REGIOSELECTIVE HECK REACTION OF ALIPHATIC OLEFINS

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"Hypothesis/fact", "learning… stone versus sponge", "stage 0-- stage 1-- stage 2", "positive/pessimistic", "How do you survive so many failures? Be an optimist!", "aggressive"… Simply take a look at these words on my plan book, which Dr. Steve gave me the very first day I came here, it reminds me the moments when he wrote down these words on the book trying to teach me how to do research. I must thank my supervisor Dr. Steve Zhou for giving me the opportunity to learn organotransition metal chemistry with him, not only his knowledge, but also his dedication to chemistry, to research. Dr. Steve has high standards for everyone, including himself. During these years, I have been trying hard to reach these standards; although it seems as if I could never reach the line, when I look back, I can clearly see my own progress and feel how important these trainings are to me.

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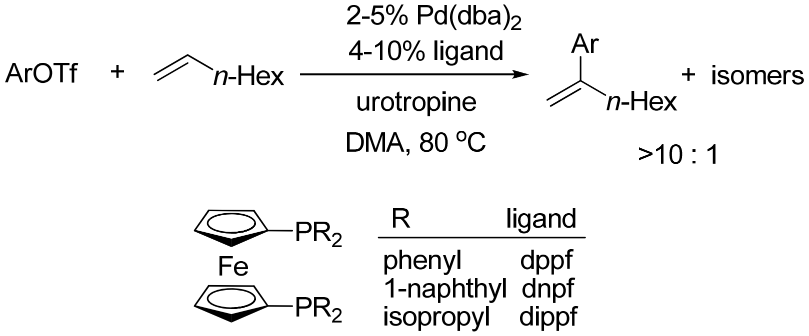
ABSTRACTS

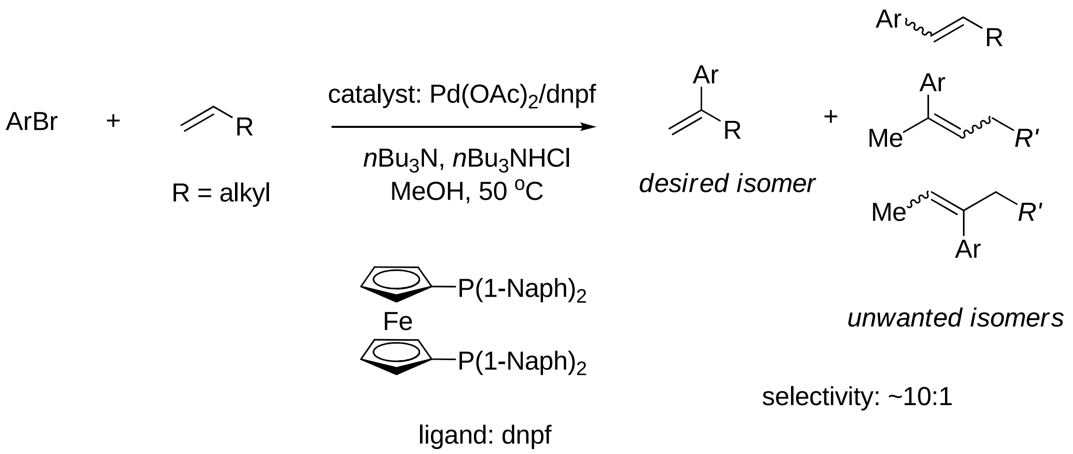
One important aspect of Mizoroki-Heck reaction is regioselectivity of olefin insertion. For electronically biased olefins, such as acrylates, the aryl group will add to the olefinic carbon carrying lower electron density. For electronically unbiased aliphatic olefins, that do not carry directing groups, it was a longstanding problem to realize high regioselectivity. In this thesis, we provided some solutions to this old problem.

The thesis is divided into two parts. The first part deals with realizing regioselective arylation of aliphatic olefins using aryl triflates (*Scheme 1*). In particular, a new ferrocene bisphosphine, dnpf bearing *P*-1-naphthyl groups, gave high regioselectivity for reactions of PhOTf and other unhindered aryl triflates. The ligand dnpf is now commercialized by Sigma-Aldrich. Our experimental and DFT studies in collaboration with Dr. Yunpeng Lu indicated that the bulky dnpf ligand sterically impeded terminal insertion, an alternative minor pathway.



Scheme 1 *Heck reaction of aliphatic olefins and aryl triflates.*

The second part is about selective Heck reaction of alphatic olefins and aryl bromides (*Scheme 2*). The new method can also be applied to α-selective Heck reaction of styrenes. The selectivity was again controlled by the bisphosphine dnpf. The use of methanol solvent was the key to this success. Hydrogen bonding promotes halide dissociation from neutral aryl-Pd center to generate cationic aryl-Pd species for olefin insertion. Acidic additive n-Bu$_3$N·HCl was also needed to promote halide dissociation. DFT calculation of halide dissociation was conducted by Prof. Hajime Hirao. It pointed out the hydrogen bonding between methanol and bromide ion affected halide dissociation both thermodynamically and kinetically.



Scheme 2 *Heck reaction of terminal olefins and aryl halides.*

PUBLICATIONS

1. Regioselective Heck Reaction of Terminal Olefins Using Aryl Halides. Liena Qin, Hajime Hirao and Jianrong (Steve) Zhou*. *Chem. Commun.* **2013***, 49,* 10236.

2. Selective Arylation and Vinylation at α Position of Vinylarenes. Yinjun Zou, Liena Qin, Xinfeng Ren, Yunpeng Lu, Yongxin Li and Jianrong (Steve) Zhou*. *Chem. Eur. J.* **2013**, *19*, 3504.

3. Intermolecular Mizoroki–Heck Reaction of Aliphatic Olefins with High Selectivity for Substitution at the Internal Position. Liena Qin, Xinfeng Ren, Yunpeng Lu, Yongxin Li and Jianrong (Steve) Zhou*. *Angew. Chem. Int. Ed.* **2012**, *51*, 5915. (**Hot paper**)

ABBREVIATIONS

Ac	Acetyl
Cy	Cyclohexyl
[bmim][BF_4]	1-Butyl-3-methylimidazolium tetrafluoroborate
BINAP	2,2'-Bis(diphenylphosphino)-1,1'-binaphthyl
n-Bu	*n*-Butyl
t-Bu	*tert*-Butyl
BQ	Benzoquinone
^{o}C	Degree Celsius
DABCO	1,4-Diazabicyclo[2.2.2]octane
dba	Dibenzylideneacetone
DCM	Dichloromethane
DFT	Density functional theory
dippf	1,1′-Bis(diisopropylphosphino)ferrocene
dnpf	1,1'-Bis[di(1-naphthyl)phosphino]ferrocene
DPEphos	Bis[(2-diphenylphosphino)phenyl] ether
dppe	1,2-Bis(diphenylphosphino)ethane
dppbz	1,2-Bis(diphenylphosphino)benzene
dppf	1,1′-Bis(diphenylphosphino)ferrocene
dppp	1,3-Bis(diphenylphosphino)propane
dpppent	1,5-Bis(diphenylphosphino)pentane
DMA	Dimethylacetamide
DMF	Dimethylformamide
DMPU	1,3-Dimethyl-3,4,5,6-tetrahydro-2(1H)-pyrimidinone
EDG	Electron donating group
equiv	Equivalent
EWG	Electron withdrawing group
Et	Ethyl

GC	Gas chromatography
GC-MS	Gas chromatography–mass spectrometry
h	hour
Hex	Hexyl
Hz	Hertz
Me	Methyl
Mol%	Molar percent
MOM	Methoxylmethyl
Neocuproine	2,9-Dimethyl-1,10-phenanthroline
NMP	N-Methyl-2-pyrrolidone
NMR	Nuclear magnetic resonance
Ph	Phenyl
rt	room temperature
THF	Tetrahydrofuran
Tf	Trifluoromethansulfonyl
TMEDA	Tetramethylethylenediamine
Ts	4-Toluenesulfonyl
Urotropine	Hexamethylenetetramine
Xantphos	4,5-Bis(diphenylphosphino)-9,9-dimethylxanthene

CHAPTER ONE

Heck Reaction of Aliphatic Olefins and Aryl Triflates

1.1 Introduction

Heck reaction, the palladium-catalyzed arylation of alkenes[1] was discovered by Mizoroki[2] and Heck[3] independently in the early 1970s. Initially, Heck prepared arylpalladium salts by exchange reactions between $Pd(OAc)_2$ or $PdCl_2$ and aryl-mercurials, -lead or -tin compounds. The stoichiometric amounts of palladium salts react with alkenes to form arylalkenes.[3c,4] Subsequently, palladium was found to react with aryl iodides directly to form organo-palladium salts. The stoichiometric version of the reaction was refined into a catalytic system.

Among the aryl halides, bromides worked poorly and chlorides very poorly, due to slow oxidative addition. Triarylphosphine was then found to greatly help the reaction with bromides. The challenging aryl chlorides were discovered by Fu *et al.* to react effectively in the presence of electron-rich tri-*tert*-butylphosphine.[5] A broad range of mono- and disubstituted olefins could react with aryl bromides as well as activated aryl chlorides at room temperature with $Pd/P(t\text{-}Bu)_3$ serving as the catalyst. Electron-neutral and electron-rich aryl chlorides proceed at elevated temperature. Aryltriflates were initially introduced by Cabri *et al.* in the internal-selective arylation of electron-rich vinyl ethers[6] and Hayashi *et al.* in the asymmetric arylation of 2,3-dihydrofuran[7], where in both cases bidentate phosphine ligands were applied.

Heck reaction has been extensively explored in the past forty years. Among the many aspects in Heck reaction, one critical aspect is the regioselectivity of olefin insertion. The selectivity issue originates from the migratory insertion step as shown in the catalytic cycle (*Figure 1.1*). In the neutral pathway, a neutral ligand L dissociates to create a vacant site for olefins to bind. The aryl group could add to the internal position of olefins to deliver branched product or terminal position to deliver linear product. In the case of acrylates, selective terminal insertion was observed as shown below.

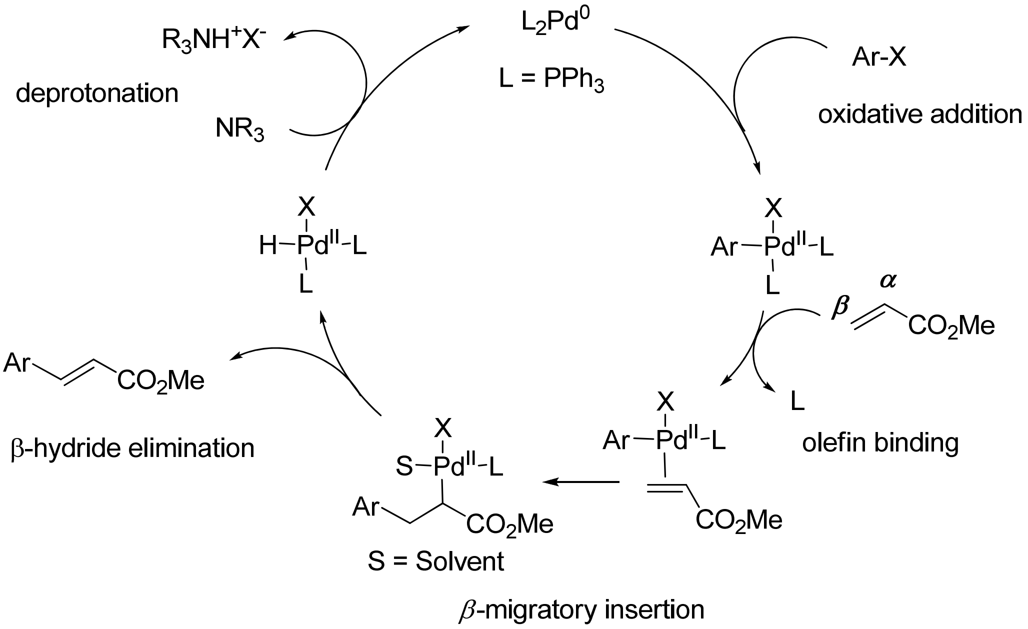
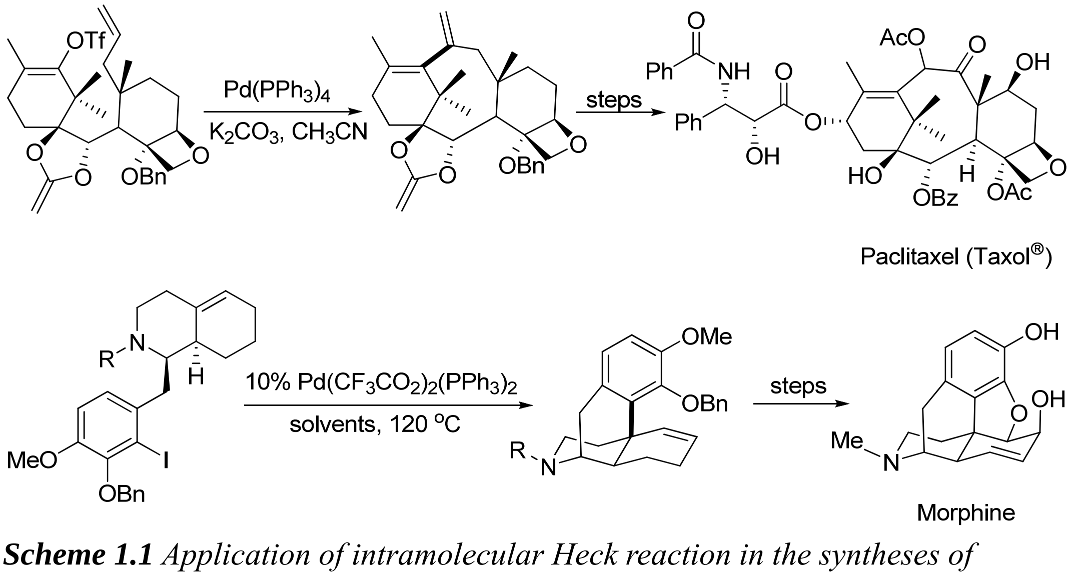


Figure 1.1 *Catalytic cycle of Heck reaction in neutral pathway.*

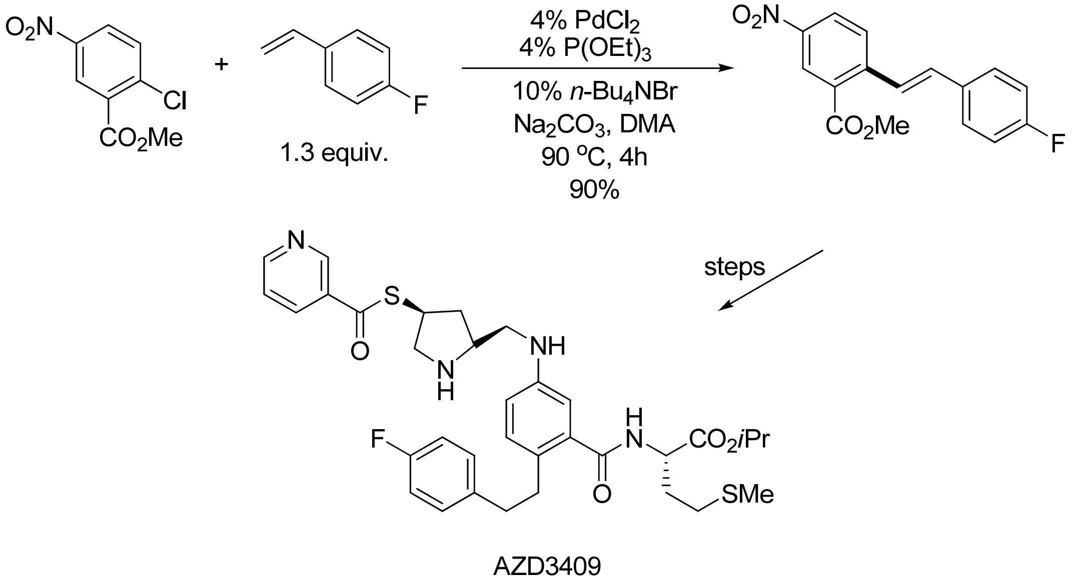
1.1.1 Application of regioselective Heck reaction

The Heck reaction has been widely applied in the syntheses of natural products[8] and biologically active compounds[9]. For example, intramolecular Heck reaction was used to form the eight-membered ring of Paclitaxel[10] and the skeleton of Morphine[11] (*Scheme 1.1*).



Scheme 1.1 *Application of intramolecular Heck reaction in the syntheses of Paclitaxel and Morphine.*

Heck reaction of styrenes routinely gives stilbenes in high terminal selectivity. In another application, the reaction was applied in kilogram synthesis of AZD3409, a pro-drug developed by AstraZeneca for the treatment of breast cancer and other tumors (*Scheme 1.2*).[12]



***Scheme 1.2** Synthesis of pro-drug AZD3409.*

1.1.2 Catalytic pathways

The regioselectivity of the Heck reaction is influenced by many factors, including electronic properties of olefin, chelating groups on olefins, catalytic pathways and nature of Pd catalysts.

One key factor that greatly influences the regioselectivity of olefin insertion is the catalytic pathway. Three major pathways can operate in olefin insertion. One is the neutral pathway, whereby a neutral ligand dissociates from the square-planer palladium center to provide a vacant site for the olefin insertion.[13] The second one is the anionic pathway, whereby the neutral phosphine is replaced by an anionic halide or acetate ligand.[14] The third pathway is the cationic pathway, whereby the olefin inserts into a cationic aryl-palladium species ligated by a chelating bisphosphine (*Figure 1.2*).[6-7]

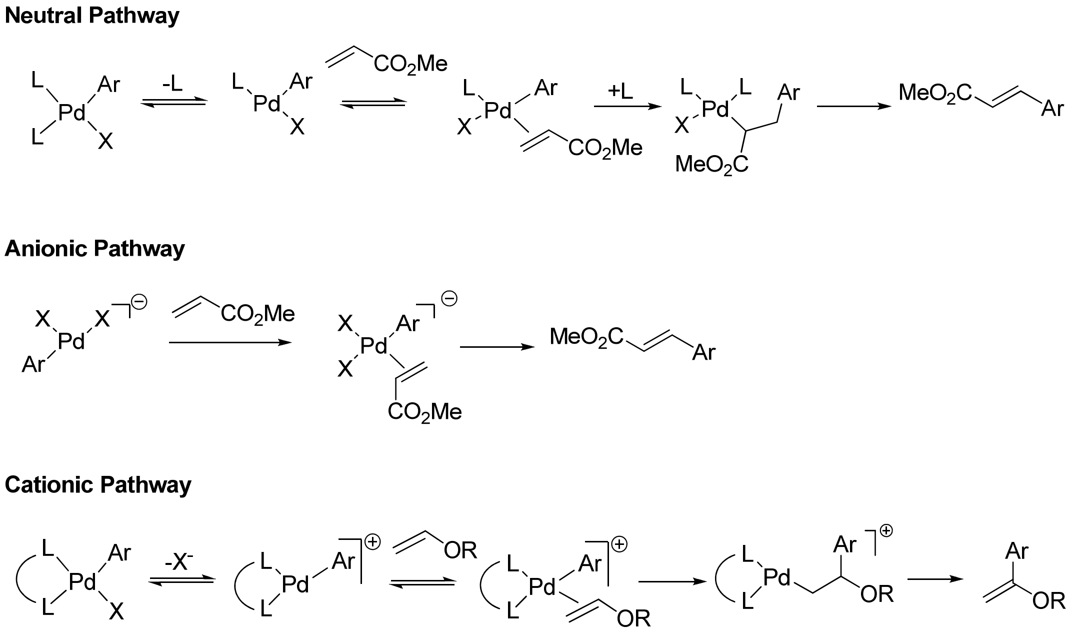


Figure 1.2 *Pathways for olefin insertion.*

The neutral pathway usually takes place in the presence of monophosphine ligands (e.g. PPh_3) and using aryl halides as substrates. Coordination of olefin takes place with dissociation of one phosphine ligand since a strong Pd-X (X=I, Br, Cl) bond will not ionize in common organic solvents and in the absence of halide abstractors.[1f]

In the neutral pathway, both electron-poor acrylates and styrenes give almost exclusively linear products (*Figure 1.3*); electron-rich vinyl ethers normally generate a mixture of Heck products. Aliphatic olefins lacking directing groups usually give a mixture of isomers. For example, Heck *et al.* reported ~1:1 ratio of the (*E*)-styrene product versus other isomers using $Pd(OAc)_2$ and PPh_3 as catatlyst.[13] The often-cited 4:1 selectivity represents the best-scenario result.

In the anionic pathway as described by Jeffery *et al.*, the regioselectivity is very similar to that observed in the neutral pathway.[2-3,15] Acrylates and styrenes give linear selectivity,[5b,15a,16] and vinyl ethers give 3:1 terminal selectivity.[14] The phosphine-free anionic arylpalladium species was recently isolated and studied by Hartwig *et al.* The results were similar to the regioselectivity observed under catalytic conditions. The ligandless anionic species was described by Hartwig *et al.* to be the intermediate in the reaction.[14]

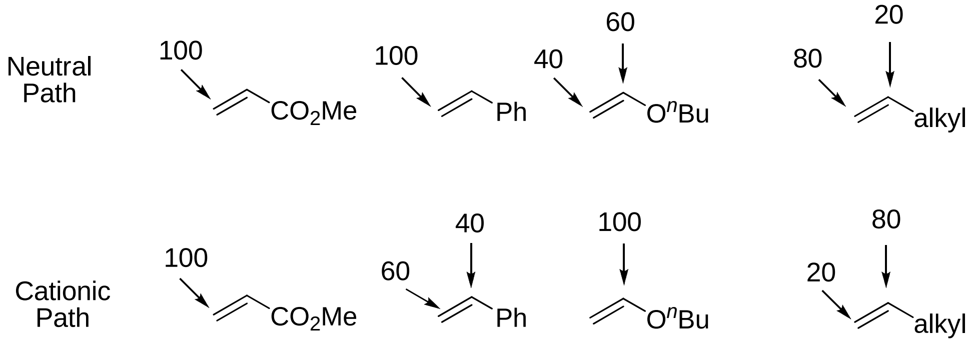


Figure 1.3 *Influence of catalytic pathway on olefins.*

In the cationic pathway, coordination of olefin takes place with the loss of an anion ligand (*Figure 1.3*). It commonly occurs when bisphosphines are used as supporting ligands and aryl triflates as substrates, since triflate anion is a good leaving group.[17] In cases where aryl halides were used as the substrates, toxic thallium or silver salts were used to promote halides ionization to access the cationic aryl-Pd species.[6] In recent years, Xiao *et al.* reported that ammonium salts can also promote halide ionization in Heck reaction of electron-rich olefins and aryl halides.[18] Alcoholic solvents such as ethylene glycol could also help halide dissociation from neutral arylpalladium centers by hydrogen bonding (*see Chapter II*).[19]

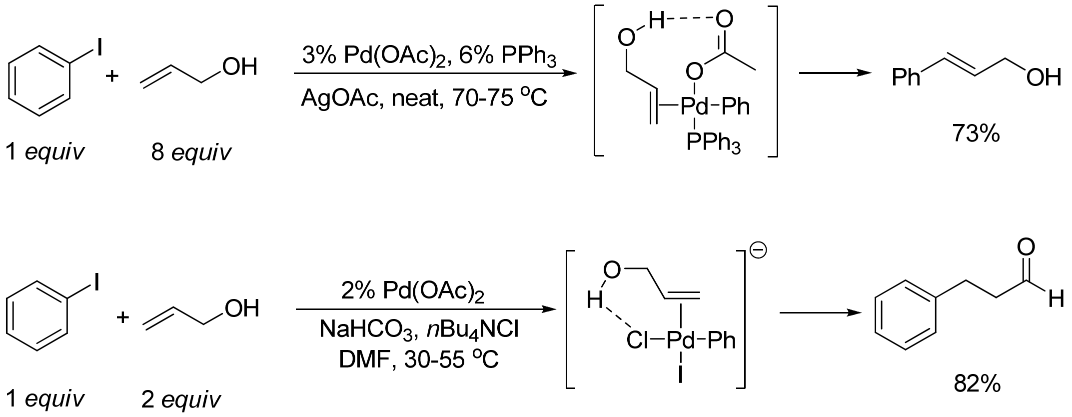
In the cationic pathway, the regioselectivty was very different from the neutral ones. Cabri *et al.* reported that vinyl ethers and other electron-rich olefins gave excellent internal regioselectivity (up to 99:1).[6] The cationic insertion transition state is relatively early as compare to neutral ones. There is a significant amount of partial positive charge established on the vinylic carbon that forms the new C-C bond. The charge can be resonance-stabilized by the neighboring oxygen or nitrogen atoms.[20] For styrenes, selective insertion into internal position is very difficult.[21] Under Cabri's condition, ~1:1 ratio was obtained.[17] Recently, Xiao *et al.*

documented ~1:1 internal selectivity for most substrate pairs of styrenes; in the best scenario, 9:1 selectivity was obtained for *p*-MeO-styrene.[19] For aliphatic olefins, the insertion could be biased towards internal position to some degree.[17] However, high internal selectivity was rare. For example, Xiao *et al.* reported that ω-hydroxyolefins gave around 4:1 selectivity.[19,22] In most cases before our investigation, the regioselectivity was only around 2:1.

1.1.3 Regioselectivity of aliphatic olefins

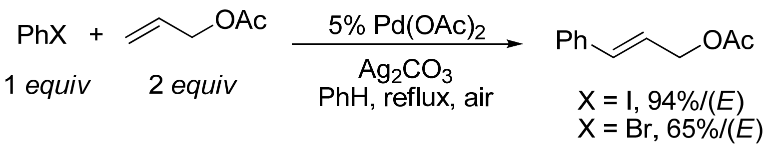
1.1.3.1 Terminal selectivity for aliphatic olefin carrying directing groups

The presence of polar directing groups on aliphatic olefins can induce high ratio of terminal arylation.[23] For example, Heck *et al.* reported that allylic alcohol gave terminal insertion exclusively to generate a mixture of cinnamyl alcohols and aldehydes.[24] Under other conditions reported by Jeffery *et al.*, either cinnamyl alcohols or aldehydes/ketones could be selectively obtained (*Scheme 1.3*).[23a] We proposed that the high terminal selectivity for allylic alcohol is caused by internal hydrogen bonding between the hydroxyl group and Pd-bound acetate or chloride ligands (*Scheme 1.3*).



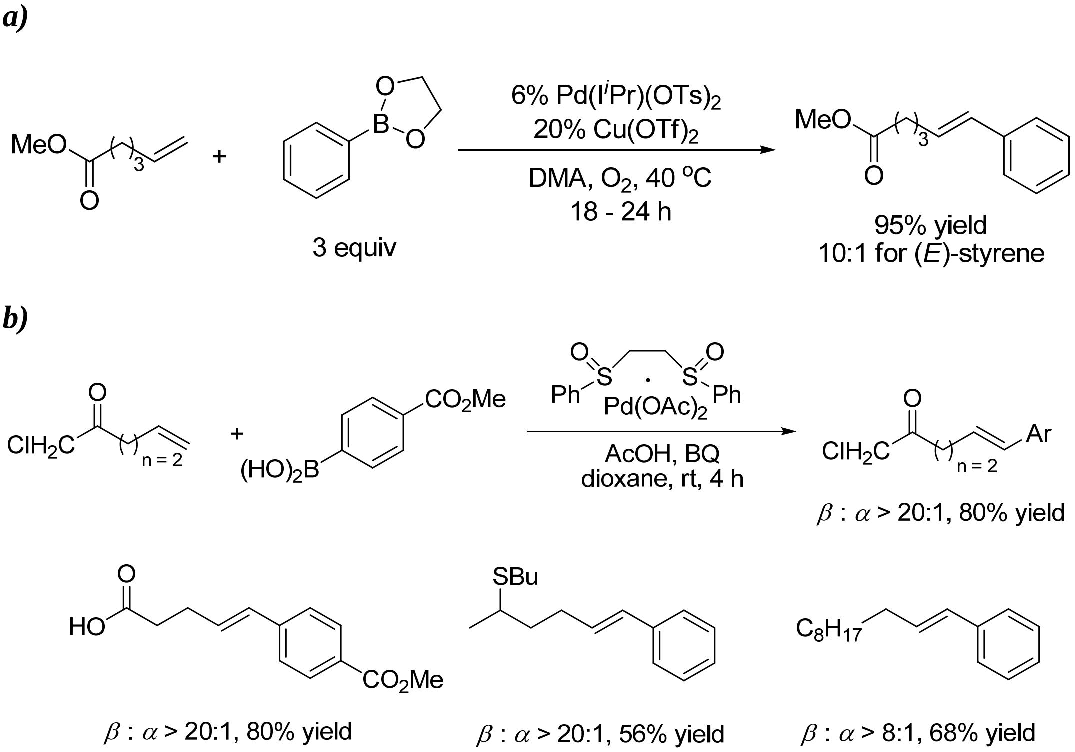
Scheme 1.3 *Terminal arylation of allylic alcohol.*

Acetate group was another example of directing groups as reported by Jiao *et al.* in allylic arylation reaction (*Scheme 1.4*).[25] In reactions of allylic acetate, silver carbonate was used to remove halides and to generate cationic arylpalladium complex for directed insertion.



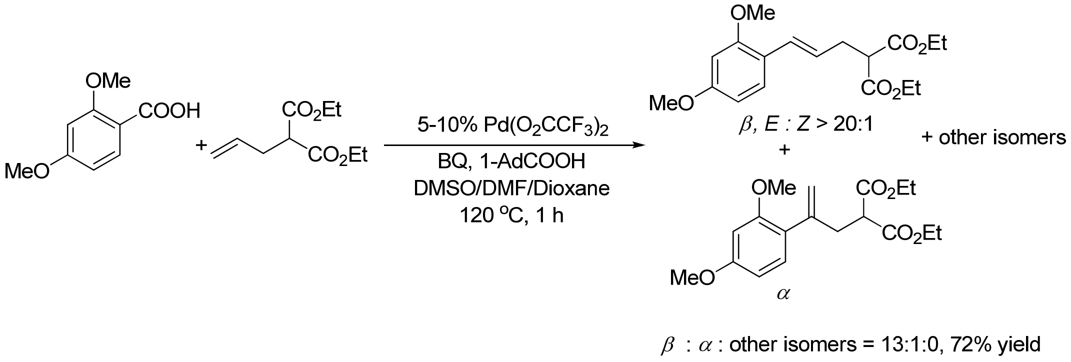
Scheme 1.4 *Acetate as chelating group in Heck reaction.*

The chelating strategy was also used in oxidative Heck reaction (*Scheme 1.5*).[26] Many functional groups, such as alcohols, ketones, esters, carboxylic acids, carboxamides, amines and thioethers, could function as chelating groups. More than 20:1 terminal selectivity was observed in most cases.



Scheme 1.5 *Chelation-controlled oxidative Heck reaction.*

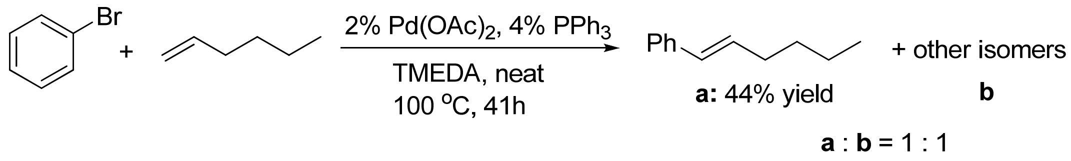
In decarboxylative Heck reaction, ester groups can play the role of directing groups (*Scheme 1.6*). [27] More than 10:1 terminal selectivity was obtained in most cases. Only electron-rich aryl rings were reported to be decarboxylated efficiently. Unfunctionalized bulky vinylcyclohexene only delivered ~4:1 terminal selectivity.



Scheme 1.6 Chelation-controlled decarboxylative Heck reaction.

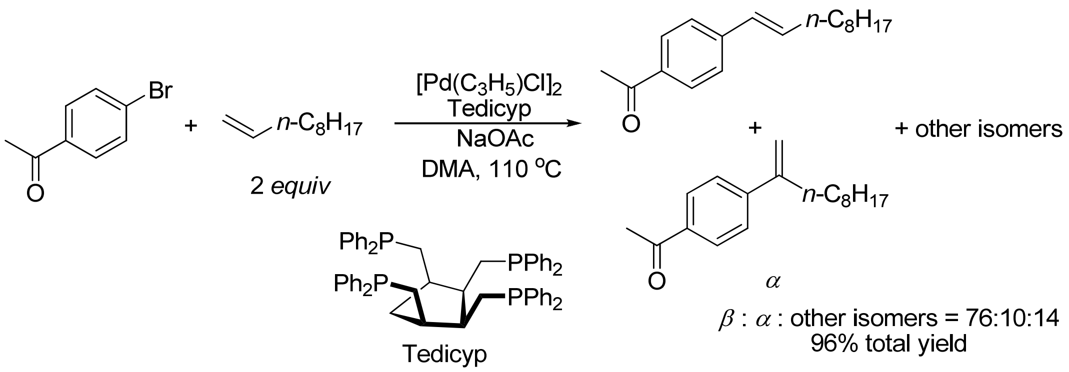
1.1.3.2 Terminal selectivity for aliphatic olefin without directing groups

For aliphatic olefins that lack of directing groups, a complex mixture of isomers usually resulted.[13,28] In the neutral pathway, the olefins were terminally arylated, but the selectivity was not good. As one example shown in *Scheme 1.7*, the reaction of phenyl bromide and 1-hexene generated only 44% of the (*E*)-styrene isomer together with an equal amount of isomers.[13]



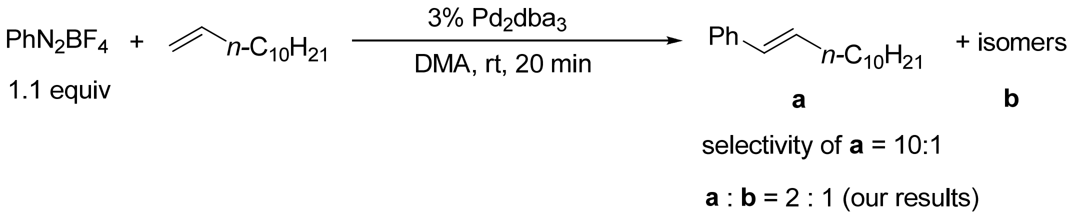
Scheme 1.7 Arylation of 1-hexene.

Santelli's tetraphosphine gave ~1:1 ratio of *trans*-styrene to all other isomers.[29] The best scenario of Santelli's gave ~4:1 selectivity when electron-deficient ArBr was used (*Scheme 1.8*).[30] Electron-neutral and electron-rich ones gave much lower selectivity.



Scheme 1.8 *Palladium-tetraphosphine catalyzed terminal selective arylation of aliphatic olefins.*

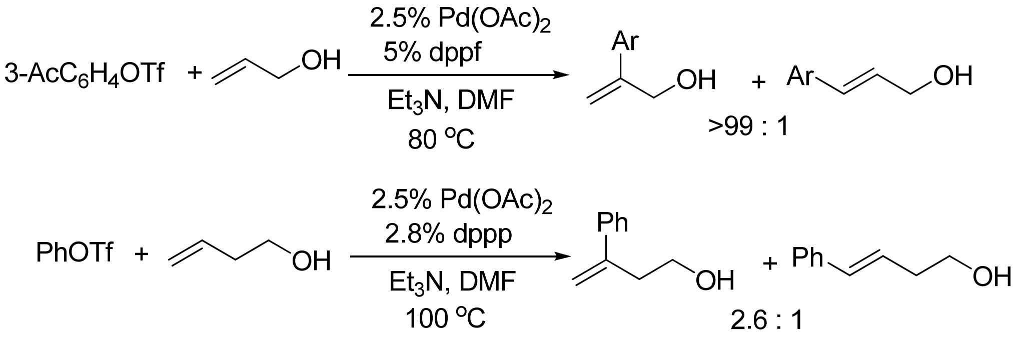
Recently, Sigman *et al.* reported regioselective Heck-Matsuda reaction of electronically unbiased olefins using aryldiazonium salts (*Scheme 1.9*).[31] 1-Dodecene was reported to give 10:1 selectivity of (*E*)-styrenes (as determined by ^{1}H NMR spectroscopy). However, in our hands we observed ~2:1 ratio of (*E*)-styrene versus *all other isomers* (judged by by GC and GCMS). Some diarylation byproducts were also observed.



Scheme 1.9 *Terminally selective arylation of electronically unbiased olefins with aryl diazonium salts.*

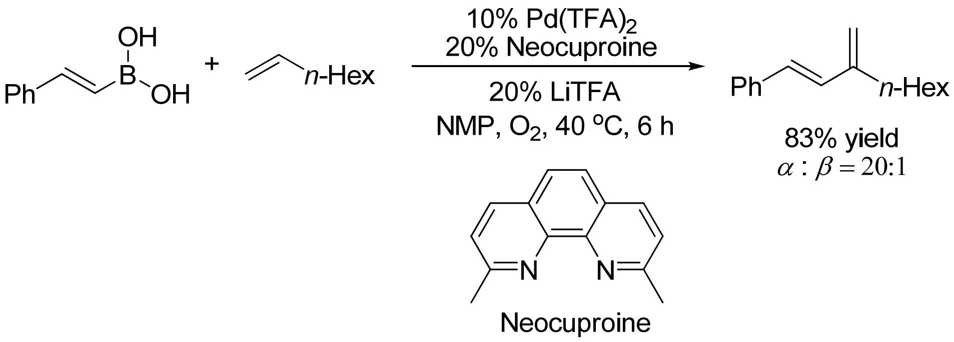
1.1.3.3 Internal selectivity for aliphatic olefins

In 1990s, Cabri *et al.* reported that olefin insertion into cationic aryl-Pd intermediates could be biased toward the internal position.[17] However, the selectivity was too low to be synthetically useful. Among aliphatic olefins, allylic alcohol was an exception that gave excellent internal selectivity. The inductive effect quickly diminishes in the example of homoallylic alcohol and the selectivity dropped to 2:1 (*Scheme 1.10*).



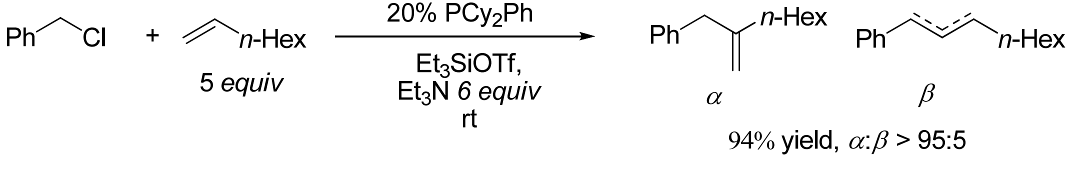
Scheme 1.10 *Heck reaction of aryl triflates with allylic and homoallylic alcohols.*

In oxidative Heck reaction using vinylboronic acids, Stahl *et al.* disclosed high internal vinylation of aliphatic olefins. A bulky phenanthroline-type ligand was used to induce internal selectivity (*Scheme 1.11*).[32]



Scheme 1.11 *Internal vinylation of aliphatic olefin in oxidative Heck reaction.*

Most recently, Jamison *et al.* reported Heck reaction of aliphatic olefins and benzyl chlorides in high internal selectivity, by using nickel catalysts.[33] It was proposed that steric effect was dominant in the internal benzylation (*Scheme 1.12*).

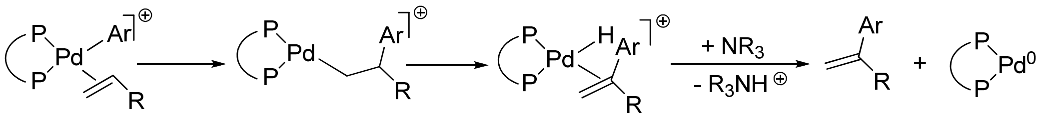


Scheme 1.12 *Internally selective benzylation of aliphatic olefin with nickel catalyst.*

1.2 Results and discussion

In a typical Cabri's condition, the internal selectivity for aliphatic olefins was only about 2:1. We hypothesized that a bulky bisphosphine may be able to enhance the regioselectivity by inhibiting terminal insertion. In the terminal-insertion transition state, the alkyl chain is close to *P*-substituents of bisphosphines and hence more sensitive to the ligand environment (*Figure 1.4*).

a) Internal insertion



b) Terminal insertion

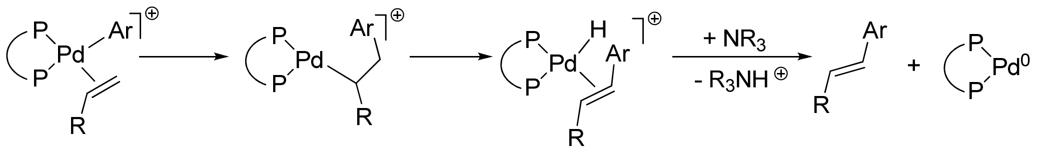
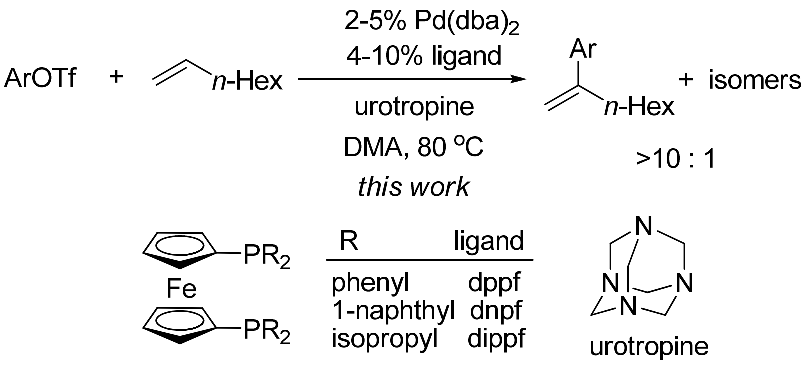


Figure 1.4 *Internal and terminal arylation of olefins.*

After screening various bisphosphines, we found a set of ferrocenyl bisphosphine ligands can deliver good internal selectivity. More than 10:1 ratio of the desired Heck product to the sum of all other isomers was obtained in most cases (*Scheme 1.13*). The major products were α-alkylstyrenes, which can be readily converted to various chiral building blocks via asymmetric catalytic hydrogenation, hydroacylation and hydroborylation.[34] They are also intermediates in asymmetric synthesis of bioactive natural products[35] and some drug candidates[36]. α-Alkylstyrenes used to be prepared from cross-couplings of 2-alkenyl electrophiles or 2-alkenylmetal reagents. Our new Heck method directly used simple olefins and did not require prior chemical activation of these olefins.



