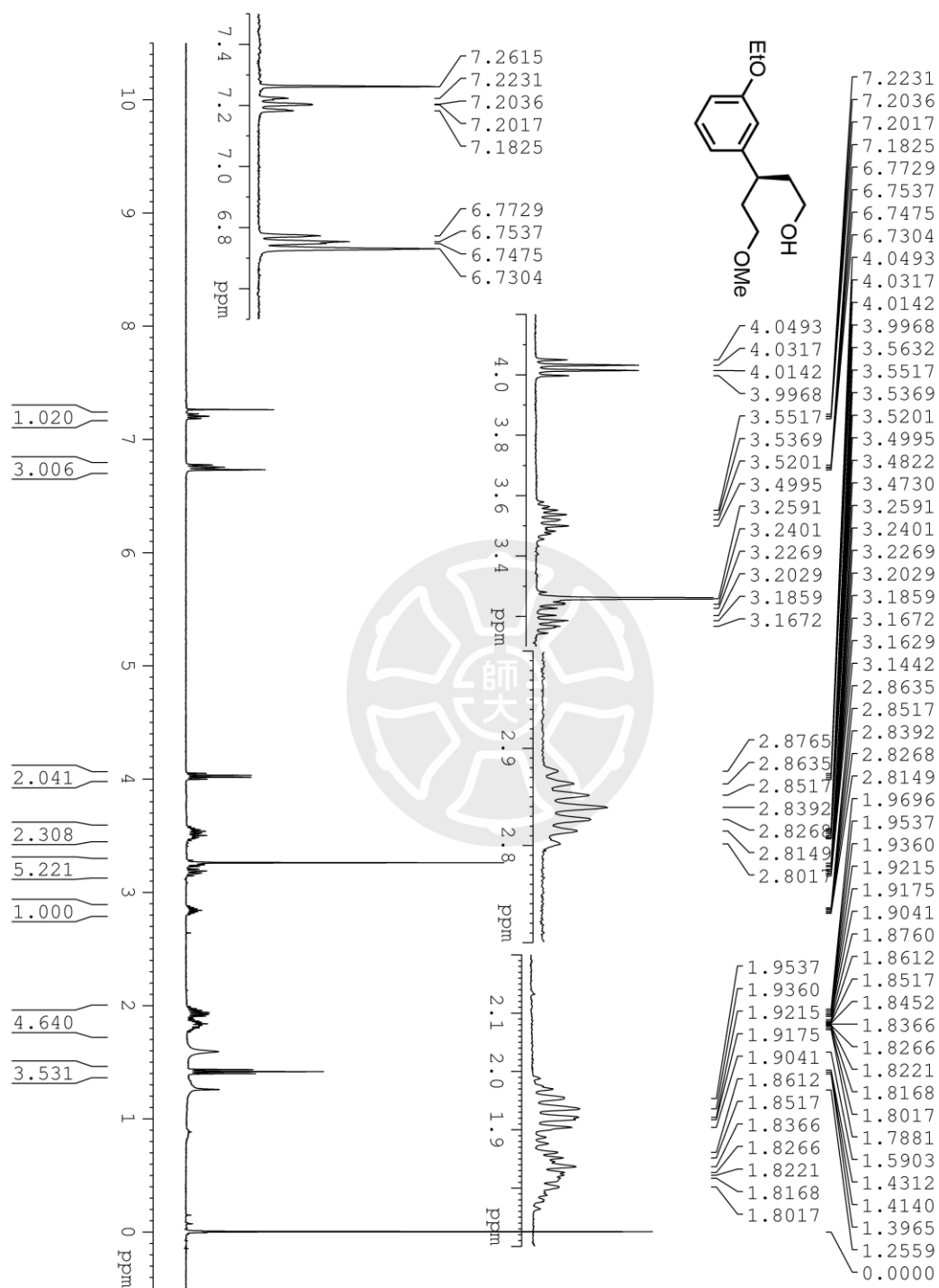


79. ^1H NMR of (*R*)-1-ethoxy-3-(5-methoxypent-1-en-3-yl)benzene (94cm)

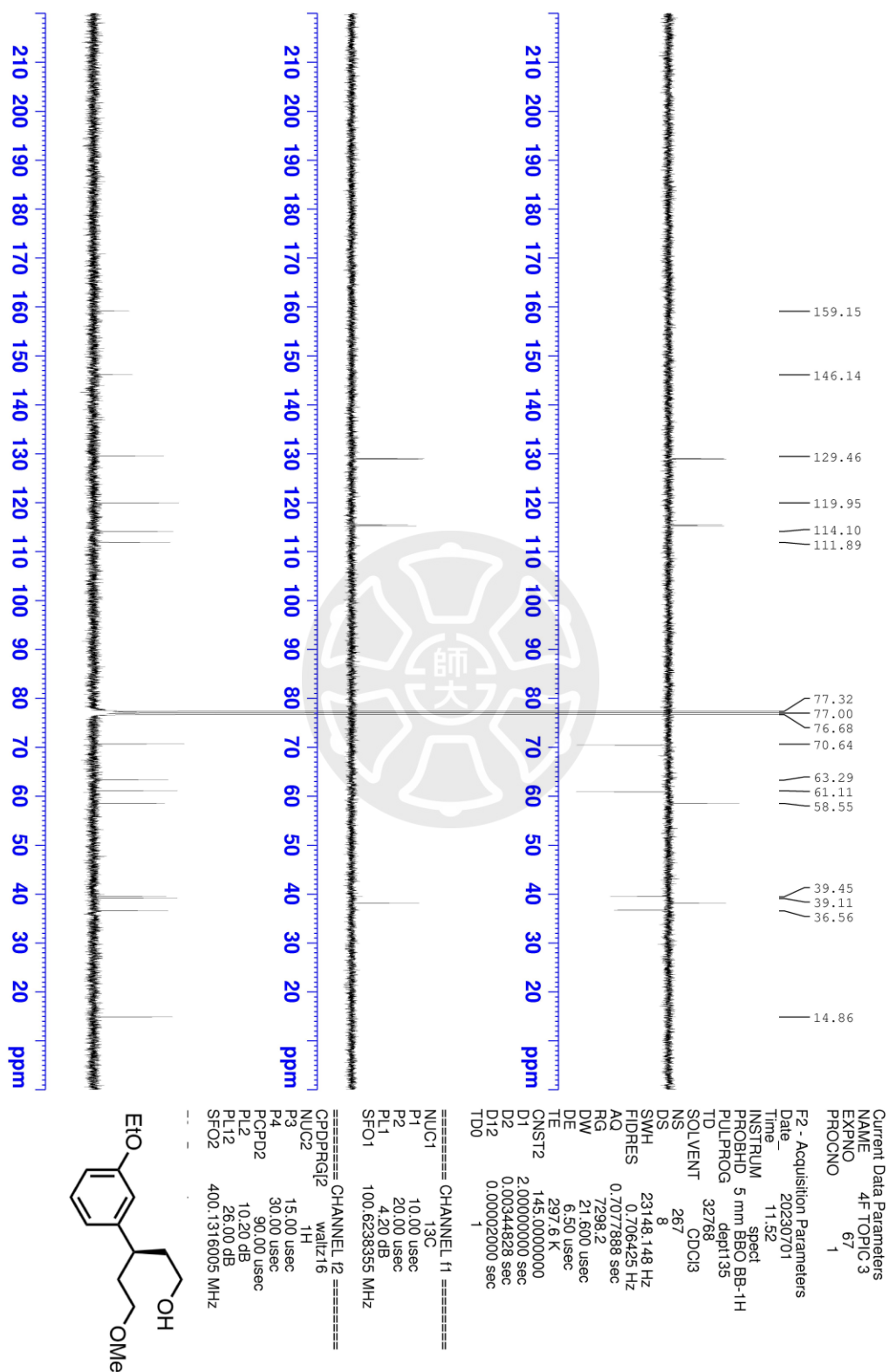


80. ¹³C NMR of (*R*)-1-ethoxy-3-(5-methoxypent-1-en-3-yl)benzene (94cm)

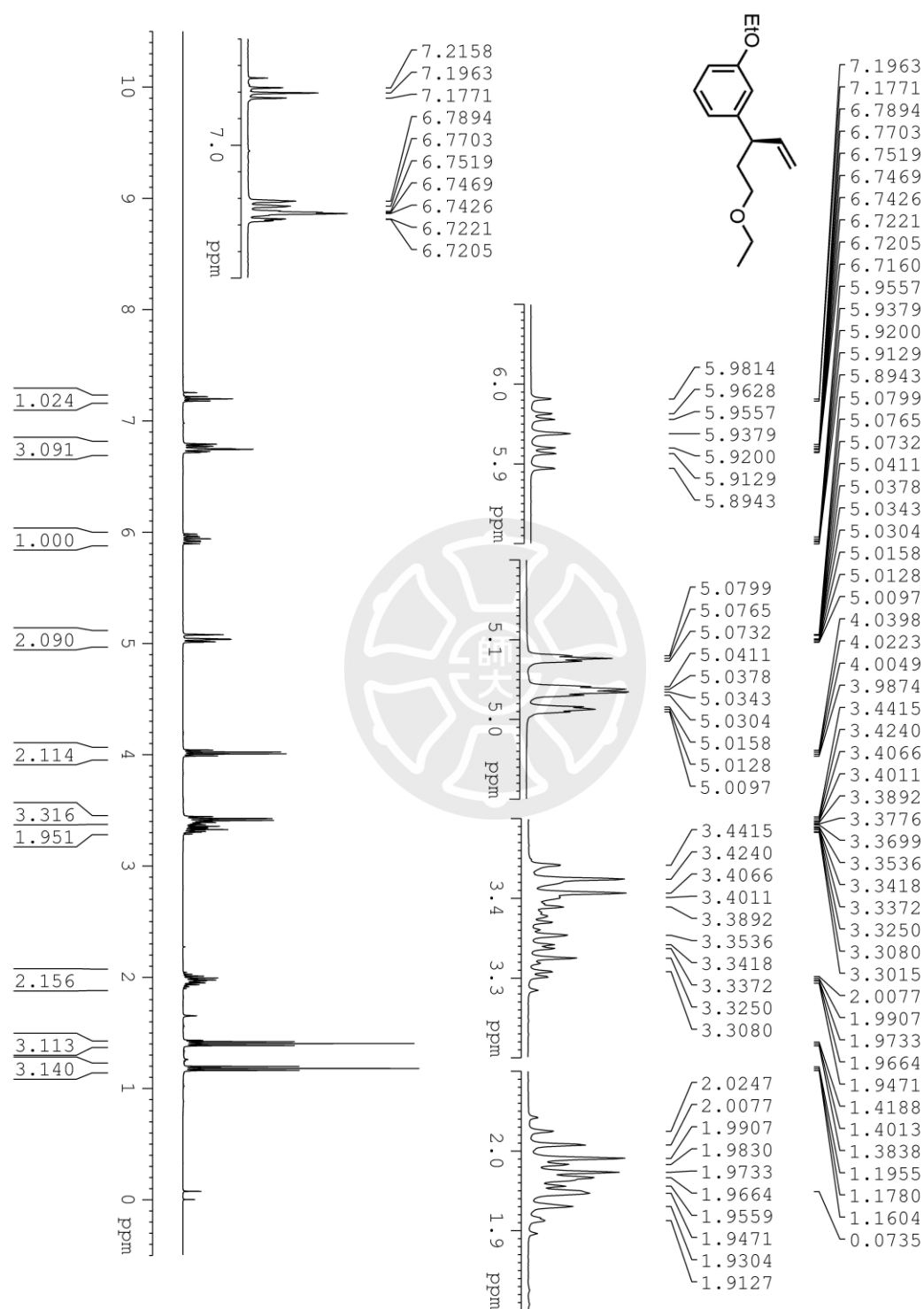
81. ^1H NMR of (*S*)-3-(3-ethoxyphenyl)-5-methoxypentan-1-ol (95cm)



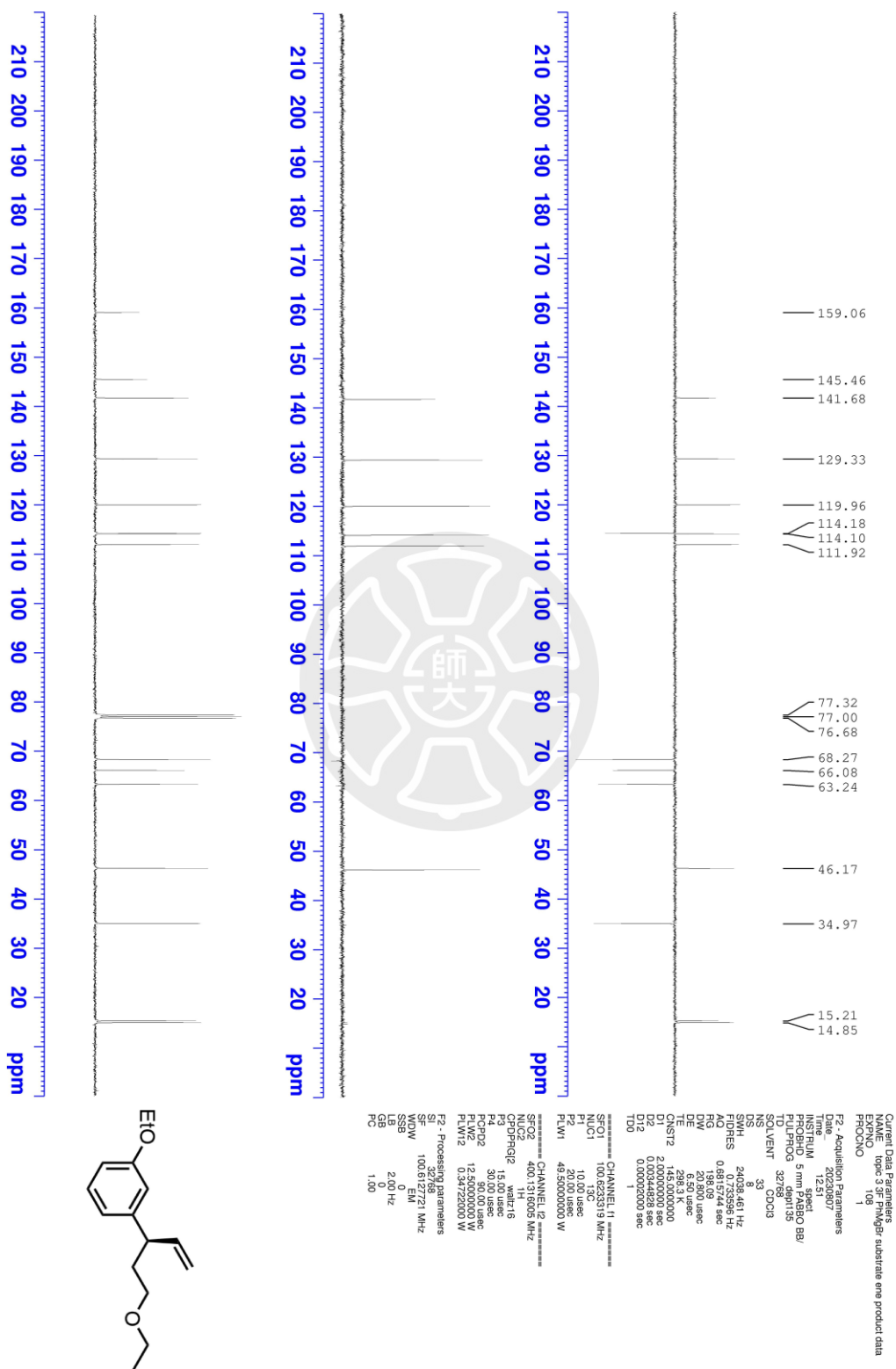
82. ^{13}C NMR of (S)-3-(3-ethoxyphenyl)-5-methoxypentan-1-ol (95cm)



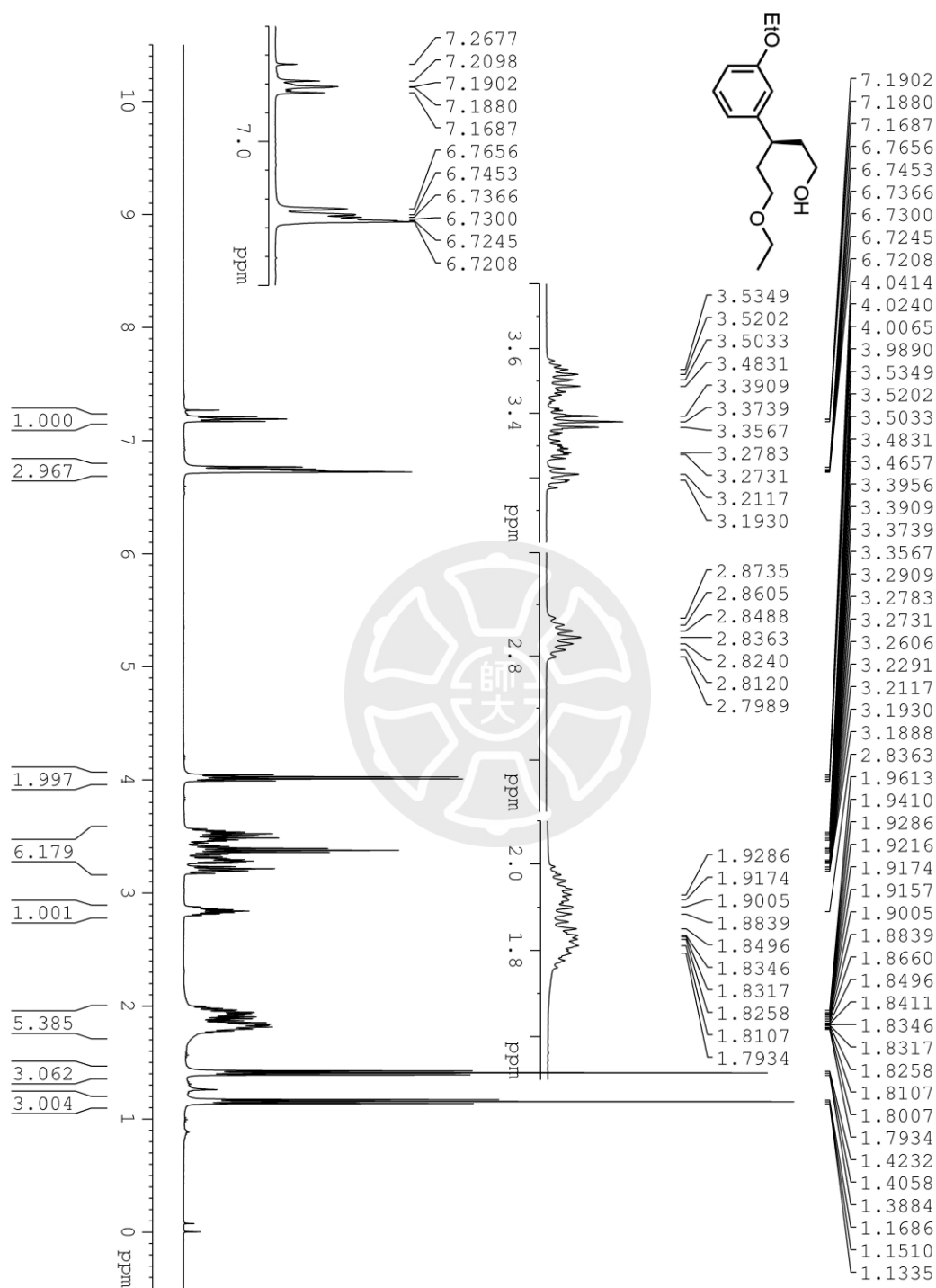
83. ^1H NMR of (*R*)-1-ethoxy-3-(5-ethoxypent-1-en-3-yl)benzene (94ce)



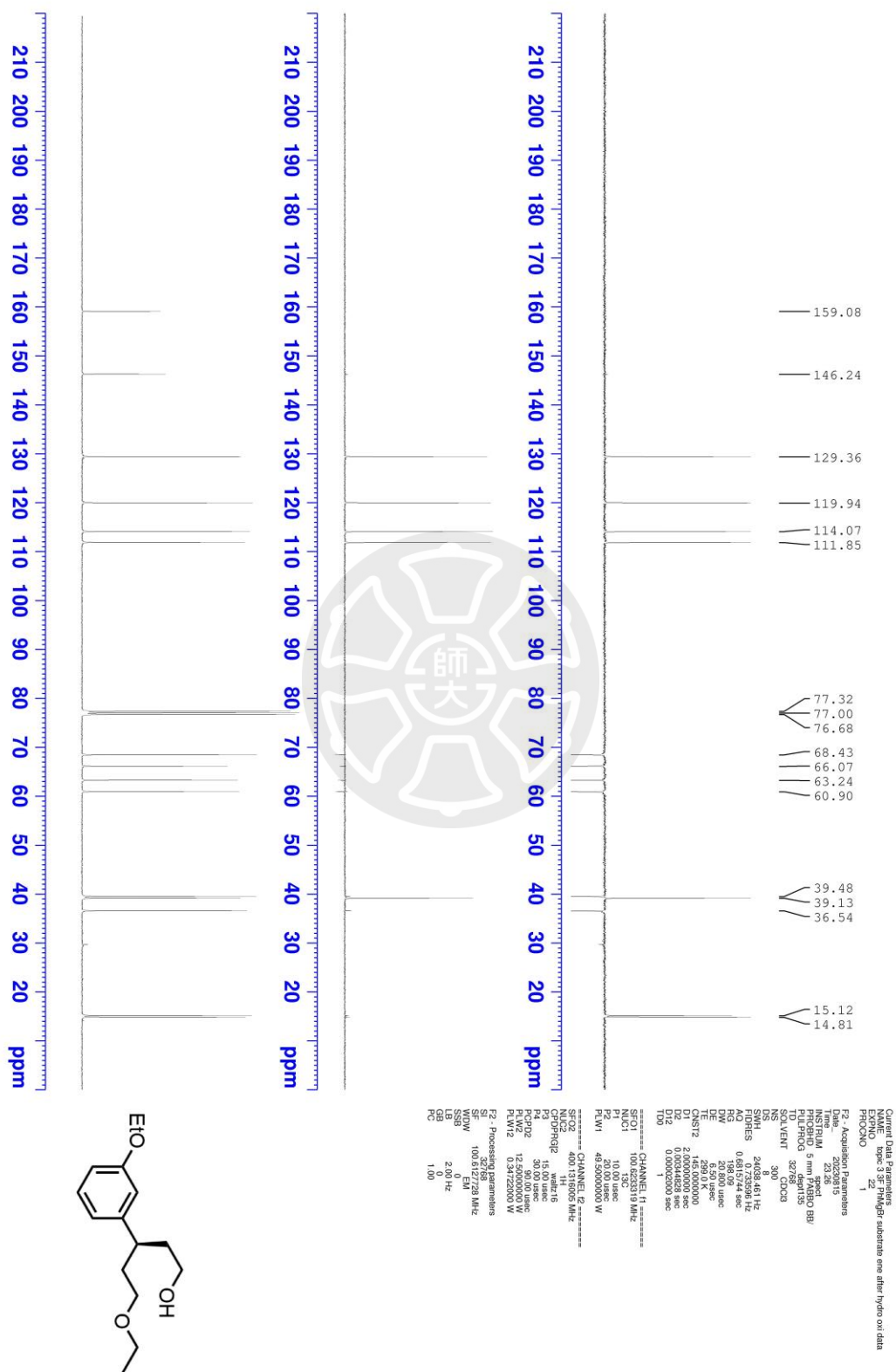
84. ^{13}C NMR of (*R*)-1-ethoxy-3-(5-ethoxypent-1-en-3-yl)benzene (94ce)