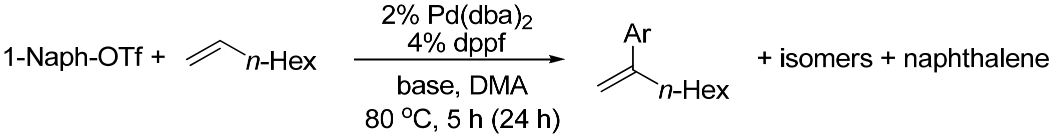
Scheme 1.13 *Intermolecular Heck reactions of aliphatic olefins.*

1.2.1 Condition optimization

This part of work was conducted in collaboration with Dr. Xinfeng Ren in our group. Initially, we used a model reaction of 1-naphthyl triflate and 1-octene and used dppf as ligand (*Table 1.1*). A dramatic effect of bases was observed. Significant reduction of aryl triflate was observed when triethylamine and Hünig's base were used as base.[37] Inorganic bases such as lithium carbonate and sodium carbonate seldom cause reduction of aryl triflate, but the catalytic reactivity was lower in DMA. To our delight, when urotropine was used as base, no reduction byproduct was detected and Heck products were formed in almost quantitative yield. The ratio of the desired isomer, 2-aryl-1-octene versus *all other isomers* was 13:1, as determined by GC. As many as five isomers of the Heck products were detected by GC.

Urotropine is a relatively weak base with pKa value of 5.05 for its conjugate acid.[38] Thus it does not bind strongly to a cationic (dppf)Pd(Ar) species. Furthermore, according to Bredt's rule, its hydrogen α to nitrogen atoms will be slow to donate hydrides to the palladium(II) center. In contrast, when more basic and donating DBU and DABCO were used, little Heck products resulted. Other non-coordinating bases such as 2,6-lutidine and proton sponge gave 50-70% yield.

Table 1.1 *Effect of bases in Heck reaction with 1-napthyl triflate.*[a]

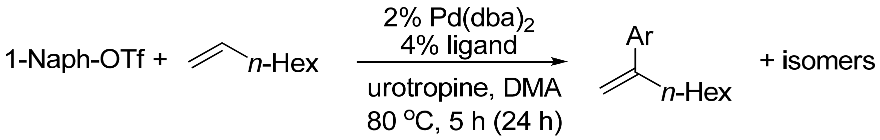


Entry	Base	1-Naph-OTf Conversion[b] (%)	Desired Product[b] (%)	Isomers[b] (%)	Selectivity[c]	Naphthalene[b] (%)
1	Li_2CO_3	68 (75)	56 (56)	5 (5)	11 (11)	1 (2)
2	Na_2CO_3	59 (68)	50 (52)	4 (5)	12 (11)	1 (2)
3	Et_3N	100	56	4	12	36
4	i-Pr_2NEt	100	77	7	12	15
5	Cy_2NMe	100	46	3	13	51
6	**urotropine**	**100**	**93**	**7**	**14**	**<1**
7	2,6-lutidine	82 (91)	70 (74)	6 (7)	11 (11)	<1 (1)
8	proton sponge	63 (74)	52 (51)	5 (5)	10 (10)	<1 (4)
9	DBU	3 (12)	2 (2)	0 (0)	--	0 (0)
10	DABCO	0 (0)	0 (0)	0 (0)	--	0 (0)

[a] Reaction condition: 1-Naph-OTf (0.20 mmol, 1 *equiv*), 1-octene (0.40 mmol, 2 *equiv*), $Pd(dba)_2$ (0.004 mmol, 2 mol%), dppf (0.008 mmol, 4 mol%), base (0.40 mmol, 2 *equiv*), DMA (1.2 mL). The numbers in parentheses refer to 24 hours results. [b] Conversion and yield were calculated by comparing starting material and product peak intergration to integration of internal standard using GC analysis. [c] Selectivity refers to the ratio of desired isomer to all the other isomers.

In the reaction of 1-naphthyl triflate, we also examined many other bisphosphines as supporting ligands (*Table 1.2*). To our delight, ferrocene 1,1'-bisphosphines were particularly selective in delivering the desired isomer. When dppf was used, 13:1 selectivity and 93% GC yield were obtained. Dippf improved the selectivity to 57:1, but the yield was only 43% after 24 hours (*entry 15*). 1,1′-Bis[di(cyclohexyl)phosphino]ferrocene provided similar results as dippf (*entry 16*).

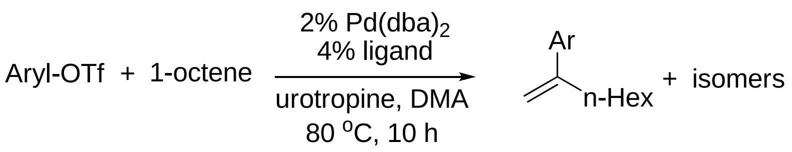
Table 1.2 *Ligand effect in Heck reaction of 1-naphthyl triflate.*[a]



Entry	Ligand	1-Naph-OTf Conversion[b] (%)	Desired Product[b] (%)	Isomers[b] (%)	Selectivity[c]
1	dppe	19 (65)	8 (35)	5 (21)	1.6 (1.6)
2	dppp	100	80	20	4.0
3	dppb	38 (40)	25 (26)	3 (4)	9.5 (6.6)
4	dpppent	10 (35)	2 (5)	0 (17)	NA (0.3)
5	dppbz	39 (69)	22 (39)	12 (21)	1.9 (1.8)
6	DPEphos	42 (57)	36 (44)	3 (6)	14.1 (6.8)
7	Xantphos	7 (12)	<1 (1)	<1 (1)	NA (0.9)
8	(*R*)-BINAP	92 (100)	79 (85)	12 (13)	6.4 (6.5)
9	**dppf**	**100**	**93**	**7**	**13.6**
10	Dppf[d]	83 (87)	68 (71)	6 (7)	11.1 (10.2)
11	d(*o*-tolyl)pf	63 (65)	54 (54)	4 (4)	13.5 (13.5)
12	d(*o*-biphenyl)pf	100	71	26	2.6
13	dnpf	47 (97)	38 (89)	2 (5)	18.4 (17.2)
14	d(2-naphthyl)pf	100	89	9	10.2
15	dippf	54 (59)	43 (43)	1 (1)	57.3 (57.3)
16	d(Cy)pf	62 (63)	50 (50)	<1 (1)	84.8 (42.9)
17	d(3,5-di-*t*-butylphenyl)pf	48 (60)	36 (43)	4 (5)	8.0 (7.9)
18	d(*p*-methoxyphenyl)pf	59 (69)	46 (51)	4 (5)	10.7 (9.0)
19	d(*p*-trifluromethylphenyl)pf	100	93	7	12.8
20	*t*-Bu$_3$PHBF$_4$ (8 mol%)	18 (83)	3 (16)	9 (55)	0.3

[a] Reaction condition: 1-Naph-OTf (0.20 mmol, 1 *equiv*), 1-octene (0.40 mmol, 2 *equiv*), Pd(dba)$_2$ (0.004 mmol, 2 mol%), ligand (0.008 mmol, 4 mol%), urotropine (0.40 mmol, 2 *equiv*), DMA (1.2 mL). The numbers in parentheses refer to 24 hours results. [b]Conversion and yield were calculated by comparing starting material and product peak intergration to integration of internal standard using GC analysis. [c]Selectivity refers to the ratio of desired isomer to all the other isomers. [d] 1.2 *equiv* of 1-octene was used instead of 2 *equiv*.

Later, we examined other aryl triflates using dppf as ligand. We found that the selectivity was highly dependent on aryl electrophiles. For example, if phenyl triflate contained a large *ortho* *t*-butyl group, dppf gave 50:1 selectivity. However, for phenyl triflate, only 4:1 selectivity was observed (*Figure 1.5*).



Aryl	dnpf	dppf	dippf
phenyl[a]	11:1	4:1	(complex)
1-naphthyl	18:1	13:1	57:1
o-t-butylphenyl	2:1	50:1	22:1

[a] 5% $Pd(dba)_2$ and 10% ligand

***Figure 1.5** Interplay between ligands and aryl triflates on selectivity. The ratio of desired Heck isomer to all other isomers was shown.*

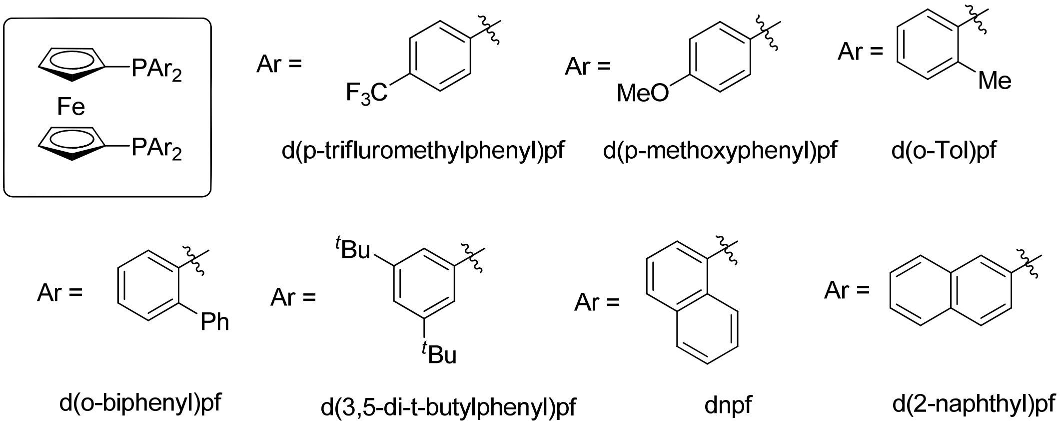
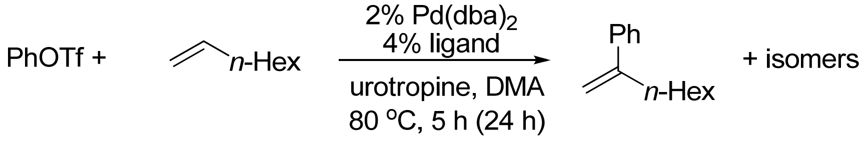


***Figure 1.6** Examples of ferrocene 1,1'-bisphosphines.*

In order to improve the internal selectivity for phenyl triflate, we then tried to modify dppf ligand by introducing electron-withdrawing *p*-CF_3 group or electron-donating *p*-MeO groups on phenyl rings (*Figure 1.6*). Unfortunately, changing electronic properties of dppf did not affect the selectivity (*Table 1.3, entry 17, 18*). Introducing *ortho*-groups on the *P*-phenyl rings had little influence, either (*entry 10, 11*). Installation of *meta*-substituent lowered the catalytic reactivity, but did not affect the selectivity (*entry 16*). Fortunately, eventually we found that, dnpf bearing 1-naphthyl groups can give 9:1 selectivity (*entry 12*). The presence of 2-naphthyl group on phosphorous atoms did not have a beneficial effect (*enty 13*). When 5% of palladium and 10% of dnpf were used as the catalyst, the selectivity was increased slightly (11:1, *Table 1.4, enty 12*). No significant improvement was found for other ligands when an increased catalyst loading was applied (*Table 1.4*). The selectivity (7:1, *Table 1.4, enty 13*) dropped when 1.2 equiv of 1-octene was used.

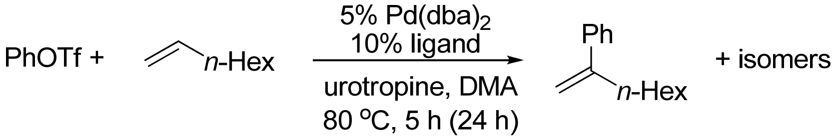
Table 1.3 *Ligand effect in Heck reaction of phenyl triflate.*[a]



Entry	Ligand	PhOTf Conversion[b] (%)	Desired Product[b] (%)	Isomers[b] (%)	Selectivity[c]
1	dppe	14 (42)	6 (14)	8 (18)	0.8 (0.8)
2	dppp	88 (99)	45 (46)	37 (45)	1.2 (1.0)
3	dppb	16 (21)	4 (5)	3 (5)	1.4 (1.0)
4	dpppent	21 (37)	3 (7)	6 (16)	0.6 (0.5)
5	dppbz	28 (60)	12 (29)	11 (25)	1.1 (1.1)
6	DPEphos	30 (62)	6 (16)	11 (32)	0.6 (0.5)
7	Xantphos	7 (12)	<1 (2)	<1 (4)	NA (0.5)
8	(*R*)-BINAP	22 (51)	7 (13)	6 (22)	1.1 (0.6)
9	dppf	98 (100)	73 (74)	19 (21)	3.8 (3.5)
10	d(*o*-Tol)pf	89 (100)	65 (76)	19 (21)	3.4 (3.6)
11	d(*o*-biphenyl)pf	87 (100)	60 (67)	24 (28)	2.5 (2.4)
12	**dnpf**	**95 (100)**	**84 (85)**	**9 (9)**	**9.0 (9.1)**
13	d(2-naphthyl)pf	100	63	17	3.7
14	dippf	13 (17)	<1 (1)	<1 (2)	NA (0.4)
15	d(Cy)pf	29 (32)	4 (4)	14 (19)	0.3 (0.2)
16	d(3,5-di-*t*-butylphenyl)pf	81 (92)	43 (50)	13 (17)	3.4 (2.9)
17	d(*p*-methoxyphenyl)pf	74 (92)	42 (57)	13 (19)	3.2 (3.0)
18	d(*p*-trifluromethylphenyl)pf	94 (100)	61 (68)	20 (22)	3.2 (3.0)
19	*t*-Bu$_3$PHBF$_4$ (8 mol%)	2 (9)	<1 (0.3)	<1 (5)	NA (0.1)

[a] Reaction condition: PhOTf (0.20 mmol, 1 *equiv*), 1-octene (0.40 mmol, 2 *equiv*), Pd(dba)$_2$ (0.004 mmol, 2 mol%), ligand (0.008 mmol, 4 mol%), urotropine (0.40 mmol, 2 *equiv*), DMA (1.2 mL). The numbers in parentheses refer to 24 hours results. [b]Conversion and yield were calculated by comparing starting material and product peak intergration to integration of internal standard using GC analysis. [c]Selectivity refers to the ratio of desired isomer to all the other isomers.

***Table 1.4** Ligand effect in Heck reaction of phenyl triflate with 5% of Pd loading.*[a]



Entry	Ligand	PhOTf Conversion[b] (%)	Desired Product[b] (%)	Isomers[b] (%)	Selectivity[c]
1	dppe	19 (46)	6 (19)	8 (24)	0.8 (0.8)
2	dppp	100	55	42	1.3
3	dppb	31 (36)	8 (8)	5 (9)	1.4 (1.0)
4	dpppent	42 (84)	7 (19)	16 (42)	0.5 (0.5)
5	dppbz	38 (83)	19 (42)	19 (37)	1 (1.1)
6	DPEphos	58 (100)	13 (29)	25 (59)	0.5 (0.5)
7	Xantphos	7 (18)	0 (6)	<1 (6)	-- (1)
8	(*R*)-BINAP	35 (89)	10 (22)	12 (46)	0.8 (0.5)
9	dppf	100	77	20	3.8
10	d(*o*-Tol)pf	100	71	28	2.5
11	d(*o*-biphenyl)pf	100	67	29	2.3
12	**dnpf**	**100**	**91**	**8**	**11.5**
13	Dnpf[d]	90 (100)	66 (69)	8 (9)	7.7 (7.3)
14	d(2-naphthyl)pf	100	51	14	3.6
15	dippf	61 (78)	8 (8)	32 (49)	0.2 (0.1)

[a] Reaction condition: PhOTf (0.20 mmol, 1 *equiv*), 1-octene (0.40 mmol, 2 *equiv*), Pd(dba)$_2$ (0.01 mmol, 5 mol%), ligand (0.02 mmol, 10 mol%), urotropine (0.40 mmol, 2 *equiv*), DMA (1.2 mL). The numbers in parentheses refer to 24 hours results. [b] Conversion and yield were calculated by comparing starting material and product peak intergration to integration of internal standard using GC analysis. [c] Selectivity refers to the ratio of desired isomer to all the other isomers. [d] 1.2 equiv of 1-octene was used.

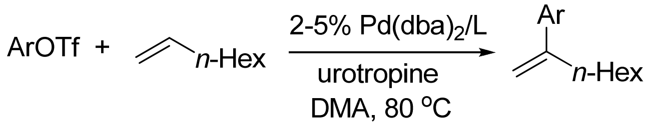
1.2.2 Substrate scope of aryl triflates and aliphatic olefins

We classified aryl triflates into three types according to the size of their *ortho*-substituents. Each type can be coupled with a model olefin 1-octene in good internal selectivity, by using a different ferrocene ligand (*Scheme 1.14*).

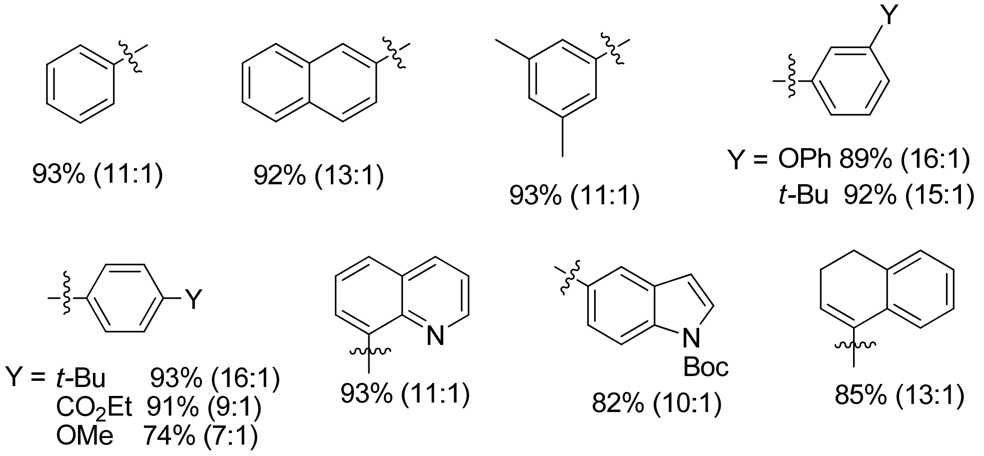
For unhindered aryl electrophiles carrying no *ortho* groups, dnpf can give >10:1 selectivity in most cases. When either electron-donating *p*-MeO group or electron-withdrawing *p*-CO$_2$Et group was present on aryl triflates, the selectivity was slightly lower. Heteroaryl triflates derived from indole and quinoline worked well. An alkenyl triflate can also couple selectively.

For aryl electrophiles carrying small *ortho* substituents, dippf afforded the desired isomer almost exclusively in most cases. Both *ortho*-C-Cl bond and *ortho*-nitrile group were tolerated. In the case of *o*-anisyl triflate, dnpf was found to be more selective than dippf (10:1 versus 7:1). Furthermore, dippf did not give full conversion.

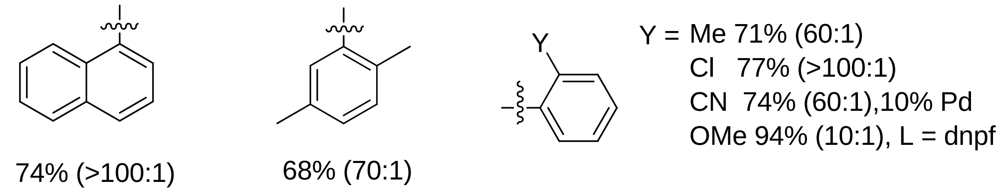
For aryl electrophiles carrying large *ortho* groups, dppf proved to be the ligand of choice. Even sterically demanding 2-mesityl triflate coupled in high selectivity at 100 °C. Notably *ortho* polar groups such as nitro and *N,N*-dimethylamino group were tolerated.

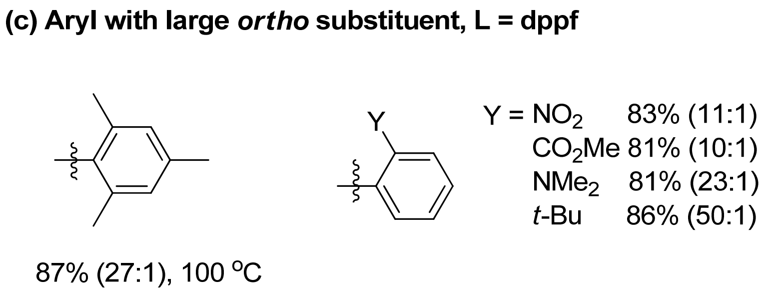


(a) Aryl without *ortho* substituent, L = dnpf



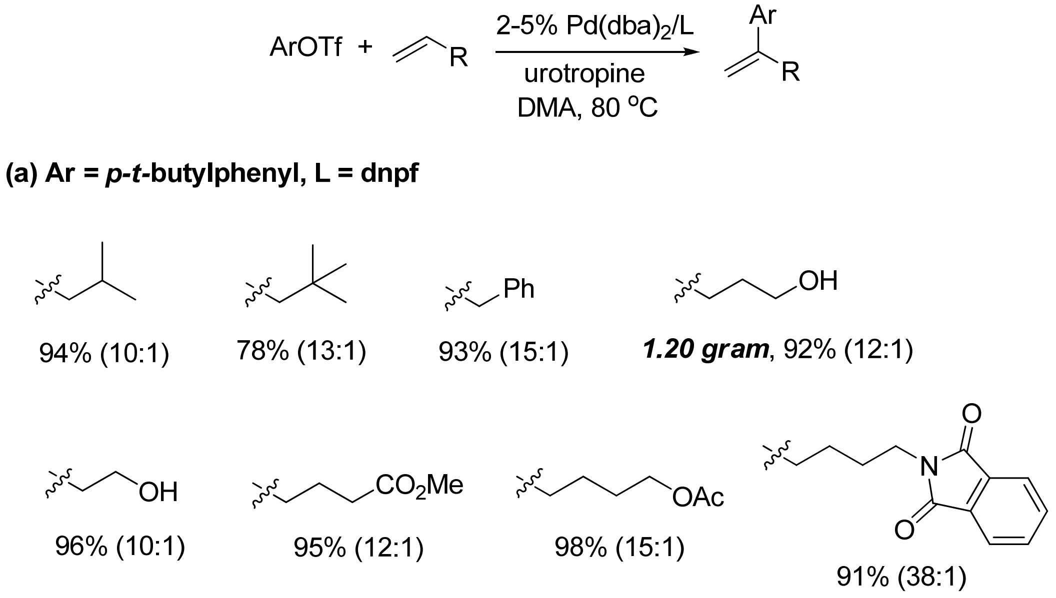
(b) Aryl with small *ortho* substituent, L = dippf



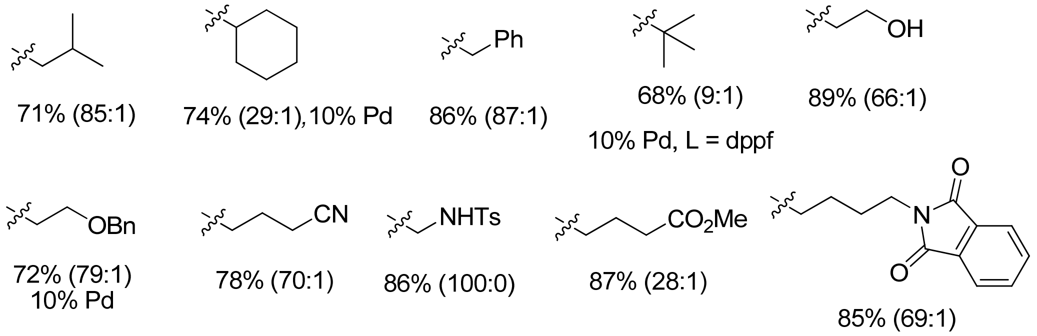


Scheme 1.14 *Scope of organic triflates in Heck reaction of 1-octene. The ratio of branched Heck products to all other isomers is given in brackets.*

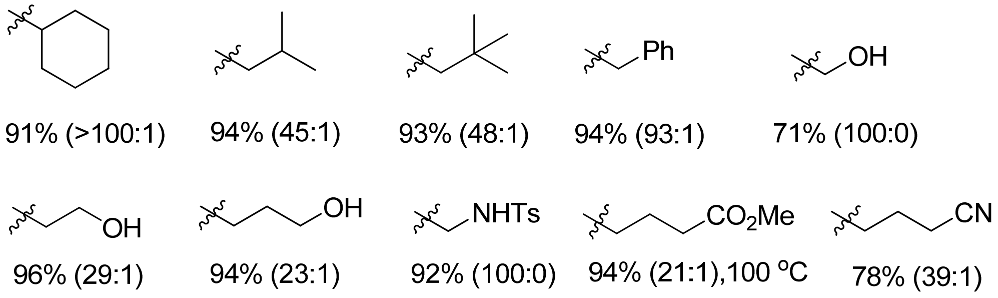
We also studied the scope of terminal olefins with three typical aryl triflates of each type (*Scheme 1.15*). Many polar groups on olefins were compatible, such as ester, nitrile, phthalimide, sulfonamide and even unprotected alcohols. Both homoallylic and bishomoallylic alcohols coupled with unhindered aryl triflates in unprecedented >10:1 selectivity.[17,19,39] Some terminal olefins, for example, vinylcyclohexane can also be used. In a reaction of *o*-tolyl triflate and very hindered *tert*-butylethylene, the aryl group added preferentially to the more hindered internal position in 9:1 selectivity using dppf ligand. Allylbenzene is prone to undergo palladium hydride-catalyzed olefin isomerization. It also reacted smoothly.[40]



(b) Ar = *o*-tolyl, L = dippf

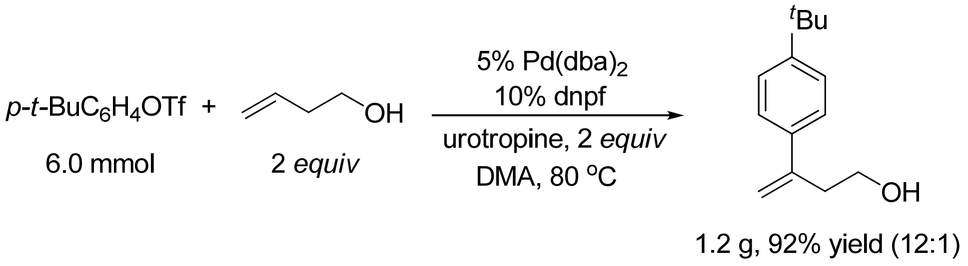


(c) Ar = *o-t*-butylphenyl, L = dppf



Scheme 1.15 *Scope of olefins in Heck reactions of model aryl triflates. The ratios of branched Heck products to all other isomers were given in brackets.*

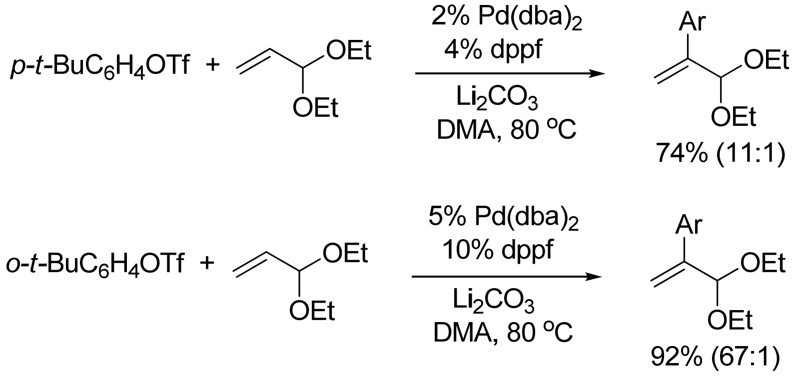
We have scaled up one reaction to gram scale. 5-Hydroxy-1-pentene produced 1.2 gram of the Heck product without loss of selectivity (12:1) (*Scheme 1.16*). The desired isomer was separated from other isomers by silica gel flash chromatography.



Scheme 1.16 *Gram-scale synthesis of 3-(p-tert-butylphenyl)-3-butene-1-ol.*

1.2.3 Acrolein acetal

To our delight, our current conditions with acrolein acetal gave high internal selectivity in the presence of dppf ligand (*Scheme 1.17*). When dnpf was used, the reaction was slower due to the steric interaction between the ligand and olefin. Lithium carbonate was more effective than urotropine. The hydrolysis product of 2-arylacrolein was known to be unstable at room temperature.[41]

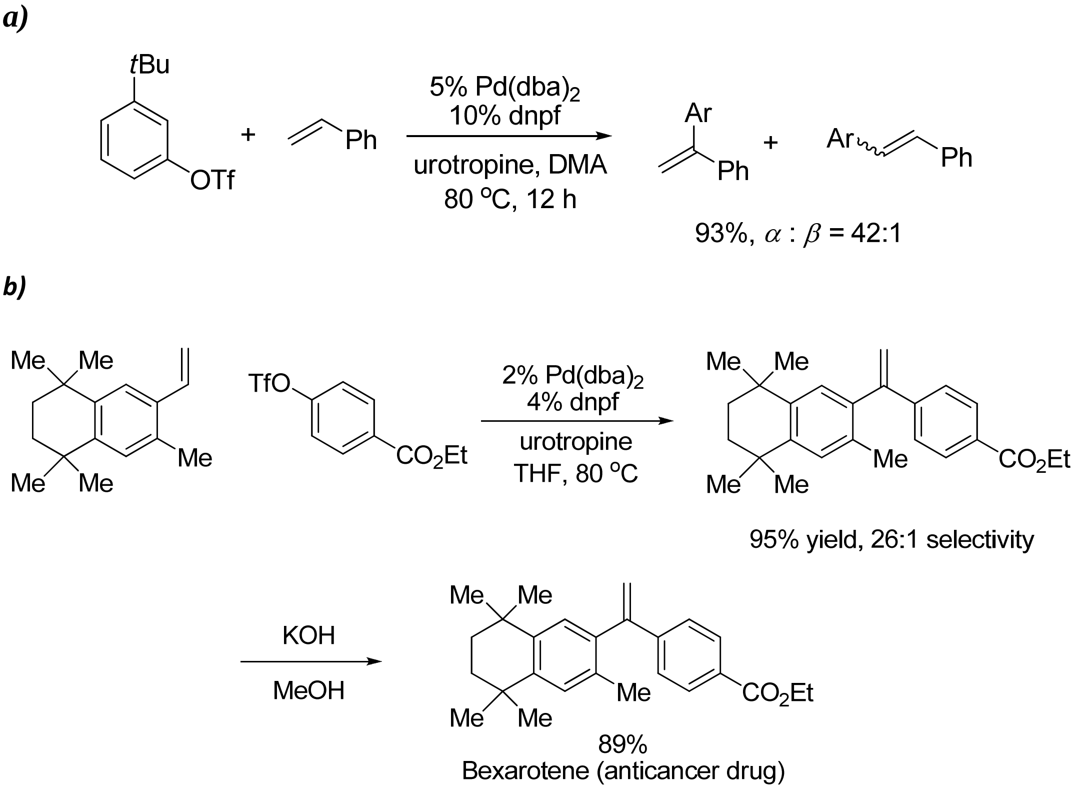


Scheme 1.17 *α-Arylation of acrolein acetal.*

In Heck reaction of acrylates, aryl groups selectively insert at the electron-poor terminal-position.[42] Under ligandless conditions reported by Cacchi *et al.,* terminal insertion almost exclusively provided.[43] In order to form *α*-arylacrylates, cross-couplings of *α*-halogenated or *α*-metallated acrylates were often employed[44]. When we applied our catalytic condition to acrylates, no reaction occurred.

1.2.4 Internal arylation of styrenes

The (dnpf)Pd catalyst was successfully applied to regioselective Heck reaction of styrenes in collaboration with Mr. Yinjun Zou in our group recently (*Scheme 1.18*).[45] Styrenes favor terminal insertion to generate (*E*)-stilbenes under many Heck conditions.[3a,5b,13-14,15c,46] Under our catalytic conditions, dnpf gave high ratio of internal-insertion products. Under Cabri's condition, the internal selectivity of styrene was only 3:1. Some vinyl triflates also worked well in THF to produce 1,3-dienes. This method was applied to synthesis of Bexarotene, an anticancer drug.



93%, $\alpha : \beta = 42:1$

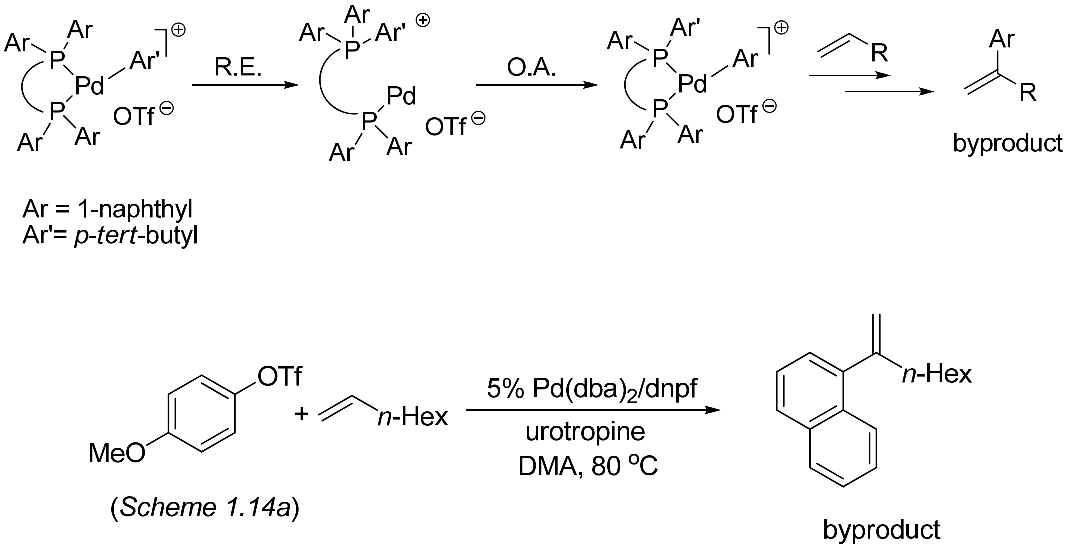
95% yield, 26:1 selectivity

89%
Bexarotene (anticancer drug)

Scheme 1.18 a) *α-Arylation of styrenes with aryl triflates;* ***b)*** *Synthesis of Bexarotene.*

1.2.5 Decomposition of dnpf ligand

In the model reaction between *p-tert*-butylphenyl triflate and 1-octene, we observed a small amount of byproduct derived from 1-naphthyl insertion into 1-octene. This is due to aryl exchange between dnpf ligand and aryl-Pd species (*Scheme 1.19*).[47] More byproduct of this kind was detected when electron-rich *p*-anisyl triflate was the substrate (*Scheme 1.19*). Other aryl triflates seldom caused this side reaction.



Scheme 1.19 *Side reaction via aryl exchange.*

1.2.6 Unsuccessful substrates

Some aryl triflates, such as *p*-Me$_2$N-phenyl triflate and 2-indolyl triflate, did not react under our standard conditions. Electron-poor *p*-CF$_3$-phenyl triflate showed very poor reactivity.

The reactivity of 4-tert-butylcyclohex-1-enyl triflate was low under our Heck conditions, less than 10% of desired product was obtained with ~3:1 selectivity. 1-Phenylvinyl triflate produced 30% of desired product with a selectivity of 15:1 in the solvent of cyclopentyl methyl ether. The vinyl triflate of 2-methyl-1H-inden-3-yl triflate only produced a small amount of Heck products although the substrates were fully consumed. The vinyl triflate derived from 1,3-diphenylpropane-1,3-dione produced very little isomers under our Heck reaction conditions.

Terminal olefins bearing halide, ketone, aldehyde and acetal groups did not generate the desired products (*Figure 1.7*).

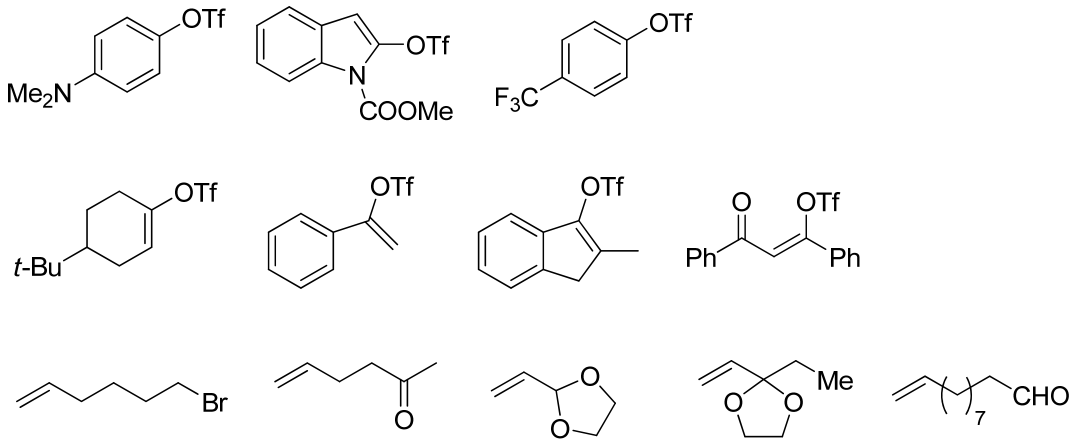
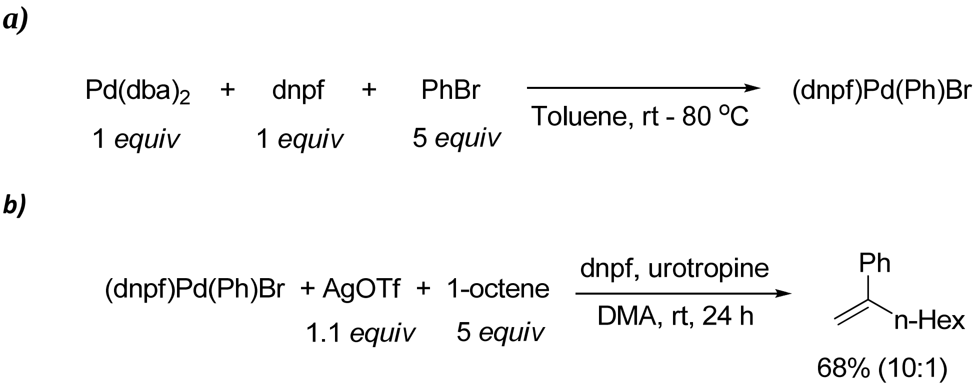


Figure 1.7 *Unsuccessful substrates under our Heck conditions.*

1.3 Mechanistic study

1.3.1 Stoichiometric reaction of (dnpf)Pd(Ph)Br complex

We prepared the oxidative-addition complex from $Pd(dba)_2$, dnpf and PhBr in order to probe the origin of high internal selectivity of dnpf (*Scheme 1.20a*). When (dnpf)Pd(Ph)Br was treated with 5 equivalents of 1-octene in the presence of silver triflate, it gave the Heck isomer in 68% yield and 10:1 internal selectivity (*Scheme 1.20b*). This is consistent with experimental results obtained from the catalytic conditions. Silver triflate was needed to abstract the bromide and generate the putative cationic phenyl-palladium species.



Scheme 1.20 a) *Synthesis of [(dnpf)Pd(Ph)Br] complex;* ***b)*** *Stoichiometric insertion of 1-octene into [(dnpf)Pd(Ph)Br].*

1.3.2 X-ray structure of (dnpf)Pd(Ph)Br complex

Single-crystal X-ray diffraction analysis of the bromide complex showed some unusual structural features (*Figure 1.8*).[48] a) The backbone of dnpf adopts a nearly eclipsed ferrocene conformation, unlike staggered ones in related dppf complexes.[49] Edge-to-edge interactions between two neighbouring *P*-naphthyl groups were identified to enforce this unusual conformation. b) The coordination geometry was significantly distorted from square planarity. For example, the bond angles of ∠P1-Pd-C(phenyl) and ∠P2-Pd-Br were deviated from linearity by >10°. c) Both the Pd-phenyl group and bromine atom were forced substantially out of the P1-Pd-P2 coordination plane. The distortion was caused by close contact with the neighboring *P*-naphthyl groups of dnpf.

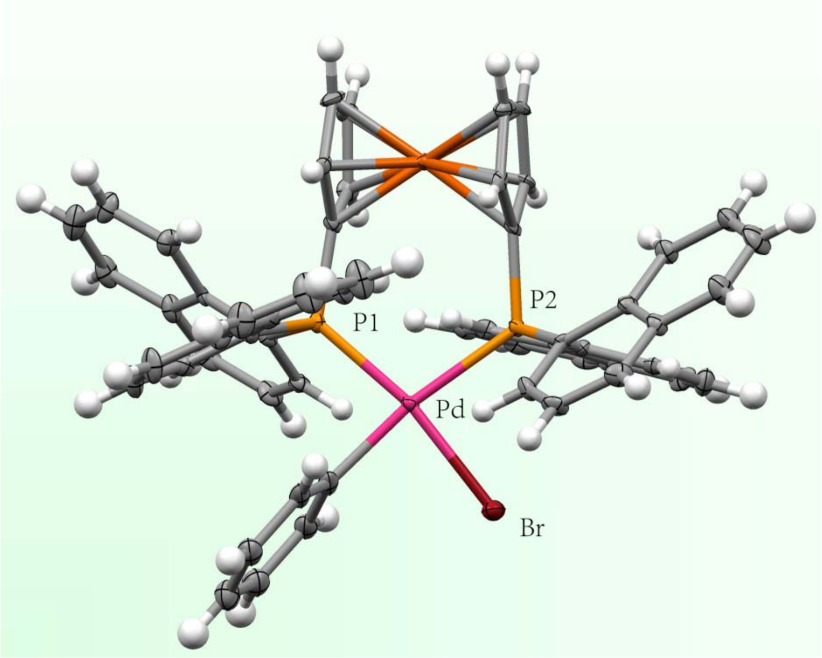


Figure 1.8 *ORTEP of (dnpf)Pd(Ph)Br complex. Important bond angles (°): ∠Br–Pd–C=84; ∠P1–Pd–P2=103; ∠P2–Pd–C=168; ∠P1–Pd–Br=166.*

1.3.3 DFT study of relative energy of transition states

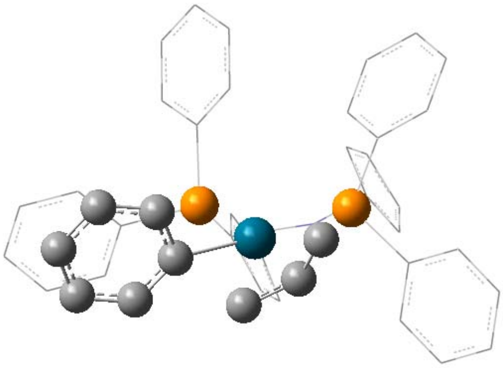
In collaboration with Dr. Yunpeng Lu, we have also conducted DFT calculation (PBE1PBE) on the insertion step using propene as the model olefin. The purpose was to understand the effect of ligands and *ortho* groups on Pd-phenyl groups on regioselectivity. Three model oxidative-addition complexes were used to calculate the relative electronic energy (ΔE) of transition states (TSs) for olefin insertion. We used three cationic complexes of $[(dppf)Pd(Ph)]^+$, [(dppf)Pd(*o*-*t*-butylphenyl)]$^+$ and $[(dnpf)Pd(Ph)]^+$. For each cationic complex, four types of ground states (i.e., olefin comformers) were calculated. Assuming fast equilibrium among olefin conformers, regioselectivity would be dictated by the difference between TS.

From cationic $[(dppf)Pd(Ph)(propene)]^+$, the difference of ΔE between the predominant TS(terminal) and TS(internal) was calculated to be 2 kcal/mol (*Figure 1.9a*). However, from the corresponding complex of [(dppf)Pd(*o*-*t*-butylphenyl)(propene)]$^+$, the energy difference increased to 4.5

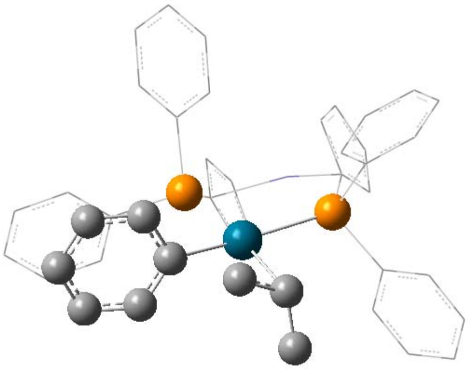
kcal/mol (*Figure 1.9b*). The reason was that the TS of terminal insertion was more sensitive to steric influence than that of internal insertion.

When dppf was changed to dnpf in the cationic complex, the difference between ΔEs in [(dnpf)Pd(Ph)(propene)]$^+$ was raised to 2.3 kcal/mol (*Figure 1.9c*). The calculation was thus in agreement with our observed selectivity, 11:1 versus 4:1.

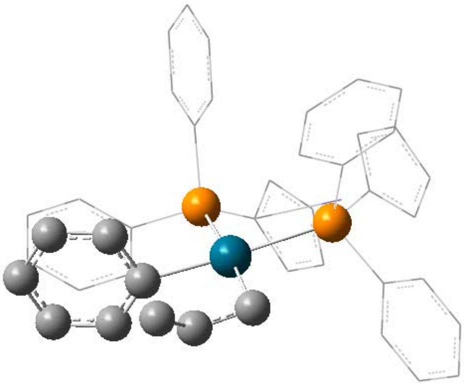
a) (dppf)Pd(Ph)(propene)



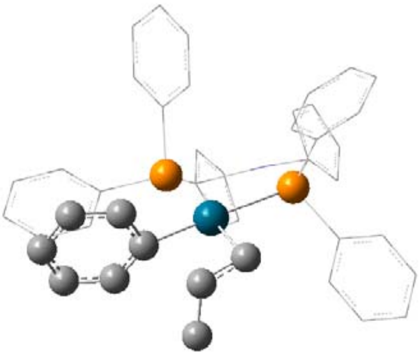
TS (terminal) + 2.1 kcal mol^{-1}



TS (terminal) + 2.7 kcal mol^{-1}

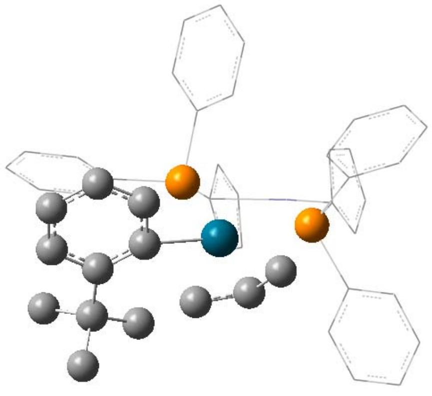


TS (internal) + 0.0 kcal mol^{-1}

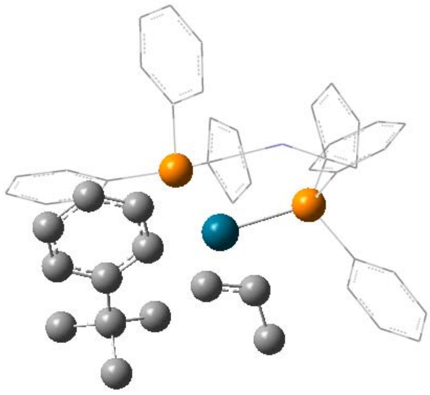


TS (internal) + 0.3 kcal mol^{-1}

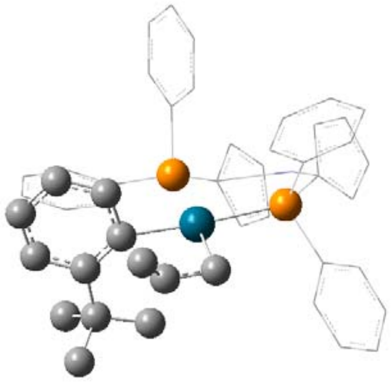
b) (dppf)Pd(o-t-butylphenyl)(propene)



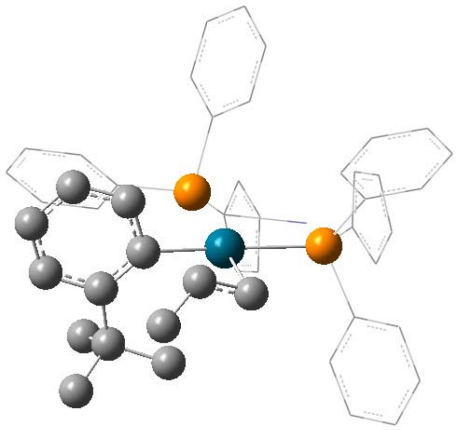
TS (terminal) + 4.5 kcal mol^{-1}



TS (terminal) + 5.5 kcal mol^{-1}

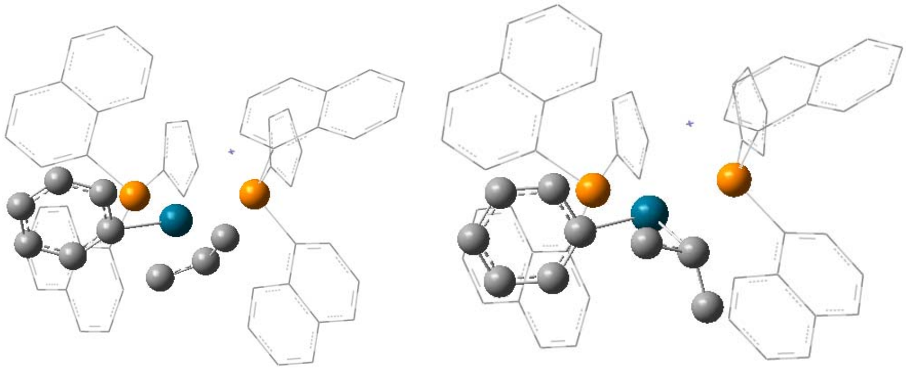


TS (internal) + 0.0 kcal mol^{-1}

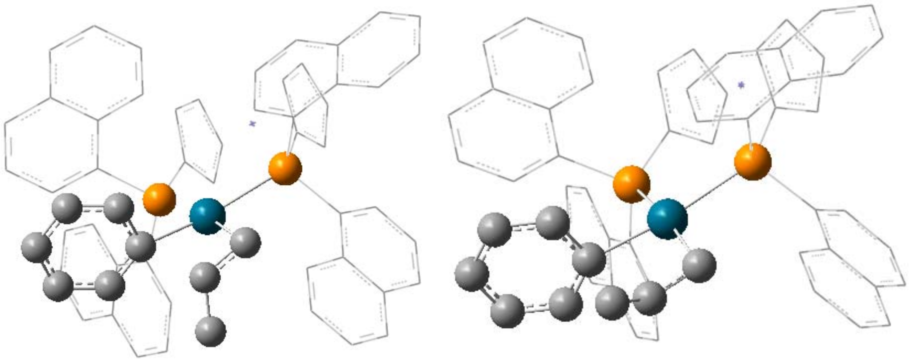


TS (internal) + 4.6 kcal mol^{-1}

c) (dnpf)Pd(Ph)(propene)



TS (terminal) + 2.3 kcal mol^{-1} TS (terminal) + 2.7 kcal mol^{-1}



TS (internal) + 0.0 kcal mol^{-1} TS (internal) + 0.0 kcal mol^{-1}

Figure 1.9 *Transition states for terminal and internal propene insertion in cationic Pd(II) complexes and their relative energies.*

1.4 Summary

In summary, we have realized a general method for selective Heck reaction of terminal olefins with aryl triflates. The ratio of the desired products of 2-aryl-1-alkenes versus the sum of all other isomers was generally >10:1. When aryl triflates carried *ortho*-substituents, internal arylation was almost exclusive. Our experimental and computational studies indicated that dnpf improved internal selectivity by inhibiting the alternative pathway of terminal insertion via steric effect.

1.5 Experimental section

1.5.1 General

^{1}H NMR spectra were acquired on Bruker 400 MHz or 300 MHz spectrometers and chemical shifts were recorded relative to tetramethylsilane (δ 0.00) or residual protiated solvent ($CDCl_3$: δ 7.26). Multiplicities were given as: s (singlet), d (doublet), t (triplet), q (quartet) and m (multiplet). The number of protons (n) for a given resonance was indicated by nH. Coupling constants were reported as a J value in *Hz*. ^{13}C NMR spectra were obtained at 100 MHz on 400 MHz or 75 MHz on 300 MHz instruments and chemical shifts were recorded relative to solvent resonance ($CDCl_3$: δ 77.16; CD_2Cl_2: δ 53.84). ^{19}F NMR spectra were obtained at 376 MHz on a 400 MHz instrument. ^{31}P NMR spectra were obtained at 121 MHz on 300 MHz instrument or 162 MHz on 400 MHz instrument. Proof of purity of new compounds was demonstrated with copies of ^{1}H, ^{13}C, ^{31}P and ^{19}F NMR spectra.

Glassware was dried in a 120 ^{o}C oven for at least 2 hours before use. Dry N,N-dimethyacetamide (Acros) was degassed by argon bubbling and stored over activated 4 Å molecular sieve beads in argon filled glove box before use. Dry hexane, diethyl ether and dichloromethane were collected from a solvent purification system containing a column of activated alumina (1 m x 2) under argon. Dry THF was freshly distilled from sodium/benzophenone under argon before use. All of anhydrous solvents were stored in Schlenk tubes in an argon-filled glove box.

Unless noted otherwise, commercially available chemicals were used without further purification. Dry N,N,N′,N′-tetramethylethlenediamine (TMEDA), diisopropylethylamine (DIPEA), triethylamine, and tributylamine were distilled from CaH_2 under argon before use. The GC internal standard, n-dodecane was degassed with argon bubbling and dried over activated 4 Å molecular sieve beads for a few days in the glove box before use.

Thin-layer chromatography (TLC) was conducted with Merck 60 F254 coated silica gel plate (0.2 mm thickness). Flash chromatography was performed using Merck silica gel 60 (0.040-0.063 mm) or SiliCycle silica gel F60 (0.040-0.063 mm).

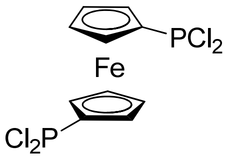
Gas chromatography (GC) analysis was performed on a Shimadzu GC-2010 instrument with Agilent J & W GC column DB-5MS-UI. GC/MS analysis was conducted on a Thermo Scientific DSQ II single quadrupole GC/MS instrument with Agilent J & W GC column DB-5MS-UI. ESI/MS analysis was conducted on a ThermoFinnigan LCQ Fleet MS spectrometer. Elemental analysis was conducted on Perkin Elmer 2400 Series II CHNS/O Analyzer.

1.5.2 Syntheses of ligands

***N,N*-Bis(diethylamino)chlorophosphine [685-83-6].** The titled product was prepared according to a reported procedure.[50] Under argon, freshly distilled phosphorous trichloride (5.20 mL, 60.0 mmol) was dissolved in 200 mL of dry diethyl ether in a dry 500-mL three-neck round-bottom flask. After the stirred solution was chilled to -20 ^{o}C in an ice/salt bath, diethylamine (24.8 mL, 240 mmol) was added dropwise via a pressure equalizing addition funnel. After the addition, the reaction mixture was allowed to warm up to room temperature and stirred for 12 hours. The white salt was removed by filtration under argon. The filtrate was concentrated under reduced pressure and the crude product was distilled at reduced pressure (200 mTorr, 70 ^{o}C) to give the pure product as colorless oil (10.80 g, 86% yield).

^{1}H NMR (400 MHz, $CDCl_3$): δ 3.16 (br s, 8H), 1.16-1.12 (t, J = 7.1 Hz, 12H).

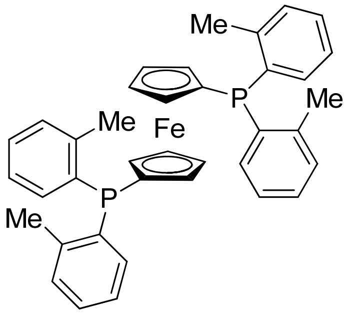
^{31}P NMR (162 MHz, $CDCl_3$): δ 151.4.



1, 1′-Bis(dichlorophosphino)ferrocene [142691-70-1]. The titled product was prepared according to a reported procedure with some modification.[50] Under argon, ferrocene (1.86 g, 10.0 mmol) and dry *N,N,N′,N′*-tetramethylethlenediamine (2.44 g, 21.0 mmol) was dissolved in 50 mL of dry hexane. The stirred solution was treated with dropwise addition of a solution of *n*-BuLi in cyclohexane (2.03 M, 10.30 mL, 21.0 mmol) at room temperature. After the mixture was stirred for additional 20 hours under argon, the resulting orange suspension was cooled to -78 ^{o}C in a dry ice/acetone bath and treated with dropwise addition of a solution of *N,N*-bis(diethylamino) -chlorophosphine (4.42 g, 21.0 mmol) in 14 mL of dry THF. After the addition, the stirred mixture was allowed to warm up to rt and stirred overnight. The complete consumption of $ClP(NEt_2)_2$ was confirmed by ^{31}P NMR spectroscopy. The reaction mixture was chilled to -78 ^{o}C under argon and treated with dropwise addition of a 4 M solution of HCl in cyclohexane (40.0 mL, 160.0 mmol). After stirring at room temperature for additional 10 hours, the salt was removed by filtration in the argon-filled glove box. The filtrate was concentrated under reduced pressure to give the pure product as yellow powder (3.20 g, 83% yield).

^{1}H NMR (300 MHz, $CDCl_3$): δ 4.72 (pseudosinglet, 8H).

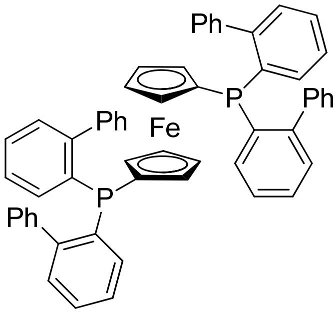
^{31}P NMR (121 MHz, $CDCl_3$): δ 163.1.



1,1′-Bis(di(*o*-tolyl)phosphino)ferrocene [73881-42-4]. The titled compound was prepared according to reported procedure[51] with modifications. Lithium wire (83 mg, 12.0 mmol) was cut into small pieces and placed in a dry 25-mL reaction tube. After the atmosphere was switched to argon, 1 mL of dry diethyl ether was added to cover the lithium chips, followed by addition of *o*-tolyl bromide (513 mg, 3.0 mmol) in 3 mL of dry diethyl ether. After the reaction mixture was stirred at room temperature overnight, the solution was transferred to another dry 25-mL reaction tube via a cannula and chilled in an ice/water bath. A solution of 1,1′-bis(dichlorophosphino)ferrocene (194 mg, 0.50 mmol) in 15 mL of dry diethyl ether was added dropwise via a syringe. The reaction mixture was then allowed to warm up to room temperature and stirred overnight. The completion of the reaction was confirmed by ^{31}P NMR spectroscopy. The resulting yellow suspension was quenched with 1 mL of methanol and then loaded on a Buchner funnel. The yellow solid was collected and washed sequentially with water (15 mL x 2), methanol (15 mL x 2) and diethyl ether (15 mL) to give the pure product as yellow solid (230 mg, 75% yield).

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.19-7.10 (m, 8H), 7.04-6.93 (m, 8H), 4.23 (s, 4H), 4.06 (s, 4H), 2.46 (s, 12H).

^{31}P NMR (121 MHz, $CDCl_3$): δ -36.7.



1,1′-Bis[di(*o*-biphenyl)phosphino]ferrocene. Under argon, to an oven-dried 25-mL reaction tube was added 2.5 mL of dry THF, *o*-bromobiphenyl (373 mg, 1.6 mmol) and dry *N,N,N′,N′*-tetramethylethlenediamine (174 mg, 1.5 mmol). The solution was chilled to -78 °C in a dry ice/acetone bath followed by dropwise addition of a 2.1 M solution of *n*-BuLi in cyclohexane (0.72 mL, 1.5 mmol). After the reaction mixture was stirred at -78 °C for 2 hours, a solution of

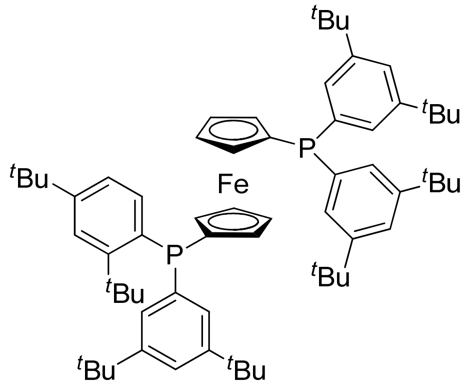
1,1′-bis(dichlorophosphino)ferrocene (97 mg, 0.25 mmol) in 3 mL of dry THF was added dropwise with vigorous stirring. After that, the reaction mixture was allowed to warm up to room temperature and kept stirred overnight. The completion of reaction was confirmed by ^{31}P NMR spectroscopy. At the completion of the reaction, it was quenched by 1 mL of methanol and the solvent was evaporated to dryness. The residue was suspended in methanol and the yellow insoluble precipitate was collected on a Buchner funnel and washed sequentially with water (10 mL x 2), methanol (10 mL x 2) and diethyl ether (10 mL) to give yellow powder as pure product (148 mg, 69% yield).

^1H NMR (400 MHz, $CDCl_3$): δ 7.31-7.11 (m, 24H), 7.00 (dd, J = 7.5 Hz, 3.0 Hz, 4H), 6.81 (d, J = 7.1 Hz, 8H), 3.40 (s, 4H), 3.38 (s, 4H).

^{13}C NMR (100 MHz, $CDCl_3$): δ 147.1 (d, J_{CP}= 28.1 Hz), 142.0 (d, J_{CP} = 4.4 Hz) 137.8 (d, J_{CP} = 18.4 Hz), 135.0, 130.4 (d, J_{CP} = 4.3 Hz), 130.3 (d, J_{CP} = 4.6 Hz), 128.3, 127.8, 127.1, 126.9, 78.2 (d, J_{CP} = 11.2 Hz), 73.0 (d, J_{CP} = 12.7 Hz), 72.0.

^{31}P NMR (162 MHz, $CDCl_3$): δ -33.8.

MS (ESI): Calcd for $C_{58}H_{44}FeP_2$: 858.76. Found [M+1]: 859.13.



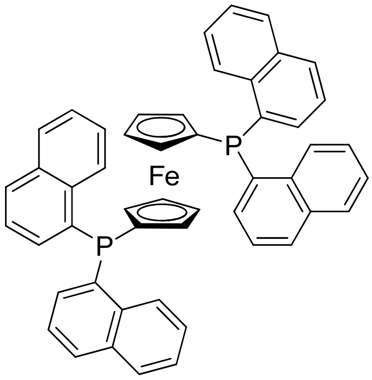
1, 1′-Bis[di(3,5-di-*tert*-butylphenyl)phosphino]ferrocene. Under argon, to an oven-dried 25-mL reaction tube was added 3 mL of dry THF, 3,5-di-*tert*-butyl phenyl bromide (942 mg, 3.5 mmol) and dry *N,N,N′,N′*-tetramethylethlenediamine (349 mg, 3.0 mmol). The solution was chilled to -78 °C in a dry ice/acetone bath followed by dropwise addition of a 2.0 M solution of *n*-BuLi in cyclohexane (1.5 mL, 3.0 mmol). After the reaction mixture was stirred at -78 °C for 3 hours, a solution of 1,1′-bis(dichlorophosphino)ferrocene (179 mg, 0.5 mmol) in 3 mL of dry THF was added dropwise with vigorous stirring. After that, the reaction mixture was allowed to warm up to room temperature and kept stirred overnight. The completion of reaction was confirmed by ^{31}P NMR spectroscopy. At the completion of the reaction, it was quenched by 1 mL of methanol and the solvent was evaporated to dryness. The residue was suspended in methanol and the yellow insoluble was collected on a Buchner funnel and washed sequentially with water (10 mL x 2), methanol (10 mL x 2) and diethyl ether (10 mL) to give yellow powder as pure product (338 mg, 67% yield).

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.32-7.31 (m, 4H), 7.21-7.19 (dd, J = 8.2 Hz, 1.8 Hz, 4H), 4.20-4.19 (m, 4H), 3.99-3.97 (m, 4H), 1.24 (s, 72H).

^{13}C NMR (100 MHz, $CDCl_3$): δ150.2 (d, J_{CP}= 6.8 Hz), 137.7 (d, J_{CP} = 8.2 Hz) 128.2 (d, J_{CP} = 10.1 Hz), 122.5, 78.3 (d, J_{CP} = 7.0 Hz), 73.3 (d, J_{CP} = 3.8 Hz), 72.2, 35.0, 31.6.

^{31}P NMR (162 MHz, $CDCl_3$): δ -16.2.

MS (ESI): Calcd for $C_{66}H_{92}FeP_2$ 1002.60. Found [M+1]: 1003.53.



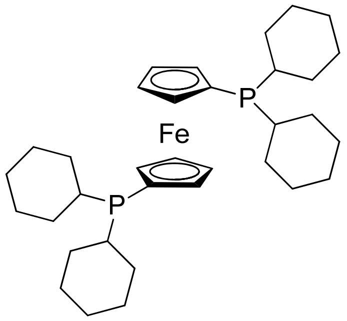
1, 1′-Bis[di(1-naphthyl)phosphino]ferrocene. Under argon, 1-bromonaphthalene (4.04 g, 19.5 mmol) and *N,N,N′,N′*-tetramethylethlenediamine (2.09 g, 18.0 mmol) were added to a dry100-mL reaction flask containing 30 mL of dry THF. The resulting solution was then chilled to -78 °C in a dry ice/acetone bath and treated with dropwise addition of a 2.03 M solution of *n*-BuLi in cyclohexane (8.87 mL, 18.0 mmol). After stirring at -78 °C for two more hours, the resulting yellow suspension was treated with dropwise addition of a solution of 1,1′-bis(dichlorophosphino)ferrocene (1.16 g, 3.0 mmol) in 25 mL of dry THF with vigorous stirring. After the addition, the reaction mixture was allowed to warm up to room temperature and kept stirred overnight. The completion of reaction was confirmed by ^{31}P NMR spectroscopy. The reaction was quenched by ~1 mL of methanol and the solvent was removed under reduced pressure. The resulting residue was dissolved in 15 mL of dichloromethane and passed through a pad of silica gel (60 g) with dichloromethane washings (200 mL). The filtrate was concentrated under reduced pressure and the resulting yellowish residue was suspended in 100 mL of hexane. The insoluble solid was collected on a Bucher funnel and washed with 5 mL of acetone to give the pure product (1.36 g, 60% yield).

^{1}H NMR (300 MHz, $CDCl_3$): δ 8.70-8.65 (m, 4H), 7.81-7.73 (m, 8H), 7.46-7.40 (m, 8H), 7.23-7.20 (d, J = 7.9 Hz, 4H), 7.12-7.08 (m, 4H), 3.97 (t, J = 1.6 Hz, 4H), 3.88 (d, J = 1.8 Hz, 4H).

^{13}C NMR (100 MHz, CD_2Cl_2): δ 136.6 (d, J_{CP} = 12.6 Hz), 135.5 (d, J_{CP} = 23.4 Hz), 133.8 (d, J_{CP} = 4.6 Hz), 132.7, 129.6, 129.1 (d, J_{CP} = 1.6 Hz), 126.48 (d, J_{CP} = 2.2 Hz), 126.28 (d, J_{CP} = 28.4 Hz), 126.24 (d, J_{CP} = 0.9 Hz), 125.6 (d, J_{CP} = 0.9 Hz), 76.8 (d, J_{CP} = 5.5 Hz), 74.8 (d, J_{CP} = 15.6 Hz), 72.8 (d, J_{CP} = 3.9 Hz).

^{31}P NMR (121 MHz, $CDCl_3$): δ -40.7.

MS (ESI): Calcd for $C_{50}H_{36}FeP_2$: 754.61. Found [M+1]: 755.26.

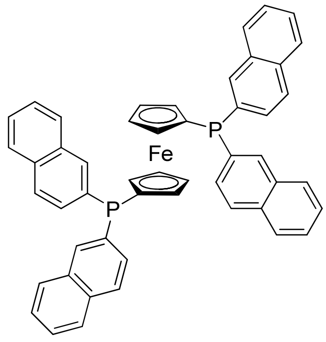


1, 1′-Bis[di(cyclohexyl)phosphino]ferrocene[146960-90-9]. The product was prepared according to reported procedure[52] with modifications. To an oven-dried 100 mL reaction flask under argon atmosphere was added Ferrocene (372 mg, 2.0 mmol) and 15 mL of dry hexane. To the solution formed was added TMEDA (488 mg, 4.2 mmol) followed by addition of *n*-butyllithium (2.1 M in cyclohexane, 2.0

mL, 4.2 mmol) at room temperature with stirring. After stirring at room temperature for 24 hours, the reaction mixture was pre-cooled at -78°C dry-ice acetone bath. To the lithium salt formed was added dicyclohexylchlorophosphine (1.02 g, 4.4 mmol) dropwise with vigorous stirring under argon. The reaction mixture was stirred over night allowing spontaneous rising of the temperature with evaporation of dry-ice. The completion of reaction was monitored by crude phosphorous NMR. The reaction mixture was applied on silica gel pad using 150 mL of frit funnel in argon filled glove box and flushed first with hexane to remove un-reacted ferrocene and then a mixture solvent of hexane/ethyl acetate (20:1) to flush out desired product. After removal of solvent under vacuum the ligand was obtained as yellow powder (960 mg, 83% yield).

^{1}H NMR (400 MHz, $CDCl_3$): *δ*. 4.25-4.24 (m, 4H), 4.14-4.13 (m, 4H), 1.93-1.00 (m, 44H).

^{31}P NMR (162 MHz, $CDCl_3$): *δ* -8.1 (s).

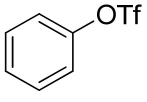


1, 1′-Bis[di(2-naphthyl)phosphino]ferrocene [73881-43-3]. Under argon, a dry 25-mL Schlenk tube was sequentially charged with 2-bromonaphthalene (673 mg, 3.3 mmol), 5 mL of freshly distilled THF and TMEDA (348 mg, 3.0 mmol). After the solution was cooled to -78 °C in a dry ice/acetone bath, it was treated with dropwise addition of a 2.03 M solution of *n*-BuLi in cyclohexane (1.48 mL, 3.0 mmol). After the addition, the solution was stirred for 2 hours at -78 °C and then treated with dropwise addition of a solution of 1,1′-bis(dichlorophosphino)ferrocene (194 mg, 0.5 mmol) in 3 mL of dry THF with vigorous stirring. Then, the reaction mixture was allowed to warm up to room temperature spontaneously and stirred at room temperature overnight. The completion of the reaction was confirmed by ^{31}P NMR spectroscopy. The reaction was quenched by ethanol (~1 mL) and the solvent was removed under reduced pressure. The resulting residue was dissolved in ~7 mL of dichloromethane and passed through a pad of silica gel (25 g) with dichloromethane washings (80 mL). The filtrate was concentrated under reduced pressure and the yellowish residue was suspended in 50 mL of hexane. The yellow insoluble was collected on a Buchner funnel and washed with acetone (5 mL) to give the desired product (213 mg, 56% yield).

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.83 (d, J = 8.8 Hz, 4H), 7.78-7.76 (m, 4H), 7.73-7.71 (m, 4H), 7.62 (d, J = 8.4 Hz, 4H), 7.49-7.43 (m, 8H), 7.29 (m, 4H), 4.32 (dd, J_{HH} = 1.8 Hz, J_{PH} = 1.8 Hz, 4H), 4.09 (dd, J_{HH} = 3.6 Hz, J_{PH} = 1.8 Hz, 4H).
^{31}P NMR (162 MHz, $CDCl_3$): δ -15.9.

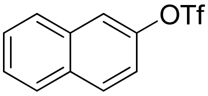
1.5.3 Syntheses of substrates

General procedure: Under argon, a solution of parent or substituted phenol (10.0 mmol) in 20 mL of dry dichloromethane was chilled to 0 °C. Analytical grade pyridine (1.60 mL, 20.0 mmol) and trifluoromethanesulfonic anhydride (2.0 mL, 12.0 mmol) were then added sequentially to the stirred solution. After the addition, the reaction mixture was warmed up to 25 °C and stirred for 5 h until the phenol was fully consumed (monitored by TLC). The product was purified by silica gel flash chromatography. The general procedure was used for the isolation of aryl triflates unless indicated otherwise.



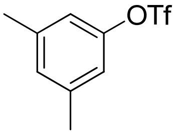
Phenyl trifluoromethanesulfonate [17763-67-6]. The titled product was obtained as colorless oil (1.84 g, 80%) after flash chromatography (hexane).
^{1}H NMR (400 MHz, $CDCl_3$): δ 7.49-7.43 (m, 2H), 7.42-7.37 (m, 1H), 7.30-7.27

(m, 2H).



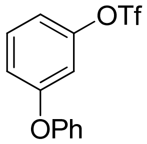
1-Naphthyl trifluoromethanesulfonate [3857-83-8]. The titled product was obtained as white solid (2.66 g, 96%) after flash chromatography (hexane).

^{1}H NMR (400 MHz, CDCl$_3$): δ 7.94-7.87 (m, 3H), 7.76 (d, *J* = 2.4 Hz, 1H), 7.61-7.55 (m, 2H), 7.38 (dd, *J* = 9.0 Hz, 2.4 Hz, 1H).



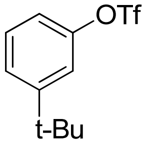
***m*-Xylyl trifluoromethanesulfonate [219667-41-1].** The titled product was obtained as colorless oil (2.42g, 95%) after flash chromatography (hexane).

^{1}H NMR (400 MHz, CDCl$_3$): δ 7.00 (s, 1H), 6.88 (s, 2H), 2.35 (s, 6H).



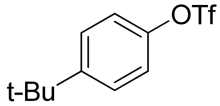
***m*-Phenoxyphenyl trifluoromethanesulfonate [864772-16-7].** The titled product was obtained as colorless oil (2.87 g, 90%) after flash chromatography (hexane/ethyl acetate 20:1).

^{1}H NMR (400 MHz, CDCl$_3$): δ 7.42-7.36 (m, 3H), 7.22-7.18 (m, 1H), 7.06-7.03 (m, 2H), 7.02-6.98 (m, 2H), 6.90-6.89 (pseudotriplet, *J* = 2.3 Hz, 1H).



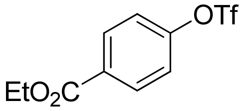
***m*-(*tert*-Butyl)phenyl trifluoromethanesulfonate [201851-06-1].** The titled product was obtained as colorless oil (2.70 g, 96%) after flash chromatography (hexane).

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.42-7.35 (m, 2H), 7.25-7.24 (pseudotriplet, J = 2.0 Hz, 1H), 7.10-7.07 (m, 1H), 1.33 (s, 9H).



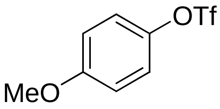
***p-tert*-Butylphenyl trifluoromethanesulfonate [154318-75-9].** The titled product was obtained as colorless oil (2.58 g, 91%) after flash chromatography (hexane).

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.45-7.43 (d, J = 8.6 Hz, 2H), 7.20-7.17 (d, J = 8.6 Hz, 2H), 1.33 (s, 9H).



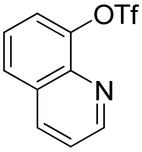
***p*-(Ethoxycarbony)phenyl trifluoromethanesulfonate [125261-30-5].** The titled product was obtained as colorless oil (2.77 g, 93%) after flash chromatography (hexane/ethyl acetate 30:1).

^{1}H NMR (400 MHz, $CDCl_3$): δ 8.17-8.13 (m, 2H), 7.37-7.33 (m, 2H), 4.40 (q, J = 7.1 Hz, 2H), 1.40 (t, J = 7.1 Hz, 3H).



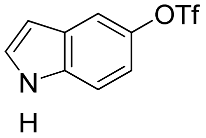
***p*-Anisyl trifluoromethanesulfonate [59099-58-0].** The titled product was obtained as colorless oil (2.27 g, 89%) after flash chromatography (hexane/ethyl acetate 20:1).

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.19 (d, J = 9.1 Hz, 2H), 6.92 (d, J = 9.1 Hz, 2H), 3.82 (s, 3H).



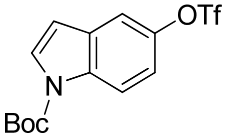
8-Quinolinyl trifluoromethanesulfonate [108530-08-1]. The titled product was obtained as white solid (2.72 g, 96%) after flash chromatography (hexane/ethyl acetate 10:1).

^{1}H NMR (400 MHz, $CDCl_3$): δ 9.06 (d, J = 4.2 Hz, 1H), 8.24-8.22 (d, J = 8.3 Hz, 1H), 7.88-7.86 (d, J = 8.0 Hz, 1H), 7.64-7.52 (m, 3H).



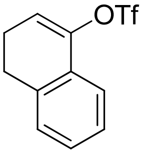
5-Indolyl trifluoromethanesulfonate [128373-13-7]. The compound was prepared according to a reported procedure with modification (replacing pyridine with triethylamine).[53] The titled compound was obtained as light yellow solid (1.13 g, 86%) after flash chromatography using 1:4 EA/hexane as eluent.

^{1}H NMR (400 MHz, $CDCl_3$): δ 8.32 (br s, 1H), 7.55 (s, 1H), 7.37 (d, J = 8.9 Hz, 1H), 7.30 (s, 1H), 7.09 (d, J = 8.9 Hz, 1H), 6.60 (s, 1H).



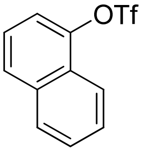
***N*-(*t*-Butoxycarbonyl)-5-indolyl trifluoromethanesulfonate [1247868-60-5].** The compound was prepared according to a reported procedure with some modification.[54] Under argon, 4-(*N,N*-dimethylamino)pyridine (24.4 mg, 0.20 mmol), 5-indolyl trilfate (530 mg, 2.0 mmol) and dry THF (10 mL) were added into a 20-mL vial containing a magnetic stirring bar. Then Boc anhydride (480 mg, 2.2 mmol) was added dropwise and the reaction mixture was kept stirring for additional 14 hours. At the conclusion of the reaction, the solvent was removed under reduced pressure and the residue was directly subjected to flash chromatography (1:9 Et_2O/hexane as eluent). The titled compound was obtained as white solid (716 mg, 97 %).

^{1}H NMR (500 MHz, $CDCl_3$): δ 8.21 (d, J = 9.0 Hz, 1H), 7.69 (d, J = 3.7 Hz, 1H), 7.47 (d, J = 2.5 Hz, 1H), 7.21 (dd, J = 9.1, 2.5 Hz, 1H), 6.60 (dd, J = 3.7 Hz, 1H), 1.68 (s, 9H).



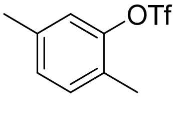
3,4-Dihydro-1-naphthyl trifluoromethanesulfonate [123994-49-0]. Under argon, to a solution of 1-tetralone (731 mg, 5.0 mmol) in 20 mL of dry dichloromethane at room temperature was added sodium carbonate (848 mg, 8.0 mmol) in one portion. Trifluoromethanesulfonic anhydride (1.68 mL, 10.0 mmol) was then added dropwise with vigorous stirring. The reaction was stirred for 24 hours at room temperature until completion. The titled product was obtained as colorless oil (918 mg, 66%) after flash chromatography (hexane).

^{1}H NMR (400 MHz, CDCl$_3$): δ 7.37-7.33 (m, 1H), 7.29-7.24 (m, 2H), 7.20-7.15 (m, 1H), 6.03-6.00 (t, J = 4.8 Hz, 1H), 2.89-2.85 (t, J = 8.2 Hz, 2H), 2.54-2.49 (td, J = 8.2 Hz, 4.8 Hz, 2H).



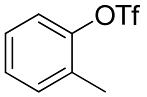
1-Naphthyl trifluoromethanesulfonate [99747-74-7]. The titled product was obtained as colorless oil (2.46 g, 89%) after flash chromatography (hexane).

^{1}H NMR (400 MHz, CDCl$_3$): δ 8.09 (d, J = 8.4 Hz, 1H), 7.92 (d, J = 7.6 Hz, 1H), 7.88 (dd, J = 7.6 Hz, 2.0 Hz, 1H), 7.68-7.58 (m, 2H), 7.51-7.46 (m, 2H).



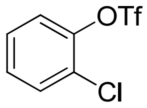
2,5-Dimethylphenyl trifluoromethanesulfonate [79644-40-9]. The titled product was obtained as colorless oil (2.27 g, 89%) after flash chromatography (hexane).

^{1}H NMR (400 MHz, CDCl$_3$): δ 7.17 (d, J = 1.1 Hz, 1H), 7.08-7.04 (m, 2H), 2.35 (s, 3H), 2.33 (s, 3H).



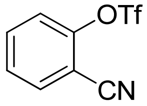
***o*-Tolyl trifluoromethanesulfonate [66107-34-4].** The titled product was obtained as colorless oil (2.09 g, 87% yield) after flash chromatography (hexane).

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.31-7.23 (m, 4H), 2.39 (s, 3H).



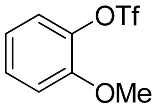
***o*-Chlorophenyl trifluoromethanesulfonate [66107-36-6].** The titled product was obtained as colorless oil (2.83 g, 92%) after flash chromatography (hexane/ethyl acetate 30:1).