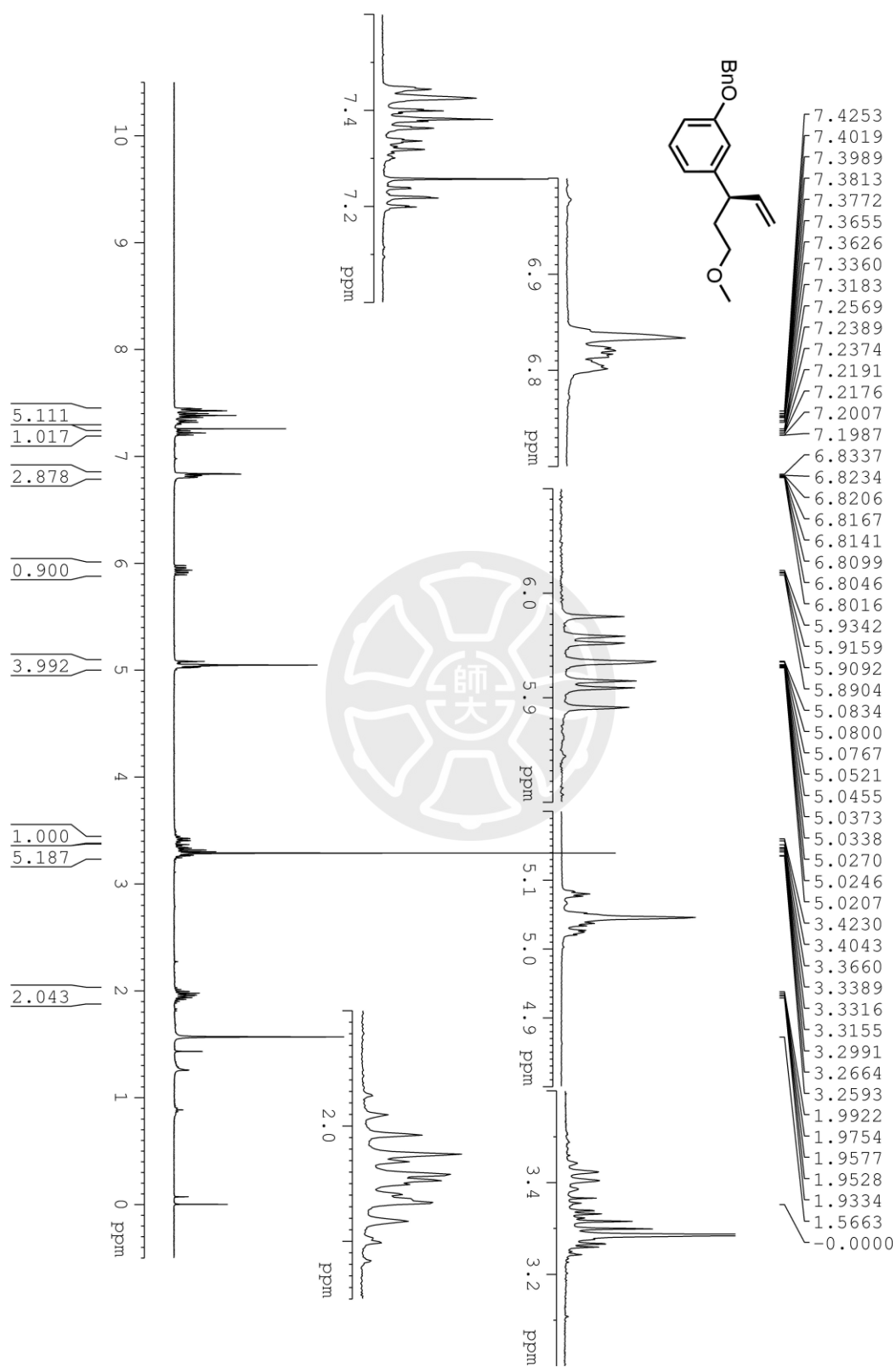
85. ^1H NMR of (S)-5-ethoxy-3-(3-ethoxyphenyl)pentan-1-ol (95ce)



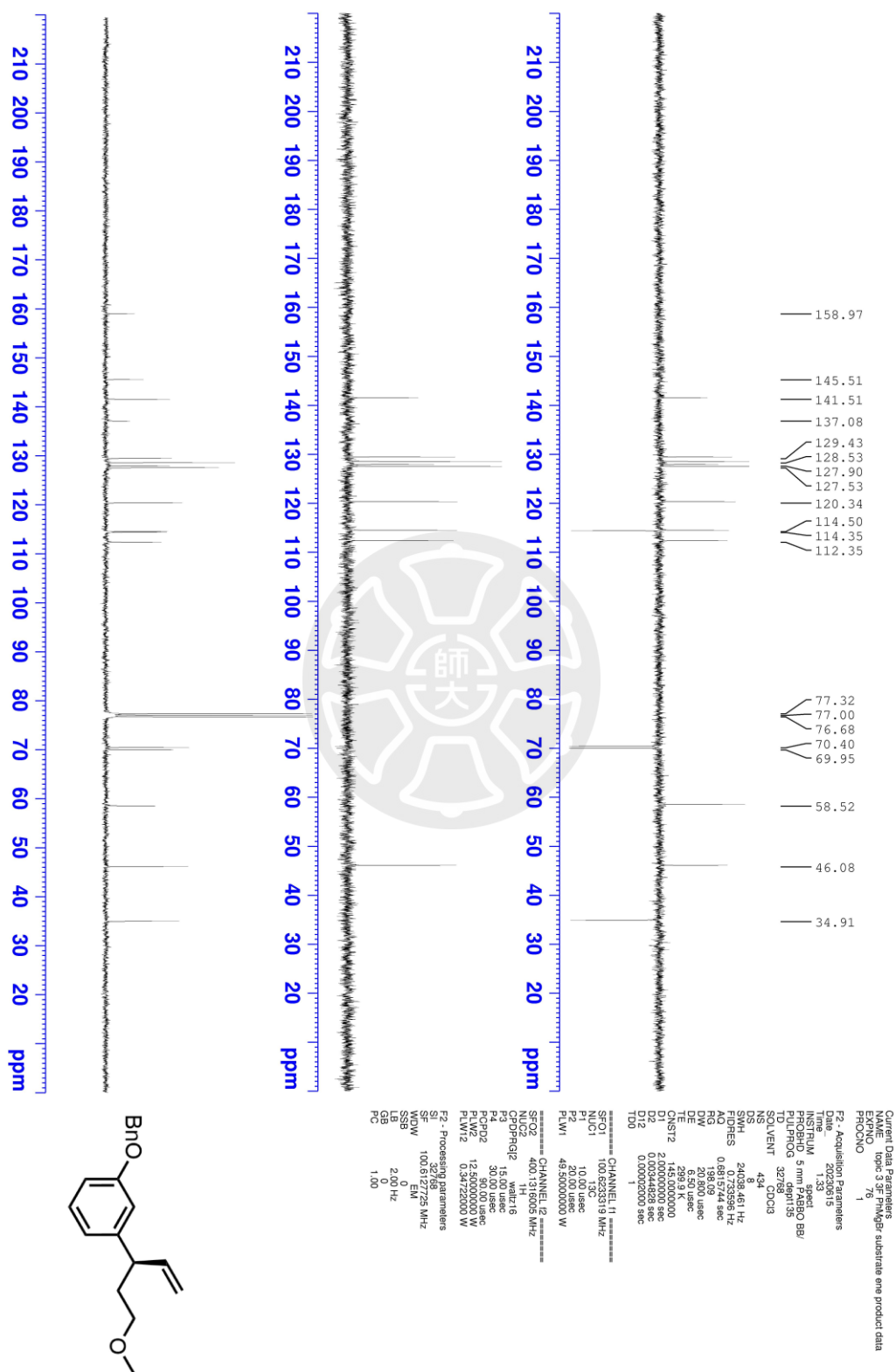
86. ^{13}C NMR of (*S*)-5-ethoxy-3-(3-ethoxyphenyl)pentan-1-ol (95ce)



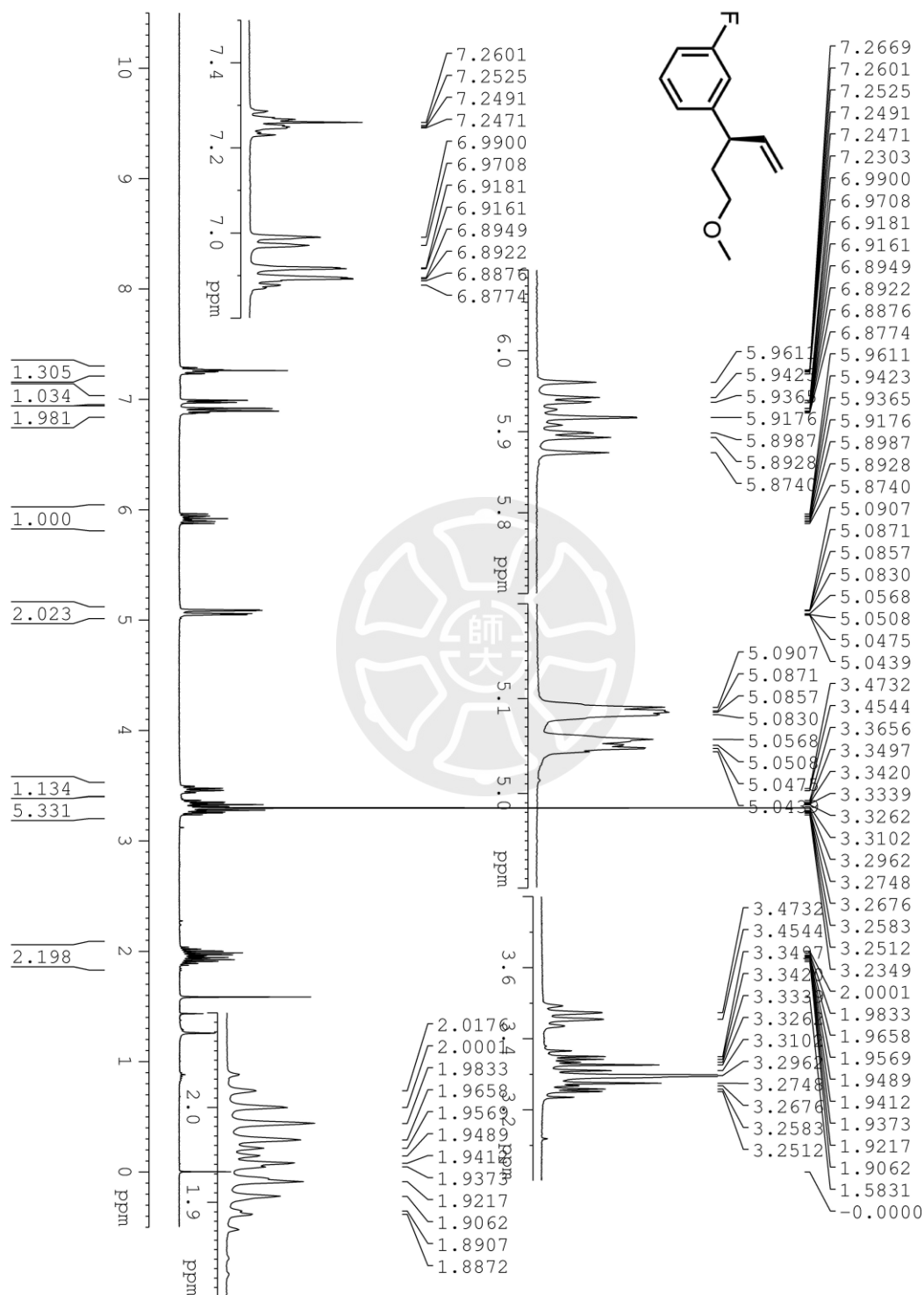
87. ^1H NMR of (*R*)-1-(benzyloxy)-3-(5-methoxypent-1-en-3-yl)benzene (94dm)



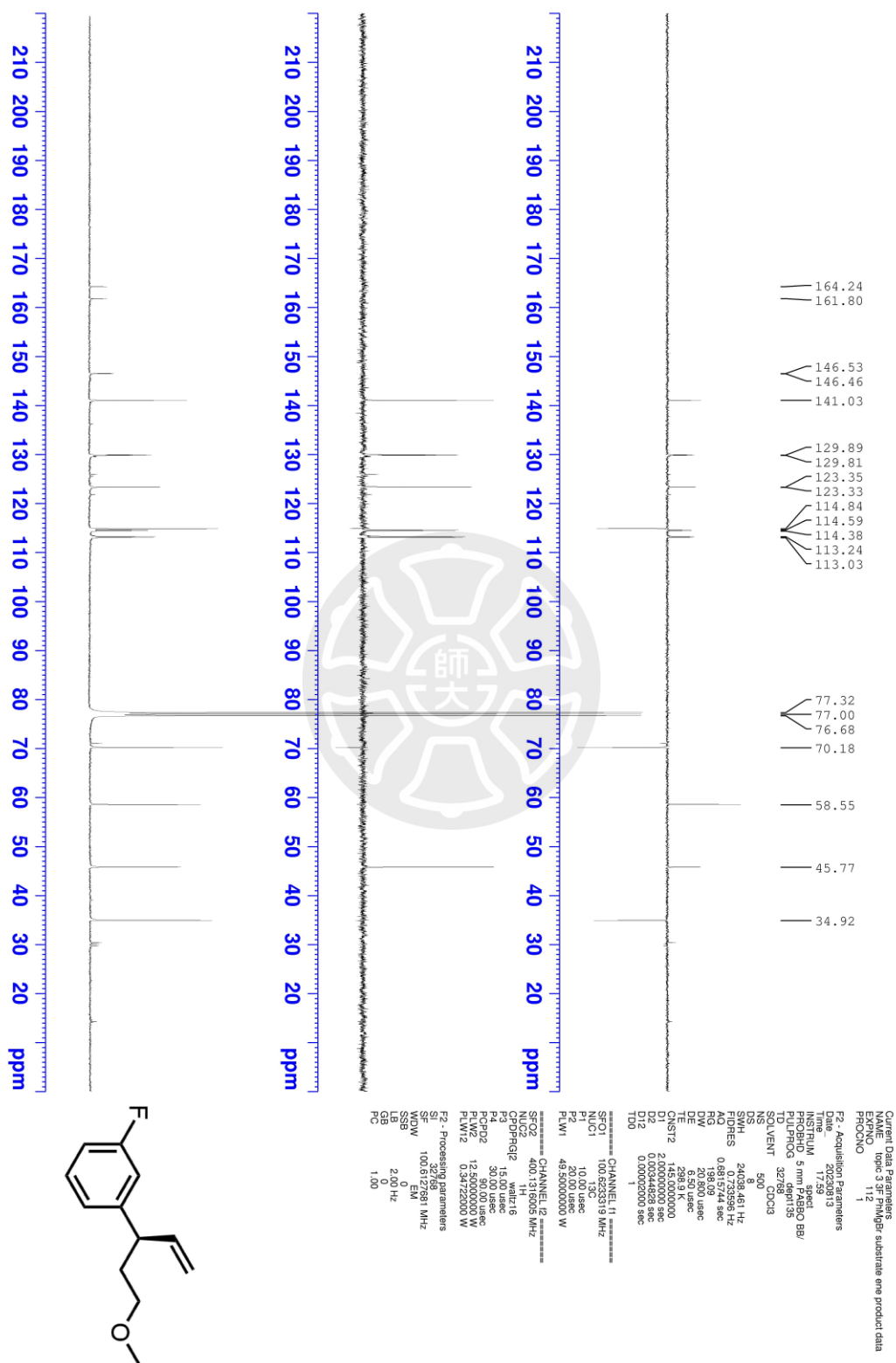
88. ^{13}C NMR of (*R*)-1-(benzyloxy)-3-(5-methoxypent-1-en-3-yl)benzene (94dm)



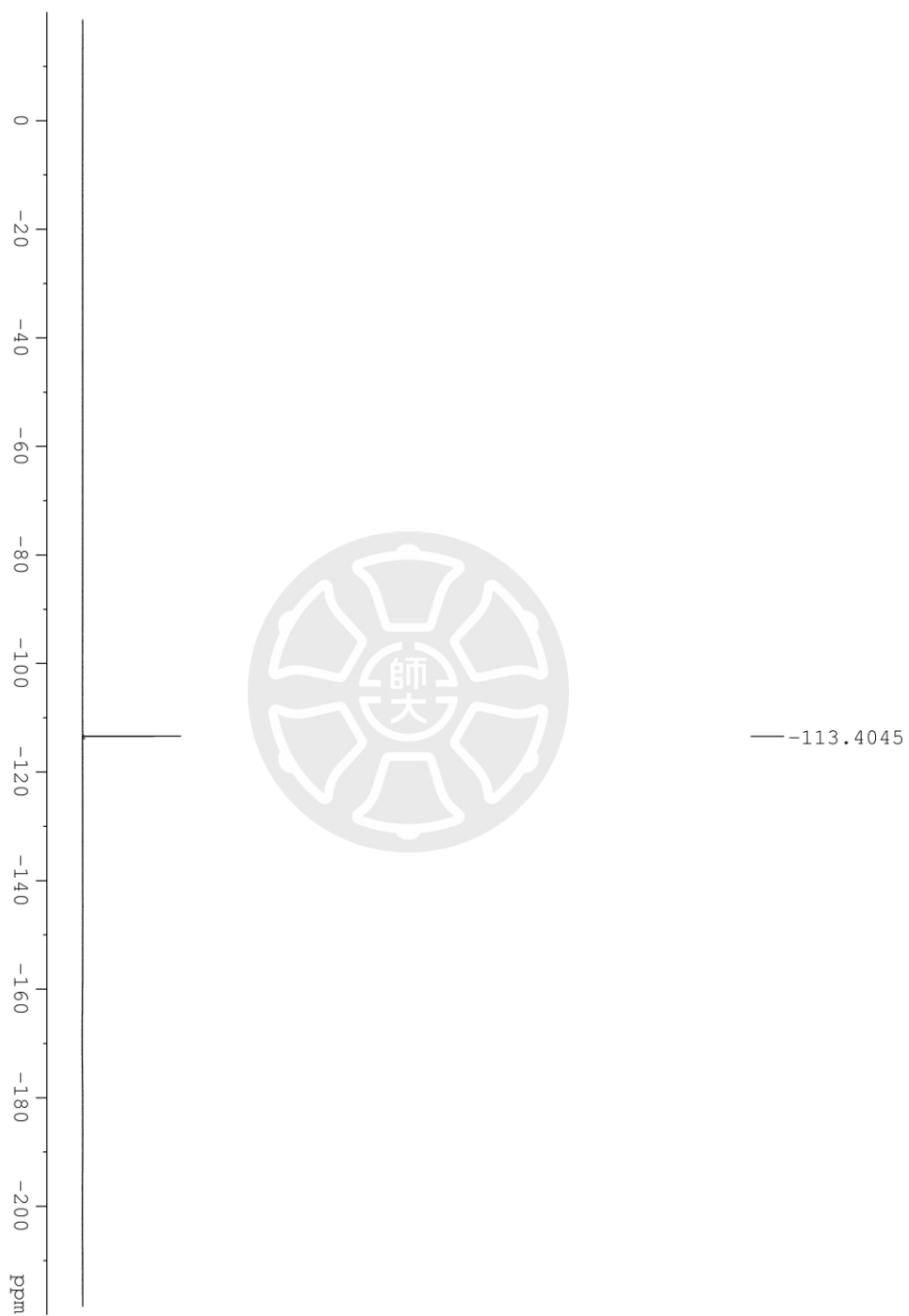
89. ^1H NMR of (*R*)-1-fluoro-3-(5-methoxypent-1-en-3-yl)benzene (94em)