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.55-7.52 (m, 1H), 7.37-7.32 (m, 3H).



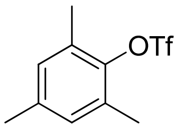
***o*-Cyanophenyl trifluoromethanesulfonate [138313-23-2**]. The titled product was obtained as colorless oil (2.20 g, 88%) after flash chromatography (hexane/ethyl acetate 10:1).

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.80-7.72 (m, 2H), 7.56-7.50 (m, 2H).



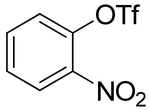
***o*-Anisyl trifluoromethanesulfonate [59099-58-0].** The titled product was obtained as colorless oil (2.50 g, 96%) after flash chromatography (hexane/ethyl acetate 20:1).

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.33 (ddd, J = 8.4, 8.0, 1.6 Hz, 1H), 7.22 (dd, J = 8.0, 1.6 Hz, 1H), 7.04 (dd, J = 8.4, 1.4 Hz, 1H), 6.98 (pseudotriplet of doublet, J = 8.0, 1.4 Hz, 1H), 3.92 (s, 3H).



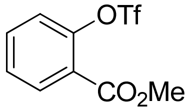
2-Mesityl trifluoromethanesulfonate [125261-32-7]. The titled product was obtained as colorless oil (2.28 g, 85%) after flash chromatography (hexane/ethyl acetae 40:1).

^{1}H NMR (400 MHz, $CDCl_3$): δ 6.91 (s, 2H), 2.34 (s, 6H), 2.28 (s, 3H).



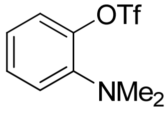
***o*-Nitrophenyl trifluoromethanesulfonate [132993-22-7].** The titled product was obtained as colorless oil (2.60 g, 92%) after flash chromatography (hexane/ethyl acetate 10:1).

^{1}H NMR (400 MHz, $CDCl_3$): δ 8.20-8.17 (dd, *J* = 8.1, 1.6 Hz, 1H), 7.79-7.74 pseudotriplet of doublet, *J* = 7.9, 1.7 Hz, 1H), 7.62-7.58 (pseudotriplet of doublet, *J* = 7.9, 1.3 Hz, 1H), 7.49-7.47 (dd, *J* = 8.2, 0.8 Hz, 1H).



***o*-(Methoxycarbonyl)phenyl trifluoromethanesulfonate [17763-70-1].** The titled product was obtained as colorless oil (2.70 g, 95%) after flash chromatography (hexane/ethyl acetate 20:1).

^{1}H NMR (400 MHz, $CDCl_3$): δ 8.11-8.09 (dd, *J* = 7.8, 1.8 Hz, 1H), 7.66-7.61 (ddd, *J* = 8.3, 7.6, 1.8 Hz, 1H), 7.51-7.46 (pseudotriplet of doublet, *J* = 7.6, 1.1 Hz, 1H), 7.32-7.26 (d, *J* = 8.3 Hz, 1H), 3.97(s, 3H).



2-(*N,N*-Dimethylamino)phenyl trifluoromethanesulfonate.

o-(*N,N*-Dimethylamino)-phenol was prepared according to a reported procedure.[55]

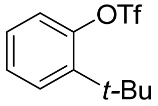
The titled product was obtained as colorless oil (2.10 g, 78%) after flash chromatography (hexane/ethyl acetate 20:1).

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.30-7.26 (pseudotriplet of doublet, *J* = 7.8, 1.6 Hz, 1H), 7.17-7.14 (dd, *J* = 8.1, 1.4 Hz, 1H), 7.11-7.08 (dd, *J* = 8.1, 1.5 Hz, 1H), 7.02-6.97 (pseudotriplet of doublet, *J* = 7.8, 1.6 Hz, 1H), 2.80 (s, 6H).

^{13}C NMR (100 MHz, $CDCl_3$): δ 147.1, 143.8, 129.4, 122.9, 122.7, 120.9, 43.5.

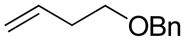
^{19}F NMR (376 MHz, $CDCl_3$): δ -74.7.

MS (ESI): Calcd for $C_9H_{10}F_3NO_3S$: 269.24. Found [M+1]: 270.04.



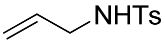
***o*(-*tert*-Butyl)phenyl trifluoromethanesulfonate [198206-03-0]**. The titled product was obtained as colorless oil (2.72 g, 96%) after flash chromatography (hexane).

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.49-7.46 (m, 1H), 7.36-7.34 (m, 1H), 7.29-7.27 (m, 2H), 1.43 (s, 9H).



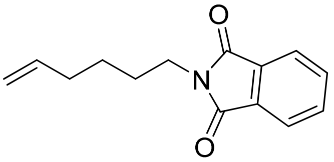
3-Butenyl benzyl ether [70388-33-9]. The titled product was prepared according to a reported procedure.[56] Under argon, sodium hydride in mineral oil (60% wt, 0.63 g, 15.0 mmol) was washed with dry THF (10 mL x 2) and then suspended in 25 mL of dry THF. The stirred suspension was chilled in a 0 °C bath and then treated with dropwise addition of 3-butene-1-ol (0.72 g, 10.0 mmol). The mixture was stirred at 0 °C for 1 h and treated with dropwise addition of benzyl bromide (1.88 g, 11.0 mmol). The reaction mixture was then stirred at 25 °C overnight. At the conclusion of the reaction, the insoluble salt was removed by filtration. After the filtrate was concentrated on a rotary evaporator under reduced pressure, the resulting residue was purified by flash chromatography (hexane/ethyl acetate 100:1 to 50:1) to give the desired product as colorless oil (1.29 g, 73%).

^{1}H NMR (400 MHz, $CDCl_3$): δ7.35-7.26 (m, 5H), 5.90-5.80 (m, 1H), 5.13-5.03 (m, 2H), 4.52 (s, 2H), 3.53 (t, *J* = 6.7 Hz, 2H), 2.41-2.38 (m, 2H).



Allyl *N*-*p*-tolylsulfonamide [50487-71-3]. The titled product was prepared according to a reported procedure.[57] Under argon, allylamine (571 mg, 10.0 mmol), triethylamine (4.20 mL, 30.0 mmol) and 4-(*N,N*-dimethylamino)pyridine (61 mg, 0.50 mmol) were added to 50 mL of dry dichloromethane. After the solution was chilled in an ice/water bath, *p*-tosyl chloride (2.10 g, 11.0 mmol) was added in one portion against argon flow. The resulting reaction mixture was stirred at room temperature for 4 h until the reaction finished. The mixture was directly subjected to flash chromatography (hexane/ethyl acetate 5:1) to give the desire product as white solid (1.95 g, 93%).

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.77-7.75 (d, *J* = 8.3 Hz, 2H), 7.33-7.31 (d, *J* = 8.3 Hz, 2H), 5.78-5.68 (m, 1H), 5.20-5.09 (m, 2H), 4.38 (br, 1H), 3.61-3.57 (m, 2H), 2.44 (s, 3H).



***N*-(5-Hexenyl)phthalimide [52898-33-6].** The titled product was prepared according to a reported procedure.[58] Under argon, potassium phthalimide (926 mg, 5.0 mmol) and tetrabutylammonium iodide (23 mg, 0.063 mmol) were suspended in 20 mL of analytical grade benzene in a dry 100-mL two-neck round-bottom flask. 6-Bromo-1-hexene (408 mg, 2.5 mmol) was then added to the stirred suspension via syringe and the reaction mixture was refluxed for one day. At the conclusion of the reaction, it was cooled down to room temperature, diluted with diethyl ether (40 mL) and filtered through Celite with diethyl ether washings. The filtrate was collected and the solvent was removed under reduced pressure. The crude product was subjected flash chromatography (30:1 to 10:1 hexane/ethyl acetate) to afford the titled product as pale yellow oil (551 mg, 96% yield).

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.85-7.82 (m, 2H), 7.73-7.70 (m, 2H), 5.82-5.75 (m, 1H), 5.03-4.93 (m, 2H), 3.71-3.67 (t, J = 7.3 Hz, 2H), 2.13-2.07 (m, 2H), 1.73-1.66 (m, 2H), 1.48-1.41 (m, 2H).

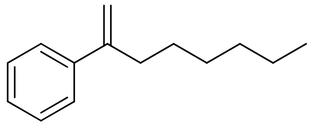
1.5.4 Optimization of conditions

Typical Procedure: In an argon-filled glove box, a dry 4-mL vial containing a magnetic stir bar was charged with 2 mol% $Pd(dba)_2$ (2.3 mg, 0.004 mmol), 4 mol% dppf (4.4 mg, 0.008 mmol) and 1.2 mL of dry DMA. After prestirring at room temperature for 10 minutes, 1-naphthyl triflate (0.20 mmol, 55.2 mg), 1-octene (2 equiv, 0.40 mmol, 44.9 mg), urotropine (2 equiv, 0.40 mmol, 56 mg) and 1-dodecane (20 μl; GC internal standard) were added sequentially via syringe. The vial was capped tightly and the mixture was heated with vigorous stirring in an 80 ^{o}C aluminum heating block (internal temperature). Aliquots were taken from the reaction mixture in the glove box after 5 hours and 24 hours and passed through a short plug of silica gel with diethyl ether washings. The filtrate was subjected to GC analysis to determine the conversion of aryl triflate, yield and selectivity of the Heck reaction products. The isomers of the products were identified by GCMS and the structure of the major isomer was assigned based on ^{1}H NMR spectroscopy of the purified sample. *^{1}H NMR spectroscopy was not suitable for determination of the amount of minor isomers due to low signal intensity and overlap of signals on the ^{1}H NMR spectra.*

1.5.5 Isolation of Heck reaction products

Typical procedure: In an argon-filled glove box, a dry 25-mL Schlenk tube containing a magnetic stir bar was charged with $Pd(dba)_2$ (14.3 mg, 0.025 mmol), 1,1′-bis[di(1-naphthyl)phosphino]ferrocene (dnpf) (37.7 mg, 0.050 mmol) and 3 mL of dry DMA. After prestirring at room temperature for 10 minutes, aryl triflate (0.50 mmol), aliphatic olefin (2 equiv, 1.0 mmol), and urotropine (2 equiv, 1.0 mmol, 140 mg) were added sequentially via syringe. The Schlenk tube was capped tightly and the mixture was heated with vigorous stirring in an 80 °C oil bath (external temperature). After the aryl triflate was fully consumed (monitored by GC), the reaction mixture was cooled to rt and passed through a pad of silica gel with diethyl ether washings (for most isolations) to remove DMA. The filtrate was concentrated under reduced pressure and the residue was directly subjected to silica gel flash chromatography for purification. The isomers of the products were identified by GCMS and the structure of the major isomer was assigned based on ^{1}H NMR spectroscopy of the purified sample. The ratio of the desired regioisomer versus all other isomers in the crude product was determined by GC analysis. The number of minor isomers can vary from 1 to 5 (detected by GC and GCMS), depending on the substrates and catalysts. *Note: ^{1}H NMR spectroscopy was not suitable for determination of the amount of minor isomers due to low signal intensity and overlap of signals on ^{1}H NMR spectra.*

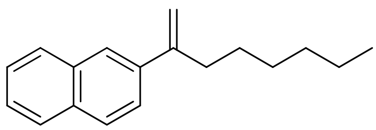
The typical procedure was used for all the isolation using 0.50 mmol of organic triflates, unless stated otherwise.



2-Phenyl-1-octene [5698-49-7]. The reaction was set up with 5% Pd(dba)$_2$ and 10% 1,1′-bis[di(1-naphthyl)phosphino]ferrocene **(**dnpf) and the reaction mixture was stirred at 80 °C for 14 hours. The product was purified by flash chromatography (hexane) as colorless oil (89 mg, 94%). The ratio of the desired regioisomer versus all other isomers in the crude product was determined to be 11:1 by GC. The minor isomers cannot be fully separated by silica gel chromatography.

^{1}H NMR (400 MHz, CDCl$_3$): δ 7.42-7.39 (m, 2H), 7.34-7.30 (m, 2H), 7.28-7.24 (m, 1H), 5.26 (d, J = 1.3 Hz, 1H), 5.05 (d, J = 1.3 Hz, 1H), 2.50 (t, J = 7.5 Hz, 2H), 1.44 (pseudoquintet, J = 7.3 Hz, 2H), 1.36-1.26 (m, 6H), 0.87 (t, J = 6.8 Hz, 3H).

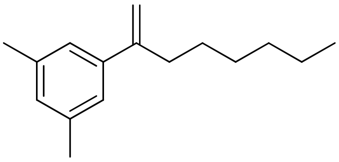
GCMS (EI): Calcd for $C_{14}H_{20}$: 188.16. Found: 188.1.



2-(2-Naphthyl)-1-octene [119796-17-7]. The reaction was set up with 5% $Pd(dba)_2$ and 10% dnpf and the reaction mixture was stirred at 80 °C for 18 hours. The product was purified by flash chromatography (hexane) as colorless oil (110 mg, 92%). The ratio of the desired regioisomer versus all other isomers in the crude product was determined to be 13:1 by GC.

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.82-7.77 (m, 4H), 7.58 (dd, *J* = 8.6, 1.8 Hz, 1H), 7.48-7.42 (m, 2H), 5.40 (d, *J* = 1.4 Hz, 1H), 5.16-5.15 (m, 1H), 2.61 (t, *J* = 7.6 Hz, 2H), 1.52-1.48 (m, 2H), 1.37-1.27 (m, 6H), 0.87 (t, *J* = 7.0 Hz, 3H).

GCMS (EI): Calcd for $C_{18}H_{22}$: 238.17. Found: 238.1.

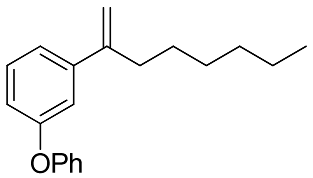


2-(*m*-Xylyl)-1-octene. The reaction was set up with 2% $Pd(dba)_2$ and 4% dnpf and the reaction mixture was stirred at 80 °C for 17 hours. The product was purified by flash chromatography (hexane) as colorless oil (101 mg, 93%). The ratio of the desired regioisomer versus all other isomers in the crude product was determined to be 11:1 by GC.

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.01 (s, 2H), 6.91 (s, 1H), 5.21 (d, *J* = 1.4 Hz, 1H), 5.01-5.00 (m, 1H), 2.46 (t, *J* = 7.5 Hz, 2H), 2.31 (s, 6H), 1.45-1.42 (m 2H), 1.34-1.26 (m, 6H), 0.87 (t, *J* = 6.8 Hz, 3H).

^{13}C NMR (100 MHz, $CDCl_3$): δ 149.2, 141.8, 137.7, 129.0, 124.2, 111.7, 35.6, 31.8, 29.2, 28.4, 22.8, 21.5, 14.2.

GCMS (EI): Calcd for $C_{16}H_{24}$: 216.36. Found: 216.1.

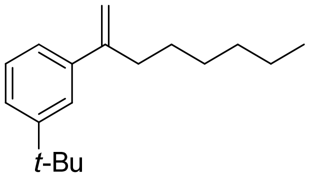


2-(*m*-Phenoxyphenyl)-1-octene. The reaction was set up with 2% Pd(dba)$_2$ and 4% dnpf and the reaction mixture was stirred at 80 °C for 29 hours. The product was purified by flash chromatography (hexane) as colorless oil (125 mg, 89%). The ratio of the desired regioisomer versus all other isomers in the crude product was determined to be 16:1 by GC.

^{1}H NMR (400 MHz, CDCl$_3$): δ 7.32-7.27 (m, 2H), 7.24-7.22 (m, 1H), 7.12 (doublet of pseudotriplet, *J* = 7.8, 1.3 Hz, 1H), 7.08-7.04 (m, 2H), 6.99-6.96 (m, 2H), 6.87-6.84 (m, 1H), 5.22 (d, *J* = 1.3 Hz, 1H), 5.01-5.00 (m, 1H), 2.41 (t, *J* = 6.9 Hz, 2H), 1.42-1.38 (m, 2H), 1.30-1.20 (m, 6H), 0.83 (t, *J* = 6.8 Hz, 3H).

^{13}C NMR (100 MHz, CDCl$_3$): δ 157.5, 157.2, 148.3, 143.6, 129.9, 129.6, 123.3, 121.3, 118.8, 117.8, 117.1, 112.7, 35.4, 31.8, 29.1, 28.4, 22.8, 14.2.

GCMS (EI): Calcd for $C_{20}H_{24}O$: 280.40. Found: 280.1.

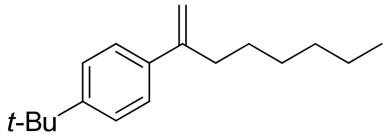


2-(*m*-*tert*-Butylphenyl)-1-octene. The reaction was set up with 5% Pd(dba)$_2$ and 10% dnpf and the reaction mixture was stirred at 80 °C for 14 hours. The product was purified by flash chromatography (hexane) as colorless oil (113 mg, 92%). The ratio of the desired regioisomer versus all other isomers in the crude product was determined to be 15:1 by GC.

^{1}H NMR (400 MHz, CDCl$_3$): δ 7.43-7.42 (pseudotriplet, *J* = 1.6 Hz, 1H), 7.31-7.20 (m, 3H), 5.25 (d, *J* = 1.5 Hz, 1H), 5.04-5.03 (m, 1H), 2.49 (t, *J* = 6.9 Hz, 2H), 1.51-1.42 (m, 2H), 1.33-1.26 (m, 15H), 0.87 (t, *J* = 6.9 Hz, 3H).

^{13}C NMR (100 MHz, CDCl$_3$): δ 151.0, 149.5, 141.4, 128.0, 124.4, 123.5, 123.3, 111.8, 35.6, 34.8, 31.8, 31.5, 29.2, 28.4, 22.8, 14.2.

GCMS (EI): Calcd for $C_{18}H_{28}$: 244.41. Found: 244.1.

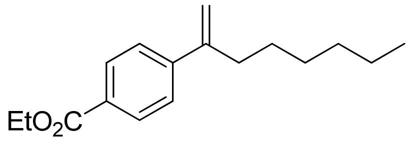


2-(*p*-*tert*-Butylphenyl)-1-octene. The reaction was set up with 5% Pd(dba)$_2$ and 10% dnpf and the reaction mixture was stirred at 80 °C for 14 hours. The product was purified by flash chromatography (hexane) as colorless oil (113 mg, 93%). The ratio of the desired regioisomer versus all other isomers in the crude product was determined to be 16:1 by GC.

^{1}H NMR (400 MHz, CDCl$_3$): δ 7.35 (pseudosinglet, 4H), 5.25 (d, *J* = 1.5 Hz, 1H), 5.01-5.00 (m, 1H), 2.48 (t, *J* = 7.6 Hz, 2H), 1.48-1.44 (m, 2H), 1.35-1.27 (m, 15H), 0.87 (t, *J* = 6.8 Hz, 3H).

^{13}C NMR (100 MHz, CDCl$_3$): δ 150.3, 148.5, 138.6, 125.8, 125.3, 111.4, 35.4, 34.6, 31.9, 31.5, 29.3, 28.5, 22.8, 14.2.

GCMS (EI): Calcd for $C_{18}H_{28}$: 244.41. Found: 244.1.

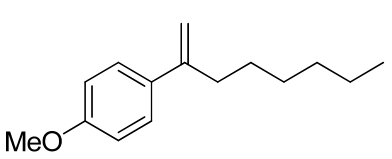


2-(*p*-Ethoxycarbonylphenyl)-1-octene. The reaction was set up with 5% Pd(dba)$_2$ and 10% dnpf and the reaction mixture was stirred at 80 °C for 22 hours. The product was purified by flash chromatography (hexane/ethyl acetate 20:1) as colorless oil (119 mg, 91%). The ratio of the desired regioisomer versus all other isomers in the crude product was determined to be 9:1 by GC.

^{1}H NMR (400 MHz, CDCl$_3$): δ 8.01-7.98 (m, 2H), 7.47-7.44 (m, 2H), 5.34 (d, *J* = 1.2 Hz, 1H), 5.15-5.14 (m, 1H), 4.37 (q, *J* = 7.1 Hz, 2H), 2.50 (t, *J* = 7.1 Hz, 2H), 1.55-1.25 (m, 11H), 0.87 (t, *J* = 6.9 Hz, 3H).

^{13}C NMR (100 MHz, CDCl$_3$): δ 166.6, 148.2, 146.1, 129.7, 129.4, 126.2, 114.0, 61.0, 35.3, 31.8, 29.1, 28.3, 22.7, 14.5, 14.2.

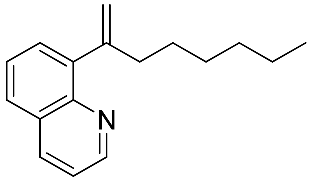
GCMS (EI): Calcd for $C_{17}H_{24}O$: 260.37. Found: 260.1.



2-(*p*-Anisyl)-1-octene [129182-23-6]. The reaction was set up with 5% Pd(dba)$_2$ and 10% dnpf and the reaction mixture was stirred at 80 ^{o}C for 22 hours. The product was purified by flash chromatography (hexane/ethyl acetate 100:1 to 20:1) as colorless oil (81 mg, 74%). The ratio of the desired regioisomer versus all other isomers in the crude product was determined to be 7:1 by GC. The minor isomers cannot be separated from the desired product by silica gel chromatography.

^{1}H NMR (400 MHz, CDCl$_3$): δ 7.36-7.34 (m, 2H), 6.87-6.85 (m, 2H), 5.18 (d, *J* = 1.4 Hz, 1H), 4.97-4.96 (m, 1H), 3.81 (s, 3H), 2.46 (t, *J* = 7.5 Hz, 2H), 1.46-1.42 (m, 2H), 1.34-1.24 (m, 6H), 0.87 (t, *J* = 6.8 Hz, 3H).

GCMS (EI): Calcd for $C_{15}H_{22}O$: 218.17. Found: 218.1.

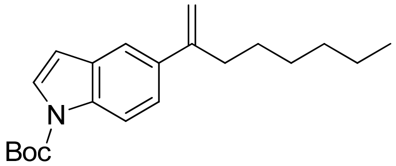


2-(8-Quinolinyl)-1-octene. The reaction was set up with 5% Pd(dba)$_2$ and 10% dnpf and the reaction mixture was stirred at 80 ^{o}C for 48 hours. The product was purified by flash chromatography (hexane/ethyl acetate 25:1) as colorless oil (111 mg, 93%). The ratio of the desired regioisomer versus all other isomers in the crude product was determined to be 11:1 by GC.

^{1}H NMR (400 MHz, CDCl$_3$): δ 8.95 (dd, *J* = 4.0, 1.6 Hz, 1H), 8.14 (dd, *J* = 8.3, 1.4 Hz, 1H), 7.74 (dd, *J* = 7.8, 1.4 Hz, 1H), 7.52-7.48 (m, 2H), 7.38 (dd, *J* = 8.2, 4.2 Hz, 1H), 5.35 (s, 1H), 5.13 (s, 1H), 2.77 (t, *J* = 7.1 Hz, 2H), 1.31-1.22 (m, 8H), 0.83 (t, *J* = 6.8 Hz, 3H).

^{13}C NMR (100 MHz, CDCl$_3$): δ 151.9, 149.9, 146.4, 143.1, 136.3, 129.3, 128.5, 127.3, 126.3, 121.0, 114.5, 37.9, 31.9, 29.1, 28.3, 22.7, 14.2.

GCMS (EI): Calcd for $C_{17}H_{21}N$: 239.36. Found: 239.1.

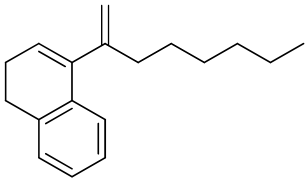


***N*-(*tert*-butoxycarbonyl)-5-(2-octenyl)indole.** The reaction was set up with 5% Pd(dba)$_2$ and 10% dnpf and the reaction mixture was stirred at 80 °C for 21 hours. The product was purified by flash chromatography (hexane/ethyl acetate 30:1) as colorless oil (134 mg, 82%). The ratio of the desired regioisomer versus all other isomers in the crude product was determined to be 10:1 by GC.

^{1}H NMR (400 MHz, CDCl$_3$): δ 8.06 (d, *J* = 8.4 Hz, 1H), 7.58-7.57 (m, 2H), 7.8 (dd, *J* = 8.6, 1.8 Hz, 1H), 6.55 (d, *J* = 3.5 Hz, 1H), 5.26 (d, *J* = 1.7 Hz, 1H), 5.05-5.04 (m, 1H), 2.55 (t, *J* = 7.4 Hz, 2H), 1.67 (s, 9H), 1.55-1.41 (m, 2H), 1.36-1.24 (m, 6H), 0.86 (t, *J* = 6.8 Hz, 3H).

^{13}C NMR (100 MHz, CDCl$_3$): δ 149.9, 149.2, 136.4, 134.6, 130.8, 126.4, 123.0, 118.6, 114.9, 111.6, 107.6, 83.8, 36.0, 31.8, 29.2, 28.5, 28.4, 22.8, 14.2.

GCMS (EI): Calcd for $C_{16}H_{21}N$ [M-Boc+H]: 227.17. Found: 227.0.

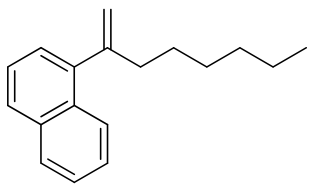


2-(3,4-Dihydro-1-naphthyl)-1-octene. The reaction was set up with 5% Pd(dba)$_2$ and 10% dnpf and the reaction mixture was stirred at 80 °C for 18 hours. The product was purified by flash chromatography (hexane) as colorless oil (103 mg, 85%). The ratio of the desired regioisomer versus all other isomers in the crude product was determined to be 13:1 by GC.

^{1}H NMR (400 MHz, CDCl$_3$): δ 7.17-7.11 (m, 4H), 5.91 (t, *J* = 4.6 Hz, 1H), 5.05 (s, 1H), 4.99 (d, *J* = 1.1 Hz, 1H), 2.75 (t, *J* = 7.9 Hz, 2H), 2.29-2.21 (m, 4H), 1.39-1.22 (m, 8H), 0.86 (t, *J* = 6.7 Hz, 3H).

^{13}C NMR (100 MHz, CDCl$_3$): δ 149.7, 140.8, 136.8, 134.4, 127.6, 126.8, 126.4, 125.6, 125.1, 113.5, 36.0, 31.9, 29.0, 28.5, 28.3, 23.3, 22.8, 14.2.

GCMS (EI): Calcd for $C_{18}H_{24}$: 240.38. Found: 240.1.

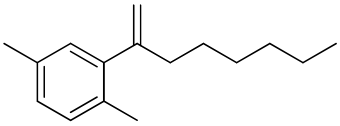


2-(1-Naphthyl)-1-octene [101720-90-5]. The reaction was set up with 5% $Pd(dba)_2$ and 10% 1,1′-bis(diisopropylphosphino)ferrocene (dippf) and stirred at 80 °C for 38 hours. The product was purified by flash chromatography (hexane) as colorless oil (88 mg, 74%). The ratio of the desired regioisomer versus all other isomers in the crude product was determined to be 137:1 by GC.

The same reaction was also conducted with 2% $Pd(dba)_2$ and 4% 1,1′-bis(diphenylphosphino)ferrocene (dippf) and stirred at 80 °C for 6 hours. The product was purified by flash chromatography (hexane) as colorless oil (108 mg, 91%). The ratio of the desired regioisomer versus all other isomers in the crude product was determined to be 13:1 by GC.

^{1}H NMR (400 MHz, $CDCl_3$): δ 8.04-8.02 (m, 1H), 7.86-7.83 (m, 1H), 7.76 (d, J = 7.2 Hz, 1H), 7.48-7.41 (m, 3H), 7.28-7.26 (m, 1H), 5.38-5.37 (m, 1H), 5.05 (d, J = 2.2 Hz, 1H), 2.50 (t, J = 7.5 Hz, 2H), 1.44-1.21 (m, 8H), 0.85 (t, J = 6.8 Hz, 3H).

GCMS (EI): Calcd for $C_{18}H_{22}$: 238.17. Found: 238.1.

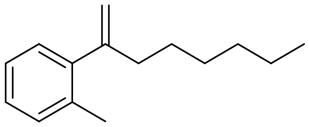


2-(2,5-Dimethylphenyl)-1-octene. The reaction was set up with 5% $Pd(dba)_2$ and 10% dippf and stirred at 80 °C for 20 hours. The product was purified by flash chromatography (hexane) as colorless oil (74 mg, 68%). The ratio of the desired regioisomer versus all other isomers in the crude product was determined to be 70:1 by GC.

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.05 (d, J = 7.7 Hz, 1H), 6.97 (dd, J = 7.7, 1.2 Hz, 1H), 6.88 (d, J = 1.2 Hz, 1H), 5.14-5.13 (m, 1H), 4.82 (d, J = 2.1 Hz, 1H), 2.32-2.28 (m, 5H), 2.24 (s, 3H), 1.40-1.23 (m, 8H), 0.87 (t, J = 6.8 Hz, 3H).

^{13}C NMR (100 MHz, $CDCl_3$): δ 150.6, 143.4, 134.8, 131.8, 130.1, 129.1, 127.5, 113.3, 37.99, 31.9, 29.3, 28.0, 22.8, 21.1, 19.5, 14.2.

GCMS (EI): Calcd for $C_{16}H_{24}$: 216.36. Found: 216.1.

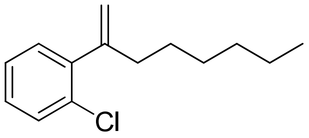


2-(*o*-Toly)-1-octene. The reaction was set up with 5% Pd(dba)$_2$ and 10% dippf and stirred at 80 °C for 20 hours. The product was purified by flash chromatography (hexane) as colorless oil (72 mg, 71%). The ratio of the desired regioisomer versus all other isomers in the crude product was determined to be 60:1 by GC.

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.25-7.11 (m, 3H), 7.07-7.05 (m, 1H), 5.17-5.15 (m, 1H), 4.84 (d, *J* = 2.1 Hz, 1H), 2.33-2.29 (m, 5H), 1.40-1.23 (m, 8H), 0.87 (t, *J* = 6.8 Hz, 3H).

^{13}C NMR (100 MHz, $CDCl_3$): δ 150.5, 143.5, 134.9, 130.2, 128.5, 126.8, 125.4, 113.8, 37.98, 31.9, 29.2, 28.0, 22.8, 20.0, 14.2.

GCMS (EI): Calcd for $C_{15}H_{22}$: 202.34. Found: 202.2.

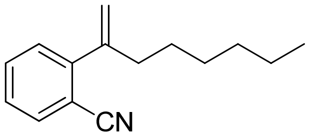


2-(*o*-Chlorophenyl)-1-octene. The reaction was set up with 5% Pd(dba)$_2$ and 10% dippf and stirred at 80 °C for 38 hours. The product was purified by flash chromatography (hexane) as colorless oil (86 mg, 77%). The ratio of the desired regioisomer versus all other isomers in the crude product was determined to be 123:1 by GC.

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.36-7.34 (m, 1H), 7.21-7.14 (m, 3H), 5.22-5.21 (m, 1H), 4.96-4.95 (m, 1H), 2.43 (t, *J* = 7.3 Hz, 2H), 1.39-1.23 (m, 8H), 0.87 (t, *J* = 6.9 Hz, 3H).

^{13}C NMR (100 MHz, $CDCl_3$): δ 149.0, 142.3, 132.2, 130.5, 129.7, 128.2, 126.6, 115.1, 36.9, 31.8, 29.1, 27.9, 22.8, 14.2.

GCMS (EI): Calcd for $C_{14}H_{19}Cl$: 222.75. Found: 222.1.

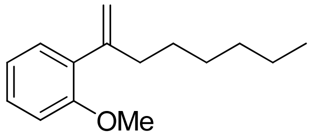


2-(*o*-Cyanophenyl)-1-octene. The reaction was set up with 10% Pd(dba)$_2$ and 12% dippf and stirred at 80 ^{o}C for 53 hours. The product was purified by flash chromatography (30:1 hexane/ ethyl acetate) as colorless oil (79 mg, 74%). The ratio of the desired regioisomer versus all other isomers in the crude product was determined to be 60:1 by GC.

^{1}H NMR (400 MHz, CDCl$_3$): δ 7.67-7.65 (m, 1H), 7.53 (pseudotriplet of doublet, J = 7.7, 1.4 Hz, 1H), 7.36-7.32 (m, 2H), 5.36-5.35 (m, 1H), 5.19 (s, 1H), 2.50 (t, J = 7.2 Hz, 2H), 1.41-1.23 (m, 8H), 0.86 (t, J = 6.9 Hz, 3H).

^{13}C NMR (100 MHz, CDCl$_3$): δ 147.3, 147.1, 133.4, 132.5, 128.6, 127.4, 118.7, 117.2, 111.3, 37.0, 31.7, 28.9, 28.0, 22.7, 14.2.

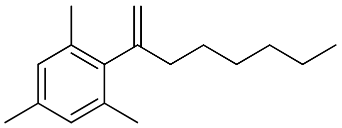
GCMS (EI): Calcd for $C_{15}H_{19}N$: 213.32. Found: 213.1.



2-(*o*-Anisyl)-1-octene [1046468-80-7]. The reaction was set up with 5% Pd(dba)$_2$ and 10% dnpf and the reaction mixture was stirred at 80 ^{o}C for 24 hours. The product was purified by flash chromatography (hexane/ethyl acetate 50:1) as colorless oil (103 mg, 94%). The ratio of the desired regioisomer versus all other isomers in the crude product was determined to be 10:1 by GC. When dippf and dppf was used as ligand, the selectivity was 7:1 and 5:1, respectively.

^{1}H NMR (400 MHz, CDCl$_3$): δ 7.26-7.21 (m, 1H), 7.13 (dd, J = 7.4, 1.8 Hz, 1H), 6.92 (pseudotriplet of doublet, J = 7.4, 1.0 Hz, 1H), 6.87 (d, J = 8.2 Hz, 1H), 5.13-5.12 (m, 1H), 4.99 (d, J = 2.2 Hz, 1H), 3.82 (s, 2H), 2.48-2.44 (t, J = 7.1 Hz, 2H), 1.35-1.21 (m, 8H), 0.87-0.84 (t, J = 6.9 Hz, 3H).

GCMS (EI): Calcd for $C_{15}H_{22}O$: 218.17. Found: 218.1.

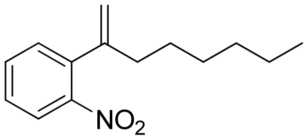


2-(2-Mesityl)-1-octene. The reaction was set up with 2% Pd(dba)$_2$ and 4% dppf and stirred at 100 °C for 24 hours. The product was purified by flash chromatography (hexane) as colorless oil (109 mg, 95%). The ratio of the desired regioisomer versus all other isomers in the crude product was determined to be 27:1 by GC.

^{1}H NMR (400 MHz, CDCl$_3$): δ 6.85 (s, 2H), 5.24-5.22 (m, 1H), 4.79-4.78 (m, 1H), 2.26 (s, 3H), 2.20-2.15 (m, 8H), 1.52-1.47 (m, 2H), 1.35-1.29 (m, 6H), 0.88 (t, *J* = 6.8 Hz, 3H).

^{13}C NMR (100 MHz, CDCl$_3$): δ 149.1, 140.7, 135.8, 135.0, 128.2, 113.0, 37.3, 32.0, 29.5, 27.6, 22.8, 21.1, 20.0, 14.2.

GCMS (EI): Calcd for $C_{17}H_{26}$: 230.39. Found: 230.2.

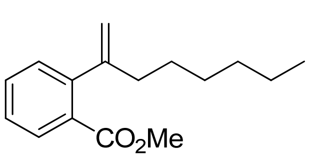


2-(*o*-Nitrophenyl)-1-octene. The reaction was set up with 10% Pd(dba)$_2$ and 12% dppf and stirred at 80 °C for 44 hours. The product was purified by flash chromatography (30:1 hexane/ ethyl acetate) as colorless oil (97 mg, 83%). The ratio of the desired regioisomer versus all other isomers in the crude product was determined to be 11:1 by GC. The minor isomers cannot be fully separated by silica gel chromatography.

^{1}H NMR (400 MHz, CDCl$_3$): δ 7.86 (dd, *J* = 8.1, 1.2 Hz, 1H), 7.54 (pseudotriplet of doublet, J = 7.6, 1.2 Hz, 1H), 7.40 (ddd, *J* = 8.1, 7.6, 1.4 Hz, 1H), 7.30 (dd, *J* = 7.6, 1.4 Hz, 1H), 5.17-5.16 (m, 1H), 4.97-4.96 (m, 1H), 2.34 (t, *J* = 7.6 Hz, 2H), 1.44-1.23 (m, 8H), 0.87 (t, *J* = 6.9 Hz, 3H).

^{13}C NMR (100 MHz, CDCl$_3$): δ 148.5, 147.5, 138.8, 132.6, 131.2, 128.0, 124.2, 114.3, 36.8, 31.8, 29.1, 28.1, 22.7, 14.2.

GCMS (EI): Calcd for $C_{14}H_{19}NO_2$: 233.31. Found: 233.1.

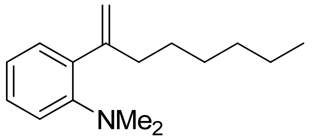


2-(*o*-Methoxycarbonylphenyl)-1-octene. The reaction was set up with 2% Pd(dba)$_2$ and 4% dppf and stirred at 80 °C for 19 hours. The product was purified by flash chromatography (30:1 hexane/ethyl acetate) as colorless oil (100 mg, 81%). The ratio of the desired regioisomer versus all other isomers in the crude product was determined to be 10:1 by GC.

^{1}H NMR (400 MHz, CDCl$_3$): δ 7.79 (dd, *J* = 7.8, 1.2 Hz, 1H), 7.44 (pseudotriplet of doublet, *J* = 7.5, 1.4 Hz, 1H), 7.31 (pseudotriplet of doublet, *J* = 7.6, 1.3 Hz, 1H), 7.21 (dd, *J* = 7.6, 1.1 Hz, 1H), 5.09-5.08 (m, 1H), 4.87-4.86 (m, 1H), 3.84 (s, 3H), 2.36 (t, *J* = 7.6 Hz, 2H), 1.42-1.23 (m, 8H), 0.86 (t, *J* = 6.9 Hz, 3H).

^{13}C NMR (100 MHz, CDCl$_3$): δ 168.6, 151.2, 144.9, 131.5, 129.94, 129.90, 129.8, 127.0, 112.6, 52.1, 37.7, 31.9, 29.2, 28.2, 22.8, 14.2.

GCMS (EI): Calcd for $C_{16}H_{22}O_2$: 246.34. Found: 246.1.

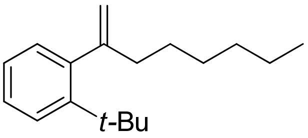


2-[*o*-(*N,N*-Dimethylamino)phenyl]-1-octene. The reaction was set up with 10% Pd(dba)$_2$ and 12% dppf and stirred at 80 °C for 15 hours. The product was purified by flash chromatography (hexane) as colorless oil (100 mg, 81%). The ratio of the desired regioisomer versus all other isomers in the crude product was determined to be 23:1 by GC.

^{1}H NMR (400 MHz, CDCl$_3$): δ 7.20 (ddd, *J* = 8.1, 7.4, 1.8 Hz, 1H), 7.09 (dd, *J* = 7.5, 1.7 Hz, 1H), 6.94 (dd, *J* = 8.0, 1.0 Hz, 1H), 6.90 (pseudotriplet of doublet, *J* = 7.4, 1.2 Hz, 1H), 5.07-5.06 (m, 1H), 5.04-5.03 (m, 1H), 2.72 (s, 6H), 2.54 (t, *J* = 6.5 Hz, 2H), 1.26-1.22 (m, 8H), 0.85 (t, *J* = 6.9 Hz, 3H).

^{13}C NMR (100 MHz, CDCl$_3$): δ 153.4, 150.9, 136.5, 131.3, 127.9, 121.4, 117.4, 113.1, 43.6, 34.5, 31.8, 29.2, 28.4, 22.8, 14.2.

GCMS (EI): Calcd for $C_{16}H_{25}N$: 231.38. Found: 231.2.

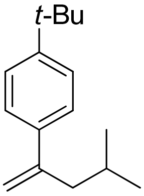


2-(*o*-*tert*-Butylphenyl)-1-octene. The reaction was set up with 2% $Pd(dba)_2$ and 4% 1,1′-bis(diphenylphosphino)ferrocene (dppf) and stirred at 80 °C for 45 hours. The product was purified by flash chromatography (hexane) as colorless oil (105 mg, 86%). The ratio of the desired regioisomer versus all other isomers in the crude product was determined to be 50:1 by GC.

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.44 (dd, *J* = 8.0, 1.2 Hz, 1H), 7.19 (pseudotriplet of doublet, *J* = 7.6, 1.6 Hz, 1H), 7.11 (pseudotriplet of doublet, *J* = 7.4, 1.2 Hz, 1H), 6.93 (dd, *J* = 7.5, 1.6 Hz, 1H), 5.16-5.15 (m, 1H), 4.92 (s, 1H), 2.30 (t, *J* = 7.8 Hz, 2H), 1.57-1.55 (m, 2H), 1.39-1.30 (m, 15H), 0.88 (t, *J* = 6.8 Hz, 3H).

^{13}C NMR (100 MHz, $CDCl_3$): δ 153.1, 146.9, 143.7, 131.3, 127.1, 126.7, 125.1, 113.5, 40.0, 36.8, 32.4, 32.0, 29.4, 27.8, 22.8, 14.3.

GCMS (EI): Calcd for $C_{18}H_{28}$: 244.41. Found: 244.2.

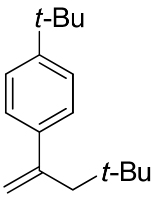


2-(*p*-*tert*-Butylphenyl)-4-methyl-1-pentene. The reaction was set up with 5% $Pd(dba)_2$ and 10% dnpf and stirred at 80 °C for 16 hours. The product was purified by flash chromatography (hexane) as colorless oil (99 mg, 94%). The ratio of the desired regioisomer versus all other isomers in the crude product was determined to be 10:1 by GC.

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.33 (pseudosinglet, 4H), 5.26 (d, *J* = 1.8 Hz, 1H), 4.98 (d, *J* = 1.3 Hz, 1H), 2.36 (d, *J* = 7.2 Hz, 2H), 1.68 (m, 1H), 1.32 (s, 9H), 0.88-0.87 (d, *J* = 6.7 Hz, 6H).

^{13}C NMR (100 MHz, $CDCl_3$): δ 150.3, 147.6, 138.5, 126.0, 125.3, 112.9, 45.3, 34.6, 31.5, 26.5, 22.6.

GCMS (EI): Calcd for $C_{16}H_{24}$: 216.36. Found: 216.1.

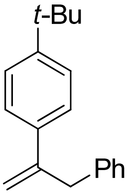


2-(*p*-*tert*-Butylphenyl)-4,4-dimethyl-1-pentene. The reaction was set up with 5% $Pd(dba)_2$ and 10% dnpf and stirred at 80 °C for 24 hours. The product was purified by flash chromatography (hexane) as colorless oil (90 mg, 78%). The ratio of the desired regioisomer versus all other isomers in the crude product was determined to be 13:1 by GC. The minor isomers cannot be fully separated by silica gel chromatography.

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.30 (pseudosinglet, 4H), 5.24 (d, J = 2.0 Hz, 1H), 4.97-4.96 (m, 1H), 2.45 (s, 2H), 1.31 (s, 9H), 0.80 (s, 9H).

^{13}C NMR (100 MHz, $CDCl_3$): δ 150.0, 147.4, 140.7, 126.3, 125.1, 115.7, 48.9, 34.6, 31.9, 31.5, 31.5.

GCMS (EI): Calcd for $C_{17}H_{26}$: 230.39. Found: 230.1.

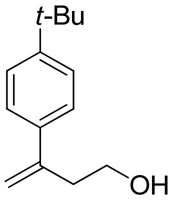


2-(*p*-*tert*-Butylphenyl)-3-phenyl-1-propene. The reaction was set up with 5% $Pd(dba)_2$ and 10% dnpf and stirred at 80 °C for 16 hours. The product was purified by flash chromatography (hexane) as colorless oil (116 mg, 93%). The ratio of the desired regioisomer versus all other isomers in the crude product was determined to be 15:1 by GC.

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.40-7.38 (m, 2H), 7.32-7.16 (m, 7H), 5.50 (s, 1H), 4.96 (s, 1H), 3.82 (s, 2H), 1.30 (s, 9H).

^{13}C NMR (100 MHz, $CDCl_3$): δ 150.6, 146.5, 139.9, 137.9, 129.1, 128.5, 126.2, 125.8, 125.3, 114.1, 41.7, 34.6, 31.4.

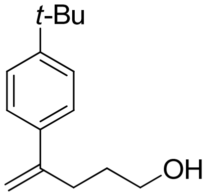
GCMS (EI): Calcd for $C_{19}H_{22}$: 250.38. Found: 250.1.



3-(*p*-*tert*-Butylphenyl)-3-butene-1-ol [1134201-55-0]. The reaction was set up with 5% $Pd(dba)_2$ and 10% dnpf and stirred at 80 °C for 16 hours. The product was purified by flash chromatography (hexane/ethyl acetate 10:1 to 5:1) as colorless oil (95 mg, 96%). The ratio of the desired regioisomer versus all other isomers in the crude product was determined to be 10:1 by GC.

^1H NMR (400 MHz, $CDCl_3$): δ 7.36 (pseudosinglet, 4H), 5.41 (d, J = 1.3 Hz, 1H), 5.12-5.12 (m, 1H), 3.73 (t, J = 6.4 Hz, 2H), 2.78 (td, J = 6.4, 0.9 Hz, 2H), 1.48 (br s, 1H), 1.32 (s, 9H).

GCMS (EI): Calcd for $C_{14}H_{20}$: 204.15. Found: 204.1.



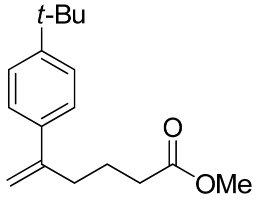
4-(*p*-*tert*-Butylphenyl)-4-pentene-1-ol. The 0.5 mmol-scale reaction was set up with 5 mol% $Pd(dba)_2$ and 10 mol% dnpf and the reaction finished after stirring at 80 °C for 7 hours. The product was purified by flash chromatography (hexane/ethyl acetate 10:1 to 5:1) as colorless oil (101 mg, 95%). The ratio of the desired regioisomer versus all other isomers in the crude product was determined to be 12:1 by GC.

Gram-scale procedure using a Schlenk manifold: In air, a 100-mL dry Schlenk tube containing a magnetic stir bar was charged with $Pd(dba)_2$ (172 mg, 0.30 mmol) and dnpf (453 mg, 0.60 mmol). The atmosphere was switched to argon after three cycles of evacuation and refilling with argon. Degassed dry DMA (30 mL) was then added. After stirring for 10 minutes at rt, the mixture was treated with *p-tert*-butylphenyl triflate (1.69 g, 6.0 mmol), 4-pentene-1-ol (2 equiv, 1.03 g, 12.0 mmol), and urotropine (2 equiv, 1.68 g, 12.0 mmol). The reaction tube was capped tightly and the mixture was heated with vigorous stirring in an 80 °C oil bath (external temperature). The aryl triflate was fully consumed after 7 hours (monitored by GC). At the conculsion of the reaction, the mixture was diluted with 40 mL of water and extracted with ethyl acetate (40 mL x 4). The organic extracts were washed with brine (40 mL x 2) and dried over anhydrous sodium sulfate. After concentration of the filtrate on a rotary evaporator in vacuo, the residue was subjected to flash chromatography using 1:5 EA/hexane as eluent. The titled compound was obtained as colorless oil (1.20 g, 92% yield). The ratio of the desired regioisomer versus all other isomers in the crude product was determined to be12:1 by GC.

^{1}H NMR (400 MHz, CDCl$_3$): δ 7.35 (pseudosinglet, 4H), 5.29 (s, 1H), 5.05 (s, 1H), 3.66 (t, *J* = 6.4 Hz, 2H), 2.59 (s, *J* = 7.5 Hz, 2H), 1.73 (tt, *J* = 7.5, 6.4 Hz, 2H), 1.40 (br s, 1H), 1.32 (s, 9H).

^{13}C NMR (100 MHz, CDCl$_3$): δ 150.6, 147.7, 138.0, 125.8, 125.4, 112.0, 62.6, 34.6, 31.6, 31.5, 31.4.

GCMS (EI): Calcd for $C_{15}H_{22}O$: 218.33. Found: 218.1.

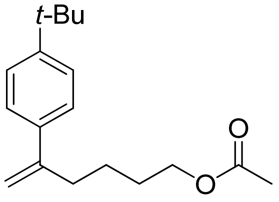


Methyl 5-(*p-tert*-butylphenyl)-5-hexenoate. The reaction was set up with 5% Pd(dba)$_2$ and 10% dnpf and stirred at 80 °C for 16 hours. Product was purified by flash chromatography (hexane/ethyl acetate 30:1) as colorless oil (124 mg, 95%). The ratio of the desired regioisomer versus all other isomers in the crude product was determined to be 12:1 by GC.

^{1}H NMR (400 MHz, CDCl$_3$): δ 7.35 (pseudosinglet, 4H), 5.30 (d, *J* = 1.1 Hz, 1H), 5.03-5.02 (m, 1H), 3.66 (s, 3H), 2.54 (t, *J* = 7.4 Hz, 2H), 2.34 (t, *J* = 7.4 Hz, 2H), 2.80 (pseudoquintet, *J* = 7.4 Hz, 2H), 1.32 (s, 9H).

^{13}C NMR (100 MHz, $CDCl_3$): δ 174.2, 150.6, 147.2, 137.9, 125.8, 125.4, 112.3, 51.6, 34.65, 34.62, 33.6, 31.4, 23.6.

GCMS (EI): Calcd for $C_{17}H_{24}O_2$: 260.37. Found: 260.1.

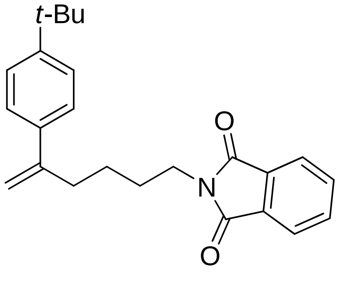


5-(*p*-*tert*-Butylphenyl)-5-hexeneyl acetate. The reaction was set up with 5% $Pd(dba)_2$ and 10% dnpf and stirred at 80 °C for 24 hours. Flash chromatography (hexane/ethyl acetate 20:1) gave the desired product contaminated with the excess olefin starting material. The latter was removed by distillation at reduced pressure (200 mTorr) at 40 °C and the pure product was thus obtained as colorless oil (134 mg, 98%). The ratio of the desired regioisomer versus all other isomers in the crude product was determined to be 15:1 by GC.

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.34 (pseudosinglet, 4H), 5.28 (s, 1H), 5.02 (s, 1H), 4.05 (t, *J* = 6.6 Hz, 2H), 2.52 (t, *J* = 7.5 Hz, 1H), 2.02 (s, 3H), 1.65 (pseudoquintet, *J* = 7.1 Hz, 2H), 1.53 (m, 2H), 1.32 (s, 9H).

^{13}C NMR (100 MHz, $CDCl_3$): δ 171.3, 150.5, 147.8, 138.2, 125.8, 125.3, 112.0, 64.5, 34.9, 34.6, 31.5, 28.3, 24.6, 21.1.

GCMS (EI): Calcd for $C_{18}H_{26}O_2$: 274.40. Found: 274.1.



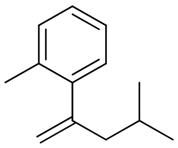
***N*-[5-(*p*-*tert*-Butylphenyl)-5-hexenyl]phthalimide.** The reaction was set up with 5%

$Pd(dba)_2$, 10% dnpf, *p*-(*tert*-butyl)phenyl triflate (1.2 equiv, 0.60 mmol, 169 mg) and *N*-(5-hexenyl)phthalimide (1.0 equiv, 0.50 mmol, 115 mg). After stirring at 80 °C for 22 hours, the titled compound was purified by flash chromatography (hexane/ethyl acetate 10:1 to 5:1) as colorless oil (165 mg, 91%). The ratio of the desired regioisomer versus all other isomers in the crude product was determined to be 38:1 by GC. When the reaction was conducted with an excess of the olefin starting material, it was difficult to separate it from the product by flash chromatography.

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.83 (dd, *J* = 5.4, 3.1 Hz, 2H), 7.70 (dd, *J* = 5.4, 3.1 Hz, 2H), 7.32 (pseudosinglet, 4H), 5.26 (d, *J* = 1.4 Hz, 1H), 5.03-5.02 (m, 1H), 3.68 (t, *J* = 7.3 Hz, 2H), 2.54 (t, *J* = 7.5 Hz, 2H), 1.72 (pseudoquintet, *J* = 7.5 Hz, 2H), 1.50 (pseudoquintet, *J* = 7.5 Hz, 2H), 1.31 (s, 9H).

^{13}C NMR (100 MHz, $CDCl_3$): δ 168.6, 150.5, 147.7, 138.2, 134.0, 132.4, 125.9, 125.3, 123.3, 112.1, 38.0, 34.9, 34.6, 31.5, 28.3, 25.6.

GCMS (EI): Calcd for $C_{24}H_{27}NO_2$: 361.48. Found: 361.1.

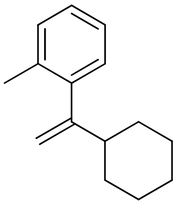


2-(*o*-Tolyl)-4-methyl-1-pentene. The reaction was set up with 5% $Pd(dba)_2$ and 10% dippf and stirred at 80 °C for 2 days. The product was purified by flash chromatography (hexane) as colorless oil (62 mg, 71%). The ratio of the desired regioisomer versus all other isomers in the crude product was determined to be 85:1 by GC.

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.17-7.06 (m, 4H), 5.16-5.15 (m, 1H), 4.90 (d, *J* = 1.1 Hz, 1H), 2.31 (s, 3H), 2.23 (d, *J* = 7.0 Hz, 2H), 1.52 (triplet of septet, *J* = 7.0, 6.6 Hz, 1H), 0.89 (d, *J* = 6.6 Hz, 6H).

^{13}C NMR (100 MHz, $CDCl_3$): δ 149.2, 143.2, 135.0, 130.3, 128.6, 126.8, 125.5, 115.2, 47.5, 26.2, 22.7, 20.1.

GCMS (EI): Calcd for $C_{13}H_{18}$: 174.28. Found: 174.1.

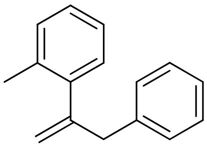


1-Cyclohexyl-1-(*o*-tolyl)ethene. The reaction was set up with 10% Pd(dba)$_2$ and 12% dippf and stirred at 80 ^{o}C for 24 hours. The product was purified by flash chromatography (hexane) as colorless oil (69 mg, 74%). The ratio of the desired regioisomer versus all other isomers in the crude product was determined to be 29:1 by GC.

^{1}H NMR (400 MHz, CDCl$_3$): δ 7.18-7.10 (m, 3H), 7.04-7.02 (m, 1H), 5.13 (pseudotriplet, *J* = 1.5 Hz, 1H), 4.81 (d, *J* = 1.6 Hz, 1H), 2.26 (s, 3H), 2.14-2.08 (m, 1H), 1.84-1.65 (m, 5H), 1.28-1.12 (m, 5H).

^{13}C NMR (100 MHz, CDCl$_3$): δ 155.4, 143.9, 135.2, 130.1, 128.8, 126.6, 125.2, 111.4, 44.8, 32.2, 26.9, 26.5, 20.1.

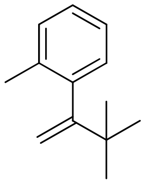
GCMS (EI): Calcd for $C_{15}H_{20}$: 200.32. Found: 200.1.



2-(*o*-Tolyl)-3-phenyl-1-propene [53423-45-3]. The reaction was set up with 5% Pd(dba)$_2$ and 10% dippf and stirred at 80 ^{o}C for 24 hours. The product was purified by flash chromatography (hexane) as colorless oil (84 mg, 86%). The ratio of the desired regioisomer versus all other isomers in the crude product was determined to be 87:1 by GC.

^{1}H NMR (400 MHz, CDCl$_3$): δ 7.27-7.06 (m, 8H), 7.00 (d, *J* = 7.1 Hz, 1H), 5.08-5.07 (m, 1H), 4.93-4.92 (m, 1H), 3.60 (s, 2H), 2.24 (s, 3H).

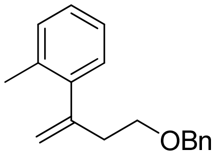
GCMS (EI): Calcd for $C_{16}H_{16}$: 208.13. Found: 208.0.



2-(*o*-Tolyl)neopentene [27561-42-8]. The reaction was set up with 10% Pd(dba)$_2$, 12% dppf and 5 equiv of neopentene (2.50 mmol, 210 mg) and stirred at 80 °C for 3 days. The product was purified by flash chromatography (hexane) as colorless oil (59 mg, 68%). The ratio of the desired regioisomer versus all other isomers in the crude product was determined to be 9:1 by GC. The minor isomer cannot be fully separated by silica gel chromatography. When dippf was used as ligand, little Heck product was formed.

^{1}H NMR (400 MHz, CDCl$_3$): δ 7.17-7.10 (m, 3H), 7.03 (d, J = 7.4 Hz, 1H), 5.29 (s, 1H), 4.75 (s, 1H), 2.25 (s, 3H), 1.11 (s, 9H).

GCMS (EI): Calcd for $C_{13}H_{18}$: 174.14. Found: 174.0.

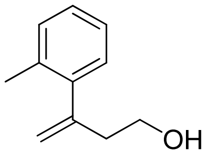


3-(*o*-Tolyl)-3-butenyl benzyl ether. The reaction was set up with 10% Pd(dba)$_2$ and 12% dippf and stirred at 80 °C for 24 hours. The product was purified by flash chromatography (hexane to 10:1 hexane/ethyl acetate) as colorless oil (90 mg, 72%). The ratio of the desired regioisomer versus all other isomers in the crude product was determined to be 79:1 by GC.

^{1}H NMR (400 MHz, CDCl$_3$): δ 7.34-7.24 (m, 5H), 7.17-7.08 (m, 4H), 5.27-5.26 (m, 1H), 4.94 (d, J = 1.9 Hz, 1H), 4.46 (s, 2H), 3.50 (t, J = 6.9 Hz, 2H), 2.68 (t, J = 6.9 Hz, 2H), 2.29 (s, 3H).

^{13}C NMR (100 MHz, CDCl$_3$): δ 146.8, 142.5, 138.6, 135.1, 130.2, 128.54, 128.47, 127.8, 127.6, 127.0, 125.5, 115.8, 73.0, 68.7, 38.0, 20.0.

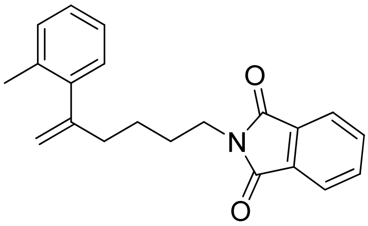
GCMS (EI): Calcd for $C_{18}H_{20}O$: 252.35. Found: 253.1.



3-(*o*-Tolyl)-3-butene-1-ol [1134201-46-9]. The reaction was set up with 5% Pd(dba)$_2$ and 10% dippf and stirred at 80 ^{o}C for 21 hours. The product was purified by flash chromatography (hexane/ethyl acetate 5:1) as colorless oil (72 mg, 88%). The ratio of the desired regioisomer versus all other isomers in the crude product was determined to be 66:1 by GC.

^{1}H NMR (400 MHz, CDCl$_3$): δ 7.19-7.12 (m, 3H), 7.08-7.07 (m, 1H), 5.28 (m, 1H), 5.00 (d, *J* = 1.8 Hz, 1H), 3.64 (t, *J* = 6.3 Hz, 2H), 2.62 (s, *J* = 6.3 Hz, 2H), 2.31 (s, 3H), 1.48 (br s, 1H).

GCMS (EI): Calcd for $C_{11}H_{14}O$: 162.10. Found: 162.0.

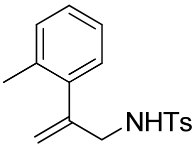


***N*-[5-(*o*-Tolyl)-5-hexenyl]phthalimide**. The reaction was set up with 5% Pd(dba)$_2$ and 10% dippf and stirred at 80 ^{o}C for 2 days. The product was purified by flash chromatography (50:1 hexane/ethyl acetate) as colorless oil (130 mg, 85%). The ratio of the desired regioisomer versus all other isomers in the crude product was determined to be 69:1 by GC.

^{1}H NMR (400 MHz, CDCl$_3$): δ 7.84-7.82 (m, 2H), 7.72-7.69 (m, 2H), 7.14-7.02 (m, 4H), 5.18-5.16 (m, 1H), 4.86 (d, *J* = 2.0 Hz, 1H), 3.66 (t, *J* = 7.3 Hz, 2H), 2.37 (t, *J* = 7.3 Hz, 2H), 2.27 (s, 3H), 1.68 (pseudoquintet, *J* = 7.6 Hz, 2H), 1.39 (pseudoquintet, *J* = 7.9 Hz, 2H).

^{13}C NMR (100 MHz, CDCl$_3$): δ 168.6, 149.6, 142.9, 134.9, 134.0, 132.3, 130.2, 128.5, 126.9, 125.5, 123.3, 114.3, 38.0, 37.3, 28.4, 25.1, 20.0.

GCMS (EI): Calcd for $C_{21}H_{21}NO_2$: 319.40. Found: 319.1.



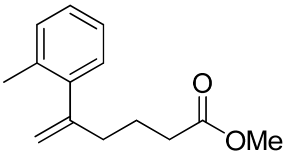
***N*-2-(*o*-Tolyl)allyl *p*-tolylsulfonamide**. The reaction was set up with 5% Pd(dba)$_2$

and 10% dippf and stirred at 80 °C for 2 days. The product was purified by flash chromatography (hexane to 10:1 hexane/ethyl acetate) as colorless oil (123 mg, 82%). Only one regioisomer was detected in the crude product by GC.

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.68 (d, J = 8.3 Hz, 2H), 7.26 (d, J = 8.1 Hz, 2H), 7.20-7.08 (m, 3H), 6.92 (d, J = 7.4 Hz, 1H), 5.39-5.38 (m, 1H), 5.00 (s, 1H), 4.49 (br t, J = 6.4 Hz, 1H), 3.81 (d, J = 6.4 Hz, 2H), 2.42 (s, 3H), 2.17 (s, 3H).

^{13}C NMR (100 MHz, $CDCl_3$): δ 144.6, 143.6, 139.3, 137.0, 135.4, 130.5, 129.8, 128.7, 127.9, 127.3, 125.9, 116.2, 48.4, 21.7, 19.8.

GCMS (EI): Calcd for $C_{17}H_{19}NO_2S$: 301.40. Found: 301.0.

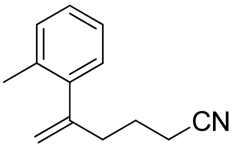


Methyl 5-(*o*-tolyl)-5-hexenoate. The reaction was set up with 5% $Pd(dba)_2$ and 10% dippf and stirred at 80 °C for 2 days. The product was purified by flash chromatography (30:1 hexane/ethyl acetate) as colorless oil (95 mg, 87%). The ratio of the desired regioisomer versus all other isomers in the crude product was determined to be 28:1 by GC.

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.18-7.11 (m, 3H), 7.07-7.04 (m, 1H), 5.20-5.19 (m, 1H), 4.90-4.89 (m, 1H), 3.65 (s, 3H), 2.38-2.32 (m, 4H), 2.29 (s, 3H), 1.73 (pseudoquintet, J = 7.6 Hz, 2H).

^{13}C NMR (100 MHz, $CDCl_3$): δ 174.1, 149.1, 142.8, 134.9, 130.3, 128.5, 127.0, 125.6, 114.5, 51.6, 37.1, 33.7, 23.2, 20.0.

GCMS (EI): Calcd for $C_{14}H_{18}O_2$: 218.29. Found: 218.1.

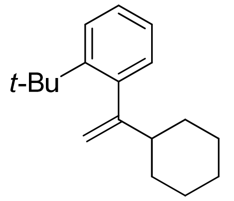


5-(*o*-Tolyl)-5-hexenenitrile. The reaction was set up with 5% $Pd(dba)_2$ and 10% dippf and stirred at 80 °C for 2 days. The product was purified by flash chromatography (hexane to 15:1 hexane/ethyl acetate) as colorless oil (73 mg, 78%). The ratio of the desired regioisomer versus all other isomers in the crude product was determined to be 70:1 by GC.

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.19-7.12 (m, 3H), 7.05 (d, *J* = 6.8 Hz, 1H), 5.25-5.24 (m, 1H), 4.96-4.95 (m, 1H), 2.51 (t, *J* = 7.5 Hz, 2H), 2.35 (t, *J* = 7.1 Hz, 2H), 2.29 (s, 3H), 1.73 (tt, *J* = 7.5, 7.1 Hz, 2H).

^{13}C NMR (100 MHz, $CDCl_3$): δ 147.8, 141.9, 134.9, 130.5, 128.4, 127.4, 125.8, 119.6, 115.7, 36.5, 23.7, 20.0, 16.8.

GCMS (EI): Calcd for $C_{13}H_{15}N$: 185.26. Found: 185.1.

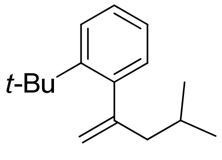


1-(*o*-*tert*-Butylphenyl)-1-cyclohexylethene. The reaction was set up with 2% $Pd(dba)_2$ and 4% dppf and stirred at 80 °C for 3 days. The product was purified by flash chromatography (hexane) as colorless oil (110 mg, 91%). The ratio of the desired regioisomer versus all other isomers in the crude product was determined to be 114:1 by GC.

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.46 (dd, *J* = 8.1, 1.3 Hz, 1H), 7.21 (ddd, *J* = 8.1, 7.2, 1.6 Hz, 1H), 7.09 (ddd, *J* = 7.5, 7.2, 1.3 Hz, 1H), 6.91 (dd, *J* = 7.5, 1.6 Hz, 1H), 5.15-5.14 (m, 1H), 4.88 (d, *J* = 1.6 Hz, 1H), 2.10-1.18 (m, 20H).

^{13}C NMR (100 MHz, $CDCl_3$): δ 158.6, 147.1, 142.8, 132.8, 127.6, 126.8, 124.7, 112.1, 45.9, 37.0, 33.8 and 31.2 (broad; 2 rotomers at 25 °C), 32.7, 27.1, 26.7.

GCMS (EI): Calcd for $C_{18}H_{26}$: 242.40. Found: 242.1.

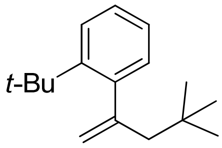


2-(*o*-*tert*-Butylphenyl)-4-methyl-1-pentene. The reaction was set up with 2% $Pd(dba)_2$ and 4% dppf and stirred at 80 °C for 40 hours. The product was purified by flash chromatography (hexane) as colorless oil (102 mg, 94%). The ratio of the desired regioisomer versus all other isomers in the crude product was determined to be 45:1 by GC.

^{1}H NMR (400 MHz, CDCl$_3$): δ 7.45 (dd, *J* = 8.0, 1.3 Hz, 1H), 7.19 (ddd, *J* = 8.0, 7.2, 1.6 Hz, 1H), 7.11 (ddd, *J* = 7.5, 7.2, 1.3 Hz, 1H), 6.91 (dd, *J* = 7.5, 1.6 Hz, 1H), 5.14-5.13 (m, 1H), 4.96 (d, *J* = 2.0 Hz, 1H), 2.22 (d, *J* = 7.0 Hz, 2H), 1.84 (triplet of septet, *J* = 7.0, 6.6 Hz, 1H), 1.40 (s, 9H), 0.97 (d, *J* = 6.6 Hz, 6H).

^{13}C NMR (100 MHz, CDCl$_3$): δ 151.3, 147.1, 143.3, 131.5, 127.3, 126.7, 125.1, 115.3, 49.8, 37.0, 32.6, 25.6, 22.9.

GCMS (EI): Calcd for $C_{16}H_{24}$: 216.36. Found: 216.1.

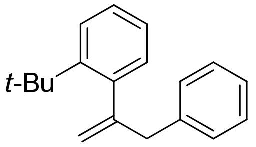


2-(*o-tert*-Butylphenyl)-4,4-dimethyl-1-pentene. The reaction was set up with 2% Pd(dba)$_2$ and 4% dppf and stirred at 80 °C for 43 hours. The product was purified by flash chromatography (hexane) as colorless oil (107 mg, 93%). The ratio of the desired regioisomer versus all other isomers in the crude product was determined to be 48:1 by GC.

^{1}H NMR (400 MHz, CDCl$_3$): δ 7.43 (d, *J* = 7.6 Hz, 1H), 7.20-7.16 (m, 1H), 7.08-7.05 (m, 2H), 5.19-5.18 (m. 1H), 5.05 (d, *J* = 2.2 Hz, 1H), 2.37 (d, *J* = 0.7 Hz, 2H), 1.41 (s, 9H), 0.91 (s, 9H).

^{13}C NMR (100 MHz, CDCl$_3$): δ 151.5, 147.0, 144.2, 132.5, 127.8, 126.7, 125.1, 117.3, 54.0, 37.0, 32.9, 32.1, 30.5.

GCMS (EI): Calcd for $C_{17}H_{26}$: 230.39. Found: 230.1.

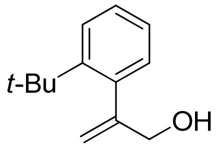


2-(*o-tert*-Butyphenyl)-3-phenyl-1-propene. The reaction was set up with 5% Pd(dba)$_2$ and 6% dppf and stirred at 80 °C for 26 hours. The product was purified by flash chromatography (hexane) as colorless oil (117 mg, 94%). The ratio of the desired regioisomer versus all other isomers in the crude product was determined to be 93:1 by GC.

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.47 (dd, J = 8.0, 1.3 Hz, 1H), 7.35-7.31 (m, 2H), 7.26-7.18 (m, 4H), 7.08 (ddd, J = 7.6, 7.2, 1.3 Hz, 1H), 6.84 (dd, J = 7.6, 1.6 Hz, 1H), 4.99-4.98 (m, 1H), 4.90-4.89 (m, 1H), 3.64 (s, 2H), 1.47 (s, 9H).

^{13}C NMR (100 MHz, $CDCl_3$): δ 152.5, 147.2, 142.9, 138.9, 131.5, 130.0, 128.5, 127.1, 126.9, 126.5, 125.2, 116.1, 46.7, 37.0, 32.5.

GCMS (EI): Calcd for $C_{19}H_{22}$: 250.38. Found: 250.2.

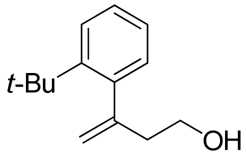


2-(*o-tert*-Butylphenyl)allyl alcohol. The reaction was set up with 3 equiv of allyl alcohol (87 mg, 1.50 mmol), 10% $Pd(dba)_2$ and 12% dppf and stirred at 80 °C for 48 hours. The product was purified by flash chromatography (20:1 to 10:1 hexane/ ethyl acetate) as colorless oil (67 mg, 71%). Only one regioisomer was detected in the crude mixture by GC. When 2 equiv of allylic alcohol was used, lower conversion resulted.

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.47 (dd, J = 8.1, 1.2 Hz, 1H), 7.24 (ddd, J = 8.1, 7.3, 1.6 Hz, 1H), 7.15 (ddd, J = 7.5, 7.3, 1.2 Hz, 1H), 6.97 (dd, J = 7.5, 1.6 Hz, 1H), 5.52-5.51 (m, 1H), 5.12-5.11 (m, 1H), 4.32 (t, J = 6.3 Hz, 2H), 1.72 (t, J = 6.3 Hz, 1H), 1.40 (s, 9H).

^{13}C NMR (100 MHz, $CDCl_3$): δ 152.0, 148.1, 139.2, 131.7, 127.5, 127.2, 125.4, 113.1, 67.8, 36.9, 32.3.

GCMS (EI): Calcd for $C_{13}H_{18}O$: 190.28. Found: 190.0.

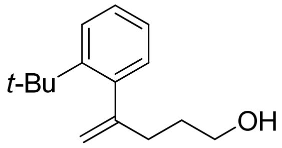


3-(*o-tert*-Butylphenyl)-3-butene-1-ol. The reaction was set up with 2% Pd(dba)$_2$ and 4% dppf and stirred at 80 °C for 3 days. The product was purified by flash chromatography (3:1 hexane/ ethyl acetate) as colorless oil (98 mg, 96%). The ratio of the desired regioisomer versus all other isomers in the crude product was determined to be 29:1 by GC.

^{1}H NMR (400 MHz, CDCl$_3$): δ 7.46 (dd, J = 8.1, 1.2 Hz, 1H), 7.22 (ddd, J = 8.1, 7.3, 1.6 Hz, 1H), 7.13 (ddd, J = 7.5, 7.3, 1.2 Hz, 1H), 6.92 (dd, J = 7.5, 1.6 Hz, 1H), 5.27-5.26 (m, 1H), 5.06 (d, J = 1.7 Hz, 1H), 3.82 (td, J = 6.3, 5.8 Hz, 2H), 2.64 (t, J = 6.3 Hz, 2H), 1.49 (t, J = 5.8 Hz, 1H), 1.40 (s, 9H).

^{13}C NMR (100 MHz, CDCl$_3$): δ 149.4, 147.2, 142.1, 131.3, 127.4, 127.1, 125.3, 116.4, 60.4, 43.0, 36.9, 32.5.

GCMS (EI): Calcd for $C_{14}H_{20}O$: 204.31. Found: 204.1.

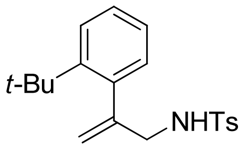


4-(*o-tert*-Butylphenyl)-4-pentene-1-ol. The reaction was set up with 2% Pd(dba)$_2$ and 4% dppf and stirred at 80 °C for 3 days. The product was purified by flash chromatography (3:1 hexane/ ethyl acetate) as colorless oil (103 mg, 94%). The ratio of the desired regioisomer versus all other isomers in the crude product was determined to be 23:1 by GC.

^{1}H NMR (400 MHz, CDCl$_3$): δ 7.45 (dd, J = 8.1, 1.2 Hz, 1H), 7.20 (ddd, J = 8.1, 7.6, 1.6 Hz, 1H), 7.12 (ddd, J = 7.6, 7.5, 1.2 Hz, 1H), 6.94 (dd, J = 7.5, 1.6 Hz, 1H), 5.20-5.19 (m, 1H), 4.96 (d, J = 1.2 Hz, 1H), 3.72 (pseudoquintet, J = 6.0 Hz, 2H), 2.42 (t, J = 7.8 Hz, 2H), 1.85 (tt, J = 7.8, 6.0 Hz, 2H), 1.39 (s, 9H), 1.27 (br s, 1H).

^{13}C NMR (100 MHz, CDCl$_3$): δ 152.3, 147.0, 143.2, 131.3, 127.2, 126.9, 125.2, 114.0, 62.9, 36.9, 36.1, 32.4, 31.0.

GCMS (EI): Calcd for $C_{15}H_{22}O$: 218.33. Found: 218.1.

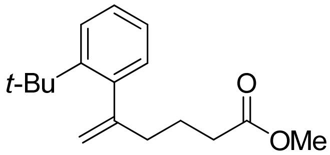


***N*-2-(*p*-*tert*-butylphenyl)allyl *p*-tolylsulfonamide**. The reaction was set up with 10% Pd(dba)$_2$ and 12% dppf and stirred at 80 °C for 40 hours. The titled compound was purified by flash chromatography (5:1 hexane/ethyl acetate) as white solid (157 mg, 92%). Only one regioisomer was detected in the crude mixture by GC.

^{1}H NMR (400 MHz, CDCl$_3$): δ 7.72 (d, *J* = 8.3 Hz, 2H), 7.42 (dd, *J* = 8.1, 1.1 Hz, 1H), 7.28 (d, *J* = 8.3 Hz, 2H), 7.22 (ddd, *J* = 8.1, 7.7, 1.6 Hz, 1H), 7.10 (ddd, *J* = 7.7, 7.6, 1.1 Hz, 1H), 6.85 (dd, *J* = 7.6, 1.6 Hz, 1H), 5.45 (d, *J* = 1.0 Hz, 1H), 5.08 (d, *J* = 1.1 Hz, 1H), 4.67 (br t, *J* = 6.6 Hz, 1H), 3.78 (d, *J* = 6.6 Hz, 2H), 2.41 (s, 3H), 1.30 (s, 9H).

^{13}C NMR (100 MHz, CDCl$_3$): δ 147.8, 147.5, 143.7, 139.1, 137.0, 131.6, 129.9, 127.7, 127.4, 127.3, 125.6, 115.5, 49.9, 36.8, 32.2, 21.7.

GCMS (EI): Calcd for $C_{20}H_{25}NO_2S$: 343.48. Found: 343.1.

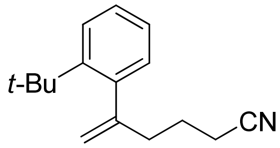


Methyl 5-(*o*-*tert*-butylphenyl)-5-hexenoate. The reaction was set up with 2% Pd(dba)$_2$ and 4% dppf and stirred at 100 °C for 24 hours. The titled compound was purified by flash chromatography (30:1 hexane/ ethyl acetate) as colorless oil (123 mg, 95%). The ratio of the desired regioisomer versus all other isomers in the crude product was determined to be 21:1 by GC.

^{1}H NMR (400 MHz, CDCl$_3$): δ 7.44 (d, *J* = 8.0 Hz, 1H), 7.22 (dd, *J* = 8.0, 7.6 Hz, 1H), 7.10 (dd, *J* = 7.6, 7.5 Hz, 1H), 6.92 (d, *J* = 7.5 Hz, 1H), 5.19 (s, 1H), 4.97 (s, 1H), 3.67 (s, 3H), 2.41-2.33 (m, 4H), 1.93-1.89 (m, 2H), 1.38 (s, 9H).

^{13}C NMR (100 MHz, CDCl$_3$): δ 174.1, 151.9, 147.0, 143.0, 131.3, 127.2, 126.9, 125.3, 114.2, 51.7, 39.2, 36.8, 33.9, 32.4, 23.1.

GCMS (EI): Calcd for $C_{17}H_{24}O$: 260.37. Found: 260.1.

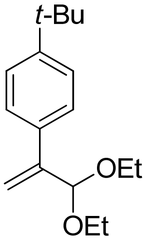


5-(*p*-*tert*-Butylphenyl)-5-hexenenitrile. The reaction was set up with 10% Pd(dba)$_2$ and 12% dnpf and stirred at 80 °C for 25 hours. The titled compound was purified by flash chromatography (20:1 hexane/ ethyl acetate) as colorless oil (89 mg, 78%). The ratio of the desired isomer versus all other isomers in the crude product was determined to be 39:1 by GC.

^{1}H NMR (400 MHz, CDCl$_3$): δ 7.46 (dd, *J* = 8.1, 1.2 Hz, 1H), 7.22 (ddd, *J* = 8.1, 7.5, 1.6 Hz, 1H), 7.13 (pseudotriplet of doublet, *J* = 7.5, 1.2 Hz, 1H), 6.88 (dd, *J* = 7.5, 1.6 Hz, 1H), 5.20-5.19 (m, 1H), 5.02 (d, *J* = 1.1 Hz, 1H), 2.49 (t, *J* = 7.8 Hz, 2H), 2.42 (t, *J* = 7.1 Hz, 2H), 1.92 (tt, *J* = 7.8, 7.1 Hz, 2H), 1.39 (s, 9H).

^{13}C NMR (100 MHz, CDCl$_3$): δ 150.8, 147.1, 142.1, 131.2, 127.4, 127.2, 125.3, 119.6, 115.1, 38.7, 36.9, 32.4, 23.7, 17.1.

GCMS (EI): Calcd for $C_{16}H_{21}N$: 227.34. Found: 227.1.

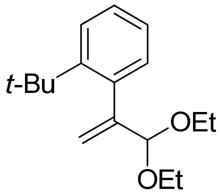


2-(*p*-*tert*-Butylphenyl)acrolein diethyl acetal. The reaction was set up with 2 mol% Pd(dba)$_2$, 4 mol% dppf and lithium carbonate (74 mg, 1.0 mmol) as base and the reaction finished after stirring at 80 °C for 34 hours. The product was purified by flash chromatography (hexane/ethyl acetate 25:1) as colorless oil (97 mg, 74%). The ratio of the desired regioisomer versus all other isomers in the crude product was determined to be 11:1 by GC. Some ethyl esters (<10%) were also isolated as byproducts. When the ligand dppf was replaced by dnpf, low conversion resulted. When urotropine was used as base, low conversion resulted.

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.48-7.46 (m, 2H), 7.35-7.33 (m, 2H), 5.55 (d, *J* = 1.4 Hz, 1H), 5.51 (s, 1H), 5.24 (s, 1H), 3.65 (dq, *J* = 9.4, 7.1 Hz, 2H), 3.55 (dq, *J* = 9.4, 7.1 Hz, 2H), 1.32 (s, 9H), 1.22 (t, *J* = 7.1 Hz, 6H).

^{13}C NMR (100 MHz, $CDCl_3$): δ 150.7, 144.6, 135.7, 126.5, 125.2, 115.1, 102.0, 61.5, 34.6, 31.4, 15.3.

GCMS (EI): Calcd for $C_{17}H_{26}O_2$: 262.39. Found: 262.1.



2-(*p-tert*-Butylphenyl)acrolein diethyl acetal. The reaction was set up with 5% Pd(dba)$_2$, 10% dppf and lithium carbonate (74 mg, 1.0 mmol) as base. The reaction mixture was stirred at 80 °C for 41 hours. The product was purified by flash chromatography (20:1 hexane/ ethyl acetate) as colorless oil (120 mg, 92%). The ratio of the desired regioisomer versus all other isomers in the crude product was determined to be 67:1 by GC. When urotropine was used as base, lower conversion resulted.