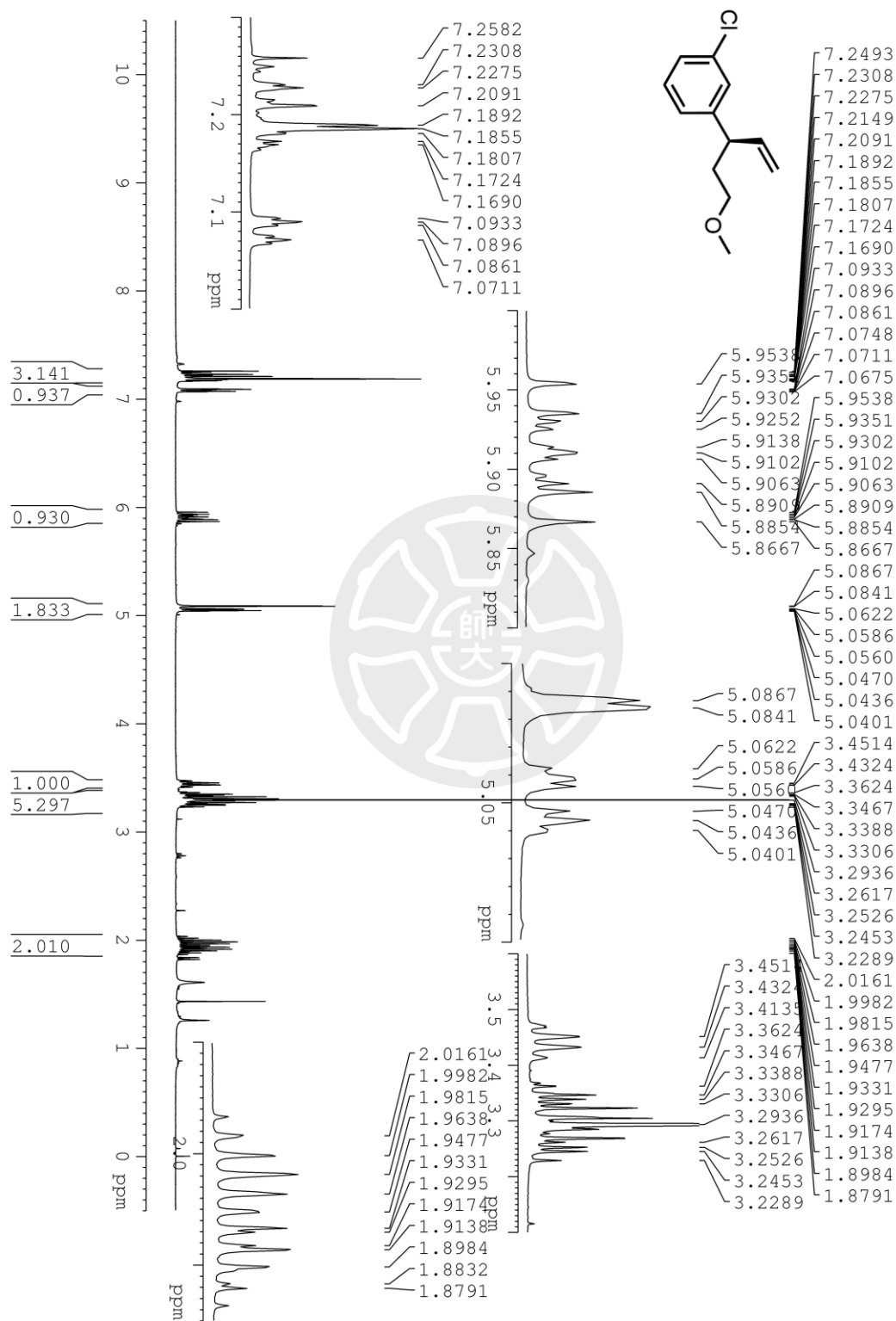
90. ^{13}C NMR of (*R*)-1-fluoro-3-(5-methoxypent-1-en-3-yl)benzene (94em)



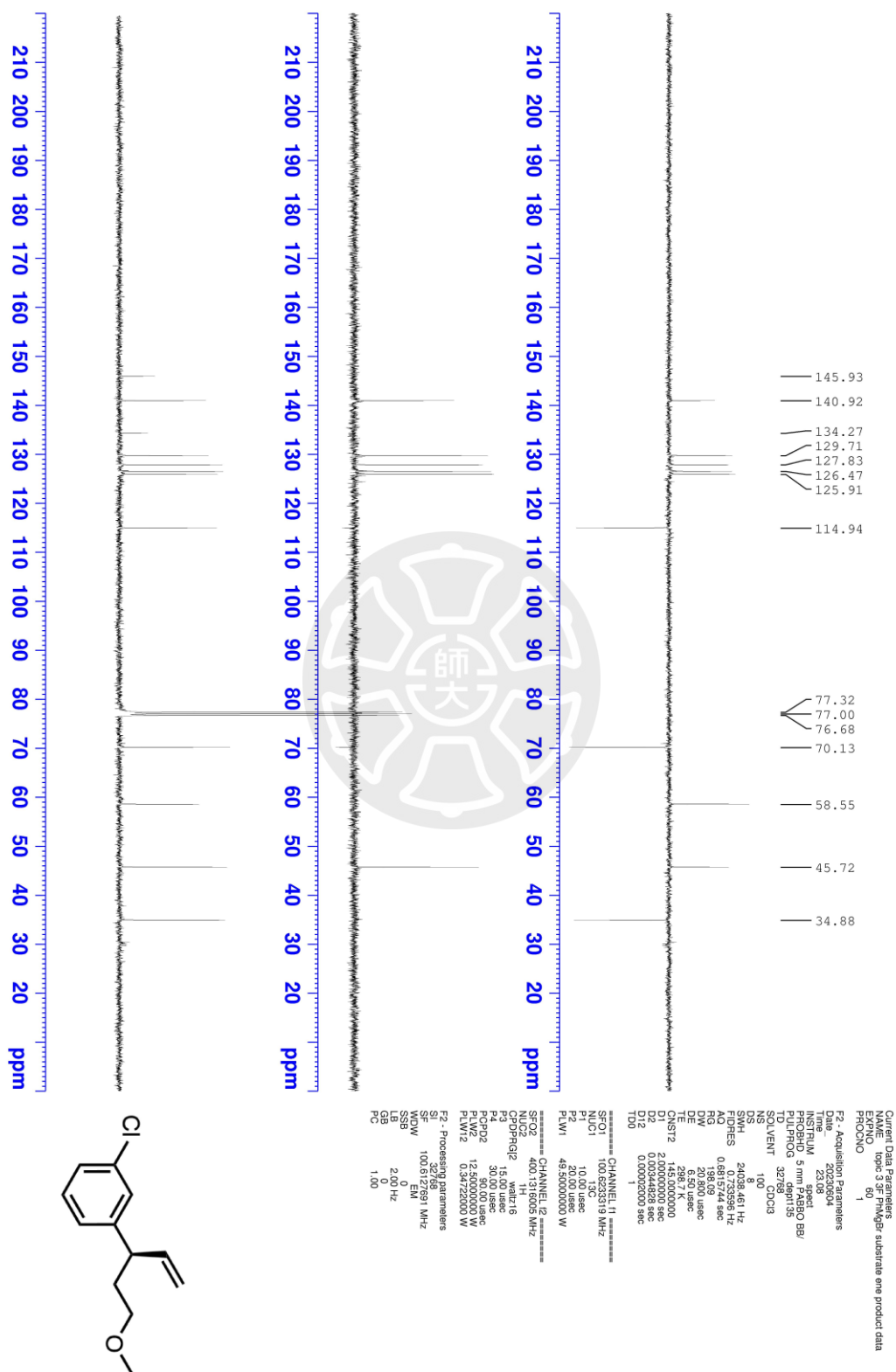
91. ^{19}F NMR of (*R*)-1-fluoro-3-(5-methoxypent-1-en-3-yl)benzene (94em)



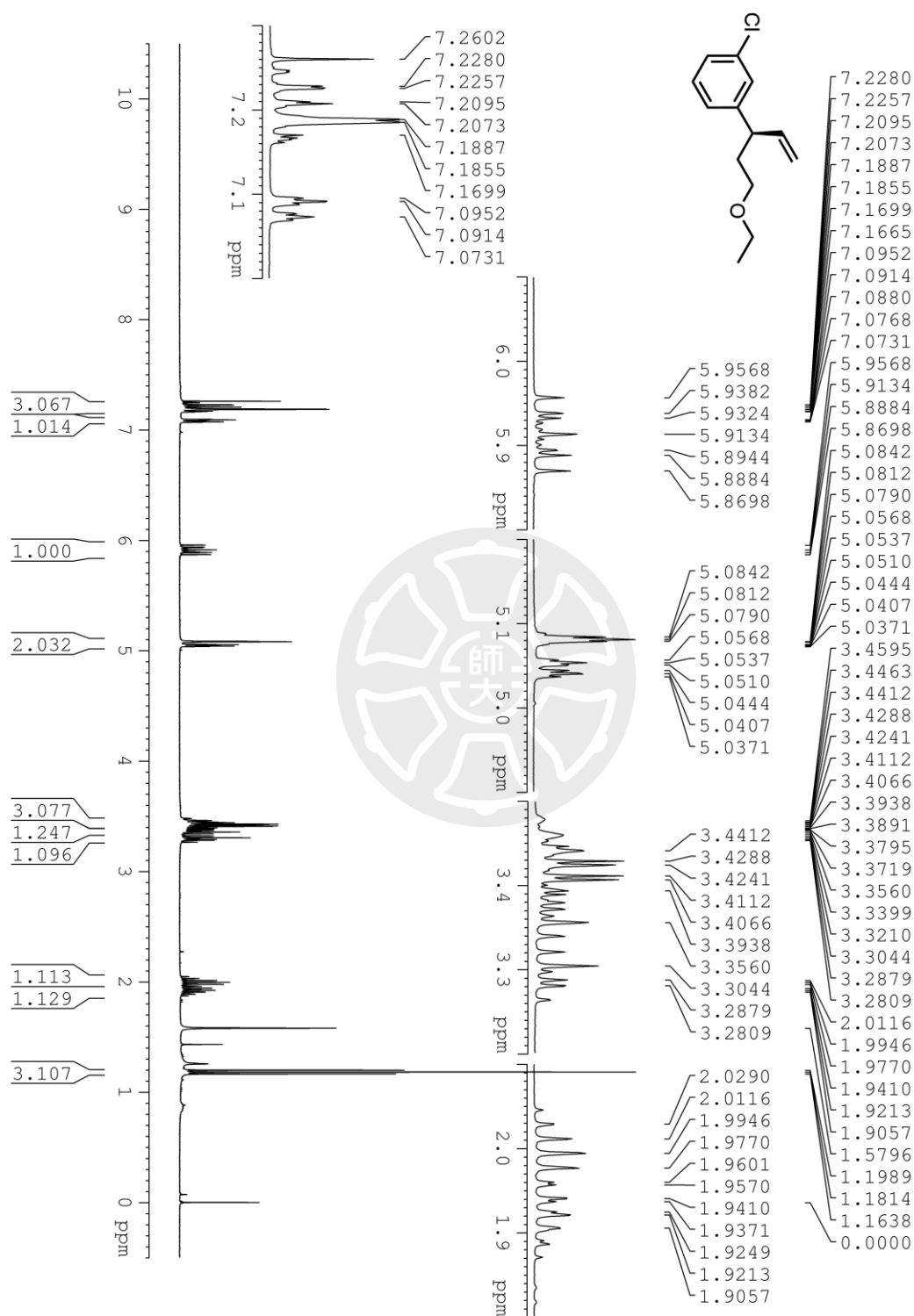
92. ^1H NMR of (*R*)-1-chloro-3-(5-methoxypent-1-en-3-yl)benzene (94fm)



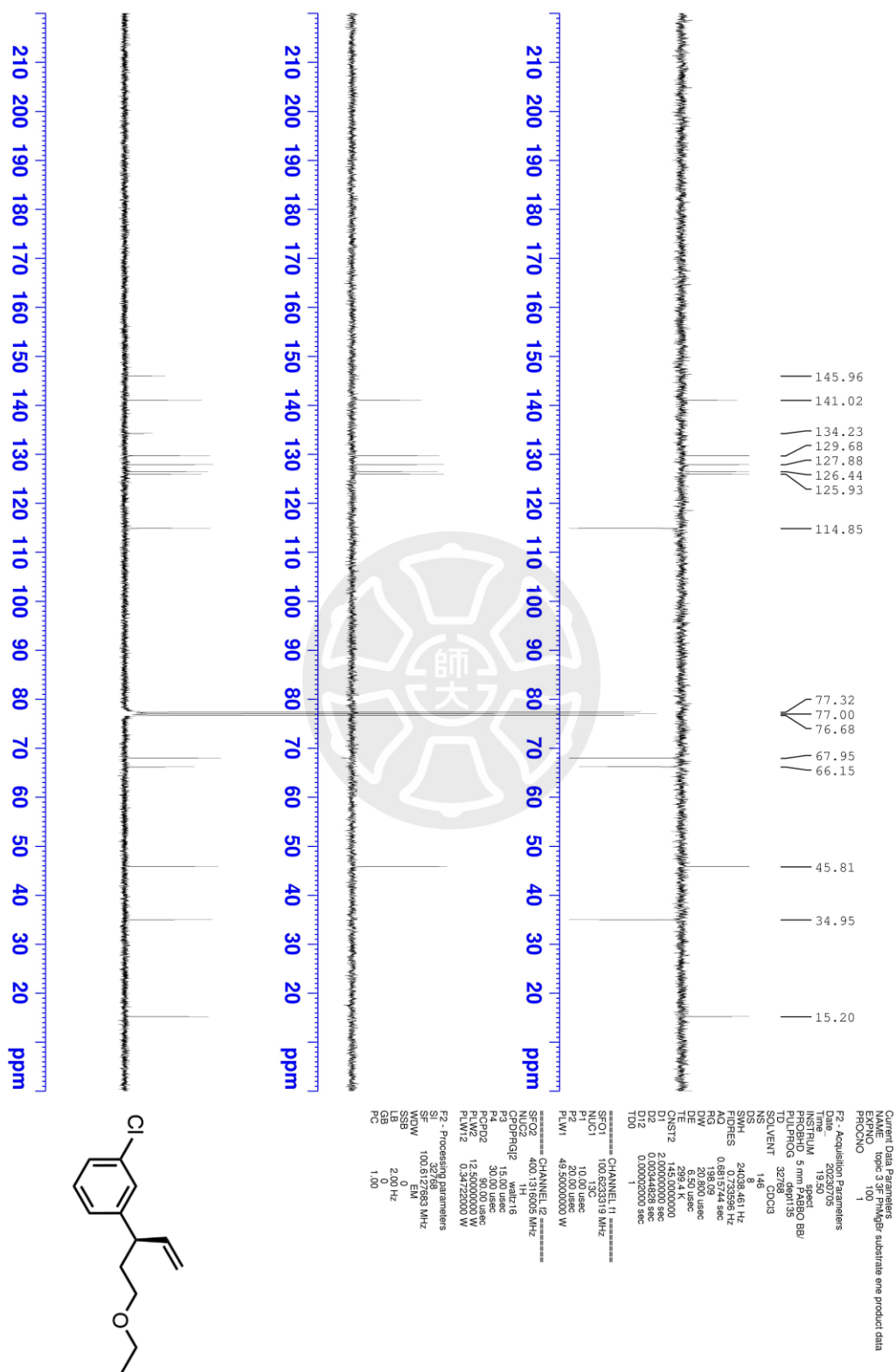
93. ^{13}C NMR of (*R*)-1-chloro-3-(5-methoxypent-1-en-3-yl)benzene (94fm)



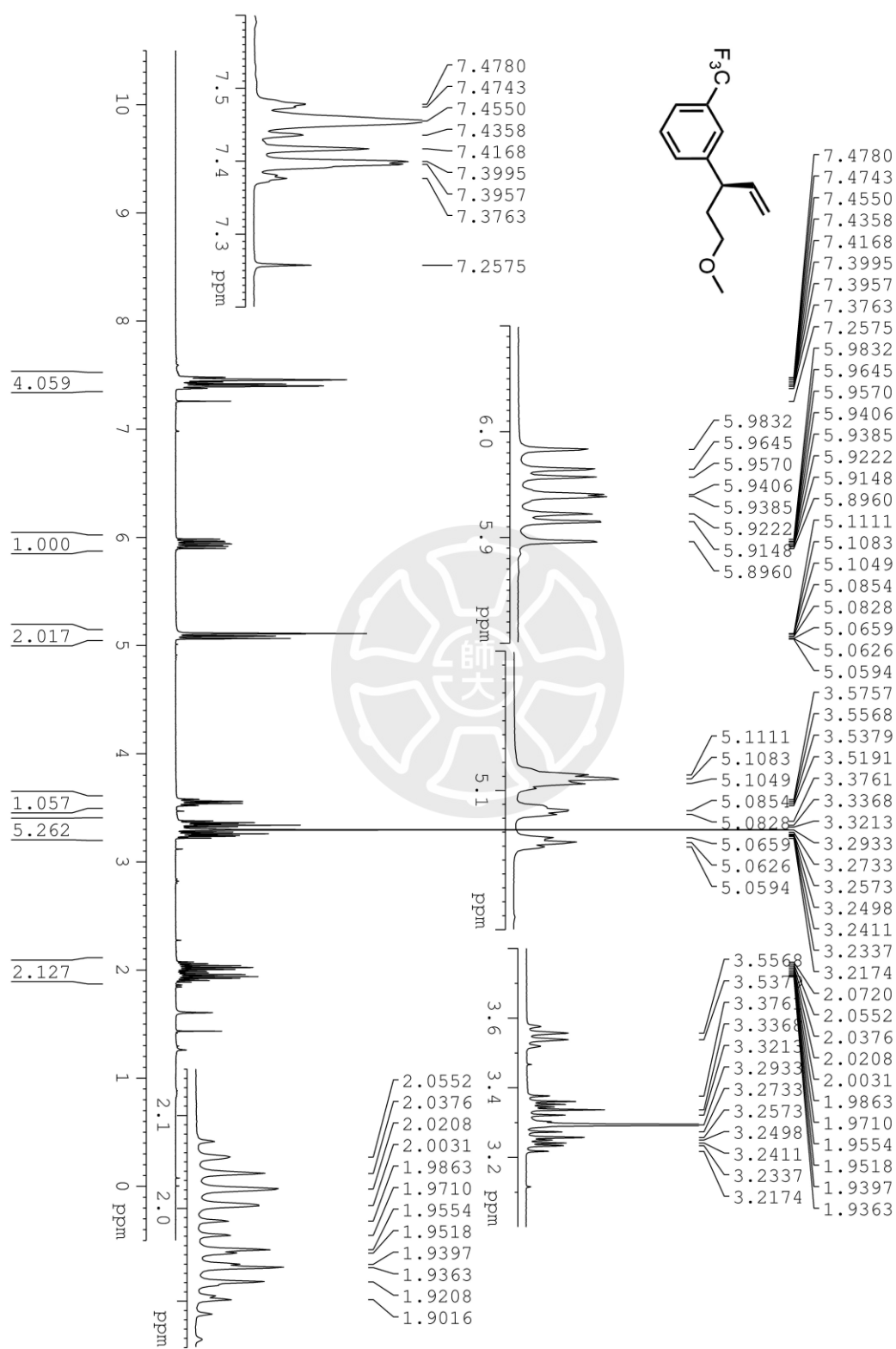
94. ^1H NMR of (*R*)-1-chloro-3-(5-ethoxypent-1-en-3-yl)benzene (94fe)



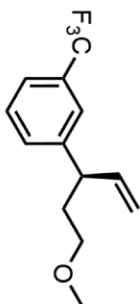
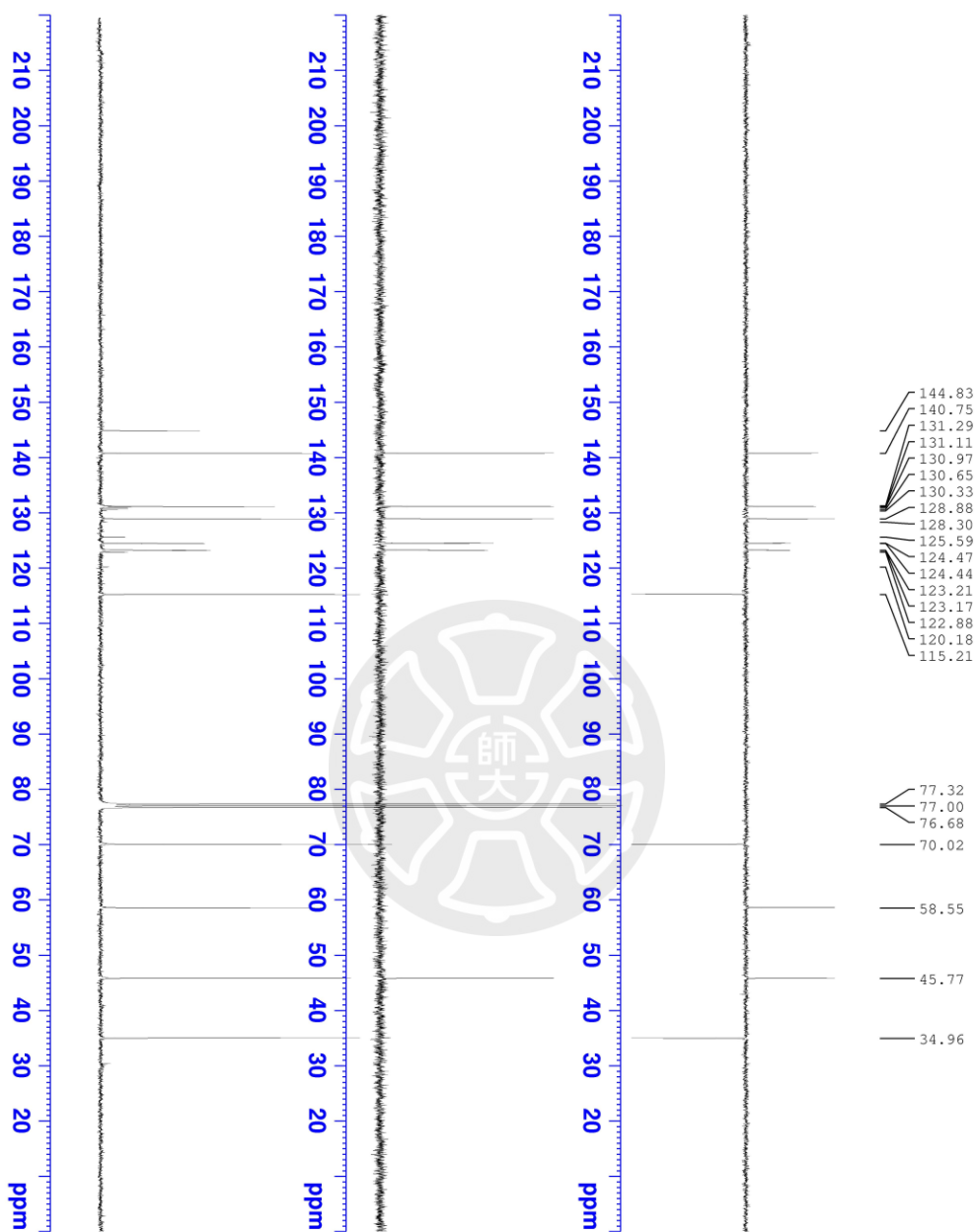
95. ^{13}C NMR of (*R*)-1-chloro-3-(5-ethoxypent-1-en-3-yl)benzene (94fe)



96. ^1H NMR of (*R*)-1-(5-methoxypent-1-en-3-yl)-3-(trifluoromethyl)benzene (94gm)