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.44 (dd, *J* = 8.1, 1.2 Hz, 1H), 7.22 (ddd, *J* = 7.6, 1.6 Hz, 1H), 7.12 (pseudotriplet of doublet, *J* = 7.6, 1.2 Hz, 1H), 7.00 (dd, *J* = 7.6, 1.6 Hz, 1H), 5.69-5.68 (m, 1H), 5.17 (d, *J* = 2.1 Hz, 1H), 4.98 (s, 1H), 3.75-3.67 (m, 2H), 3.54-3.47 (m, 2H), 1.39 (s, 9H), 1.22 (t, *J* = 7.1 Hz, 6H).

^{13}C NMR (100 MHz, CD_2Cl_2): δ 148.3, 148.1, 139.3, 132.6, 127.41, 127.35, 125.1, 117.0, 103.0, 61.8 (br s), 37.1, 32.6, 15.3.

GCMS (EI): Calcd for $C_{17}H_{26}O_2$: 262.39. Found: 262.1.

1.5.6 Mechanistic study

Synthesis of (dnpf)Pd(Ph)Br. In an argon-filled glove box, a 25-mL Schlenk tube containing a magnetic stir bar was charged with $Pd(dba)_2$ (115 mg, 0.20 mmol), dnpf (151 mg, 0.20 mmol) and dry toluene (10 mL). After stirring for 10 min at room temperature, phenyl bromide (3 equiv, 94 mg, 0.60 mmol) was added. The reaction was stirred at rt for 3 hours followed by stirring in an 80 ^{o}C oil bath for another 3 hours. The progress of the reaction was monitored by ^{31}P NMR spectroscopy. Then the solvent was removed in vacuo and the residue subjected to flash chromatography with DCM as eluent. The titled compound was obtained as yellow powder in 94% purity (84 mg, 41%). The complex was dissolved in hot ~1:8 DCM/toluene and the solution was allowed to cool down to rt. Slow evaporation of solvents over a few days at rt gave orange single crystals suitable for X-ray crystallographic analysis.

^{1}H NMR (400 MHz, $CDCl_3$): δ 9.85-9.76 (m, 3H), 9.57 (d, *J* = 8.0 Hz, 1H), 8.16 (pseudotriplet, *J* = 9.1 Hz, 2H), 8.05-8.00 (m, 2H), 7.95-7.89 (m, 3H), 7.84 (d, *J* = 8.1 Hz, 2H), 7.74-7.66 (m, 3H), 7.62 (pseudotriplet, *J* = 7.5 Hz, 1H), 7.46-7.32 (m, 5H), 7.27-7.21 (m, 1H), 7.13 (d, *J* = 8.6 Hz, 2H), 7.00-6.92 (m, 2H), 6.82-6.78 (m, 1H), 6.56-6.51 (m, 2H), 6.30 (pseudotriplet, *J* = 7.0 Hz, 1H), 5.95 (br s, 1H), 5.61 (br s, 1H), 4.57 (s, 1H), 4.41 (s, 1H), 4.15 (s, 2H), 3.97 (pseudosinglet, 4H).
^{13}C NMR (100 MHz, CD_2Cl_2): δ 154.3 (d, *J* = 125.7 Hz), 144.7 (d, *J* = 33.2 Hz), 143.9 (d, *J* = 30.5 Hz), 138.3 (br s), 135.2 (d, *J* = 3.6 Hz), 135.1 (d, *J* = 4.2 Hz), 134.5 (2 overlapping signals), 134.4, 134.2, 133.9 (d, *J* = 14.1 Hz), 133.7, 133.5 (d, *J* = 12.3 Hz), 133.0, 132.4, 131.0, 130.8, 129.9, 129.8, 129.7, 129.6, 129.5, 129.3, 129.1, 129.0, 128.9, 128.7, 128.6, 128.4, 127.2, 126.7, 126.4, 126.2, 126.1, 125.9 (2 overlapping signals), 125.6, 125.2 (d, *J* = 3.8 Hz), 125.0, 124.8, 124.7, 124.6, 122.0, 93.1 (dd, *J* = 44.2, 10.9 Hz), 86.7 (dd, *J* = 33.7, 2.2 Hz), 77.1 (d, *J* = 5.4 Hz), 76.1 (d, *J* = 11.0 Hz), 75.5 (d, *J* = 3.7 Hz), 74.9 (d, *J* = 10.2 Hz), 70.9 (d, *J* = 4.6 Hz), 70.5 (d, *J* = 6.3 Hz), 70.0 (d, *J* = 3.0 Hz), 69.7 (d, *J* = 4.3 Hz). Some doublets may have been recorded as singlets.

^{31}P NMR (162 MHz, $CDCl_3$): δ 28.7 (d, J = 28.1 Hz), 13.9 (d, J = 28.1 Hz)

ESI/MS: calcd for $C_{56}H_{41}FeP_2Pd$ [M-Br]: 937.11. Found: 936.92.

Anal. Calcd for $C_{56}H_{41}BrFeP_2Pd$: C, 66.29; H, 4.5.

Stoichiometric study of 1-octene insertion into (dnpf)Pd(Ph)Br in the presence of AgOTf. In an argon-filled glove box, a 4-mL vial containing a magnetic stir bar was charged with (dnpf)Pd(Ph)Br (20.0 mg, 0.020 mmol), dnpf (1 equiv, 15.1 mg, 0.020 mmol) and dry DMA (0.50 mL). After stirring at rt for 5 min, 1-octene (5 equiv, 11.2 mg, 0.10 mmol), 5 μL of dodecane (GC internal standard), AgOTf (1.2 equiv, 6.2 mg, 0.024 mmol) and urotropine (5 equiv, 14 mg, 0.10 mmol) were sequentially added and the vial was then capped and covered with aluminum foil. The reaction mixture was vigorously stirred at room temperature in the glove box. At intervals, an aliquot was removed and passed through a short plug of silica gel. The filtrate was subjected to GC analysis to determine yield and selectivity of the Heck products. The calibrated GC yields of the Heck product after 1, 5 and 24 hours were determined to be 61%, 64% and 68%, respectively. The selectivity of 2-phenyl-1-octene versus all other isomers was determined to be 10:1 and remained constant at different conversions. The isomers of Heck products were confirmed by GCMS.

CHAPTER TWO

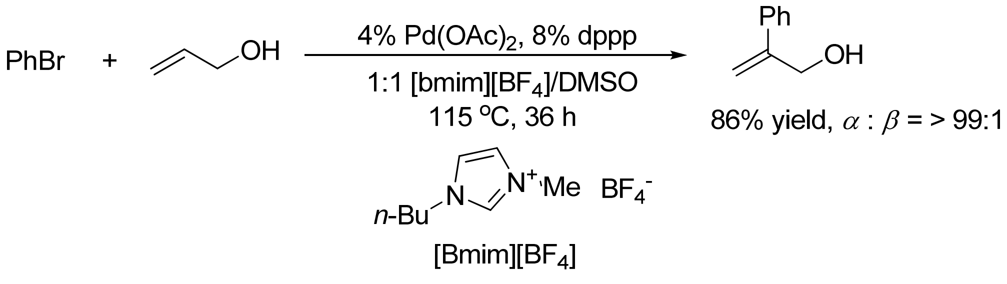
Heck Reaction of Terminal Olefins and Aryl Halides

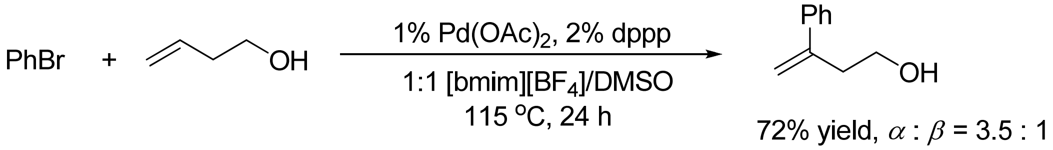
2.1 Introduction

Heck reaction is widely used in preparation of agrochemicals, drugs, fragrances and advanced materials.[1b,59] The Heck reaction of acrylates and styrenes introduce aryl groups selectively at terminal positions. Aliphatic olefins that lack electronic biases and directing groups gave a mixture of Heck isomers.[13,28a,30,60] Furthermore, double-bond migration was often seen in both starting material of aliphatic olefins and Heck products by the action of Pd-hydride species. This made selective Heck reaction of aliphatic olefins more difficult to achieve.

Previously, we have reported internal-selective Heck reaction of aliphatic olefins using a bulky ferrocenyl bisphosphine dnpf to impede the undesired terminal insertion (*Fig. 2.1*).[61] The reaction of ArOTf gave a key cationic arylpalladium species for olefin insertion. The method was a significant improvement of the Cabri's results.[17,19,39] We wondered whether it is possible to expand the scope of this transformation from rather expensive aryl triflates to readily available aryl halides.

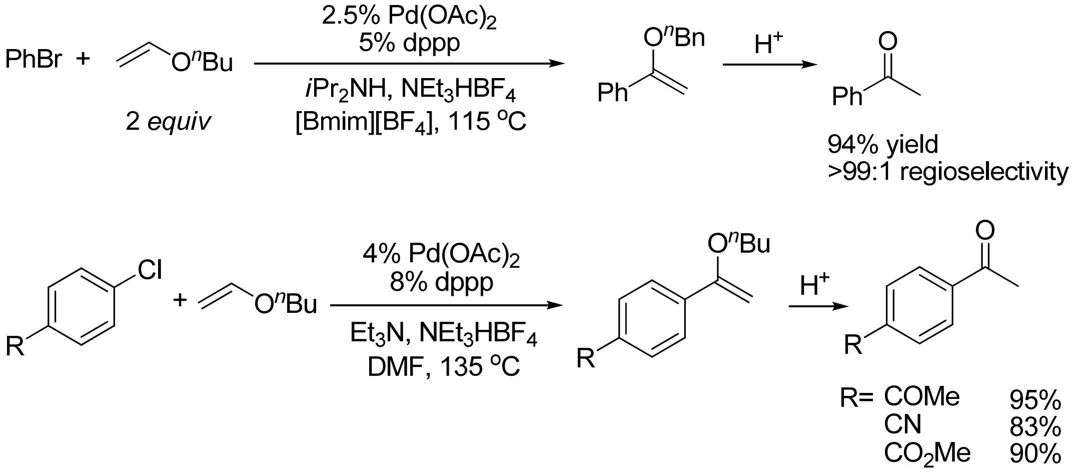
Previously, Xiao *et al.* reported regioselective Heck reaction of ArBr using allylic alcohol and other ω-hydroxy olefins. Ionic liquid was used to promote ionization of neutral aryl-palladium halides[22]. Around 4:1 regioselectivity was observed in most cases (*Scheme 2.1*).





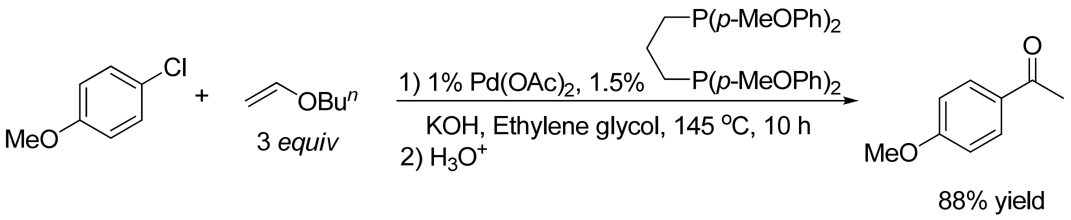
Scheme 2.1 *Arylation of unsaturated alcohols with aryl bromide in ionic liquid.*

Xiao *et al.* also reported that ammonium salt $Et_3N·HBF_4$ can promote halide dissociation from neutral Pd complexes in Heck reaction of vinyl ethers and vinyl amines with aryl bromides.[18] The solvent can be ionic liquid or DMF. The scope of electrophiles was limited to electron-deficient aryl chlorides (*Scheme 2.2*).



Scheme 2.2 *Proton donors accelerated α-selective arylation of electron-rich olefins.*

Recently, Xiao *et al* showed that ethylene glycol can help the ionization of chlorides from neutral complexes in Heck reaction between aryl halides and vinyl ethers or styrenes (*Scheme 2.3*).[19,62] Based on DFT calculations, they proposed that hydrogen bonding between ethylene glycol and the chloride helped halide dissociation from neutral aryl-palladium complexes.[19] A simple dissociative pathway was examined to produce a cationic aryl-palladium complex carrying a vacant site. No computational details on other possible pathways were reported.



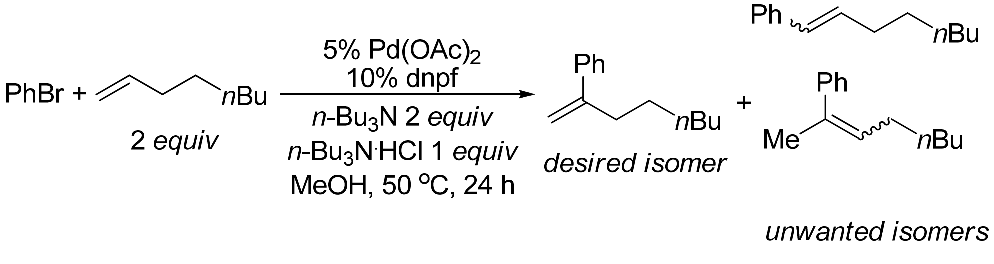
***Scheme 2.3** Ethylene glycol as hydrogen-bond donor in arylation of olefins with aryl chlorides.*

Historically, methanol solvent was used to promote halide dissociation in Schrock-Osborn's preparation of cationic rhodium and iridium catalysts for olefin hydrogenation.[63] It was also used to prepare cationic complexes of ruthenium and osmium.[64]

2.2 Results and discussion

Initially, we tried to use silver salts as halide abstractors in a model reaction of 1-naphthyl bromide and 1-octene. However, almost no Heck product was obtained in DMA with silver triflate. After many experiments, we were only able to obtain <40% yield of the desired product in dichloroethane solvent. With $Pd(OAc)_2$ and dppf as catalyst, ~5:1 selectivity was obtained in the best scenario. Phenyl bromide also did not couple with 1-octene in DMA with silver salts. Less than 5% of Heck products were produced with poor 2:1 selectivity using dnpf ligand and methanol solvent. The failure of silver salts may be attributed to the competitive binding of silver salts to phosphine ligands.

After screening various conditions for phenyl bromide and 1-octene, we found that a combination of palladium acetate and dnpf formed the most active and selective catalyst in methanol with n-$Bu_3N{\cdot}HCl$ additive. The desired Heck isomer was obtained in 83% yield and 11:1 selectivity (*Table 2.1*). The selectivity refers to the ratio of the amount of desired product to the sum of all other isomers. After catalytic hydrogenation of the crude mixture, the selectivity was determined to be 16:1 (*Scheme 2.4*). Thus, a very small amount of desired isomer underwent *in situ* olefin isomerization under catalytic conditions.



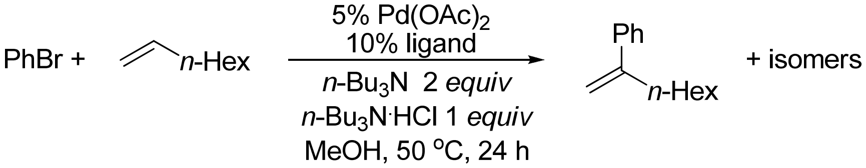
desired isomer : all other isomers = 11:1
intrinsic regioselectivity $\alpha : \beta$ = 16:1

***Scheme 2.4** The ratio of α-phenylation of 1-octene to β-phenylation of 1-octene.*

2.2.1 Effects of ligands, palladium, solvents and additives

Bisphosphine ligand dnpf formed the most selective and active ligand in our model reaction (*Table 2.1*). Bulky tri-*tert*-butylphosphine salt gave little desired isomer. Another ferrocenyl bisphosphine dppf gave only 14% of desired isomer. Dippf, dppe, dppp, dppb, Xantphos and rac-BINAP were almost inactive in the model reaction.

Table 2.1 Effect of ligands.[a]

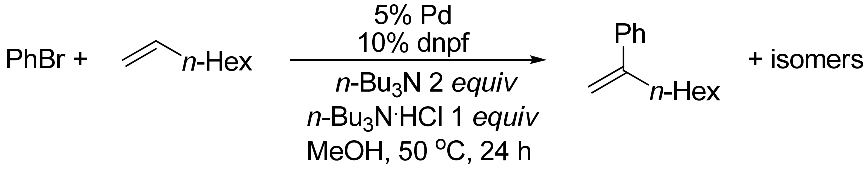


Entry	Ligand	PhBr Conv[b] (%)	Desired isomer[b] (%)	Isomers[b] (%)	Selectivity[c]
1	dppe	19	0	0	-
2	dppp	8	0	0	-
3	dppb	5	0	0	-
4	Xantphos	12	0	0	-
5	*rac*-BINAP	12	2	0	-
6	DPEphos	86	5	47	0.1
7	dppf	39	14	2	7
8	dippf	17	2	1	2
9	**dnpf**	**99**	**83**	**8**	**11**
10	d(2-naphthyl)pf	27	5	7	0.8

[a] Reaction condition: PhBr(0.10 mmol, 1 *equiv*), 1-octene (0.20 mmol, 2 *equiv*), MeOH (0.5 mL). [b] Conversion and yield were calculated by comparing starting material and product peak intergration to integration of internal standard using GC analysis. [c] Selectivity refers to the ratio of desired isomer to all the other isomers.

When $Pd(OAc)_2$ was replaced by $Pd(dba)_2$ or $Pd_2(dba)_3$, <10% converstion of PhBr was observed and no Heck product was formed (*Table 2.2*). The dba might bind strongly to the active $(dnpf)Pd^0$ catalyst under our conditions and thus reduce its effective concentration.[65] $Pd(acac)_2$ almost give similar results compared with $Pd(OAc)_2$ while $Pd(CF_3CO_2)_2$ showed lower reactivity.

Table 2.2 Effect of palladium source.[a]

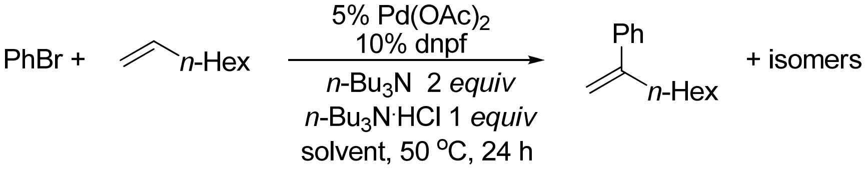


Entry	Pd source	PhBr Conv[b] (%)	Desired isomer[b] (%)	Other isomers[b] (%)	Selectivity[c]
1	$Pd(OAc)_2$	99	83	8	11
2	$Pd(acac)_2$	98	77	7	11
3	$Pd(CF_3CO_2)_2$	74	63	5	12
4	$Pd(dba)_2$	7	0	0	-
5	$Pd_2(dba)_3$	8	0	0	-

[a] Reaction condition: PhBr(0.10 mmol, 1 *equiv*), 1-octene (0.20 mmol, 2 *equiv*), MeOH (0.5 mL). [b] Conversion and yield were calculated by comparing starting material and product peak intergration to integration of internal standard using GC analysis. [c] Selectivity refers to the ratio of desired isomer to all the other isomers.

Notably, the desired Heck process could only proceed in methanol solvent. In other alcoholic solvents, the catalytic activity dropped quickly as the polarity of alcohols decreased. (*Table 2.3*) For example, no desired Heck product was even found in *tert*-butanol. Other common solvents did not give Heck product at all, including acetonitrile, DMA, DMF, NMP, DMSO, acetone, 1,4-dioxane and toluene (*Table 2.3*).

Table 2.3 Effect of solvents on model reaction.[a]

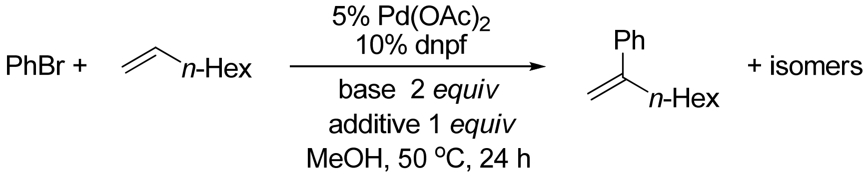


Entry	Solvent	PhBr Conv[b] (%)	Desired isomer[b] (%)	Selectivity[c]
1	MeOH	99	83	11
2	EtOH	55	38	10
3	*n*BuOH	45	32	11
4	*i*PrOH	20	6	10
5	*t*BuOH	15	0	-
6	Ethylene glycol	39	13	4
7	MeCN	14	0	-
8	DMF	13	0	-
9	DMA	12	0	-
10	NMP	10	0	-
11	DMPU	16	0	-
12	DMSO	16	0	-
13	Toluene	10	0	-
14	1,4-Dioxane	10	0	-

[a] Reaction condition: PhBr(0.10 mmol, 1 *equiv*), 1-octene (0.20 mmol, 2 *equiv*), MeOH (0.5 mL). [b]Conversion and yield were calculated by comparing starting material and product peak intergration to integration of internal standard using GC analysis. [c]Selectivity refers to the ratio of desired isomer to all the other isomers.

Acidic additive nBu$_3$N·HCl was also important for this reaction. Without it, the model reaction with phenyl bromide proceeded at 80 °C, but gave moderate yield and selectivity. In the presence of 1 equivalent of n-Bu$_3$N·HCl, the reaction temperature could be lowered down to 50 °C and gave 83% yield and 11:1 selectivity after 24 hours (*Table 2.4, entry 2*). n-Bu$_3$N·HOTf had little effect (*entry 3*). When n-Bu$_4$NCl or n-Bu$_4$NBr was added as additive, the yield was only 60%; they probably increased ionic strength of the reaction medium (*entries 4 and 5*). Surprisingly, the use of n-Et$_3$N·HCl together with n-Et$_3$N was not effective (*entry 6*). The use of a Lewis acid ZnCl$_2$ did not benefit the model reaction (*entry 7*).

Table 2.4 Effect of additives on the model Heck reaction. The conversion of PhBr, the yield of the desired isomer and internal selectivity were determined by GC.



Entry	Additive	PhBr Conv[b] (%)	Desired isomer[b] (%)	Selectivity[c]
1	None	64	41	5
2	**nBu$_3$N·HCl**	**99**	**83**	**11**
3	nBu$_3$N·HOTf	60	45	6
4	nBu$_4$NCl	80	65	7
5	nBu$_4$NBr	71	57	11
6	Et$_3$N·HCl, Et$_3$N	16	13	5
7	ZnCl$_2$	61	44	5

[a] Reaction condition: PhBr(0.10 mmol, 1 *equiv*), 1-octene (0.20 mmol, 2 *equiv*), MeOH (0.5 mL). [b] Conversion and yield were calculated by comparing starting material and product peak intergration to integration of internal standard using GC analysis. [c] Selectivity refers to the ratio of desired isomer to all the other isomers.

2.2.2 Substrates of aliphatic olefins and aryl halides

With the established conditions in hand, we examined various terminal olefins in reactions with *p-tert*-butylphenyl bromide (*Fig. 2.1*). Polar groups such as nitriles, esters and phthalimides can be present. Even unprotected alcohols did not advertently affect the desired Heck pathway.[17,19,39] While allylbenzene was known to undergo palladium hydride-catalyzed olefin isomerisation, it coupled well under our conditions.[40] Selective insertion was also seen with vinylcyclohexane at the internal position.

Allylic alcohol did not couple to give the desired product. N-Tosyl allylamine did not react and significant migration of double bond of starting material was observed. Bulky 3,3-dimethyl-1-butene reacted with *p-tert*-butylphenylbromide to give linear product with selectivity of ~15:1.

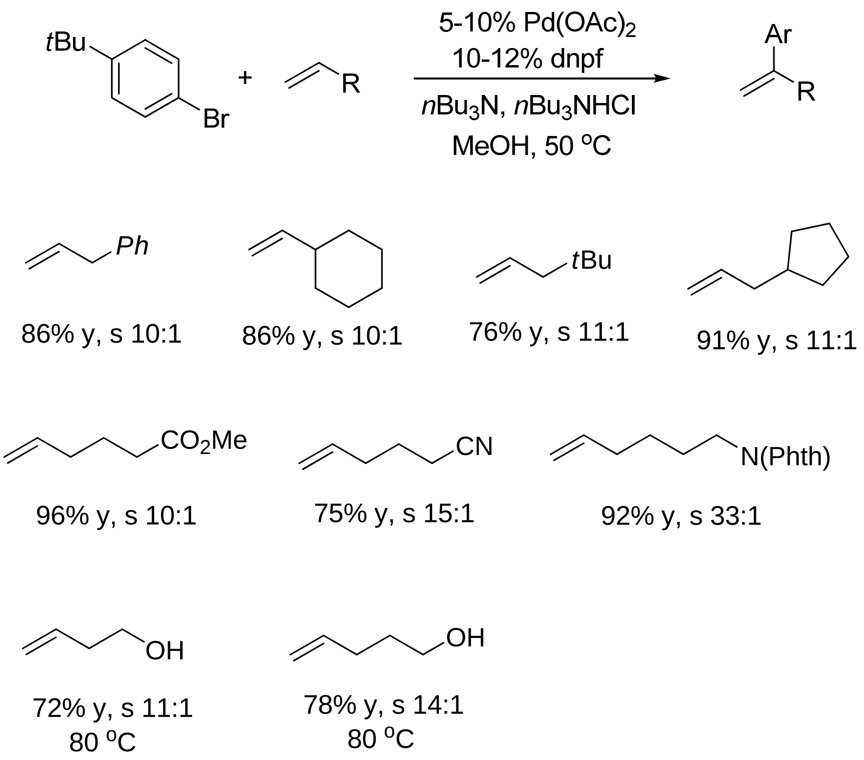


Figure 2.1 Examples of aliphatic olefins.

Aryl bromides bearing various *para*- and *meta*-substituents can couple efficiently (*Fig. 2.2*). Heteroaryl bromides derived from benzothiazole, indole and quinoline also coupled well. One alkenyl bromide, 4-bromo-1,2-dihydro-naphthalene produced a 1,3-diene in good selectivity. However, for aryl bromides bearing *ortho*-substituents, such as *o*-tolyl bromide and 1-naphthyl bromide, only moderate yields were obtained due to competing reduction of aryl bromides to arenes. Alkylamines were known to donate hydrides to arylpalladium species and led to reduction.[37a] The slow olefin insertion of the hindered aryl group on Pd centers may be the origin of the problem.

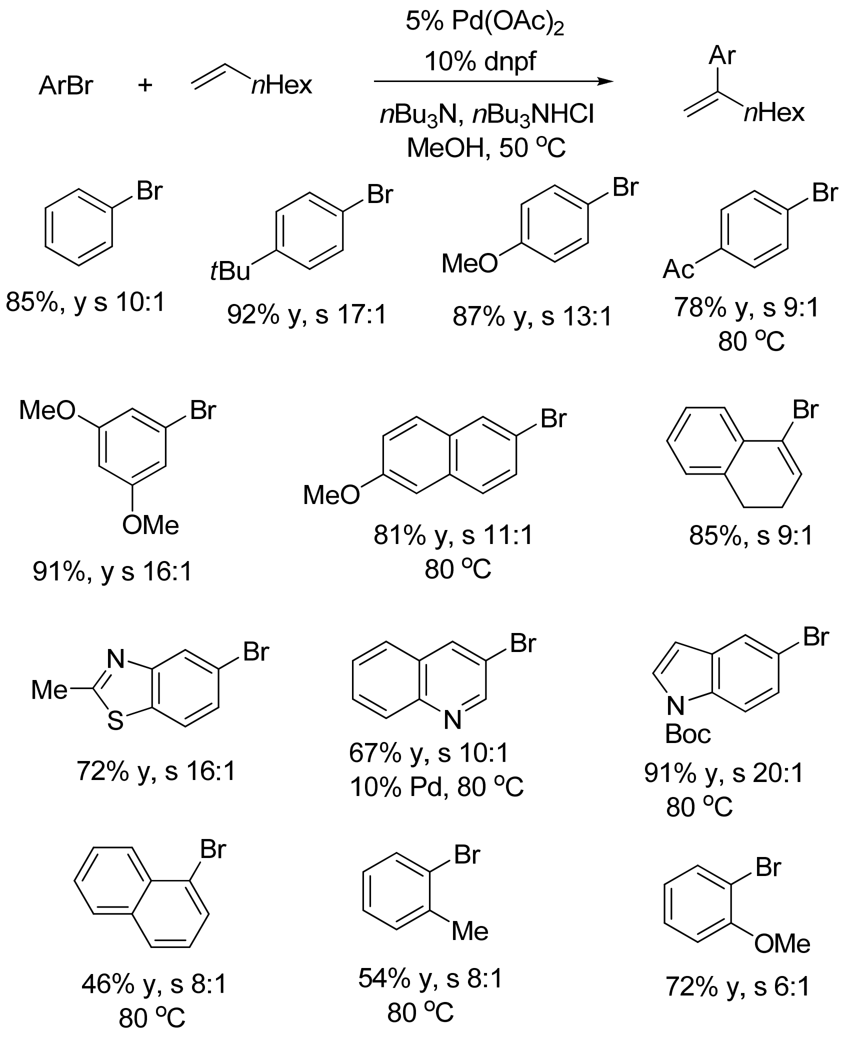


Figure 2.2 Examples of aryl and vinyl bromides.

In a cyclic amine DABCO, its hydrogens α to nitrogens are slow to eliminate because it would give a bridgehead iminium specie according to Bredt's rule.[66] Indeed, when we replaced *n*-tributylamine with DABCO, the reduction was minimized to <5% (*Fig. 2.3*). In the modified procedure, the *n*-Bu$_3$N·HCl additive was unnecessary. Furthermore, we found in some cases the less hindered dppf performed better than dnpf.

The new procedure can be applied to electron-poor aryl chlorides (*Figure 2.3*). Electron-neutral and electron-rich aryl chlorides did not react due to slow oxidative addition. Aryl iodides, such as phenyl iodide and 1-iodonaphthalene, gave poor internal selectivity (3:1).

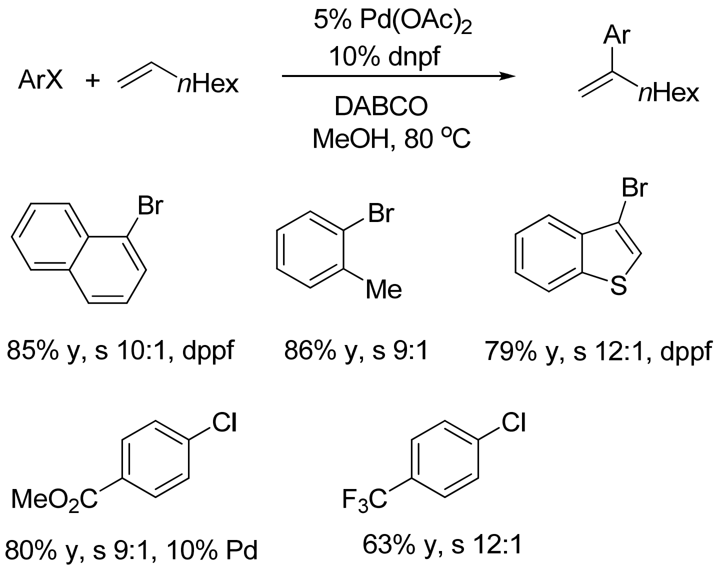
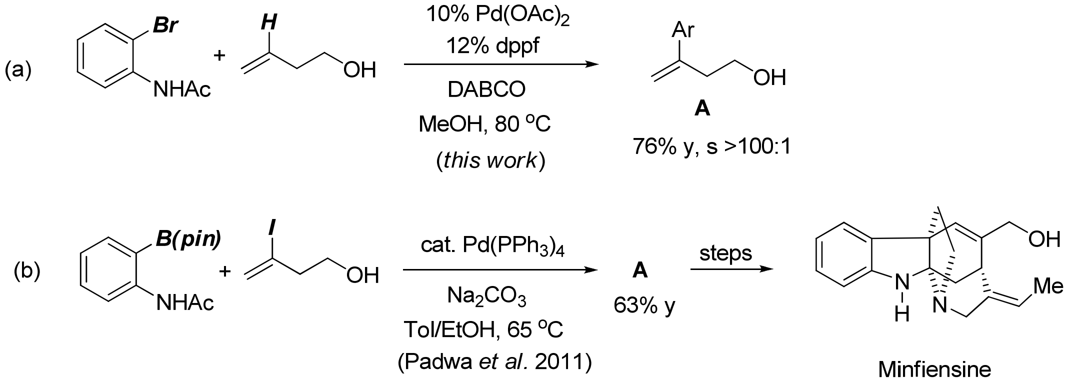


Figure 2.3 Examples of aryl bromides and chlorides (no acidic additive was used).

As an example of application, we used the new method to access arylalkene **A** directly from homoallylic alcohol (*Scheme 2.5*). Dppf afforded better yield than dnpf. Alkene **A** was an early-stage intermediate in Padwa's total synthesis of minfiensine. It was previously made via Suzuki coupling of a functionalized arylboron reagent and an alkenyl iodide.[35b]



Scheme 2.5 One example of synthetic application.

2.2.3 Unsuccessful substrates

Some aryl bromides did not give satisfactory results in reactions with 1-octene under our catalytic reactions (*Figure 2.4*).

a) *p*-NMe_2-phenyl bromide generated a mixture of isomers.

b) Some electron-deficient aryl bromides showed poor reactivity and gave only ~3:1 selectivity. This can be attributed to slow halide dissociation on Pd centers because of electronic effect.

c) Some electron-deficient *ortho*-substituted aryl bromides showed poor reactivity.

d) Hindered aryl bromides such as bromomesitylene showed very low reactivity.

e) 3-Bromo-*N*-methylindole only produced reduction product of *N*-methylindole. 5-Bromoisoquinoline produced little Heck product.

f) A vinyl bromide, α-bromostyrene, did not generate the desired Heck products under our catalytic reactions.

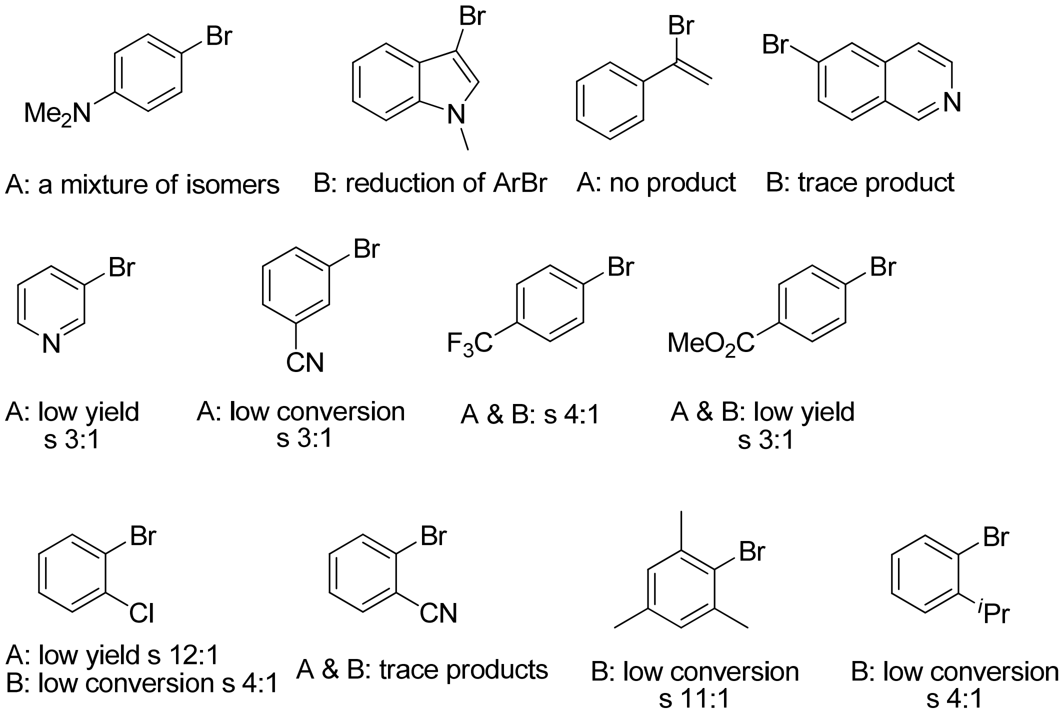
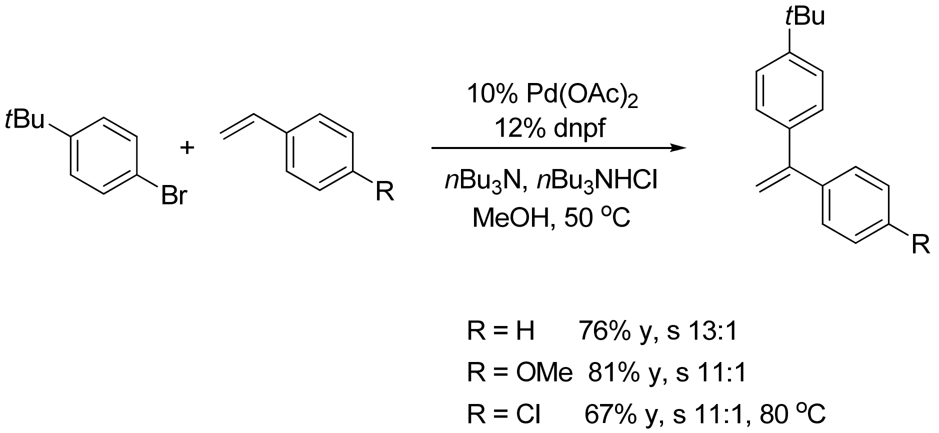


Figure 2.4 *Unsuccessful substrates. Condition A: condition I with dnpf, n-*Bu_3N *and* $^{n}Bu_3NHCl$*; Condition B: conditon II with dppf or dnpf, DABCO.*

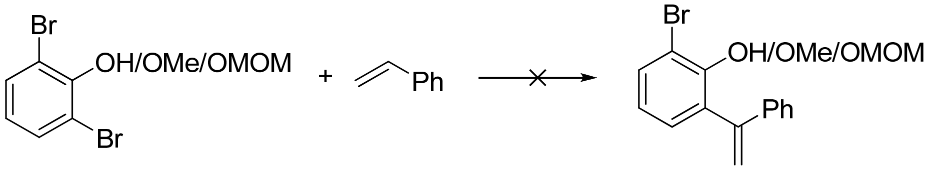
2.2.4 Internal selective arylation of styrenes

1,1–Diarylethylenes are core structures in anticancer agents bexarotene[67] and isocombretastatins A.[68] Under most Heck conditions, stilbenes were major products and selective α-arylation of styrene was difficult to achieve.[21a,69] We previously reported internal-selective arylation of styrenes with aryl triflates.[45] The new Heck procedure can be applied to styrenes to give 1,1'-diarylethenes (*Scheme 2.6*). The minor isomers of stilbenes can be easily removed by flash chromatography.



Scheme 2.6 *Examples of Heck reaction of aromatic olefins.*

In the reaction of 1,3-dibromophenol with styrene, no reaction was observed. Protecting the hydroxy group with methoxylmethyl or methyl group, did not help the reaction either (*Scheme 2.7*).



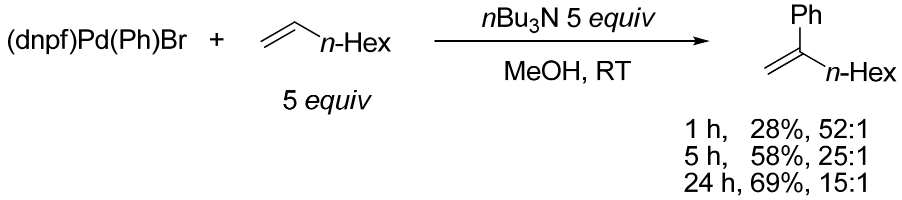
Scheme 2.7 *Unsuccessful reaction with styrene.*

2.3 Mechanistic study

2.3.1 Stoichiometric reaction of (dnpf)Pd(Ph)Br complex

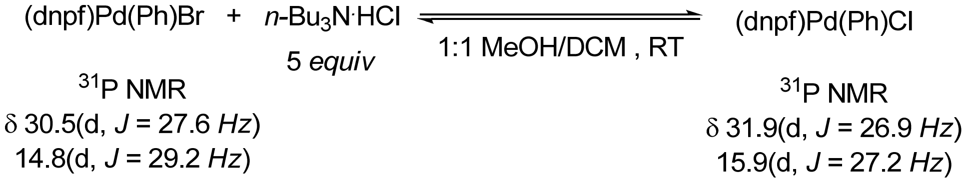
Experimentally, when we treated (dnpf)Pd(phenyl)(Br) with 5 equiv of 1-octene *in methanol*, the expected Heck isomer was produced in 69% yield and 15:1 selectivity after 24 hours at room temperature (*Scheme 2.8*). The internal selectivity was exceptionally high in initial hours, which was characteristic of olefin insertion into the cationic complex $[(dnpf)Pd(Ph)]^+$ species. In comparison, no Heck product was detected if the methanol solvent was replaced by 1,4-dioxane or DMA. Thus, we gained indirect evidence that methanol solvent helped ionization of bromide from the neutral aryl palladium complex to produce the key cationic $[(dnpf)Pd(Ph)]^+$ species.