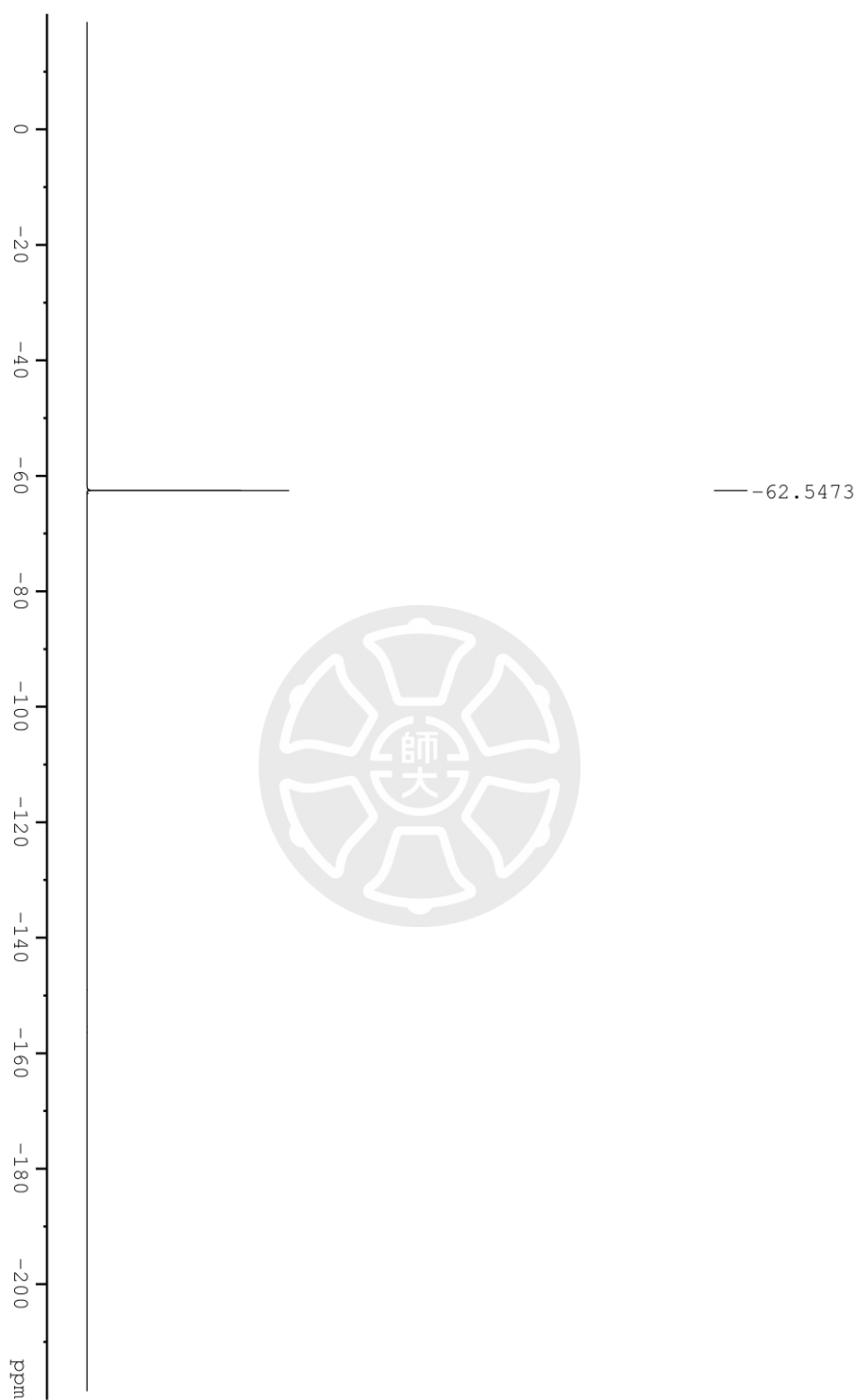


97. ^{13}C NMR of (R)-1-(5-methoxypent-1-en-3-yl)-3-(trifluoromethyl)benzene (94gm)

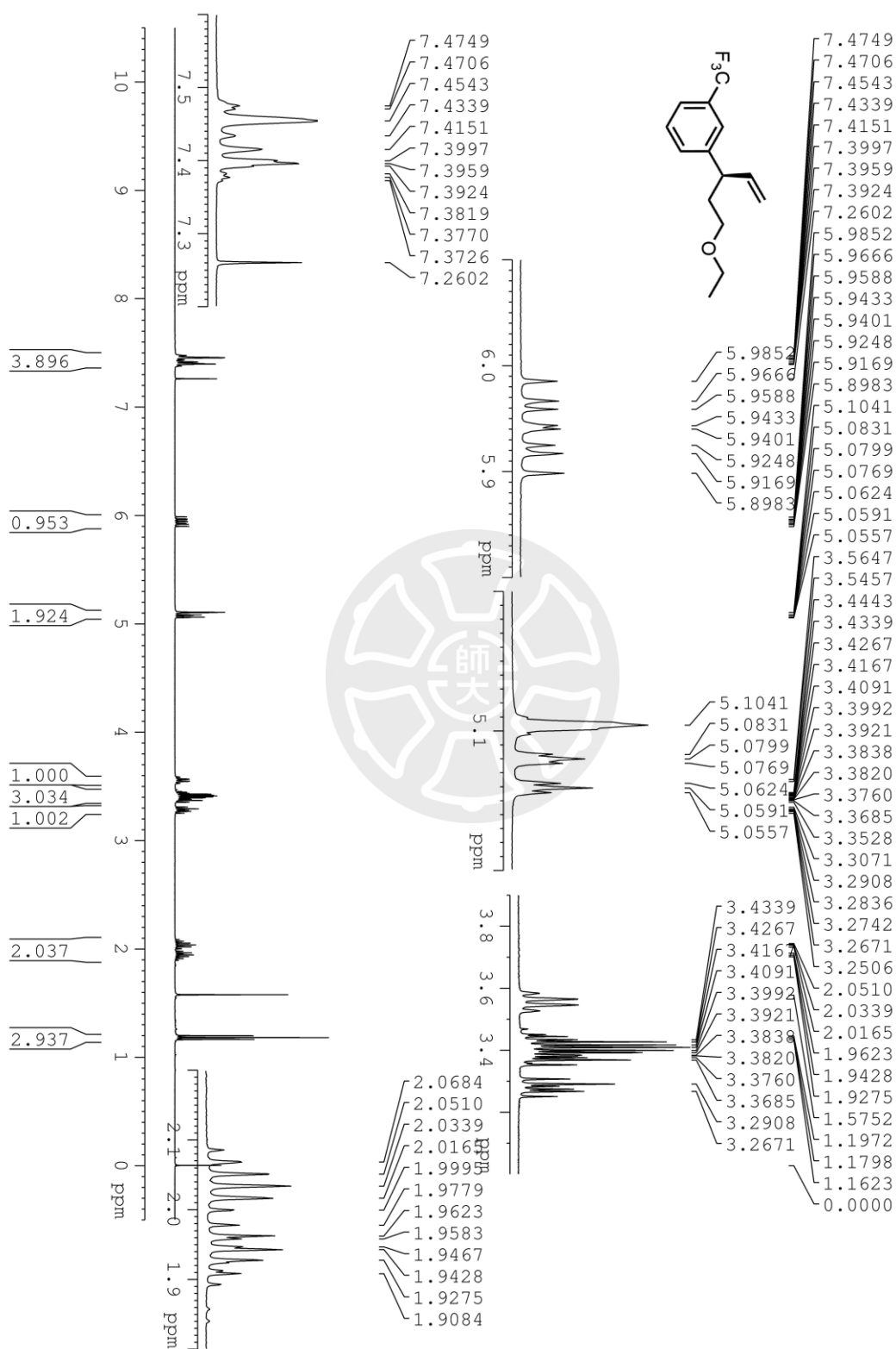


Current Data Parameters
NAME: topic 3 of 3: Phlogifer substrate ene product data
EXPNO: 69
PROCNO: 1
F2: Acquisition Parameters
Date_ : 20230608
Time : 5.12
INSTRUM : spect
PROBHD : 5 mm 1H/13C BBI
PULPROG : zgpg30
TD : 65536
SOLVENT : DMSO
NS : 72
DS : 8
SWH : 24028.461 Hz
FIDRES : 0.000335 Hz
AQ : 0.6815744 sec
RG : 188.09
RG2 : 3.850000 usec
DE : 6.50 usec
TE : 298.6 K
CNS12 : 145.000000
CNS13 : 125.760000 sec
D2 : 0.00344888 sec
D12 : 0.00002000 sec
TD0 : 1
===== CHANNEL f1 =====
NUC1 : ^{13}C
P1 : 10.00 usec
PL1 : 20.00 usec
PLW1 : 49.5000000 W
===== CHANNEL f2 =====
NUC2 : ^1H
P2 : 1.00 usec
PL2 : 0.0000000 W
===== CHANNEL f3 =====
CPDPRG2 : waltz16
P3 : 15.00 usec
PL3 : 0.0000000 W
PLW3 : 30.00 usec
PLW2 : 12.5000000 W
PLW12 : 0.3472200 W
F2 - Processing parameters
SI : 32768
WDW : EM
SSB : 0
GB : 2.00 Hz
PC : 1.00

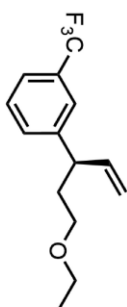
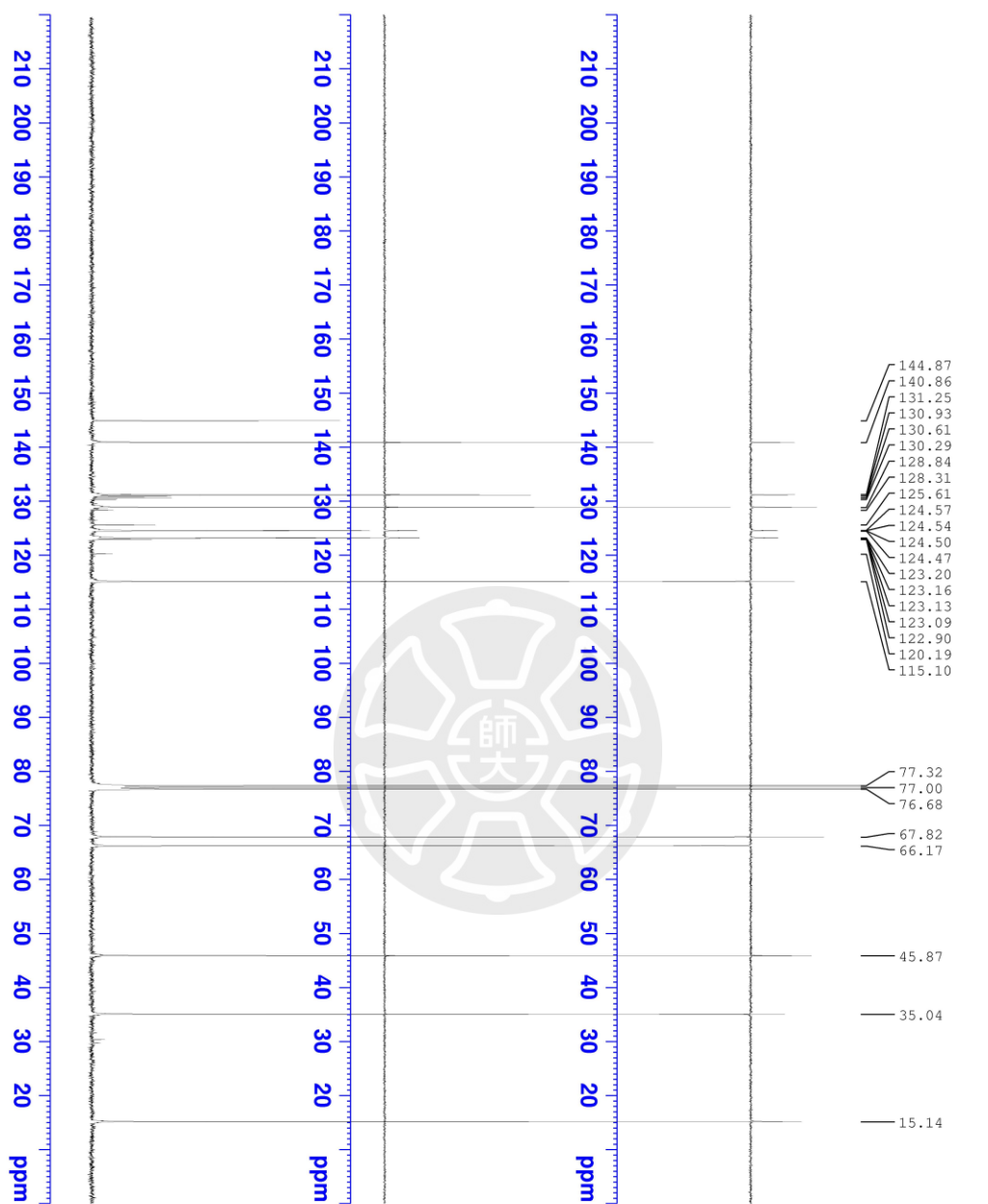
98. ^{19}F NMR of (*R*)-1-(5-methoxypent-1-en-3-yl)-3-(trifluoromethyl)benzene (94gm)



99. ^1H NMR of (*R*)-1-(5-ethoxypent-1-en-3-yl)-3-(trifluoromethyl)benzene (94ge)

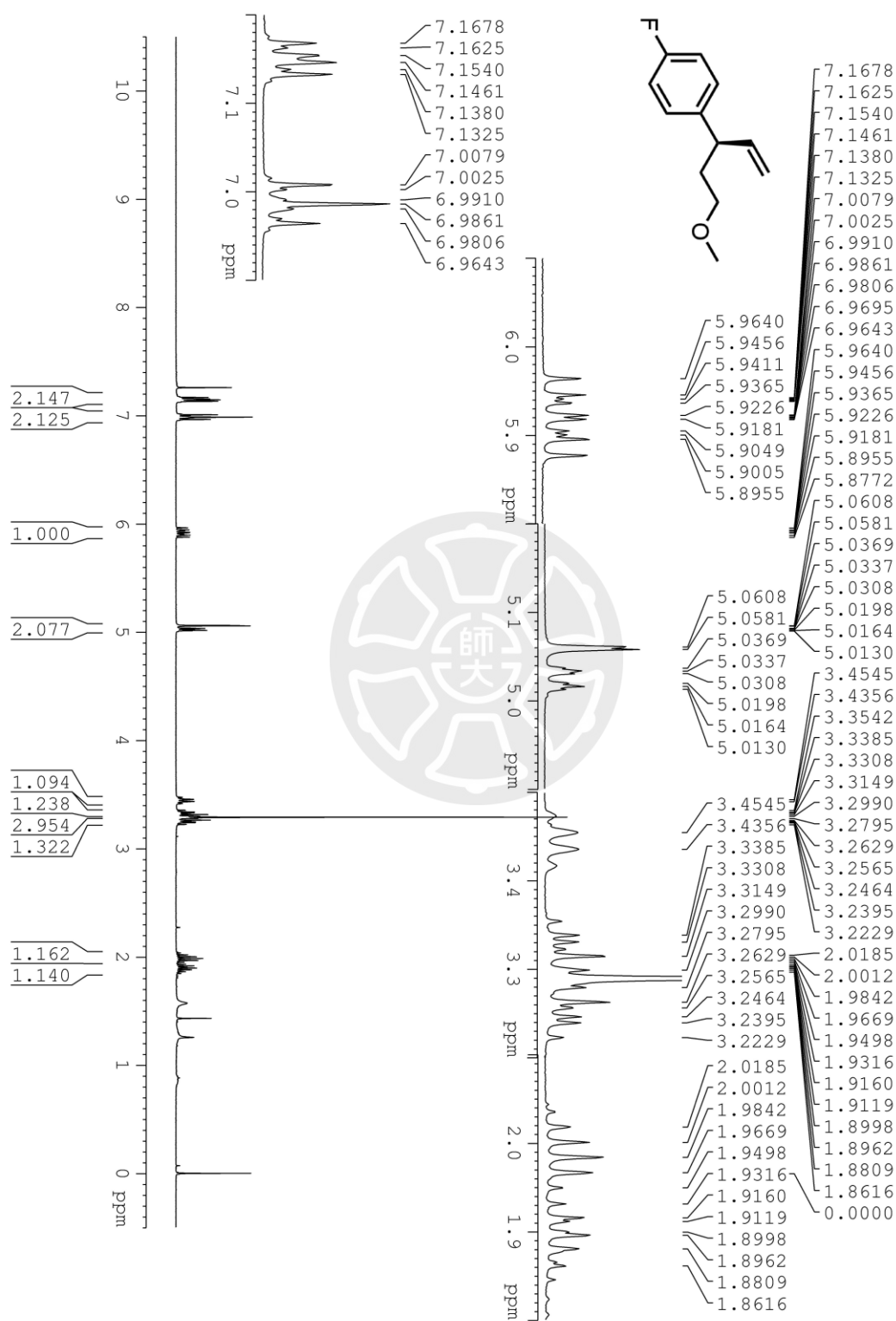


100. ^{13}C NMR of (*R*)-1-(5-ethoxypent-1-en-3-yl)-3-(trifluoromethyl)benzene (94g)

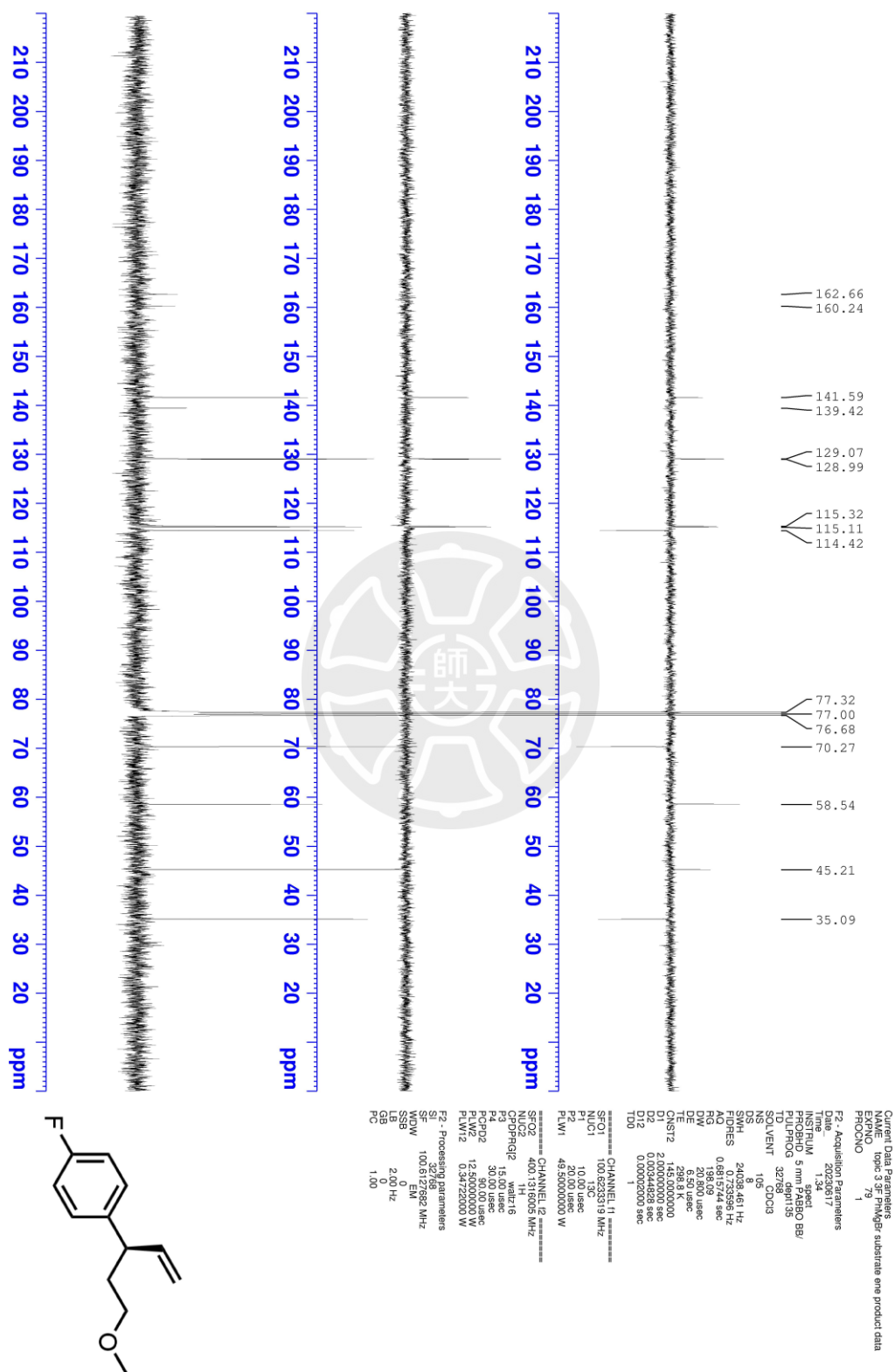


Current Data Parameters
NAME: topic 3 9f: Phlogifer substrate ene product data
EXPNO: 371
PROCNO: 1
F2 - Acquisition Parameters
Date_ : 20230604
Time : 22:09
INSTRUM : spect
PROBHD : 5 mm 1H/13C BBO
PULPROG : zgpg30
TD : 65536
SOLVENT : DMSO
NS : 32768
DS : 8
SWH : 24028.461 Hz
FIDRES : 0.000335 Hz
AQ : 0.6815744 sec
RG : 198.09
GB : 32768
DE : 6.50 usec
TE : 298.3 K
CNS12 : 145.000000
D1 : 2.00000000 sec
D2 : 0.00344828 sec
D12 : 0.00002000 sec
TD0 : 1
===== CHANNEL f1 =====
NUC1 : ^{13}C
P1 : 100.625319 MHz
PL1 : 10.00 usec
PLW1 : 49.5000000 W
===== CHANNEL f2 =====
NUC2 : ^1H
P2 : 400.1319005 MHz
PL2 : 11.00 usec
PLW2 : 12.5000000 W
===== CHANNEL f3 =====
CPDPRG2 : waltz16
P3 : 15.50 usec
P4 : 30.00 usec
PCHP2 : 50.00 usec
PLW2 : 12.5000000 W
PLW12 : 0.3472200 W
F2 - Processing parameters
SI : 32768
WDW : EM
SSB : 0
GB : 2.00 Hz
PC : 1.00