We also noticed that the selectivity in methanol dropped progressively over time, which was consistent with in situ product isomerization under catalytic conditions. The inclusion of the $n\text{Bu}_3\text{N}\cdot\text{HCl}$ additive had little influence on the reaction outcome. The neutral palladium bromide complex was poorly soluble in methanol, which interfered with the kinetic studies.



Scheme 2.8 *Stoichiometric reactions of olefin insertion. Both the yield and selectivity of the desired isomer were determined by GC.*

We tried to detect the cationic aryl palladium species in a solution of (dnpf)Pd(Ph)(Br) in 1:1 MeOH/DCM by ^{31}P NMR spectroscopy, but to no avail. Only the neutral complex was detected at room temperature. The neutral complex was barely soluble in MeOH alone. When $n\text{Bu}_3\text{N}\cdot\text{HCl}$ (5 *equiv*) was included, (dnpf)Pd(Ph)(Cl) was detected. Its ratio to the neutral bromide complex was 2:1 after 2 hours at room temperature (*Scheme 2.9*).

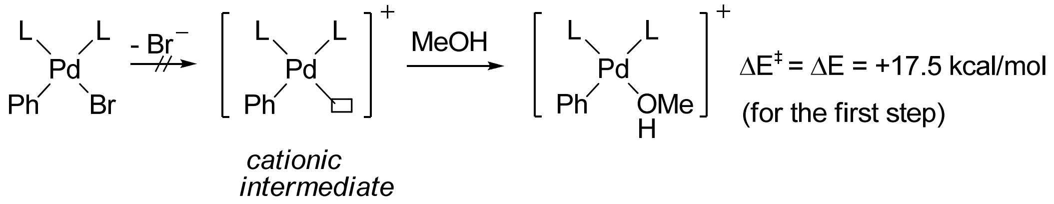


Scheme 2.9 *Anions exchange in mixture solvent of MeOH and DCM.*

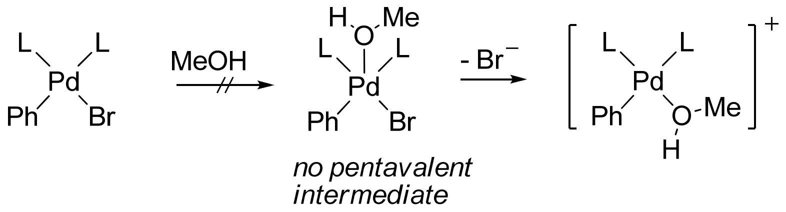
2.3.2 DFT study of hydrogen-bonding-assisted concerted substitution

DFT calculations were performed by Prof. Hajime Hirao in collaboration, on the step of halide ionization from (dnpf)Pd(phenyl)(Br). We found that both methanol and the Me_3NH^+ acted together to lower the activation barrier of halide ionization and to shift the equilibrium towards halide ionization (*Figure 2.5*). No significant effect of the hydrogen bonding was seen in the oxidative addition of (dnpf)Pd^0 and ArBr, thus it was not considered herein.

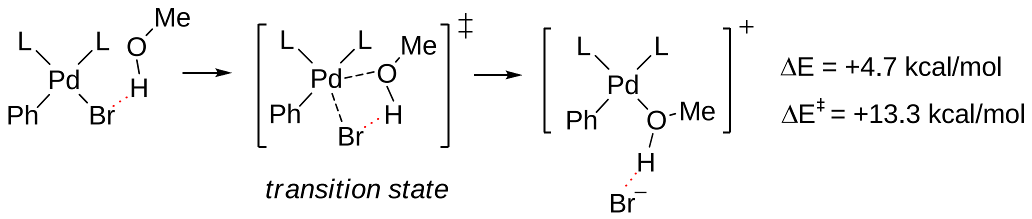
(a) Dissociative substitution



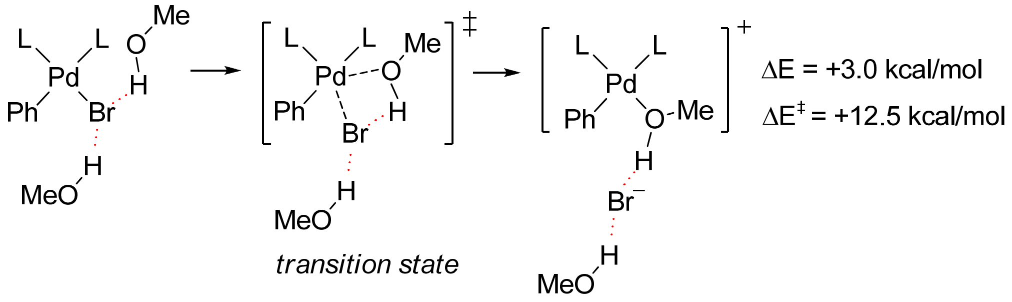
(b) Associative substitution



(c) Hydrogen-bonding-assisted substitution aided by one MeOH



(d) Hydrogen-bonding-assisted substitution aided by two MeOHs



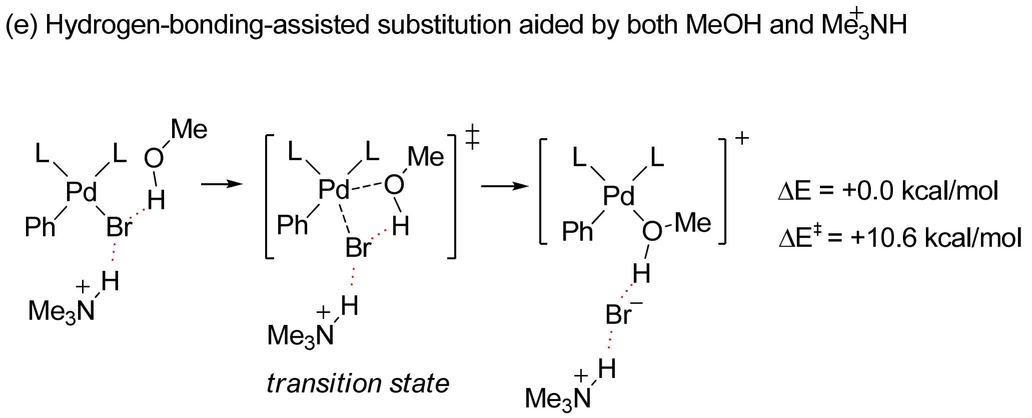

(e) Hydrogen-bonding-assisted substitution aided by both MeOH and $Me_3\overset{+}{N}H$

Figure 2.5 *Possible pathways for halide ionization in methanol. The B3LYP DFT functional was used in conjunction with the Lanl2dz ECP basis set for Fe and Pd. The solvent effect in methanol was taken into account by IEFPCM. The supporting ligand (L and L) was dnpf.*

When we modeled a simple *dissociative* pathway (a), no energy minimum could be located for the cationic arylpalladium species as the Pd-Br distance was increased. The fully ionized arylpalladium species was about 17 kcal/mol higher in energy than the neutral species. In a simple *associative* pathway (b), no stable intermediate could be located for the putative pentacoordinate species, either.[70] Instead, the pentacoordinate species was found to be an energy maximum.

Instead, a *new* pathway (c) was found to be energetically more favorable, which we coined "*hydrogen-bonding-assisted concerted substitution*". In the ground state, methanol does not coordinate to the metal center. The "pentavalent" species with methanol approaching the Pd center was found to be *a transition state instead of an intermediate*. Importantly, in the entire course of ligand displacement, the bromide remained hydrogen-bonded to the incoming methanol. Consequently, the barrier was reduced to 13 kcal/mol and the whole process became endergonic only by 4 kcal/mol.

Furthermore, when two methanol molecules acted in concert via double hydrogen bonding with the bromide, the barrier was further reduced and the substitution process became less endergonic (*Figure. 2.5d*). When an analogous ionization pathway was calculated by replacing two methanol molecules with 1,4-dioxane, no stable species can be found that involved new coordination of dioxane oxygen to the Pd center and hydrogen bonding between α-CH bonds of dioxane and the bromide.

Calculations using one explicit MeOH molecule and one Me_3NH cation as dual hydrogen bond donors further reduced the barrier to 11 kcal/mol. The whole process became almost thermoneutral (*Figure. 2.5 e*).

2.4 Summary

In conclusion, we realized herein a quite general method for regioselective Heck reaction of aliphatic alkenes at internal sites, using *aryl halides*. In comparison, existing methods used to provide a mixture of isomers. Based on DFT studies, a new pathway for *concerted* halide displacement by methanol was identified, which we coined "hydrogen-bonding-assisted concerted substitution". Mechanistically, it was different from common associative or dissociative substitutions on transition metal complexes. In the concerted pathway, the transition state was stabilized by internal hydrogen bonding between the incoming methanol and departing bromide ion. We have gained indirect evidence to support the special role played by methanol solution in promoting halide dissociation in stoichiometric olefin insertion.

2.5 Experimental section

2.5.1. General

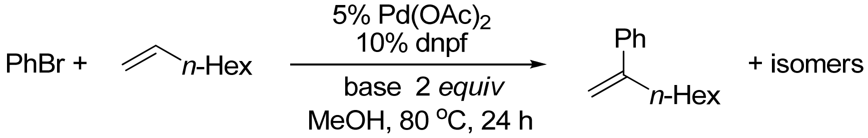
^{1}H NMR spectra were acquired on Bruker 400 MHz spectrometers and chemical shifts were recorded relative to tetramethylsilane (δ 0.00) or residual protiated solvent ($CDCl_3$: δ 7.26). Multiplicities were given as: s (singlet), d (doublet), t (triplet), q (quartet) and m (multiplet). The number of protons (n) for a given resonance was indicated by nH. Coupling constants were reported as a *J* value in *Hz*. ^{13}C NMR spectra were obtained at 100 MHz on 400 MHz instruments and chemical shifts were recorded relative to solvent resonance ($CDCl_3$: δ 77.16). Proof of purity of new compounds was demonstrated with copies of ^{1}H and ^{13}C spectra. Flash chromatography was performed using Merck silica gel 60 (0.040-0.063 mm). Gas chromatography (GC) analysis was performed on a Shimadzu GC-2010 instrument with Agilent J & W GC column DB-5MS-UI. GC/MS analysis was conducted on a Thermo Scientific DSQ II single quadrupole GC/MS instrument with Agilent J & W GC column DB-5MS-UI.

1,1′-Bis[di(1-naphthyl)phosphino]ferrocene and 1,1′-bis[di(2-naphthyl)phosphino]-ferrocene were prepared according to our previous reported procedures.[61] *N*-(2-Bromophenyl)acetamide[71], *N*-(5-hexenyl)phthalimide[61], *tert*-butyl 5-bromo-1*H*-indole-1-carboxylate[72] and 1-bromo-3,4-dihydronaphthalene[73] was prepared by using reported procedures. Methanol was distilled over sodium under argon atmosphere and stored in a Schlenk tube in an argon-filled glove box.

2.5.2. Condition optimization for Heck reaction

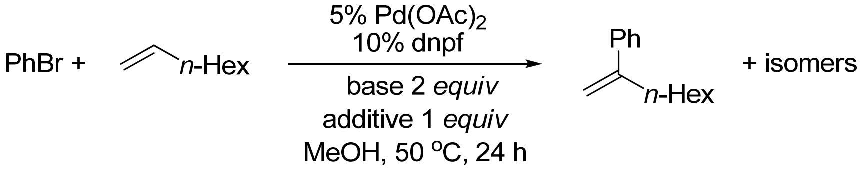
Typical procedure using 0.1 mmol of PhBr: In an argon-filled glove box, a dry 4-mL vial containing a magnetic stir bar was charged with $Pd(OAc)_2$ (5 mol%, 1.1 mg, 0.005 mmol), dnpf (10 mol%, 7.5 mg, 0.010 mmol) and 0.5 mL of dry Methanol. After stirring at room temperature for 10 minutes, phenyl bromide (0.1 mmol, 15.7 mg), 1-octene (2 equiv, 0.20 mmol, 22.4 mg) and tri-*n*-butyl amine (2 equiv, 0.20 mmol, 37 mg) were added sequentially via syringe. To the reaction mixture was added tri-*n*-butylamine hydrochloride (1 equiv, 0.10 mmol, 22.2 mg) at last. The vial was capped tightly and the mixture was heated with vigorous stirring in aluminum heating block maintained at 50 ^{o}C. After stirring for 24 hours, the reaction mixture was cooled to room temperature and 1-dodecane was added (10 μl). The reaction mixture was diluted with dichloromethane to give a homogeneous solution. Aliquots were taken and passed through a short plug of silica gel with diethyl ether washings. The filtrate was subjected to GC analysis to determine the conversion of aryl bromide, yield and selectivity of the Heck products. The isomers of the products were identified by GCMS. *^{1}H NMR spectroscopy was unsuitable to determine the amount of minor isomers due to low signal intensity and overlap of signals on the ^{1}H NMR spectra.*

Table 2.5 Effect of base without using acidic additives.



Entry	Base	Conv (%)	Desired isomer (%)	Selectivity
1	NaOAc	7	1	0.2
2	Li_2CO_3	67	36	2
3	K_3PO_4	100	6	0.3
4	Et_3N	43	20	2
5	DIPEA	61	38	3
6	Cy_2NMe	96	70	4
7	Urotropine	37	24	2.5
8	2,6-Lutidine	8	4	1
9	Proton sponge	91	61	3
10	DBU	40	12	2
11	DABCO 1.2 *equiv*	17	12	2
12	DABCO	24	16	3
13	nBu$_3$N	99	60	4

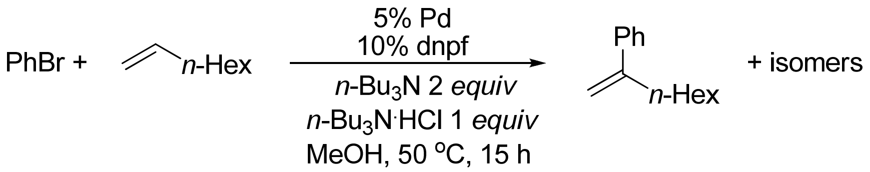
Table 2.6 Effect of base together with acidic additives.



Entry	Base + Additive	Conv (%)	Desired isomer (%)	Selectivity
1	nBu$_3$N 2 *equiv*	64	41	5
2	nBu$_3$N 2 *equiv* nBu$_3$N·HCl 0.2 *equiv*	65	48	7
3	nBu$_3$N 2 *equiv* nBu$_3$N·HCl 0.5 *equiv*	80	63	10
5	nBu$_3$N 2 *equiv* nBu$_3$N·HCl 1 *equiv*	99	83	11
6	nBu$_3$N 2 *equiv* nBu$_3$N·HOTf 1 *equiv*	60	45	6
7	nBu$_3$N 2 *equiv* nBu$_3$N·HOTs 1 *equiv*	59	30	3.5
8	nBu$_3$N 2 *equiv* nBu$_4$NCl 1 *equiv*	80	65	7

9	*n*Bu$_3$N 2 *equiv* *n*Bu$_4$NBr 1 *equiv*	71	57	11
10	*n*Bu$_3$N 2 *equiv* *n*Bu$_4$NOAc 1 *equiv*	57	39	6
11	Et$_3$N 2 equiv Et$_3$N·HCl 1 *equiv*	16	13	5
12	DIPEA 2 *equiv* DIPEA·HOTf 1 *equiv*	20	13	2
13	*n*Bu$_3$N 2 *equiv* ZnCl$_2$ 1 *equiv*	61	44	5
14	*n*Bu$_3$N 2 *equiv* Zn(OTf)$_2$ 1 *equiv*	36	13	2
15	*n*Bu$_3$N 2 *equiv* Sc(OTf)$_3$ 1 *equiv*	40	14	2
16	DABCO 1.2 *equiv*	8	8	14

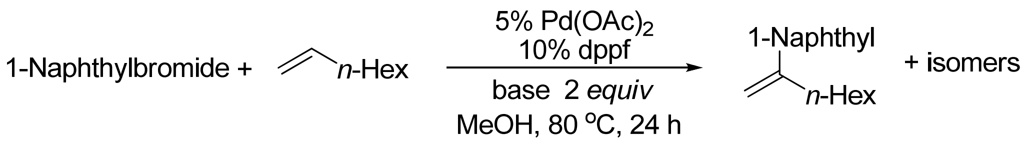
Table 2.7 Amount of the olefin and catalyst.



Entry	1-Octene	Conversion of PhBr (%)	Desired product (%)	Isomers (%)	Selectivity
1	1.2 *equiv*	47	25	6	4
2	1.5 *equiv*	56	34	6	5
3	2 *equiv*	86	70	6	11
4[a]	2 *equiv*	53	40	4	10

[a] Catalyst: 2% of Pd(OAc)$_2$ and 4% of dnpf.

Table 2.8 Effect of bases in Heck reaction of 1-naphthyl bromide using 0.1 mmol of ArBr.



Entry	Base	Conv (%)	Desired isomer (%)	Selectivity	ArH (%)
1	*n*Bu$_3$N 2 *equiv*	100	61	10	21
2	*n*Bu$_3$N 2 *equiv* *n*Bu$_3$N·HCl 1 *equiv*	100	59	11	27
3[a]	*n*Bu$_3$N 2 *equiv*	100	48	8	38

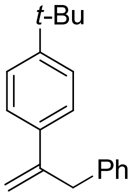
	nBu$_3$N·HCl 1 *equiv*				
4	DABCO 2 *equiv*	100	88	10	3
5[a]	DABCO 2 *equiv*	63	52	6	2
6	DABCO *1.2 equiv*	100	83	9	5
7	DABCO 2 *equiv* DABCO·HCl 1 *equiv*	95	84	9	2
8	Cy$_2$NMe 2 *equiv*	99	78	9	13
9	DIPEA 2 *equiv*	100	53	9	32
10	Et$_3$N 2 *equiv*	100	79	10	11
11	2,6-Lutidine 2 *equiv*	41	32	8	1
12	Proton sponge 2 *equiv*	100	88	10	2
13	Li$_2$CO$_3$ 2 *equiv*	100	81	9	3
14	Urotropine 2 *equiv*	87	67	9	3

[a] Using Dnpf as supporting ligand.

2.5.3. Isolation of Heck products

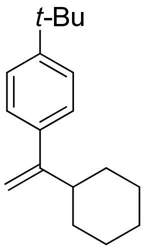
Typical procedure I using tri-*n*-butylamine hydrochloride additive: In an argon-filled glove box, to a dry 10-mL Schlenk tube containing a magnetic stir bar was charged Pd(OAc)$_2$ (5.6 mg, 0.025 mmol), dnpf (37.7 mg, 0.05 mmol) and 2.5 mL of dry methanol. After stirring at room temperature for 10 minutes, aryl bromide (0.5 mmol), terminal olefin (2 equiv, 1.0 mmol), tri-*n*-butylamine (2 equiv, 1.0 mmol, 185 mg) and tri-*n*-butylamine hydrochloride (1 equiv, 0.5 mmol, 111 mg) were added sequentially. The Schlenk tube was capped tightly and the mixture was heated with vigorous stirring in a 50 ^{o}C oil bath. After the aryl bromide was fully consumed (monitored by GC), the reaction mixture was cooled to room temperature and the solvent was removed on a rotary evaporator under reduced pressure. The resulting residue was purified by silica gel flash chromatography. The isomers in a reaction mixture were identified by GCMS. In the crude product, the ratio of the desired isomer versus all other isomers was determined by GC unless stated otherwise. The minor isomers can vary from 1 to 8 depending on the substrates, catalysts and conditions (detected by GC and GCMS). The typical procedure was used for all the isolation on 0.50 mmol scales (aryl bromides), unless stated otherwise. *Note: ^{1}H NMR spectroscopy was unsuitable to determine* *the amount of minor isomers due to low signal intensity and overlap of signals on ^{1}H NMR spectra.*

Typical procedure II without using tri-*n*-butylamine hydrochloride additive: In an argon-filled glove box, to a dry 10-mL Schlenk tube containing a magnetic stir bar was charged $Pd(OAc)_2$ (5.6 mg, 0.025 mmol), dnpf (37.7 mg, 0.05 mmol) and 2.5 mL of dry methanol. After stirring at room temperature for 10 minutes, aryl bromide (0.50 mmol), aliphatic olefin (2 equiv, 1.0 mmol) and DABCO (1.2 equiv, 0.6 mmol, 67 mg) were added sequentially. The Schlenk tube was capped tightly and the mixture was heated with vigorous stirring in an 80 ^{o}C oil bath. After the aryl bromide was fully consumed (monitored by GC), the reaction mixture was worked up as described above.



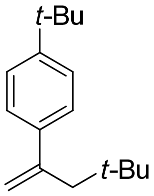
***p-tert*-Butyl-1-benzylstyrene [1393539-25-7].** The reaction was set up following typical procedure I with 10% $Pd(OAc)_2$, 12% dnpf and 3 equiv of allylbenzene and stirred at 50 ^{o}C for 2 days. The product was purified by flash chromatography (hexane) as colorless oil (107 mg, 86%). The ratio of the desired isomer versus all other isomers in the crude product was determined to be 10:1 by GC. 10:1 after purification.

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.41-7.36 (m, 2H), 7.32-7.16 (m, 7H), 5.51 (d, *J* = 1.0 Hz, 1H), 4.96 (d, *J* = 1.0 Hz, 1H), 3.82 (s, 2H), 1.30 (s, 9H).
GCMS (EI): Calcd for $C_{19}H_{22}$: 250.38. Found: 250.1.



***p-tert*-Butyl-1-cyclohexylstyrene**. The reaction was set up following typical procedure I with 10% Pd(OAc)$_2$, 12% dnpf and 5 equivalent of olefin and stirred at 80 °C for 32 hours. The product was purified by flash chromatography (hexane) as colorless oil (104 mg, 86%). The ratio of the desired isomer versus all other isomers in the crude product was determined to be 10:1 by GC. 10:1 after purification. When 2 equivalents of the olefin was used, only 62% of the desired product was obtained with 13:1 selectivity.

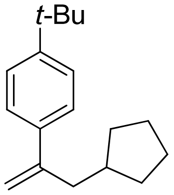
^{1}H NMR (400 MHz, CDCl$_3$): δ 7.34-7.25 (m, 4H), 5.14 (d, *J* = 1.1 Hz, 1H), 4.97 (m, 1H), 2.44-2.38 (m, 1H), 1.86-1.69 (m, 5H), 1.37-1.12 (m, 14H).
^{13}C NMR (100 MHz, CDCl$_3$): δ 154.8, 150.0, 140.0, 126.3 (2 overlapping signals), 125.2(x2), 109.8, 42.6, 34.6, 33.0, 31.5, 27.0, 26.6.
GCMS (EI): Calcd for $C_{18}H_{26}$: 242.2. Found: 242.2.



***p-tert*-Butyl-1-neopentylstyrene [1393539-22-4].** The reaction was set up following typical procedure I with 5% Pd(OAc)$_2$ and 10% dnpf and stirred at 50 °C for 3 days. The product was purified by flash chromatography (hexane) as colorless oil (89 mg, 76%). The ratio of the desired isomer versus all other isomers in the crude product was determined to be 11:1 by GC. 13:1 after purification.

^{1}H NMR (400 MHz, CDCl$_3$): δ 7.30 (ψs, 4H), 5.24-5.23 (d, *J* = 2.1 Hz, 1H), 4.97-4.96 (m, 1H), 2.45 (s, 2H), 1.31 (s, 9H), 0.81 (s, 9H).

GCMS (EI): Calcd for $C_{17}H_{26}$: 230.39. Found: 230.1.

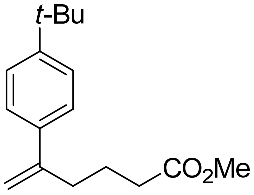


***p-tert*-Butyl-1-(cyclopentylmethyl)styrene .** The reaction was set up following typical procedure I with 5% $Pd(OAc)_2$ and 10% dnpf and stirred at 50 °C for 3 days. The product was purified by flash chromatography (hexane) as colorless oil (110 mg, 91%). The ratio of the desired isomer versus all other isomers in the crude product was determined to be 11:1 by GC. 11 :1 after purification.

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.34 (ψs, 4H), 5.23 (s, 1H), 5.00 (s, 1H), 2.49-2.47 (d, *J* = 7.4 Hz, 2H), 1.98-1.91 (m, 1H), 1.71-1.65 (m, 2H), 1.62-1.57 (m, 2H), 1.49-1.44 (m, 2H), 1.32 (s, 9H), 1.20-1.11 (m, 2H).

^{13}C NMR (100 MHz, $CDCl_3$): δ 150.3, 148.1, 138.7, 125.0, 125.2, 112.2, 42.1, 38.3, 34.6, 32.6, 31.5, 25.2.

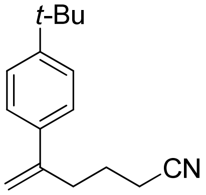
GCMS (EI): Calcd for $C_{18}H_{26}$: 242.2. Found: 242.1.



Methyl 5-(*p-tert*-butylphenyl)-5-hexenoate [1393539-26-8]. The reaction was set up following typical procedure I with 10% $Pd(OAc)_2$ and 12% dnpf and stirred at 50 °C for 2 days. The product was purified by flash chromatography (hexane/ethyl acetate 10:1) as colorless oil (125 mg, 96%). The ratio of the desired isomer versus all other isomerswas determined by GC to be 10:1 in the crude product and 10:1 after purification.

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.35 (ψs, 4H), 5.30 (d, *J* = 1.1 Hz, 1H), 5.03-5.02 (m, 1H), 3.66 (s, 3H), 2.54 (t, *J* = 7.4 Hz, 2H), 2.34 (t, *J* = 7.4 Hz, 2H), 1.80 (ψqn, *J* = 7.4 Hz, 2H), 1.32 (s, 9H).

GCMS (EI): Calcd for $C_{17}H_{24}O_2$: 260.37. Found: 260.1.

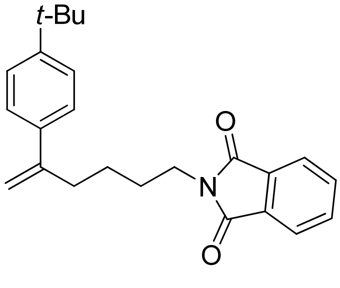


5-(*p*-*tert*-Butylphenyl)-5-hexenenitrile. The reaction was set up following typical procedure I with 10% $Pd(OAc)_2$ and 12% dnpf and stirred at 50 °C for 2 days. The product was purified by flash chromatography (hexane/ethyl acetate 20:1) as colorless oil (85 mg, 75%). The ratio of the desired isomer versus all other isomers in the crude product was determined to be 15:1 by GC. 12:1 after purification.

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.37-7.25 (m, 4H), 5.34 (s, 1H), 5.09 (d, *J* = 1.0 Hz, 1H), 2.68 (t, *J* = 7.2 Hz, 2H), 2.32 (t, *J* = 7.1 Hz, 2H), 1.81 (ψqn, *J* = 7.2 Hz, 2H), 1.32 (s, 9H).

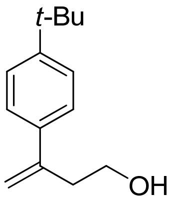
^{13}C NMR (100 MHz, $CDCl_3$): δ 151.3, 146.2, 137.4, 126.2, 125.9, 120.1, 113.8, 35.0, 34.4, 31.8, 24.2, 16.8.

GCMS (EI): Calcd for $C_{16}H_{21}N$: 227.3. Found: 227.0.



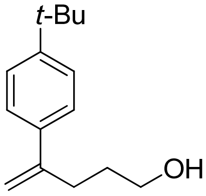
***2-p-tert*-Butylphenyl-6-phthalimido-1-hexene [1393539-33-7].** The reaction was set up following typical procedure I with 10% $Pd(OAc)_2$ and 12% dnpf and stirred at 50 °C for 29 hours. The desired product and starting material coeluted during flash chromatography (hexane/ethyl acetate 10:1). The desired product was obtained as colorless oil after bulb-to-bulb distillation to remove unreacted starting material (167mg, 92%). The ratio of the desired isomer versus all other isomers in the crude product was determined to be 33:1 by GC.

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.83 (dd, *J* = 5.4, 3.1 Hz, 2H), 7.70 (dd, *J* = 5.4, 3.1 Hz, 2H), 7.32 (ψs, 4H), 5.26 (d, *J* = 1.4 Hz, 1H), 5.03-5.02 (m, 1H), 3.68 (t, *J* = 7.3 Hz, 2H), 2.54 (t, *J* = 7.5 Hz, 2H), 1.72 (ψqn, *J* = 7.5 Hz, 2H), 1.50 (ψqn, *J* = 7.5 Hz, 2H), 1.31 (s, 9H).
GCMS (EI): Calcd for $C_{24}H_{27}NO_2$: 361.48. Found: 361.1.



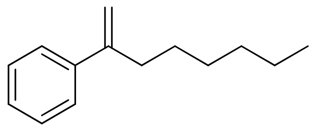
2-(*p*-*tert*-Butylphenyl)-1-butene-4-ol [1134201-55-0]. The reaction was set up following typical procedure I with 10% $Pd(OAc)_2$, 12% dnpf and 3 equivalents of olefin and stirred at 80 °C for one day. The product was purified by flash chromatography (hexane/ethyl acetate 10:1) followed by using bulb to bulb distillation (for removal of tri-*n*-butylamine) as colorless oil (74 mg, 72%). The ratio of the desired isomer versus all other isomers in the crude product was determined to be 11:1 by GC. 11:1 after purification.

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.36 (ψs, 4H), 5.41 (d, *J* = 1.3 Hz, 1H), 5.12-5.12 (m, 1H), 3.73 (t, *J* = 6.4 Hz, 2H), 2.78 (td, J = 6.4, 0.9 Hz, 2H), 1.48 (br s, 1H), 1.32 (s, 9H).
GCMS (EI): Calcd for $C_{14}H_{20}$: 204.15. Found: 204.1.



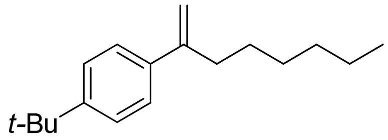
2-(*p*-*tert*-Butylphenyl)-1-pentene-5-ol [1393539-27-9]. The reaction was set up following typical procedure I with 5% $Pd(OAc)_2$ and 10% dnpf and stirred at 80 °C for 28 hours. The product was purified by flash chromatography (hexane/ethyl acetate 10:1 to 5:1) followed by using bulb to bulb distillation (for removal of tri-*n*-butylamine) as colorless oil (85 mg, 78%). The ratio of the desired isomer versus all other isomers in the crude product was determined to be 14:1 by GC. 14:1 after purification.

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.35 (ψs, 4H), 5.29 (s, 1H), 5.05 (s, 1H), 3.66 (t, *J* = 6.4 Hz, 2H), 2.59 (t, *J* = 7.5 Hz, 2H), 1.73 (tt, *J* = 7.5, 6.4 Hz, 2H), 1.40 (br s, 1H), 1.32 (s, 9H).
GCMS (EI): Calcd for $C_{15}H_{22}O$: 218.33. Found: 218.1.



2-Phenyl-1-octene [5698-49-7]. The reaction was set up following typical procedure I with 5% $Pd(OAc)_2$ and 10% dnpf and the reaction mixture was stirred at 50 °C for 2 days. The product was purified by flash chromatography (hexane) as colorless oil (80 mg, 85%). The ratio of the desired isomer versus all other isomers in the crude product was determined to be 10:1 by GC. 10:1 after purification.

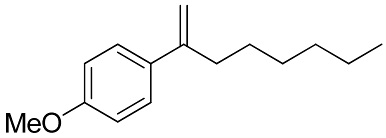
^{1}H NMR (400 MHz, $CDCl_3$): δ 7.42-7.39 (m, 2H), 7.34-7.30 (m, 2H), 7.28-7.24 (m, 1H), 5.26 (d, *J* = 1.3 Hz, 1H), 5.05 (d, *J* = 1.3 Hz, 1H), 2.50 (t, *J* = 7.5 Hz, 2H), 1.44 (ψqn, *J* = 7.3 Hz, 2H), 1.36-1.26 (m, 6H), 0.87 (t, *J* = 6.8 Hz, 3H).
GCMS (EI): Calcd for $C_{14}H_{20}$: 188.16. Found: 188.1.



2-(*p*-*tert*-Butylphenyl)-1-octene [1393538-91-4]. The reaction was set up following typical procedure I with 5% $Pd(OAc)_2$ and 10% dnpf and the reaction mixture was stirred at 50 °C for 2 days. The product was purified by flash chromatography (hexane) as colorless oil (112 mg, 92%). The ratio of the desired isomer versus all other isomers in the crude product was determined to be 17:1 by GC. 12:1 after purification.

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.35 (ψs, 4H), 5.25 (d, *J* = 1.5 Hz, 1H), 5.01-5.00 (m, 1H), 2.48 (t, *J* = 7.6 Hz, 2H), 1.48-1.44 (m, 2H), 1.35-1.27 (m, 15H), 0.87 (t, *J* = 6.8 Hz, 3H).

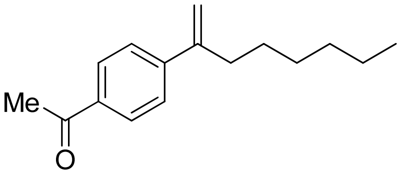
GCMS (EI): Calcd for $C_{18}H_{28}$: 244.41. Found: 244.1.



2-(*p*-Anisyl)-1-octene [129182-23-6]. The reaction was set up following typical procedure I with 5% $Pd(OAc)_2$ and 10% dnpf and the reaction mixture was stirred at 50 °C for 3 days. The product was purified by flash chromatography (hexane) as colorless oil (95 mg, 87%). The ratio of the desired isomer versus all other isomers in the crude product was determined to be 13:1 by GC. 15:1 after purification.

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.36-7.34 (m, 2H), 6.87-6.85 (m, 2H), 5.18 (d, *J* = 1.4 Hz, 1H), 4.97-4.96 (m, 1H), 3.81 (s, 3H), 2.46 (t, *J* = 7.5 Hz, 2H), 1.46-1.42 (m, 2H), 1.34-1.24 (m, 6H), 0.87 (t, *J* = 6.8 Hz, 3H).

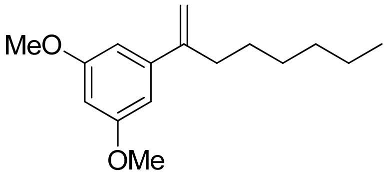
GCMS (EI): Calcd for $C_{15}H_{22}O$: 218.17. Found: 218.1.



2-(*p*-Acetylphenyl)-1-octene [688805-09-6]. The reaction was set up following typical procedure I with 5% $Pd(OAc)_2$, 10% dnpf and 3 equivalents of 1-octene and the reaction mixture was stirred in 80 °C oil bath for 2 days. The product was purified by flash chromatography (hexane/ethyl acetate 50:1) as colorless oil (90 mg, 78%). The ratio of the desired isomer versus all other isomers in the crude product was determined to be 9:1 by GC. 13:1 after purification.

^{1}H NMR (400 MHz, CDCl$_3$): δ 7.92 (d, *J* = 8.4 Hz, 2H), 7.48 (d, *J* = 8.4 Hz, 2H), 5.35 (s, 1H), 5.16 (d, *J* = 1.1 Hz, 1H), 2.60 (s, 3H), 2.51 (t, *J* = 7.5 Hz, 2H), 1.47-1.39 (m, 2H), 1.35-1.26 (m, 6H), 0.87 (t, *J* = 6.8 Hz, 3H).

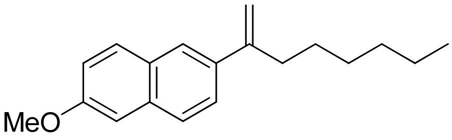
GCMS (EI): Calcd for $C_{16}H_{22}O$: 230.17. Found: 230.2.



2-(3,5-Dimethoxyphenyl)-1-octene [499237-38-6]. The reaction was set up following typical procedure I with 5% Pd(OAc)$_2$ and 10% dnpf and the reaction mixture was stirred at 50 °C for 2 days. The product was purified by flash chromatography (hexane/ethyl acetate 20: 1) as colorless oil (113 mg, 91%). The ratio of the desired isomer versus all other isomers in the crude product was determined to be 16:1 by GC. 16:1 after purification.

^{1}H NMR (400 MHz, CDCl$_3$): δ 6.55 (d, *J* = 2.2 Hz, 2H), 6.39 (t, *J* = 2.2 Hz, 1H), 5.25 (s, 1H), 5.04 (s, 1H), 3.80 (s, 6H), 2.46-2.42 (t, *J* = 7.5 Hz, 2H), 1.47-1.40 (m, 2H), 1.33-1.27 (m, 6H), 0.87 (t, *J* = 6.8 Hz, 3H).

GCMS (EI): Calcd for $C_{16}H_{24}O_2$: 248.18. Found: 248.2.



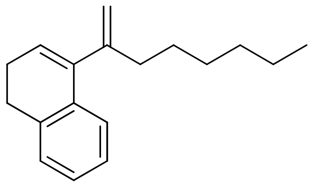
2-(6-Methoxy-2-naphthyl)-1-octene. The reaction was set up following typical procedure I with 5% Pd(OAc)$_2$, 10% dnpf and 3 equivalents of 1-octene and the reaction mixture was stirred in an 80 °C oil bath for 2 days. The product was purified by flash chromatography (hexane/ethyl acetate 50:1) as colorless oil (108 mg, 81%). The ratio of the desired isomer versus all other isomers in the crude product was determined to be 11:1 by GC. 11:1 after purification.

^{1}H NMR (400 MHz, CDCl$_3$): δ 7.75-7.67 (m, 3H), 7.55 (d, *J* = 8.6, 1.8 Hz, 1H), 7.15-7.10 (m, 2H), 5.37 (d, *J* = 1.3 Hz, 1H), 5.11 (m, 1H), 3.91 (s, 3H), 2.60 (t, *J* =

7.5 Hz, 2H), 1.51-1.47 (m, 2H), 1.37-1.25 (m, 6H), 0.87 (t, *J* = 6.9 Hz, 3H).

^{13}C NMR (100 MHz, $CDCl_3$): δ 157.8, 148.7, 136.7, 134.0, 129.8, 129.0, 126.7, 125.4, 124.6, 119.0, 111.9, 105.7, 55.4, 35.5, 31.8, 29.2, 28.5, 22.8, 14.2.

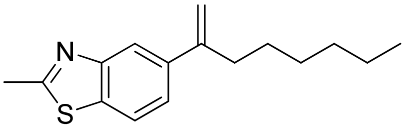
GCMS (EI): Calcd for $C_{19}H_{24}O$: 268.2. Found: 268.2.



3,4-Dihydro-1-(1-octe-2-nyl)naphthalene [1393538-99-2]. The reaction was set up following typical procedure I by using 5% $Pd(OAc)_2$ and 10% dnpf and the reaction mixture was stirred at 50 °C for 3 days. The product was purified by flash chromatography (hexane) as colorless oil (102 mg, 85%). The ratio of the desired isomer versus all other isomers in the crude product was determined to be 9:1 by GC. (46:1 after purification)

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.16-7.12 (m, 4H), 5.92 (t, *J* = 4.6 Hz, 1H), 5.05 (m, 1H), 4.99 (d, *J* = 2.4 Hz, 1H), 2.75 (t, *J* = 7.9 Hz, 2H), 2.29-2.22 (m, 4H), 1.53-1.34 (m, 2H), 1.29-1.21 (m, 6H), 0.86 (t, *J* = 4.6 Hz, 3H).

GCMS (EI): Calcd for $C_{18}H_{24}$: 240.38. Found: 240.1.

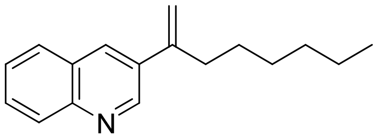


2-(2-Methyl-5-benzothiazolyl)-1-octene . The reaction was set up following typical procedure I by using 5% $Pd(OAc)_2$ and 10% dnpf and the reaction mixture was stirred at 50 °C for 24 hours. The product was purified by flash chromatography (hexane/ethyl acetate 30:1) as colorless oil (94 mg, 72%). The ratio of the desired isomer versus all other isomers in the crude product was determined to be 16:1 by GC. 18:1 after purification.

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.97 (d, *J* = 1.6 Hz, 1H), 7.75 (d, *J* = 8.3 Hz, 1H), 7.42 (dd, *J* = 8.3, 1.7 Hz, 1H), 5.34 (d, *J* = 1.4 Hz, 1H), 5.12 (m, 1H), 2.83 (s, 3H), 2.56 (td, *J* = 7.6, 0.7 Hz), 1.63-1.36 (m, 2H), 1.34-1.23 (m, 6H), 0.86 (t, *J* = 6.8 Hz, 3H).

^{13}C NMR (100 MHz, $CDCl_3$): δ 167.5, 153.9, 148.5, 139.9, 134.5, 123.4, 121.1, 119.9, 112.8, 35.8, 31.8, 29.2, 28.5, 22.8, 20.3, 14.2.

GCMS (EI): Calcd for $C_{16}H_{21}NS$: 259.1. Found: 259.1.



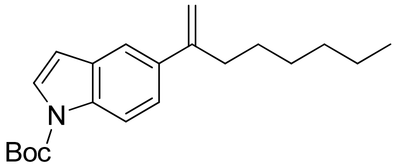
2-(3-Quinolinyl)-1-octene. The reaction was set up following typical procedure I by using 10% $Pd(OAc)_2$, 15% dnpf and 5 equivalent of olefin and the reaction mixture was stirred at 80 °C for 3 days. The product was purified by flash chromatography (hexane/ethyl acetate 10: 1 containing 1% triethylamine) and subsequent vacuum distillation (to remove tri-*n*-butylamine) as colorless oil (80 mg, 67%). The ratio of the desired regioisomer versus all other isomers in the crude product was determined to be 10:1 by GC. 10:1 after purification.