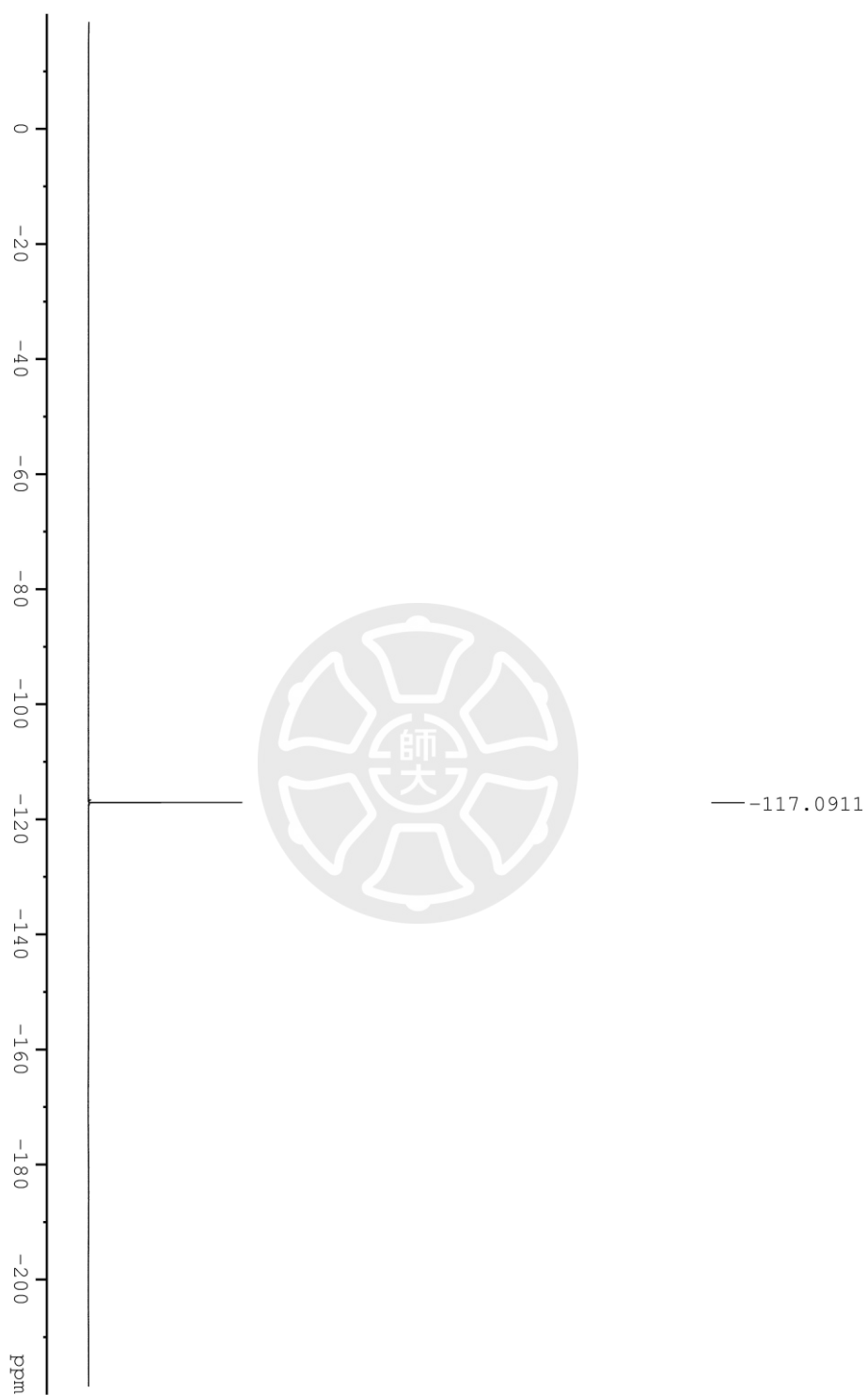
101. ¹H NMR of (*R*)-1-fluoro-4-(5-methoxypent-1-en-3-yl)benzene (94hm)



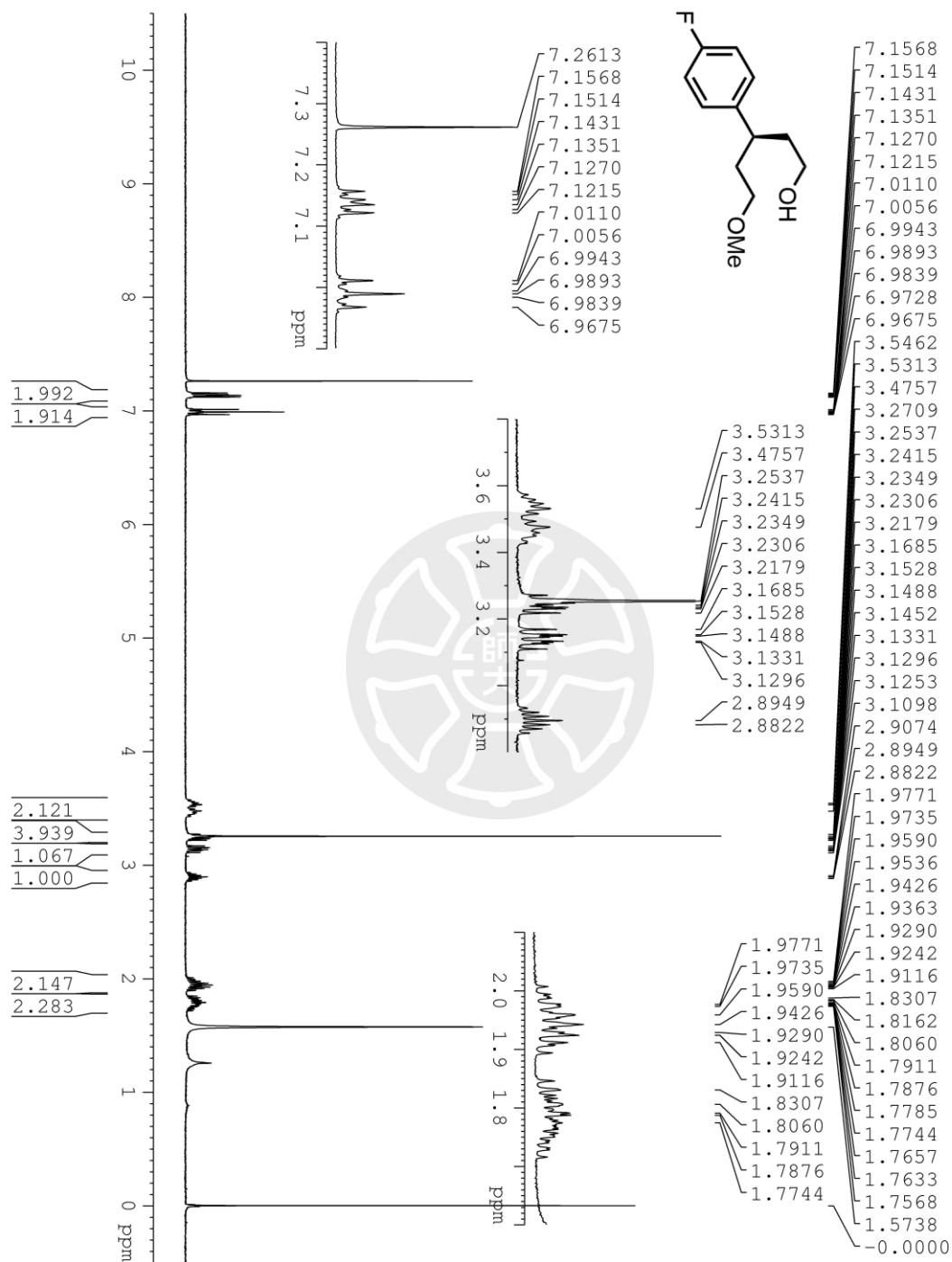
102. ^{13}C NMR of *(R)*-1-fluoro-4-(5-methoxypent-1-en-3-yl)benzene (94hm)



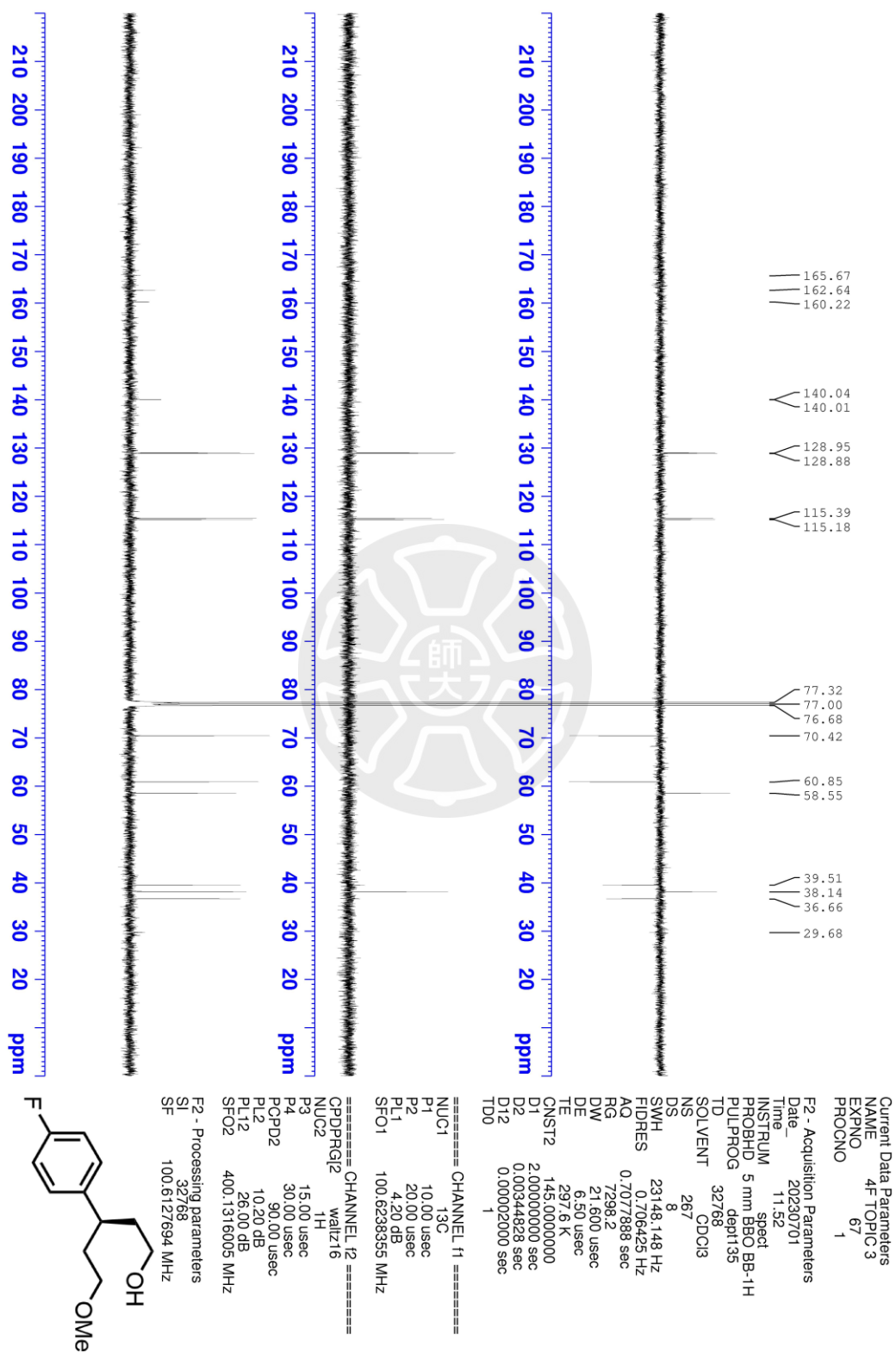
103. ^{19}F NMR of *(R)*-1-fluoro-4-(5-methoxypent-1-en-3-yl)benzene (94hm)



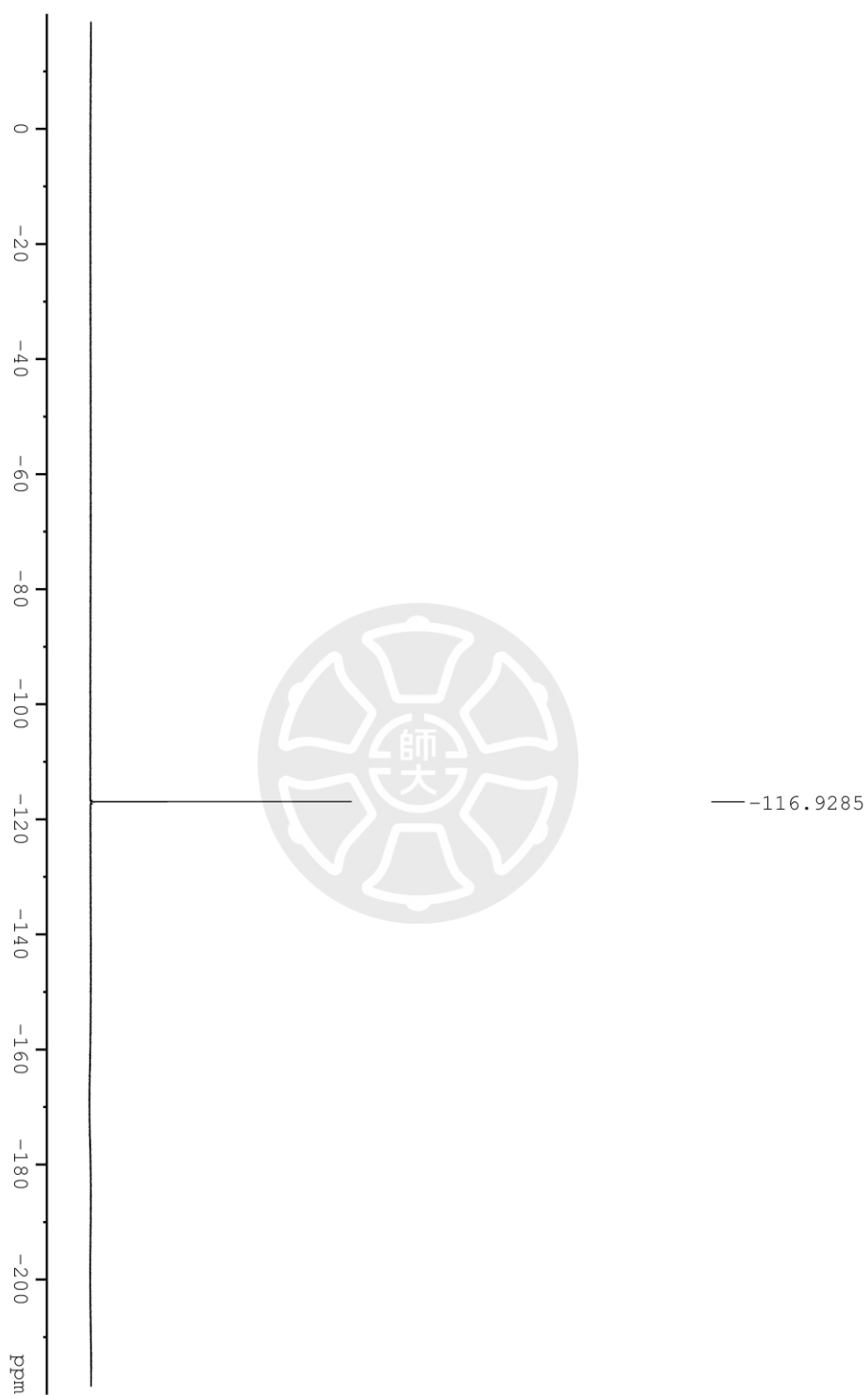
104. ^1H NMR of (*S*)-3-(4-fluorophenyl)-5-methoxypentan-1-ol (95hm)



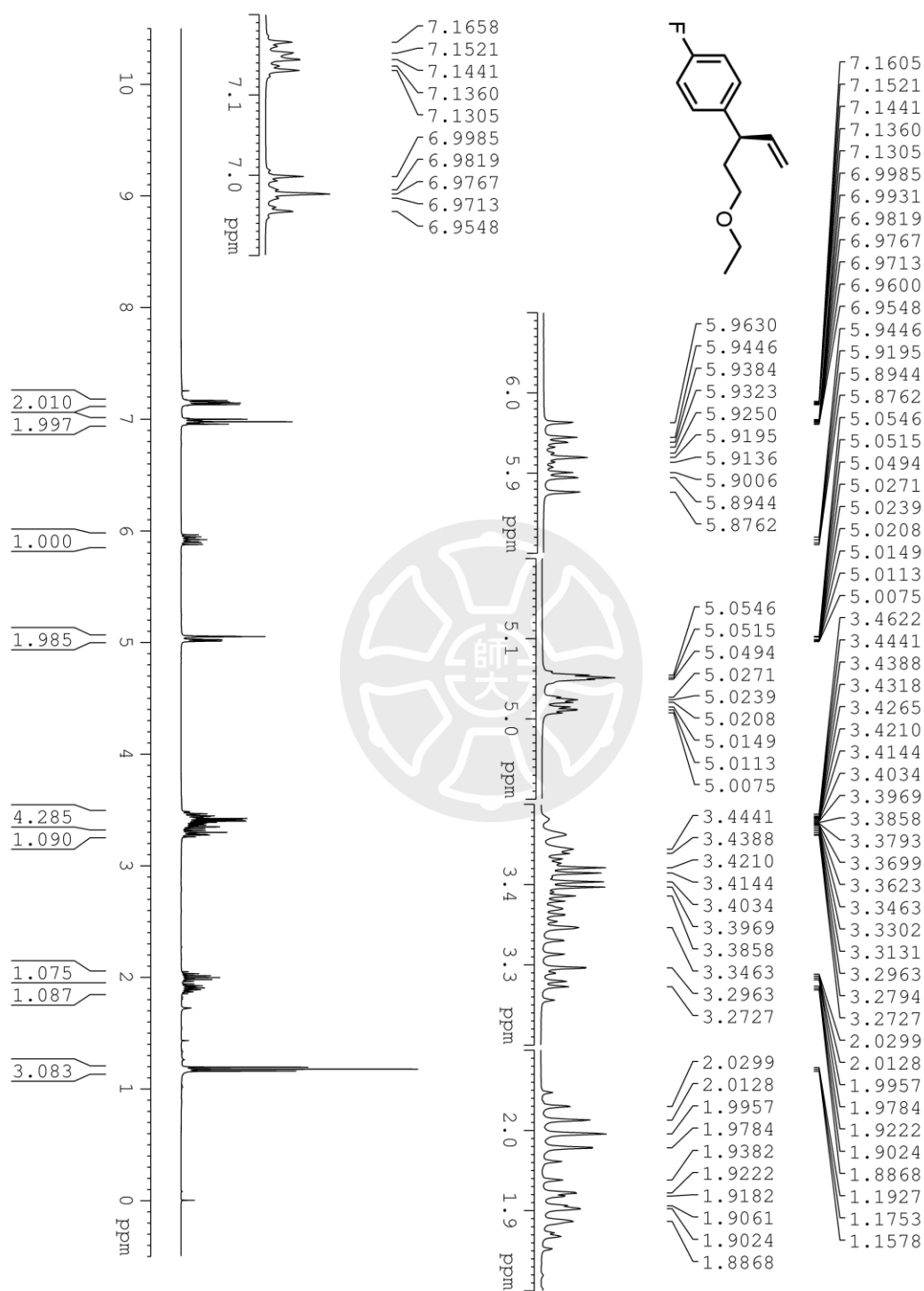
105. ^{13}C NMR of *(S)*-3-(4-fluorophenyl)-5-methoxypentan-1-ol (95hm)



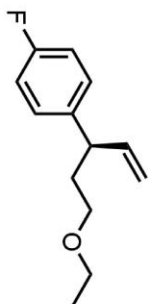
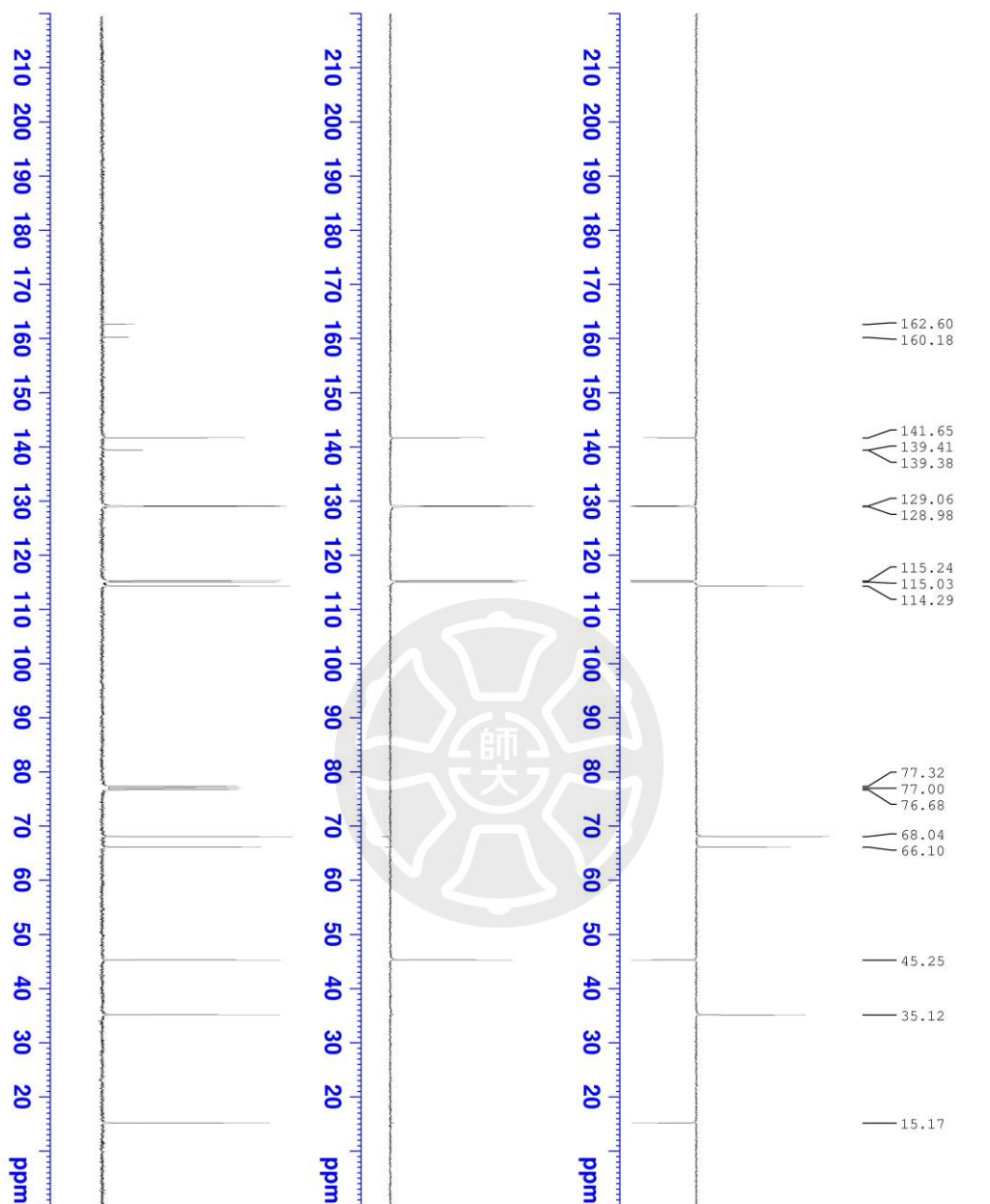
106. ^{19}F NMR of (*S*)-3-(4-fluorophenyl)-5-methoxypentan-1-ol (95hm)



107. ¹H NMR of (*R*)-1-(5-ethoxypent-1-en-3-yl)-4-fluorobenzene (94he)

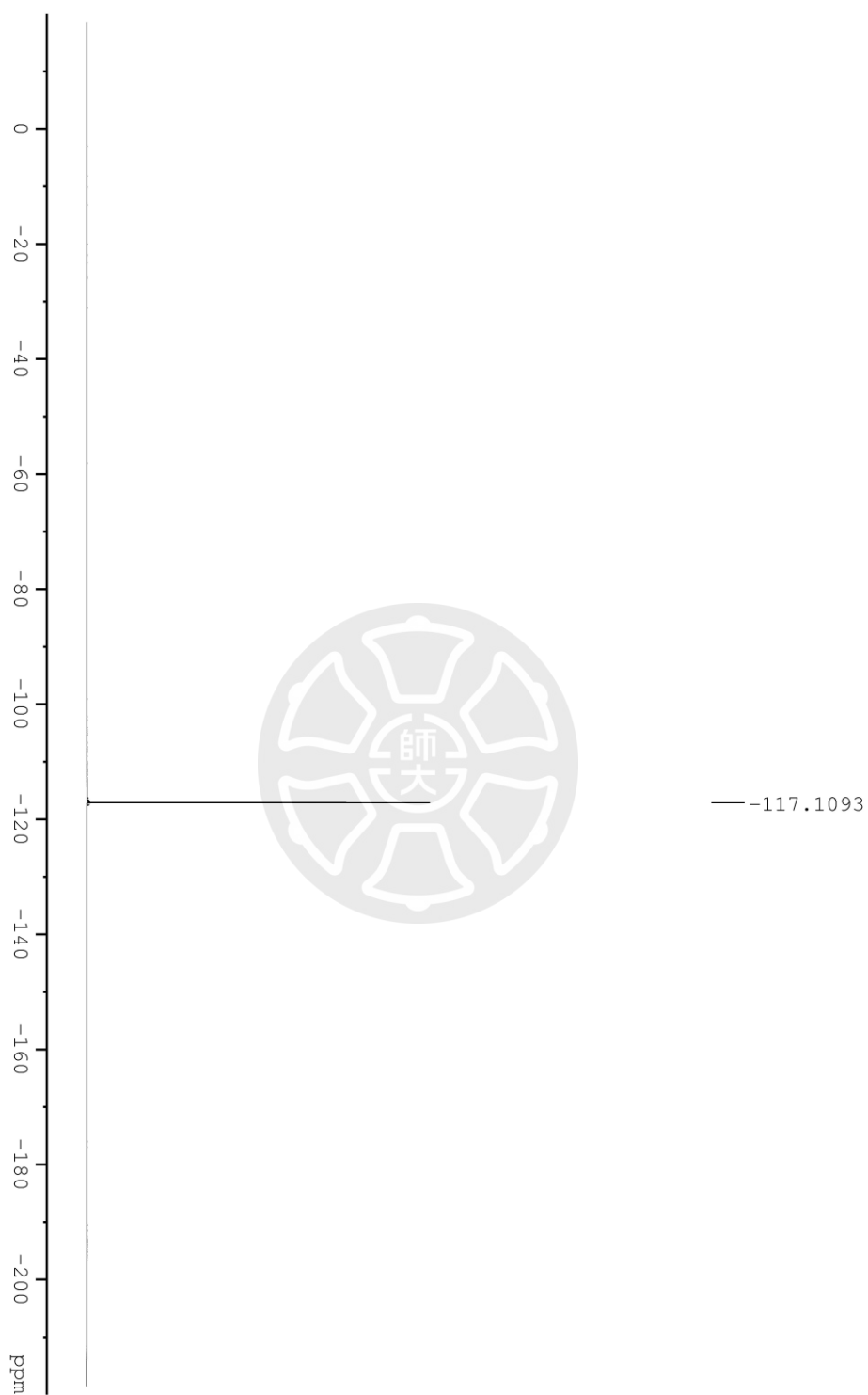


108. ^{13}C NMR of (*R*)-1-(5-ethoxypent-1-en-3-yl)-4-fluorobenzene (94he)

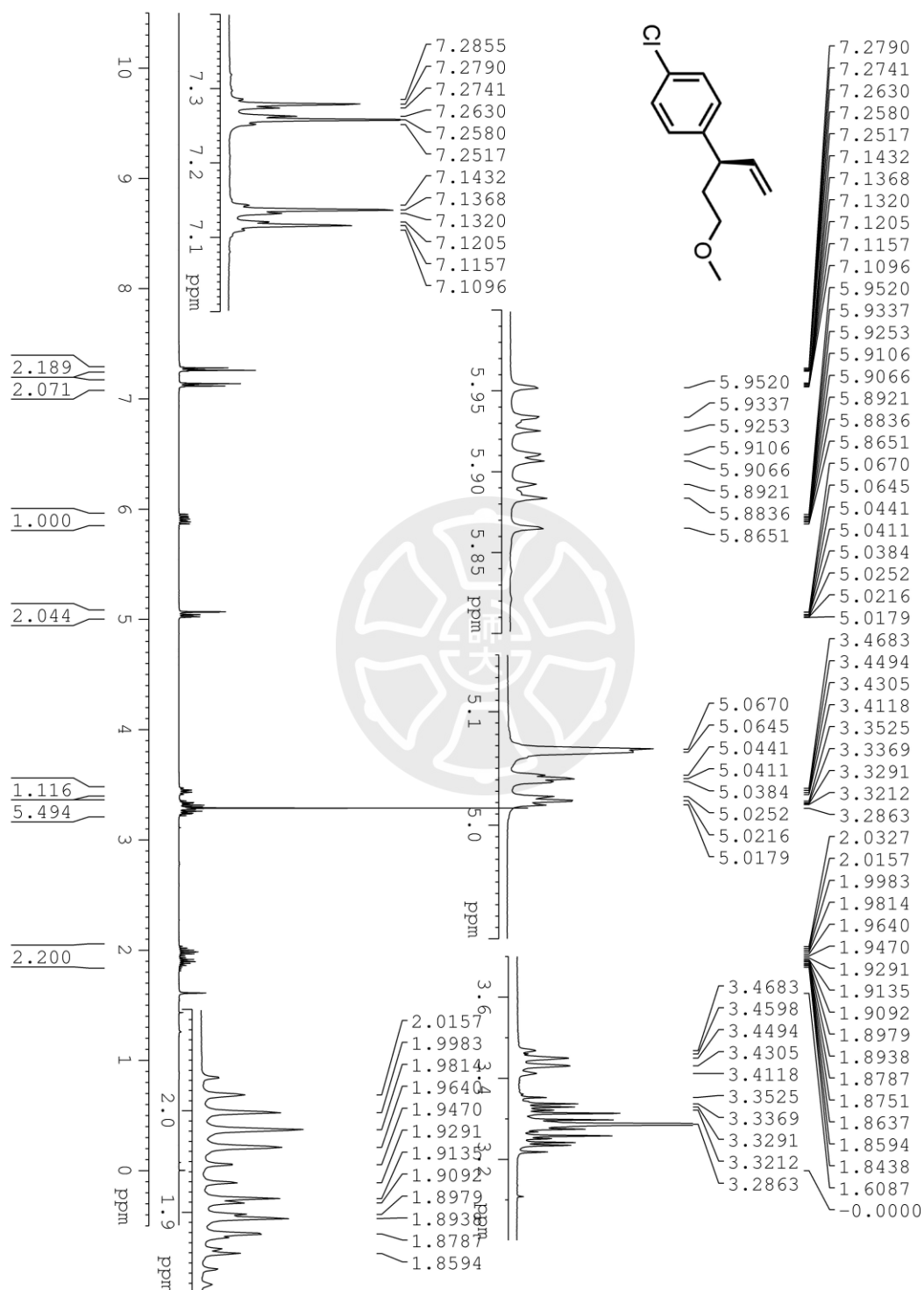


Current Data Parameters
NAME: topic 3 3F-PhMagier substrate ene product data
EXPNO: 1
PROCNO: 1
F2 - Acquisition Parameters
Date_ : 20230205
Time : 9.45
INSTRUM : spect
PROBHD : 5 mm 1H/13C BBO
PULPROG : zgpg30
TD : 65536
SOLVENT : DMSO
NS : 59
DS : 8
SWH : 24028.461 Hz
FIDRES : 0.000351 Hz
AQ : 0.6815744 sec
RG : 188.09
RG2 : 327.68
DE : 6.50 usec
TE : 300.3 K
CNS12 : 145.000000
D1 : 2.00000000 sec
D2 : 0.00344828 sec
D12 : 0.00002000 sec
TDO : 1
===== CHANNEL f1 =====
NUC1 : ^{13}C
P1 : 100.625319 MHz
PL1 : 10.00 usec
PLW1 : 49.5000000 W
===== CHANNEL f2 =====
NUC2 : ^1H
P2 : 400.1318005 MHz
PL2 : 11.77 usec
PLW2 : 15.50 usec
PCPD2 : 300.00 usec
PLW2 : 12.5000000 W
PLW12 : 0.34722000 W
F2 - Processing parameters
SI : 32768
WDW : EM
SSB : 0
GB : 2.00 Hz
PC : 1.00

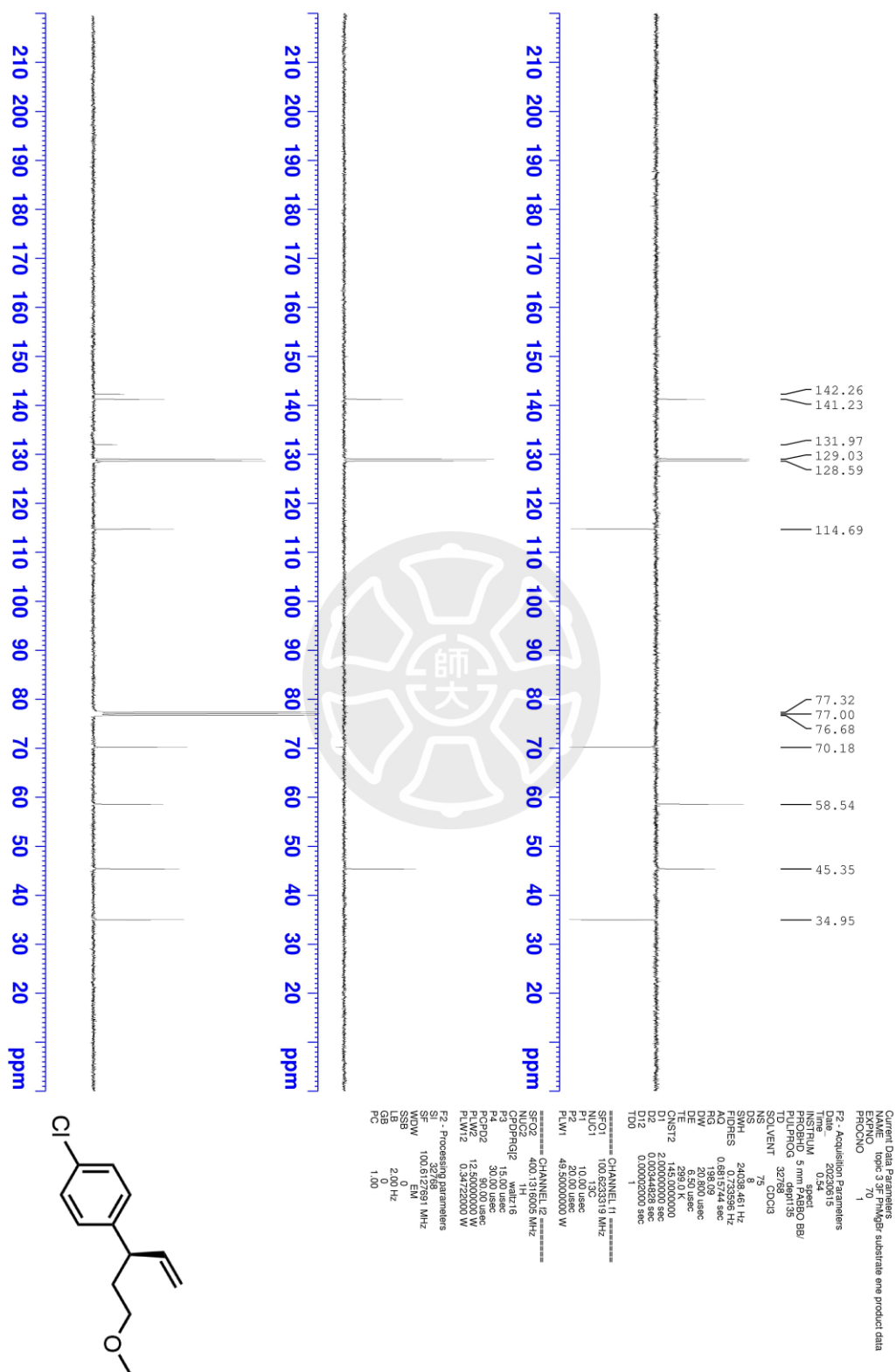
109. ^{19}F NMR of (*R*)-1-(5-ethoxypent-1-en-3-yl)-4-fluorobenzene (94he)



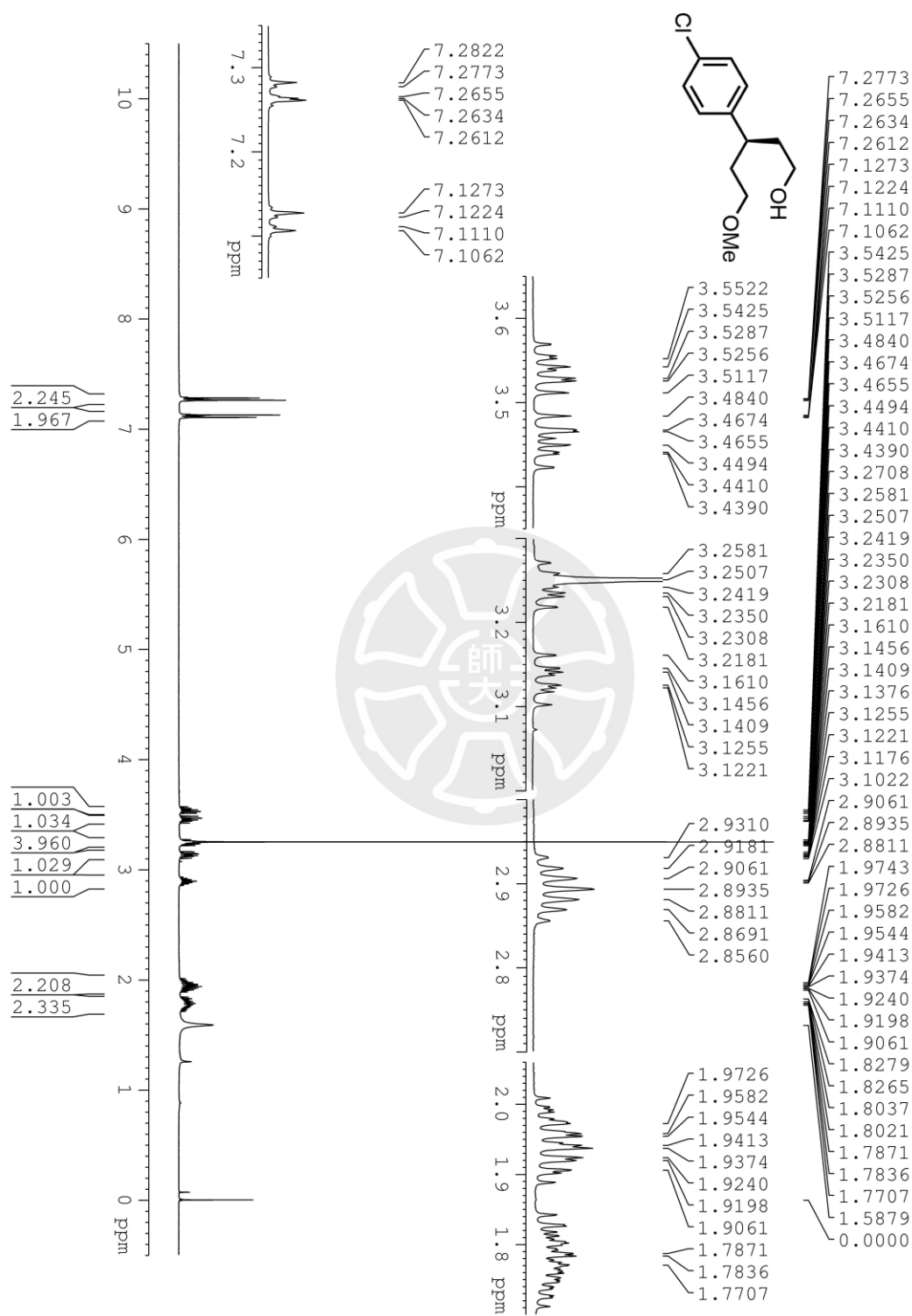
110. ^1H NMR of (*R*)-1-chloro-4-(5-methoxypent-1-en-3-yl)benzene (94im)



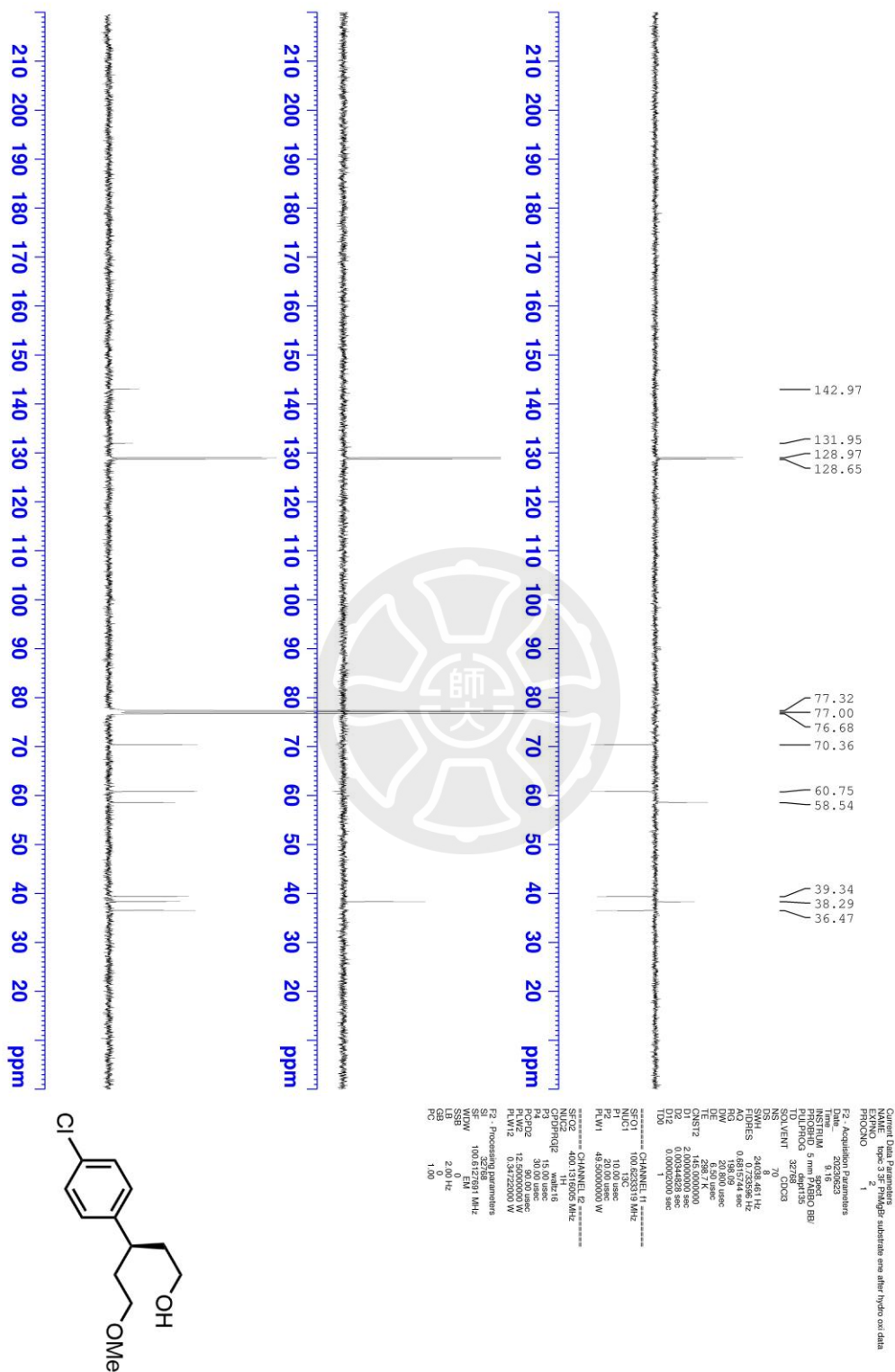
111. ^{13}C NMR of (*R*)-1-chloro-4-(5-methoxypent-1-en-3-yl)benzene (94im)



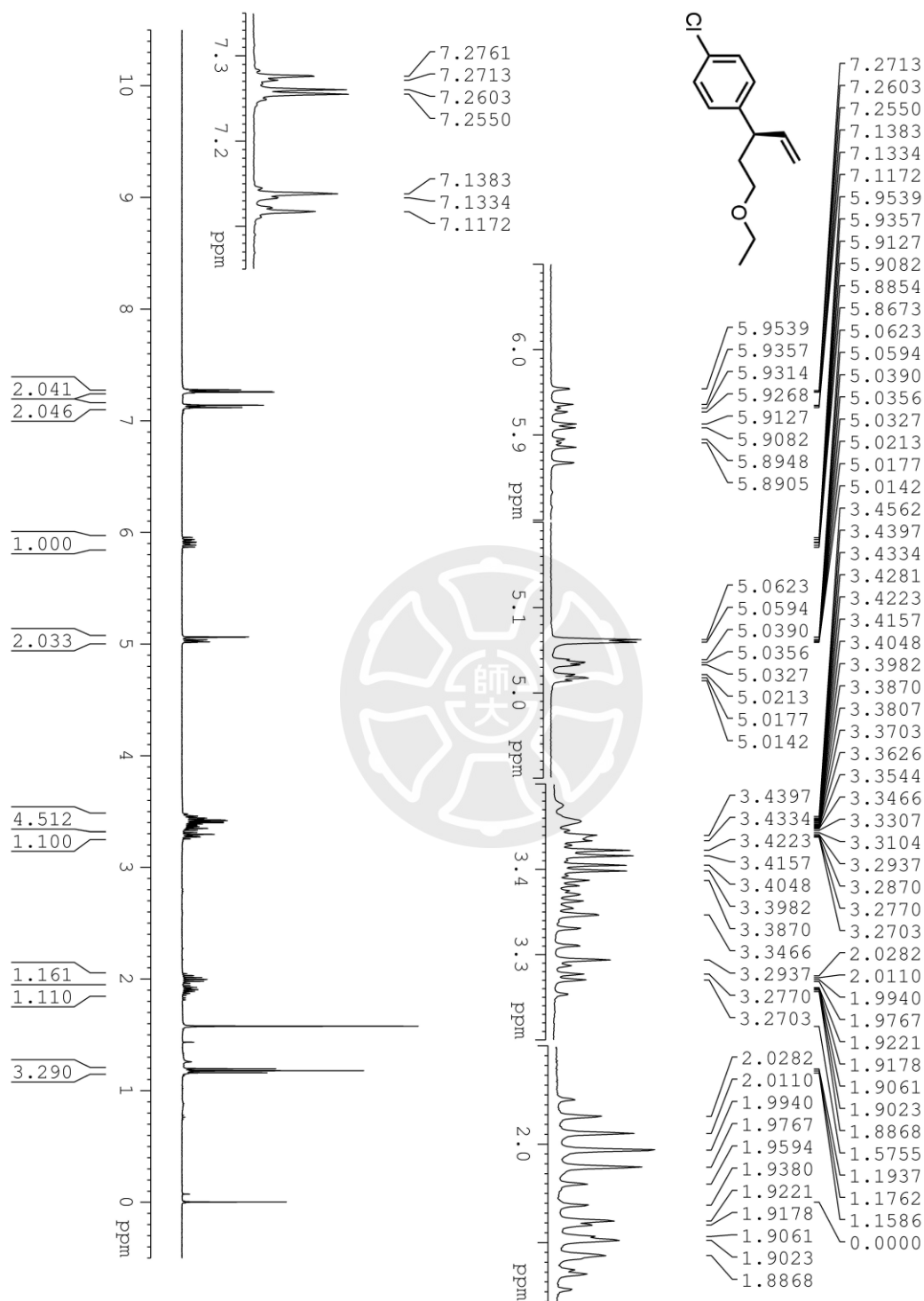
112. ^1H NMR of (*S*)-3-(4-chlorophenyl)-5-methoxypentan-1-ol (95im)



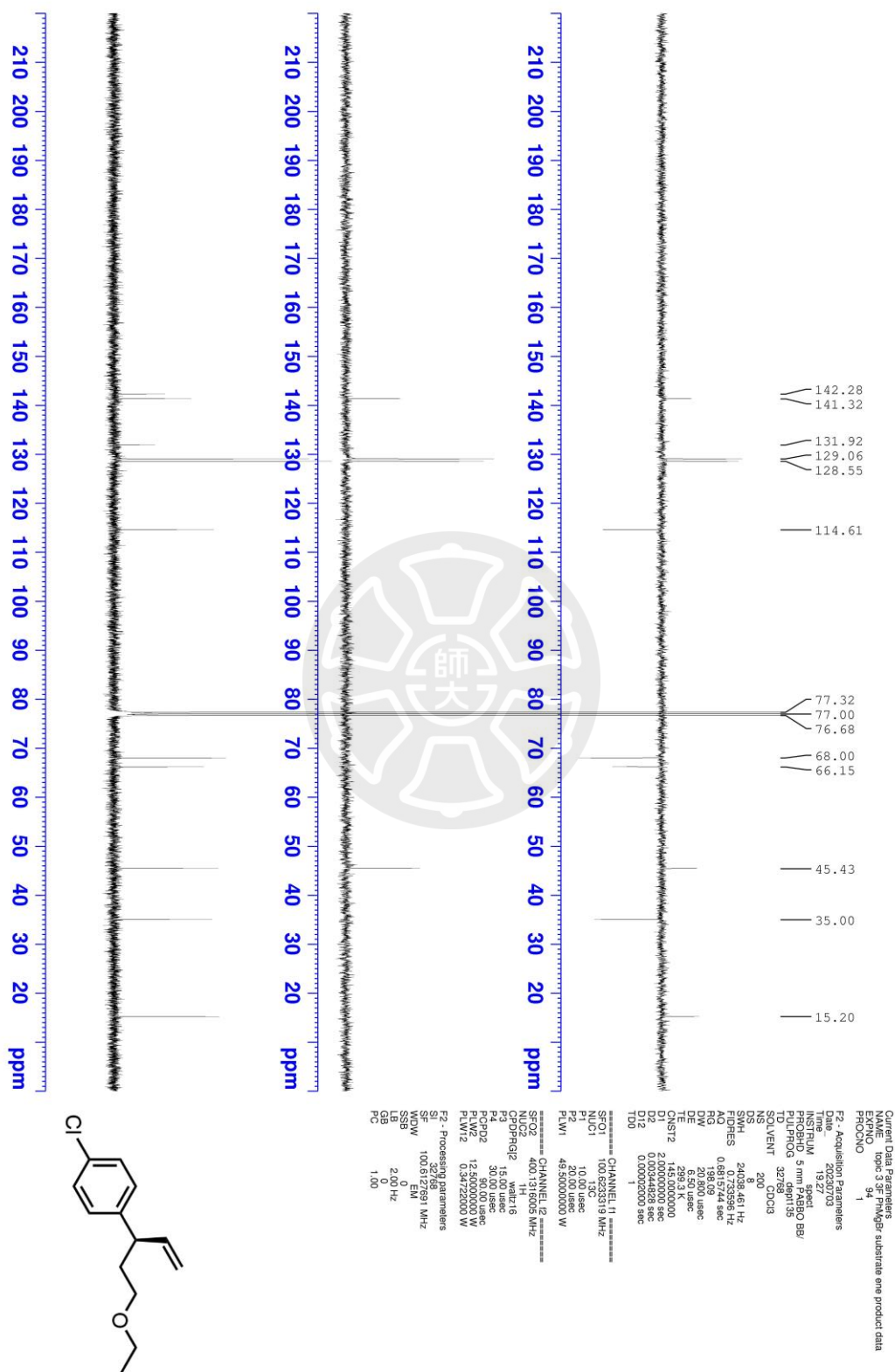
113. ¹³C NMR of (S)-3-(4-chlorophenyl)-5-methoxypentan-1-ol (95im)



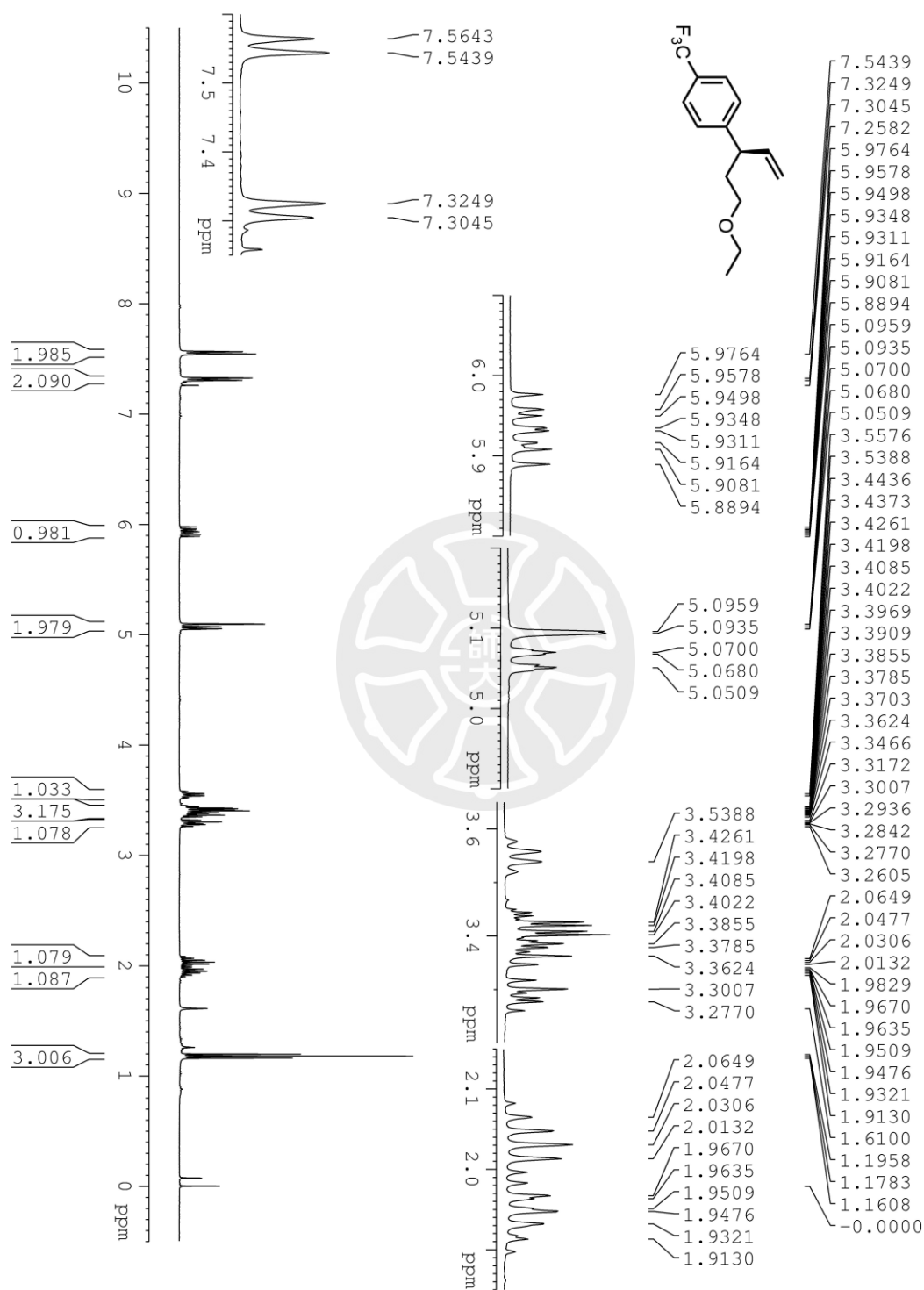
114. ^1H NMR of (*R*)-1-chloro-4-(5-ethoxypent-1-en-3-yl)benzene (94ie)



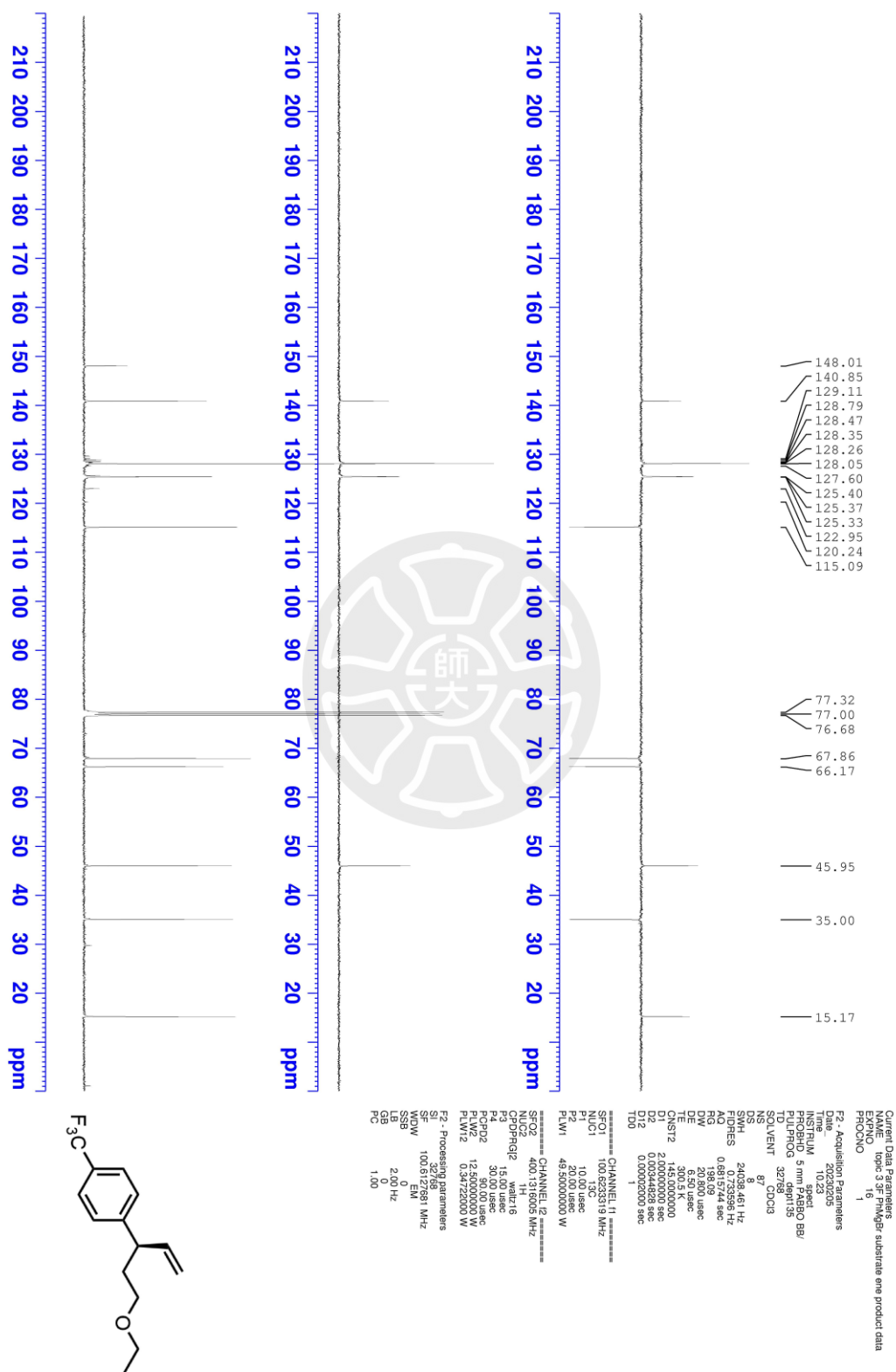
115. ^{13}C NMR of *(R)*-1-chloro-4-(5-ethoxypent-1-en-3-yl)benzene (94ie)



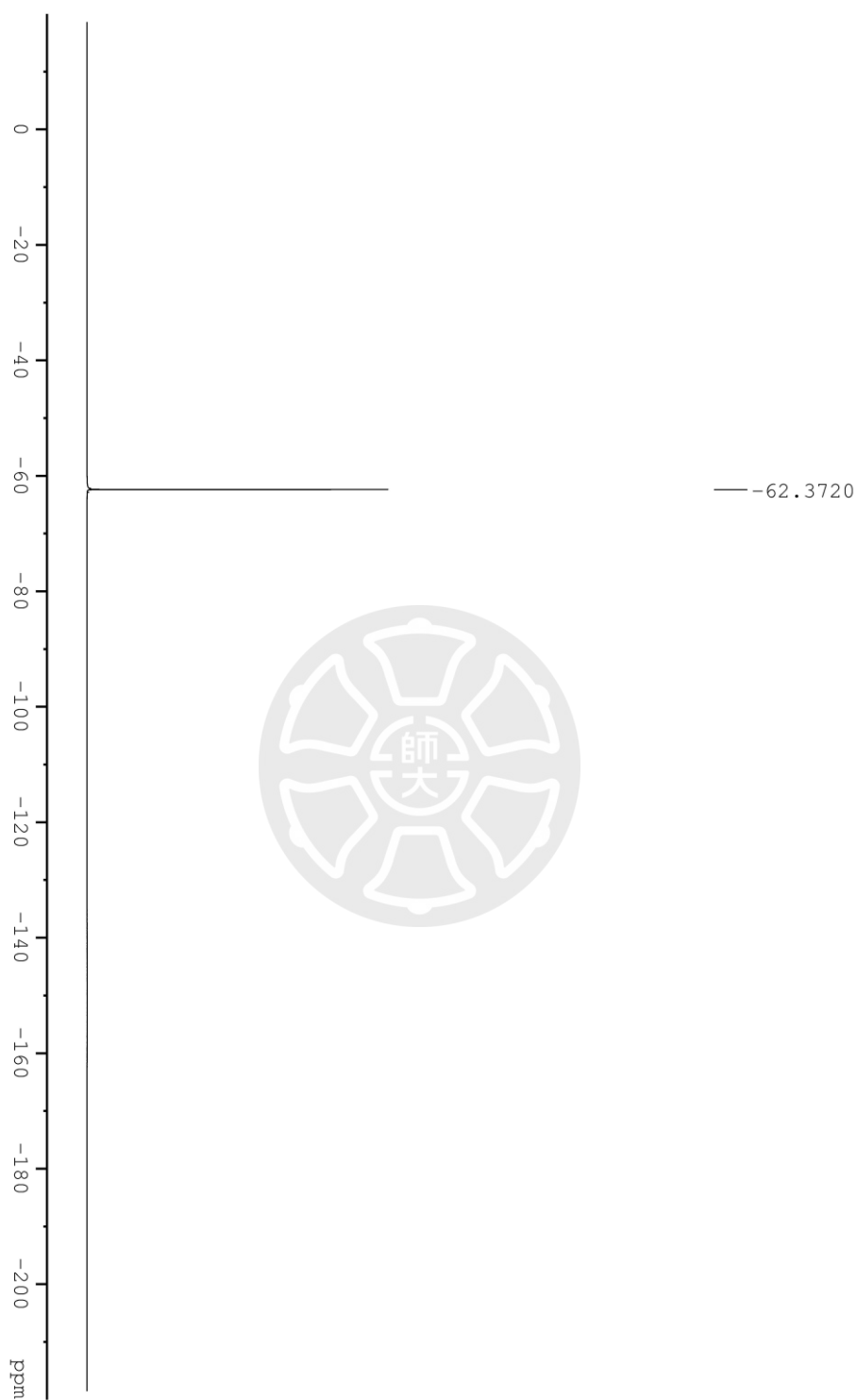
116. ¹H NMR of (R)-1-(5-ethoxypent-1-en-3-yl)-4-(trifluoromethyl)benzene (94je)



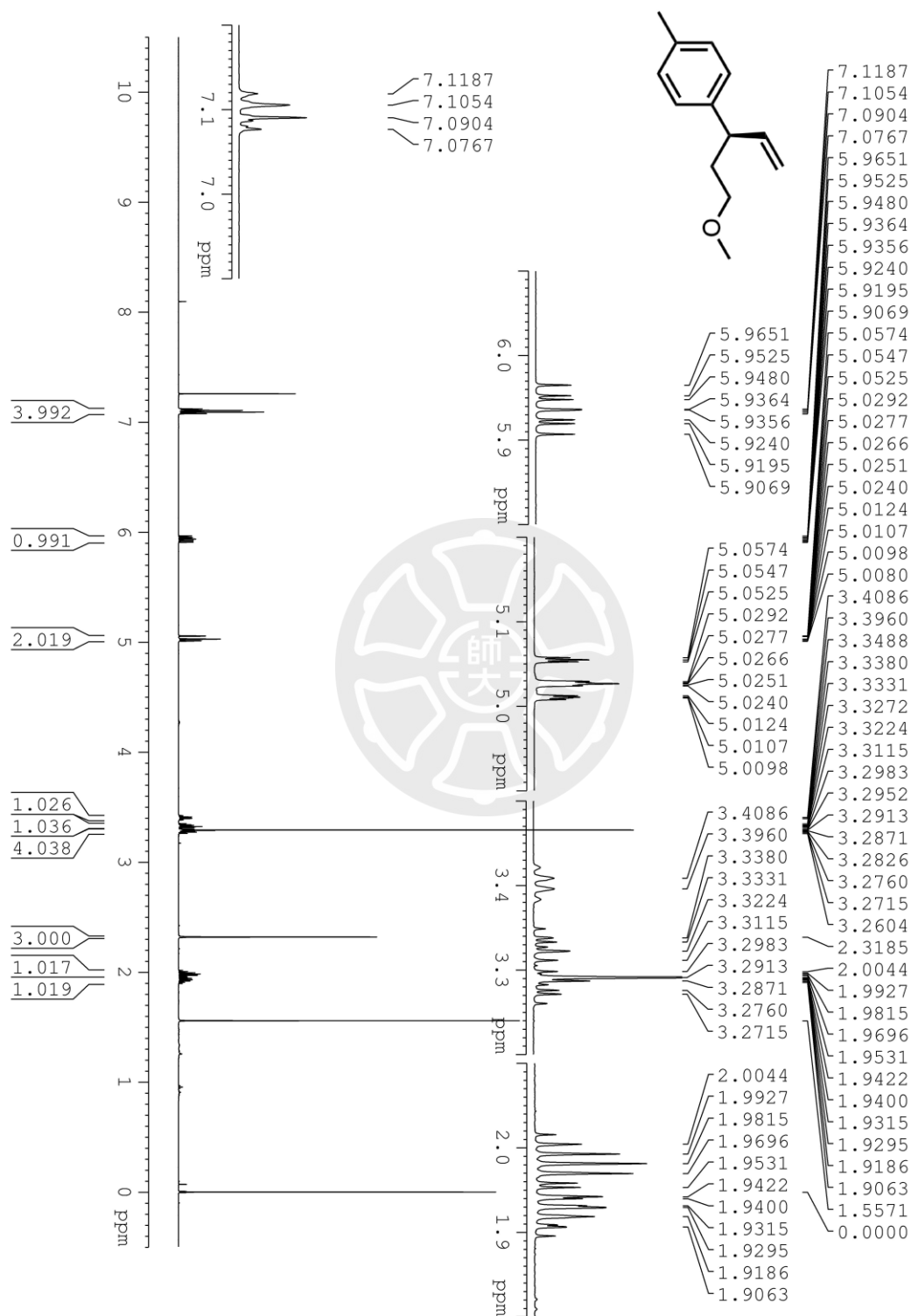
117. ^{13}C NMR of *(R)*-1-(5-ethoxypent-1-en-3-yl)-4-(trifluoromethyl)benzene (94je)

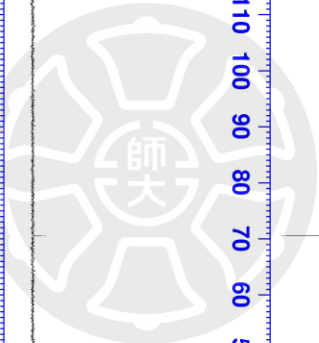


.118. ^{19}F NMR of *(R)*-1-(5-ethoxypent-1-en-3-yl)-4-(trifluoromethyl)benzene (94jm)



119. ¹H NMR of (R)-1-(5-methoxypent-1-en-3-yl)-4-methylbenzene (94km)





```

Current data parameters
EVALUATION: 1
EVALUATION type: 3 (F)
Substrate: substrate
one product data
PROTOCOL: 41

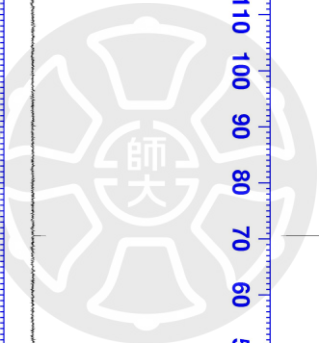
F2: Acquisition Parameters
Date: 20230425
Time: 8:16
INSTRUM: F2
PROBOD: 5 mm PABBO BB/
FLUOROPRO: 4000
ID: 32788
SUB: 1
SOLVENT: 72 DMSO
DMSO: 6
DMF: 24.6
FIDRES: 0.733661 Hz
AQ: 0.881574 sec
RG: 128
DI: 0.06404
F2: 125.000000 u/sec
TE: 6.50 u/sec
DE: 297.8 K
DMS12: 11.45
D2: 2.000000000 sec
D3: 0.000944828 sec
D7: 0.000000000 sec
D72: 0.000000000 sec

CHANNEL 1:
SFO: 100.625313 MHz
P1: 10.00 usec
P2: 10.00 usec
NUC1: 13C
PL1: 0.00 dB
PL2: 0.00 dB
PLW: 41.55000000 W

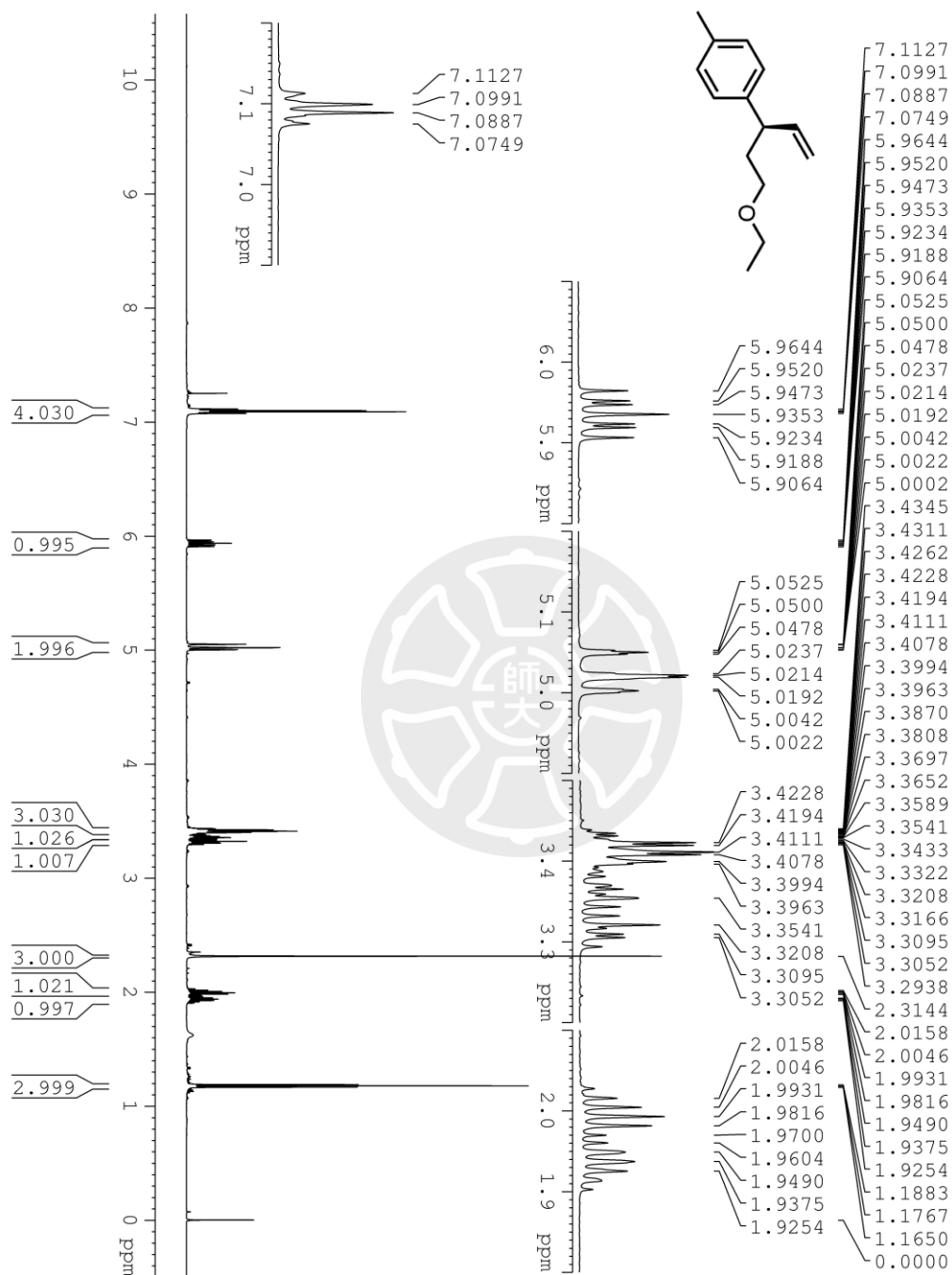
CHANNEL 2:
SFO: 400.146063 MHz
P1: 40.00 usec
P2: 40.00 usec
NUC2: 1H
CPDPRG2: zgpg30
F2: 400.146063 MHz
F2CD2: 12.50000000 u/sec
PLW2: 0.50000000 W
PLW12: 0.50000000 W

F2: Processing parameters
SF: 100.6127885 MHz
WDW: EM
SSB: 0
GB: 2.00 Hz
GC: 1.00

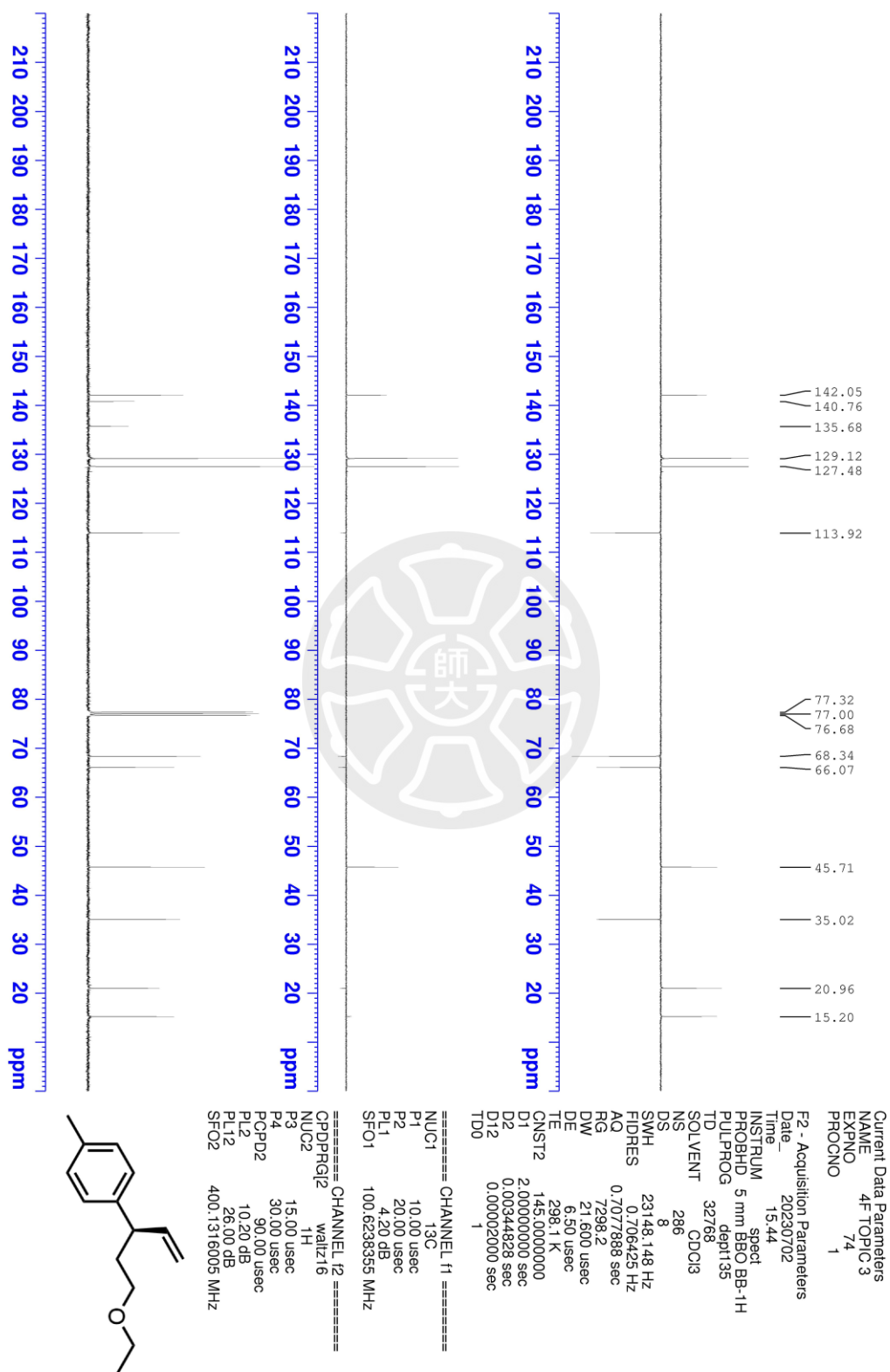
```



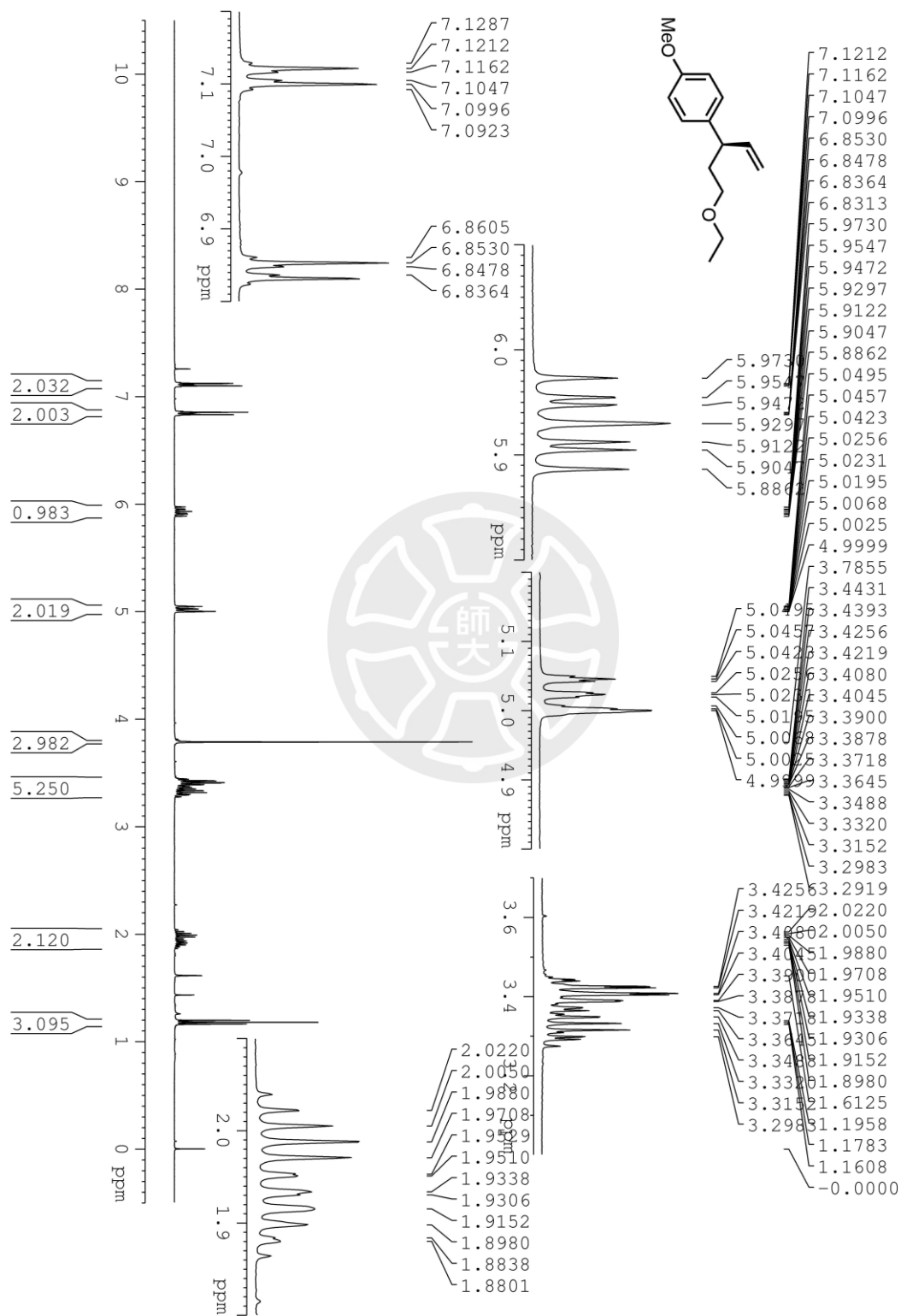
121. ^1H NMR of (*R*)-1-(5-ethoxypent-1-en-3-yl)-4-methylbenzene (94ke)



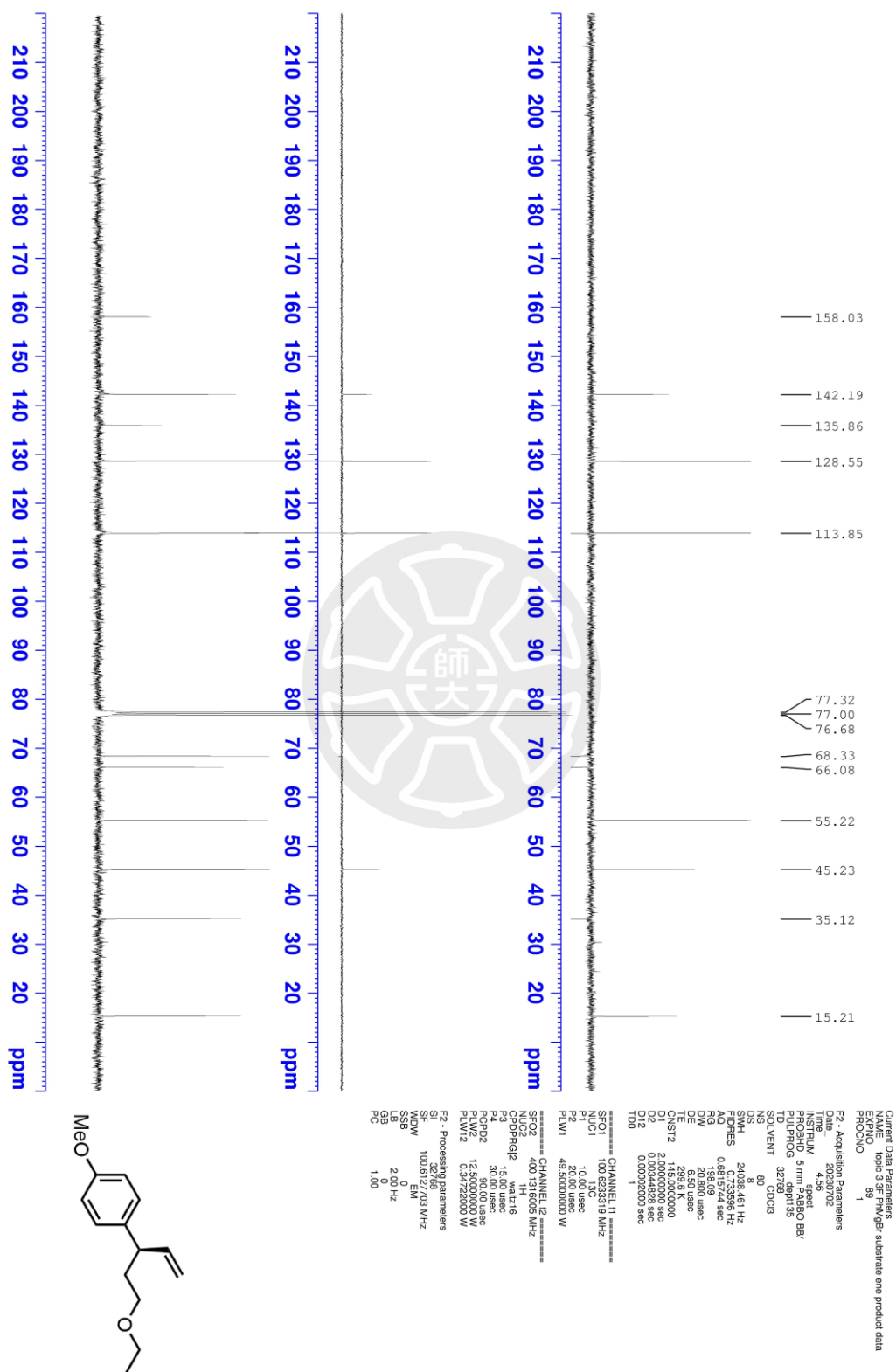
122. ^{13}C NMR of *(R)*-1-(5-ethoxypent-1-en-3-yl)-4-methylbenzene (94ke)



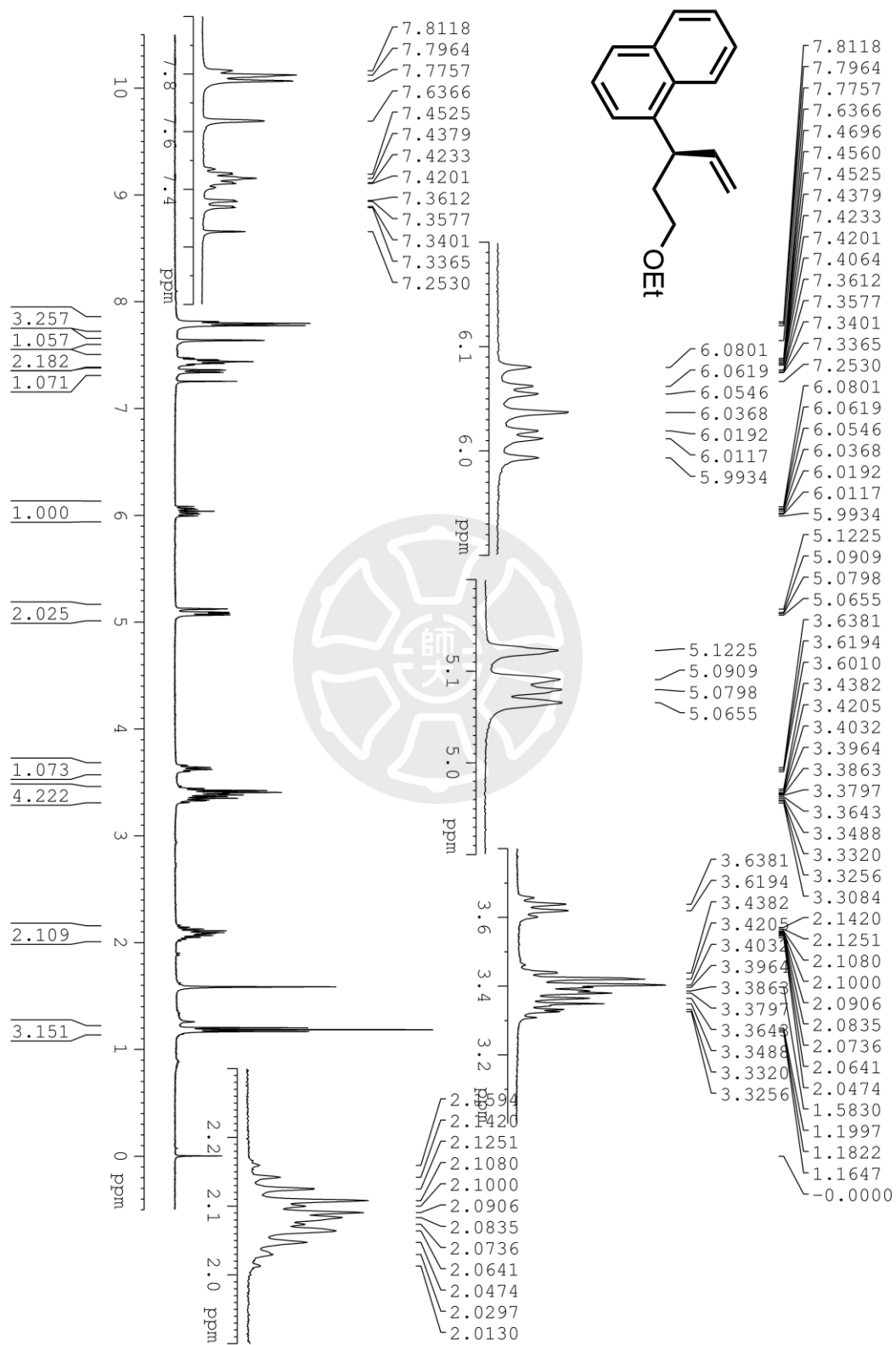
123. ^1H NMR of (*R*)-1-(5-ethoxypent-1-en-3-yl)-4-methoxybenzene (94le)



124. ^{13}C NMR of *(R)*-1-(5-ethoxypent-1-en-3-yl)-4-methoxybenzene (94le)



125. ¹H NMR of (*R*)-2-(5-ethoxypent-1-en-3-yl)naphthalene (94me)



126. ^{13}C NMR of (*R*)-2-(5-ethoxypent-1-en-3-yl)naphthalene (94me)