When 15% Pd and 18% dnpf were used as catalyst and 3 equiv of the olefin was used, 61% yield and 6:1 selectivity was obtained after 4 days at 80 °C.

^1H NMR (400 MHz, $CDCl_3$): δ 9.02 (d, *J* = 2.2 Hz, 1H), 8.10-8.07 (m, 2H), 7.81 (d, *J* = 8.2 Hz, 1H), 7.70-7.66 (m, 1H), 7.56-7.52 (m, 1H), 5.47 (s, 1H), 5.26 (d, *J* = 1.0 Hz, 1H), 2.62 (t, *J* = 7.5 Hz, 2H), 1.52-1.46 (m, 2H), 1.38-1.25 (m, 6H), 0.87 (t, *J* = 6.9 Hz, 3H).

^{13}C NMR (100 MHz, $CDCl_3$): δ 149.7, 147.5, 145.9, 134.1, 132.1, 129.3, 129.2, 128.1, 127.9, 126.9, 114.4, 35.3, 31.8, 29.1, 28.2, 22.7, 14.2.

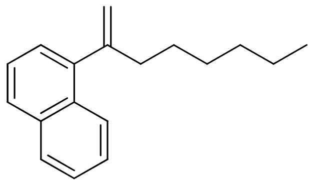
GCMS (EI): Calcd for $C_{17}H_{21}N$: 239.2. Found: 239.1.



***N*-(*t*-Butoxycarbonyl)-5-(2-octenyl)indole [1393538-97-0].** The reaction was set up following typical procedure I by using 5% $Pd(OAc)_2$ and 10% dnpf and the reaction mixture was stirred at 80 °C for 20 hours. The product was purified by flash chromatography (hexane/ethyl acetate 50:1) as colorless oil (149 mg, 91%). The ratio of the desired isomer versus all other isomers in both the crude and purified samples was determined to be 20:1 by NMR spectroscopy.

^{1}H NMR (400 MHz, $CDCl_3$): δ 8.05 (d, *J* = 8.6 Hz, 1H), 7.58-7.57 (m, 2H), 7.38 (dd, *J* = 8.6, 1.7 Hz, 1H), 6.58 (d, *J* = 3.5 Hz, 1H), 5.26 (d, *J* = 1.7 Hz, 1H), 5.04 (m, 1H), 2.55 (t, *J* = 7.4 Hz, 2H), 1.67 (s, 9H), 1.55-1.41 (m, 2H), 1.36-1.24 (m, 6H), 0.86 (t, *J* = 6.8 Hz, 3H).

GCMS (EI): Calcd for $C_{16}H_{21}N$ [M-Boc+H]: 227.17. Found: 227.0.

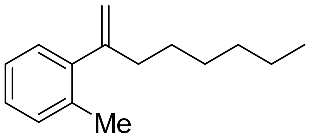


2-(1-Naphthyl)-1-octene [101720-90-5]. The reaction was set up following typical procedure II by using 5% $Pd(OAc)_2$ and 10% dppf and the reaction mixture was stirred in 80 °C oil bath for 38 hours. The product was purified by flash chromatography (hexane) as colorless oil (102 mg, 85%). The ratio of the desired isomer versus all other isomers in the crude product was determined to be 10:1 by GC. 12:1 after purification. When 5% $Pd(OAc)_2$ and 10% dppf were used as catalyst, 52% yield and 6:1 selectivity was obtained after 24 h at 80 °C.

Typical procedure I by using 5% $Pd(OAc)_2$ and 10% dnpf and the reaction mixture was stirred in 80 °C oil bath for 17 hours. The product was purified by flash chromatography (hexane) as colorless oil (55 mg, 46%). The ratio of the desired isomer versus all other isomers in the crude product was determined to be 8:1 by GC. 34:1 after purification. The reduction byproduct naphthalene was about 25%.

^{1}H NMR (400 MHz, $CDCl_3$): δ 8.04-8.02 (m, 1H), 7.86-7.83 (m, 1H), 7.76 (d, *J* = 7.2 Hz, 1H), 7.48-7.41 (m, 3H), 7.28-7.26 (m, 1H), 5.38-5.37 (m, 1H), 5.05 (d, *J* = 2.2 Hz, 1H), 2.50 (t, *J* = 7.5 Hz, 2H), 1.44-1.21 (m, 8H), 0.85 (t, *J* = 6.8 Hz, 3H).

GCMS (EI): Calcd for $C_{18}H_{22}$: 238.17. Found: 238.1.

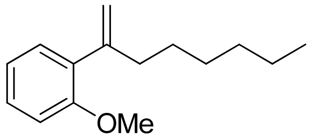


2-(*o*-Toly)-1-octene [1393539-01-9]. The reaction was set up following typical procedure II by using 5% Pd(OAc)$_2$ and 10% dnpf and the reaction mixture was stirred in 80 ^{o}C oil bath for 2 days. The product was purified by flash chromatography (hexane) as colorless oil (87 mg, 86%). The ratio of the desired isomer versus all other isomers in the crude product was determined to be 9:1 by GC. 11:1 after purification.

Typical procedure I by using 5% Pd(OAc)$_2$ and 10% dnpf and the reaction mixture was stirred in 80 ^{o}C oil bath for 2 days. The product was purified by flash chromatography (hexane) as colorless oil (55 mg, 54%). The ratio of the desired isomer versus all other isomers in the crude product was determined to be 8:1 by GC. 13:1 after purification. A significant amount of ArBr reduction was observed by GC.

^{1}H NMR (400 MHz, CDCl$_3$): δ 7.25-7.11 (m, 3H), 7.07-7.05 (m, 1H), 5.17-5.15 (m, 1H), 4.84 (d, *J* = 2.1 Hz, 1H), 2.33-2.29 (m, 5H), 1.40-1.23 (m, 8H), 0.87 (t, *J* = 6.8 Hz, 3H).

GCMS (EI): Calcd for $C_{15}H_{22}$: 202.34. Found: 202.2.

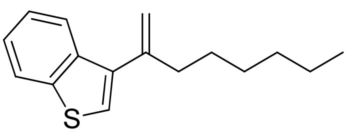


2-(*o*-Anisyl)-1-octene [1046468-80-7]. The reaction was set up following typical procedure I with 5% Pd(OAc)$_2$ and 10% dnpf and the reaction mixture was stirred at 50 ^{o}C for 2 days. The product was purified by flash chromatography (hexane) as colorless oil (78 mg, 72%). The ratio of the desired isomer versus all other isomers in the crude product was determined to be 6:1 by GC. 7:1 after purification.

^{1}H NMR (400 MHz, CDCl$_3$): δ 7.26-7.21 (m, 1H), 7.13 (dd, *J* = 7.4, 1.8 Hz, 1H), 6.92 (ψtd, *J* = 7.4, 1.0 Hz, 1H), 6.87 (d, *J* = 8.2 Hz, 1H), 5.13-5.12 (m, 1H), 4.99 (d, *J* = 2.2 Hz, 1H), 3.82 (s, 2H), 2.46 (t, *J* = 7.1 Hz, 2H), 1.35-1.21 (m, 8H), 0.86

(t, *J* = 6.9 Hz, 3H).

GCMS (EI): Calcd for $C_{15}H_{22}O$: 218.17. Found: 218.1.

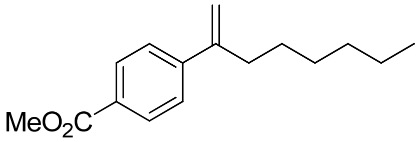


3-(2-Octenyl)benzothiophene. The reaction was set up following typical procedure II by using 5% $Pd(OAc)_2$ and 10% dppf and the reaction mixture was stirred in 80 °C oil bath for 38 hours. The product was purified by flash chromatography (hexane) as colorless oil (96 mg, 79%). The ratio of the desired isomer versus all other isomers in the crude product was determined to be 12:1 by GC. 12:1 after purification. When 5% $Pd(OAc)_2$ and 10% dnpf were used as catalyst, low yield and 4:1 selectivity resulted after 24 h at 80 °C.

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.93-7.84 (m, 2H), 7.40-7.32 (m, 2H), 7.23 (s, 1H), 5.31-5.30 (m, 1H), 5.26 (d, *J* = 1.6 Hz, 1H), 2.52 (t, *J* = 7.5 Hz, 2H), 1.48-1.40 (m, 2H), 1.35-1.21 (m, 6H), 0.85 (t, *J* = 6.8 Hz, 3H).

^{13}C NMR (100 MHz, $CDCl_3$): δ 144.1, 140.6, 138.8, 138.3, 124.3, 124.2, 123.4, 122.9, 122.3, 114.4, 37.7, 31.8, 29.1, 28.3, 22.8, 14.2.

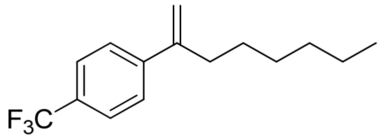
GCMS (EI): Calcd for $C_{16}H_{20}S$: 244.1. Found: 244.1



2-(*p*-Methoxycarbonylphenyl)-1-octene [947607-39-8]. The reaction was set up following typical procedure II by using 10% $Pd(OAc)_2$, 12% dnpf, 3 equivalents of 1-octene and 2 equivalents of DABCO and the reaction mixture was stirred in 80 °C oil bath for 5 days. The product was purified by flash chromatography (hexane) as colorless oil (99 mg, 80%). The ratio of the desired isomer versus all other isomers in the crude product was determined to be 9:1 by GC. 11:1 after purification.

^{1}H NMR (400 MHz, $CDCl_3$): δ 8.00-7.97 (m, 2H), 7.47-7.44 (m, 2H), 5.34 (s, 1H), 5.15 (d, *J* = 1.2 Hz, 1H), 3.92 (s, 3H), 2.50 (t, *J* = 7.5 Hz, 2H), 1.54-1.41(m, 2H), 1.34-1.26 (m, 6H), 0.87 (t, *J* = 6.8 Hz, 3H).

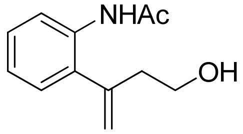
GCMS (EI): Calcd for $C_{16}H_{22}O_2$: 246.16. Found: 246.1.



2-(*p*-Trifluoromethylphenyl)-1-octene [947607-37-6]. The reaction was set up following typical procedure II by using 5% $Pd(OAc)_2$, 10% dnpf, 5 equivalent of 1-octene and 2 equivalents of DABCO and the reaction mixture was stirred in 80 °C oil bath for 3 days (70% conversion of ArBr). The product was purified by flash chromatography (hexane) as colorless oil (80 mg, 63%). The ratio of the desired isomer versus all other isomers in the crude product was determined to be 12:1 by GC. 12:1 after purification.

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.57 (d, *J* = 8.3 Hz, 2H), 7.49 (d, *J* = 8.3 Hz, 2H), 5.31 (s, 1H), 5.15-5.14 (m, 1H), 2.50 (t, *J* = 7.5 Hz, 2H), 1.45-1.35 (m, 2H), 1.34-1.26 (m, 6H), 0.87 (t, *J* = 6.8 Hz, 3H).

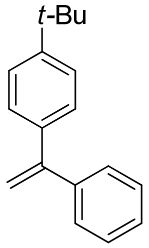
GCMS (EI): Calcd for $C_{15}H_{19}F_3$: 256.14. Found: 256.0.



2-(*o*-Acetamidophenyl)-1-penten-5-ol [1312597-98-0]. The reaction was set up following typical procedure II by using 10% $Pd(OAc)_2$, 12% dppf, 3 equivalents of the olefin and 2 equivalents of DABCO and the reaction mixture was stirred in 80 °C oil bath for 2 days. The product was purified by silica gel chromatography (hexane/ethyl acetate 1:2 containing 1% triethylamine) as yellow colored oil and only desired product was found from NMR spectrum (78 mg, 76%). The product was found to decompose on untreated silica gel and thus, powder silica gel must be treated first with triethylamine before dry packing. The ratio of the desired isomer versus all other isomers in the crude product was >100:1 as determined by GC.

^{1}H NMR (400 MHz, CDCl$_3$): δ 8.21 (d, *J* = 8.2 Hz, 1H), 8.12 (br s, 1H), 7.30-7.25 (m, 1H), 7.10-7.06 (m, 2H), 5.44 (d, *J* = 1.1 Hz, 1H), 5.13 (s, 1H), 3.70-3.66 (ψq, *J* = 5.0 Hz, 2H), 2.63 (t, *J* = 5.6 Hz, 2H), 2.11 (s, 3H), 1.70 (br s, 1H).

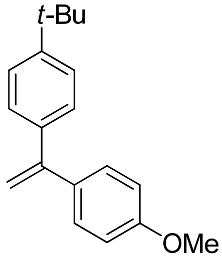
MS (ESI): Calcd for $C_{12}H_{15}NO_2$: 205.11. Found [M+1]: 205.98.



α-(*p*-*t*-Butylphenyl)styrene [17582-85-3]. The reaction was set up following typical procedure I with 10% Pd(OAc)$_2$ and 12% dnpf and stirred at 50 °C for 2 days. The product was purified by flash chromatography (hexane) as colorless oil (90 mg, 76%). The ratio of the desired isomer versus all other isomers in the crude product was determined to be 13:1 by GC. 88:1 after purification.

^{1}H NMR (400 MHz, CDCl$_3$): δ 7.35-7.25 (m, 9H), 5.45 (d, *J* = 1.2 Hz, 1H), 5.40 (d, *J* = 1.2 Hz, 1H), 1.34 (s, 9H).

GCMS (EI): Calcd for $C_{18}H_{20}$: 236.16. Found: 236.1.

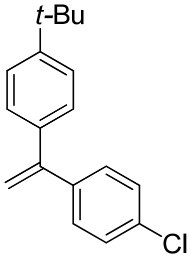


1-(*p*-*t*-Butylphenyl)-1-(*p*-methoxyphenyl)ethene [124419-76-7]. The reaction was set up following typical procedure I with 10% Pd(OAc)$_2$,12% dnpf, *p*-(*tert*-butyl)bromobenzene (1.5 equiv, 0.75 mmol, 160 mg) and *p*-methoxystyrene (1.0 equiv, 0.50 mmol, 67 mg) and stirred at 50 °C for 2 days. The product was purified by flash chromatography (hexane) as white solid (107 mg, 81%). The ratio of the desired isomer versus all other isomers in the crude product was determined to be 11:1 by GC. 66:1 after purification.

^{1}H NMR (400 MHz, CDCl$_3$): δ 7.36-7.33 (m, 2H), 7.31-7.25 (m, 4H), 6.88-6.84

(m, 2H), 5.35-5.34 (m, 2H), 3.83 (s, 3H), 1.34 (s, 9H).

GCMS (EI): Calcd for $C_{19}H_{22}O$: 266.17. Found: 266.1.



1-(*p*-*t*-Butylphenyl)-1-(*p*-chlorophenyl)ethene. The reaction was set up following typical procedure I with 10% Pd(OAc)$_2$, 20% dnpf, *p*-*t*-butylphenyl bromide (1.5 equiv, 0.75 mmol, 160 mg) and *p*-chlorostyrene (1.0 equiv, 0.50 mmol, 69 mg) and stirred at 80 °C for 2 days. The product was purified by flash chromatography (hexane) as white solid (91 mg, 67%). The ratio of the desired isomer versus all other isomers in the crude product was determined to be 11:1 by GC. 48:1 after purification.

^{1}H NMR (400 MHz, CDCl$_3$): δ 7.36-7.33 (m, 2H), 7.29-7.28 (m, 4H), 7.26-7.23 (m, 2H), 5.45 (d, J = 1.1 Hz, 1H), 5.38 (d, J = 1.1 Hz, 1H), 1.33 (s, 9H).

^{13}C NMR (100 MHz, CDCl$_3$): δ 151.2, 148.9, 140.3, 138.1, 133.6, 129.8, 128.4, 127.9, 125.3, 114.3, 34.7, 31.5.

GCMS (EI): Calcd for $C_{18}H_{19}Cl$: 270.8. Found: 270.1.

2.5.4 Mechanistic studies

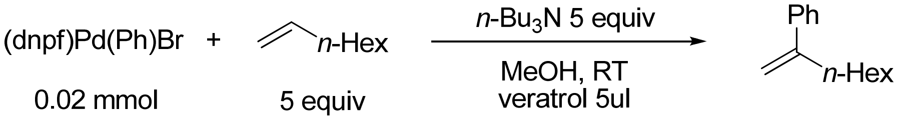
***Synthesis of (dnpf)Pd(Ph)Br* [1393539-72-4]**. The complex was synthesized according to our previously reported procedure with some modification.[1] In an argon-filled glove box, to a 25-mL Schlenk tube containing a magnetic stirring bar was added $Pd(dba)_2$ (172 mg, 0.30 mmol), dnpf (226 mg, 0.30 mmol) and dry toluene (15 mL). After stirring at room temperature for 10 minutes, PhBr (3 equiv, 141 mg, 0.90 mmol) was added. The reaction mixture was stirred at room temperature for 3 hours and then in an $80^{o}C$ oil bath for 2 days. The progress of the reaction was monitored by ^{31}P NMR spectroscopy. After cooling down to room temperature, the yellow precipitation was collected by filtration in the air. The contaminant of palladium black was removed after the yellow powder was dissolved in dichloromethane and filtered through a pad of Celite. The filtrate was concentrated to dryness to give the titled complex in 98% purity (240 mg, 78%).

^1H NMR (400 MHz, $CDCl_3$): δ 9.85-9.76 (m, 3H), 9.57 (d, J = 8.0 Hz, 1H), 8.16 (pseudotriplet, J = 9.1 Hz, 2H), 8.05-8.00 (m, 2H), 7.95-7.89 (m, 3H), 7.84 (d, J = 8.1 Hz, 1H), 7.74-7.66 (m, 3H), 7.62 (pseudotriplet, J = 7.5 Hz, 1H), 7.46-7.32 (m, 5H), 7.27-7.21 (m, 2H), 7.13 (d, J = 8.6 Hz, 2H), 7.00-6.92 (m, 2H), 6.82-6.78 (m, 1H), 6.56-6.51 (m, 2H), 6.30 (pseudotriplet, J = 7.0 Hz, 1H), 5.95 (br s, 1H), 5.61 (br s, 1H), 4.57 (s, 1H), 4.41 (s, 1H), 4.15 (s, 2H), 3.97 (pseudosinglet, 4H).

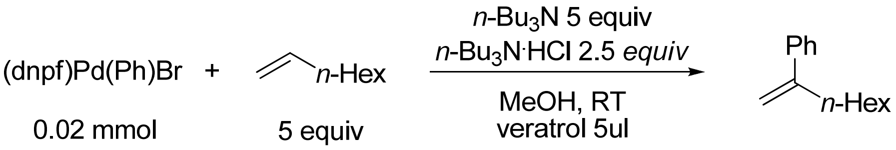
^{31}P NMR (162 MHz, $CDCl_3$): δ 28.7 (d, J = 28.1 Hz), 13.9 (d, J = 28.1 Hz)

Stoichiometric reaction between (dnpf)Pd(Ph)Br and 1-octene in methanol. To oven-dried 4-mL vial equipped with a magnetic stirring bar in an argon-filled glove box was added the complex *(dnpf)Pd(Ph)Br* (20.4 mg, 0.02 mmol) followed by dry methanol (0.5 mL). To this suspension was then added 1-octene (5 equiv, 11.2 mg, 0.10 mmol), nBu_3N (5 equiv, 18.5 mg, 0.10 mmol) and GC standard 1,2-dimethoxybenzene (5.0 uL). The reaction mixture was vigorously stirred at room temperature and at intervals aliquots of the sample were taken and passed through a short plug of silica gel with diethyl ether washings. The filtrate was analyzed by GC to determine the yield and the selectivity of Heck products. In a separate experiment, *n*Bu$_3$N·HCl (2.5 equiv, 11 mg, 0.05 mmol) was included as additive and the results were also listed below (Condition B).

Condition A:



Condition B:



Entry	Condition	Time	Desired isomer (%)	Trans selectivity
1	A	10 min	11	>100:1
2	B	10 min	10	>100:1
3	A	30 min	19	>100:1
4	B	30 min	15	>100:1
5	A	1 h	28	52:1
6	B	1 h	24	55:1
7	A	5 h	58	25:1
8	B	5 h	57	26:1
9	A	24 h	69	15:1
10	B	24 h	67	17:1

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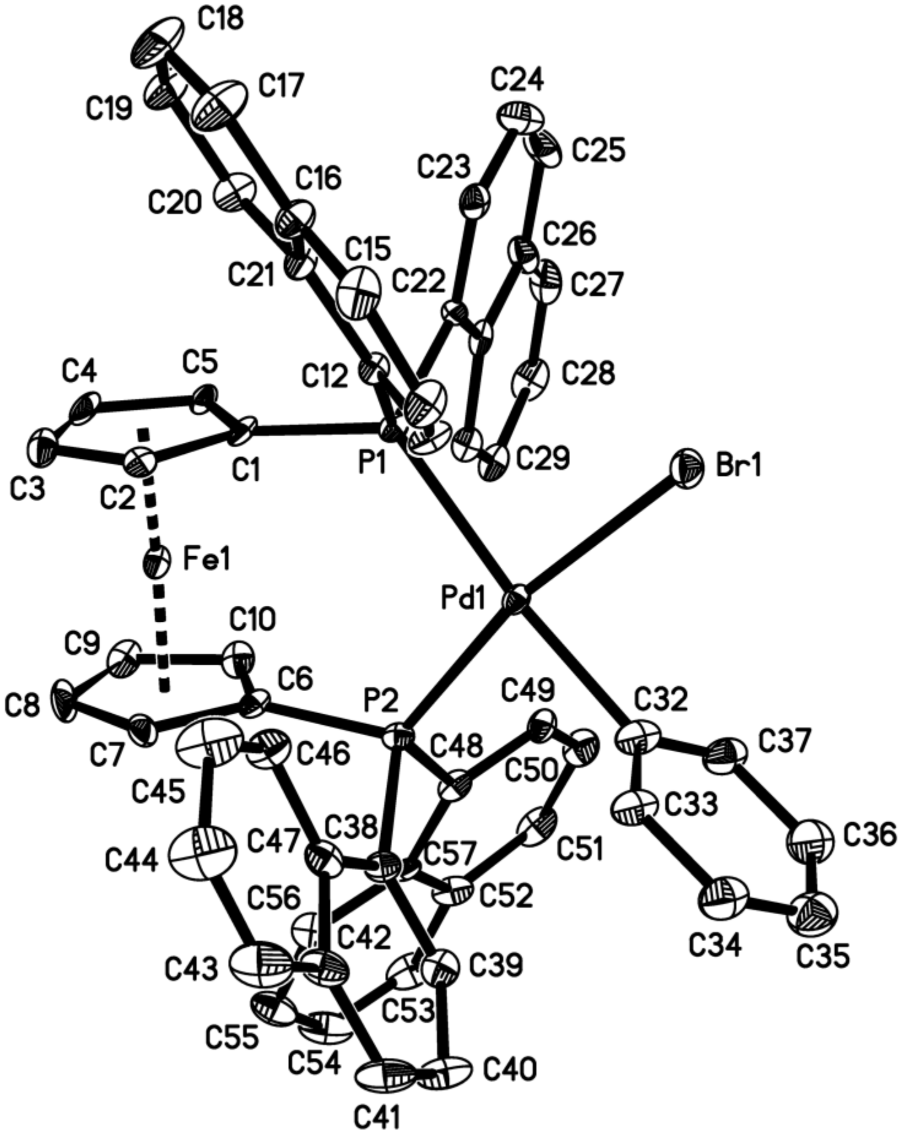
APPENDIX

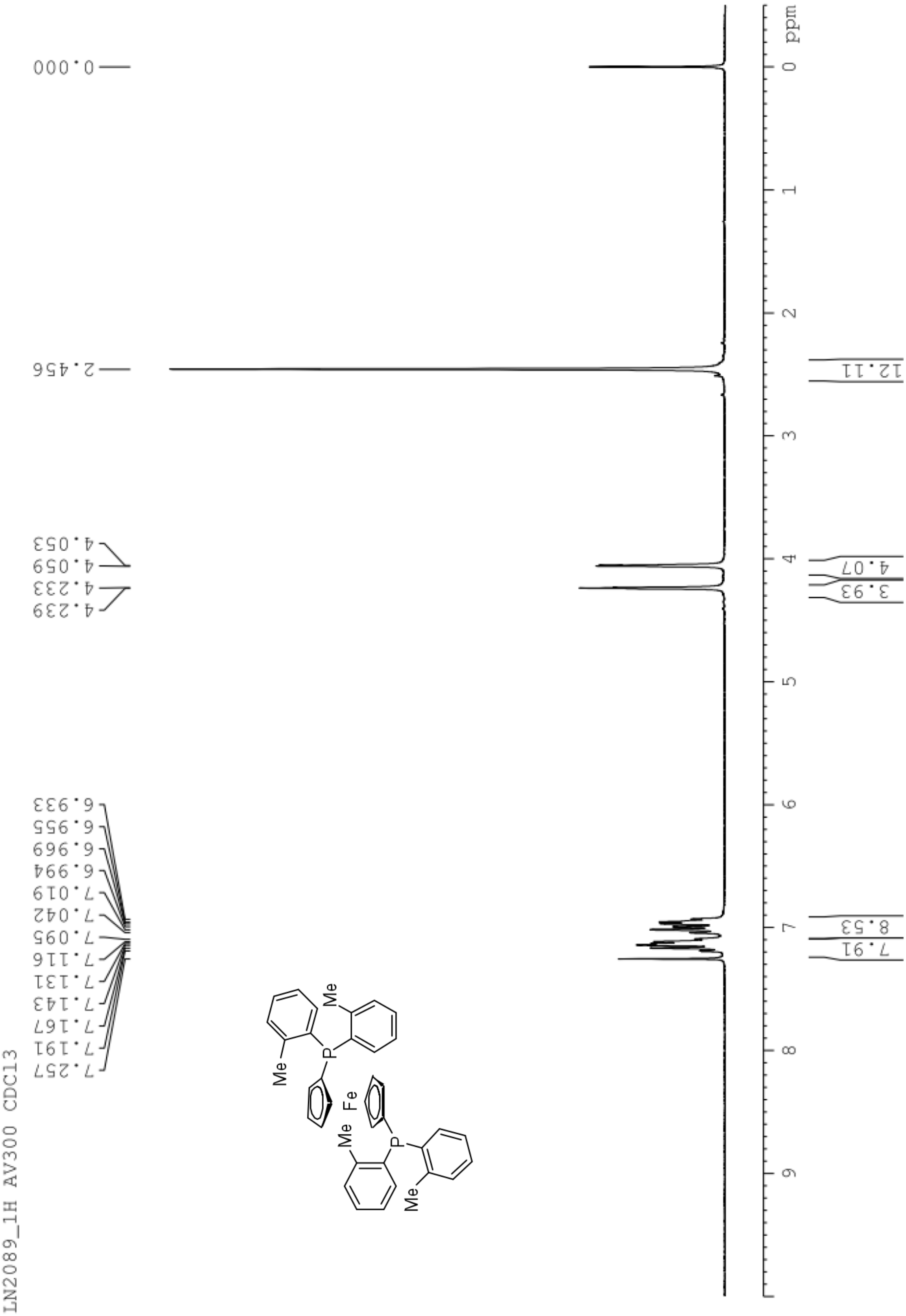
X-ray Data of (Dnpf)Pd(Ph)Br

CCDC 870134



Crystal data and structure refinement for (Dnpf)Pd(Ph)Br

Identification code	zhou48	
Empirical formula	C70 H57 Br Fe P2 Pd	
Formula weight	1202.26	
Temperature	103(2) K	
Wavelength	0.71073 Å	
Crystal system	Monoclinic	
Space group	C2/c	
Unit cell dimensions	a = 31.8096(16) Å	α= 90°.
	b = 16.6964(8) Å	β= 108.370(3)°.
	c = 21.7812(13) Å	γ = 90°.
Volume	10978.6(10) Å^3	
Z	8	
Density (calculated)	1.455 Mg/m^3	
Absorption coefficient	1.422 mm^{-1}	
F(000)	4912	
Crystal size	0.30 x 0.22 x 0.12 mm^3	
Theta range for data collection	1.58 to 28.33°.	
Index ranges	-42<=h<=42, -20<=k<=22, -29<=l<=28	
Reflections collected	54267	
Independent reflections	13635 [R(int) = 0.1268]	
Completeness to theta = 28.33°	99.6 %	
Absorption correction	Semi-empirical from equivalents	
Max. and min. transmission	0.8479 and 0.6750	
Refinement method	Full-matrix least-squares on F^2	
Data / restraints / parameters	13635 / 416 / 736	
Goodness-of-fit on F^2	1.046	
Final R indices [I>2sigma(I)]	R1 = 0.0617, wR2 = 0.1368	
R indices (all data)	R1 = 0.1274, wR2 = 0.1858	
Largest diff. peak and hole	1.599 and -1.779 e.Å^{-3}	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6.994
7.019
7.042
7.095
7.116
7.131
7.143
7.167
7.191
7.257
12.11
4.07
3.93
8.53
7.91
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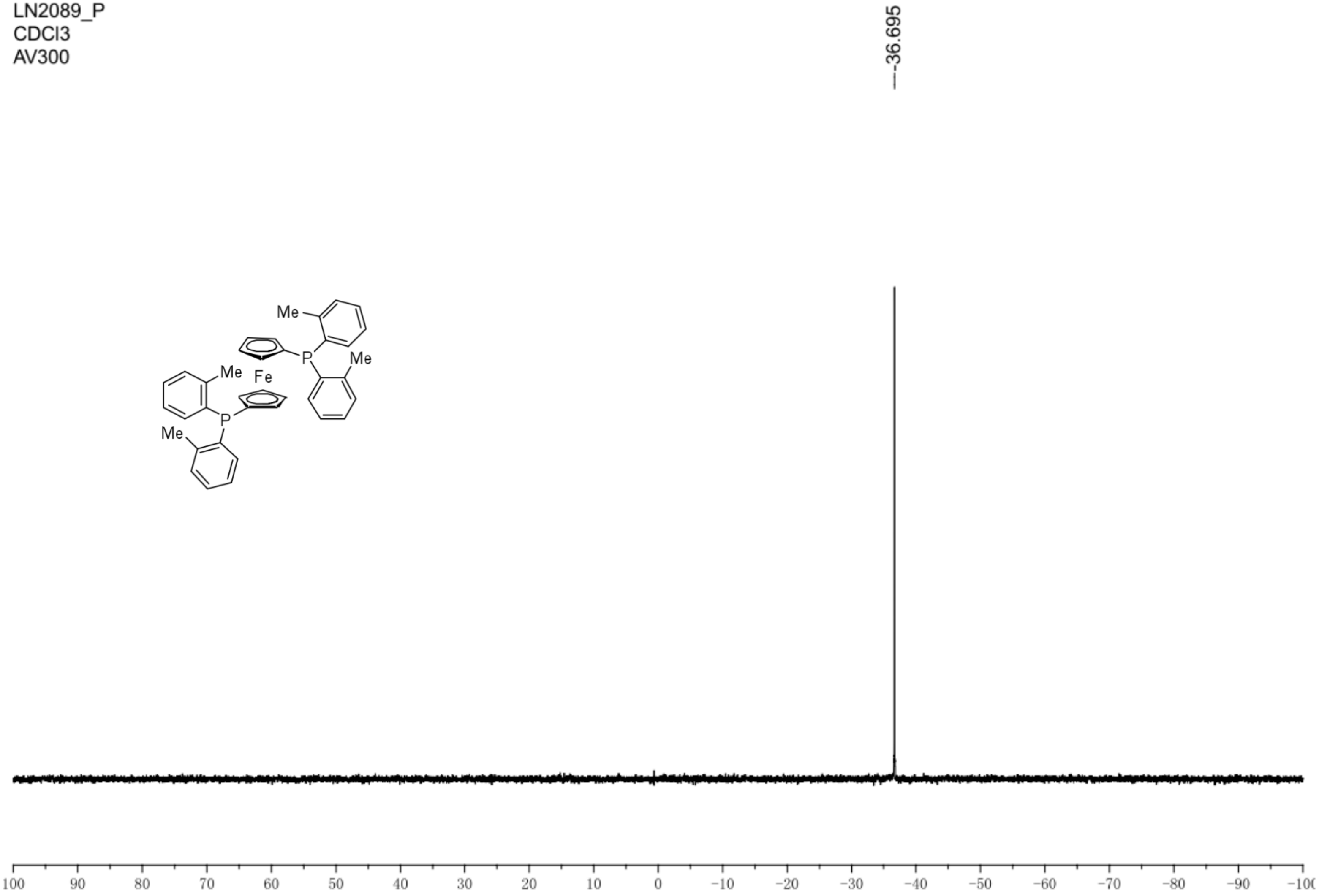
1
2
3
4
5
6
7
8
9
Me
Me
Me
Me
P
P
Fe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Fe
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Me
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80
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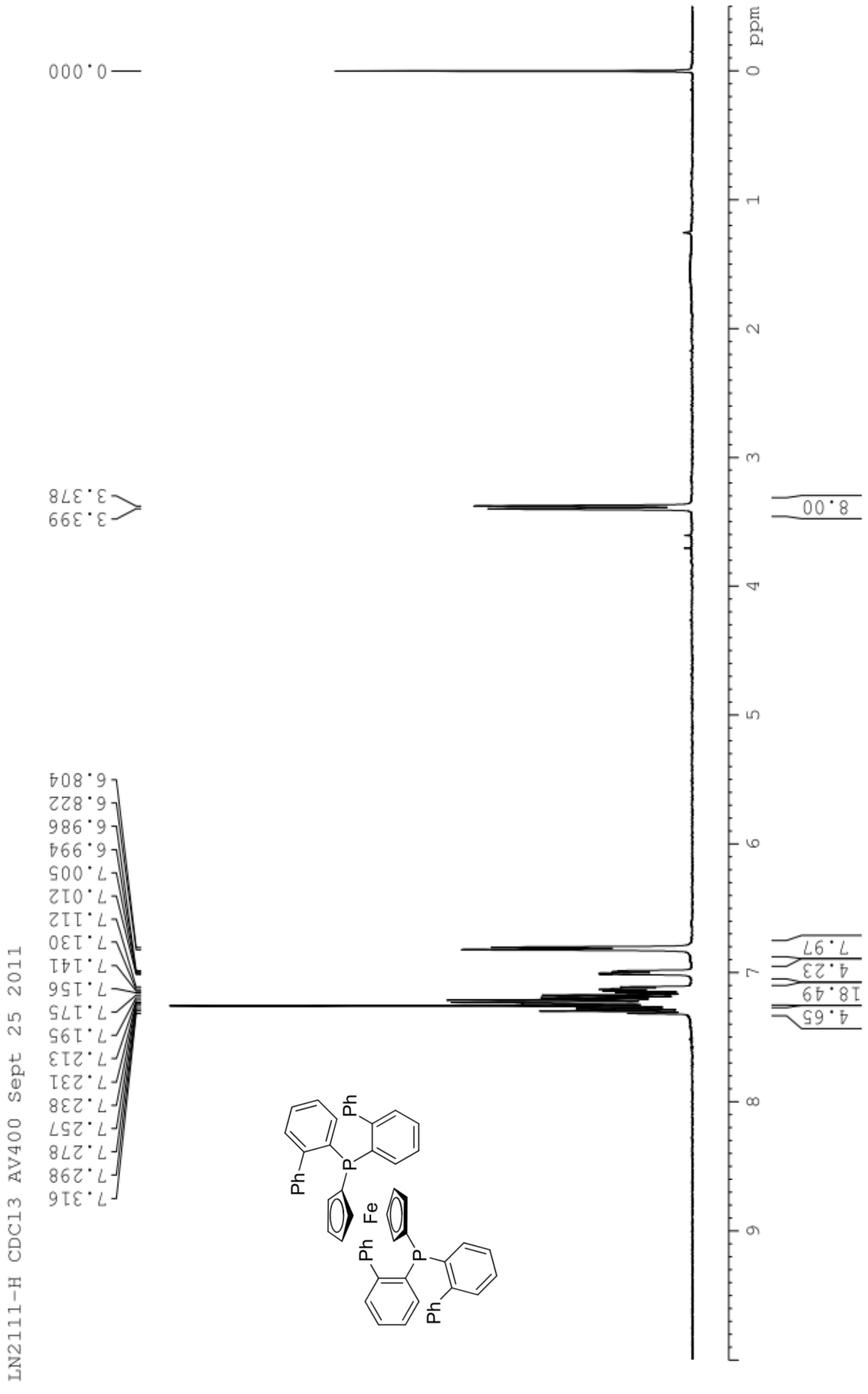
−50
−60
−70
−80
−90
−100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7.130
7.141
7.156
7.175
7.195
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7.231
7.238
7.257
7.278
7.298
7.316
8.00
7.97
4.23
18.49
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Ph
P
Fe
Ph
P
Ph
ppm
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2
3
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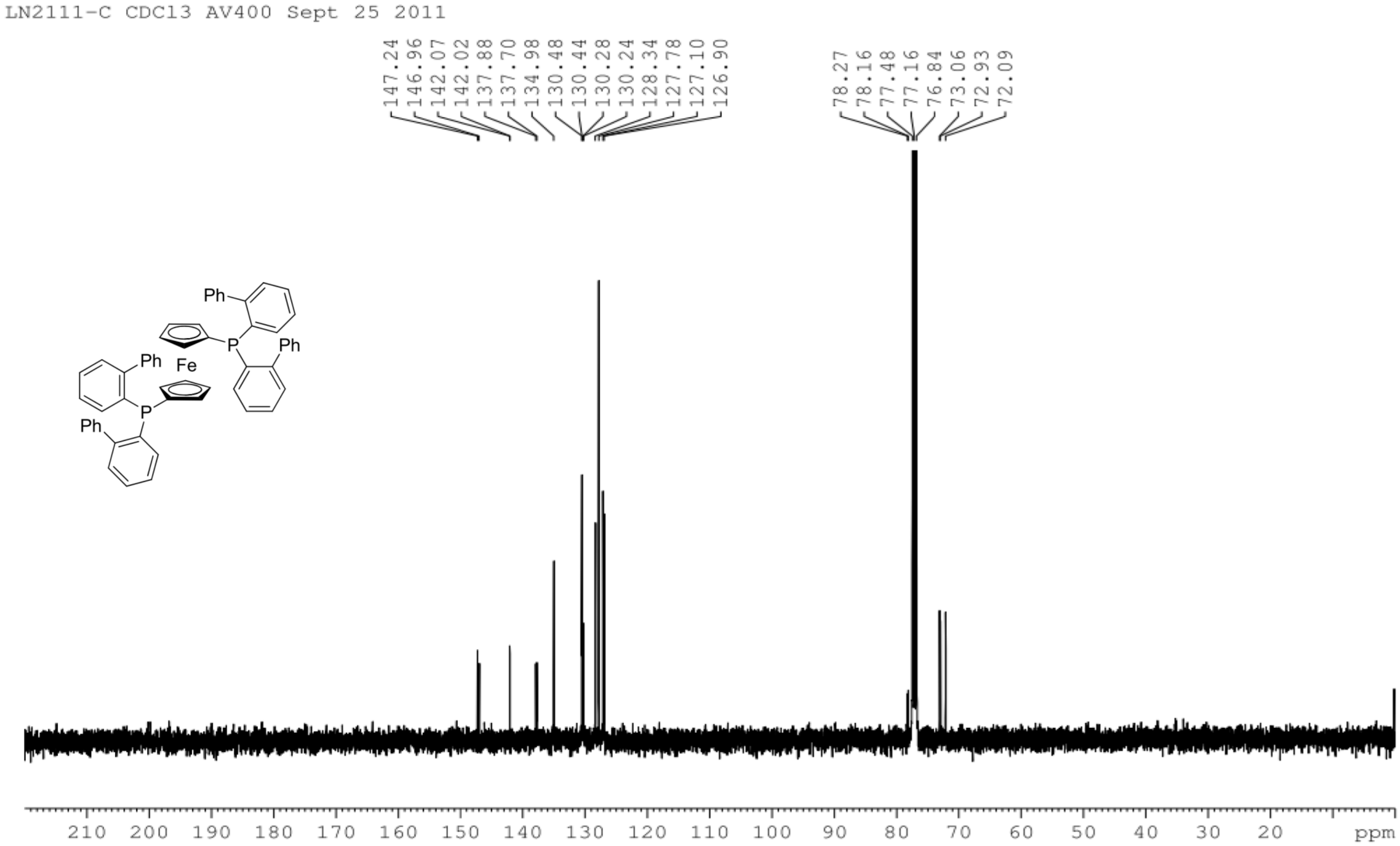
5
6
7
8
9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142.07
142.02
137.88
137.70
134.98
130.48
130.44
130.28
130.24
128.34
127.78
127.10
126.90
78.27
78.16
77.48
77.16
76.84
73.06
72.93
72.09
Ph
Ph
Fe
P
Ph
P
Ph
210
200
190
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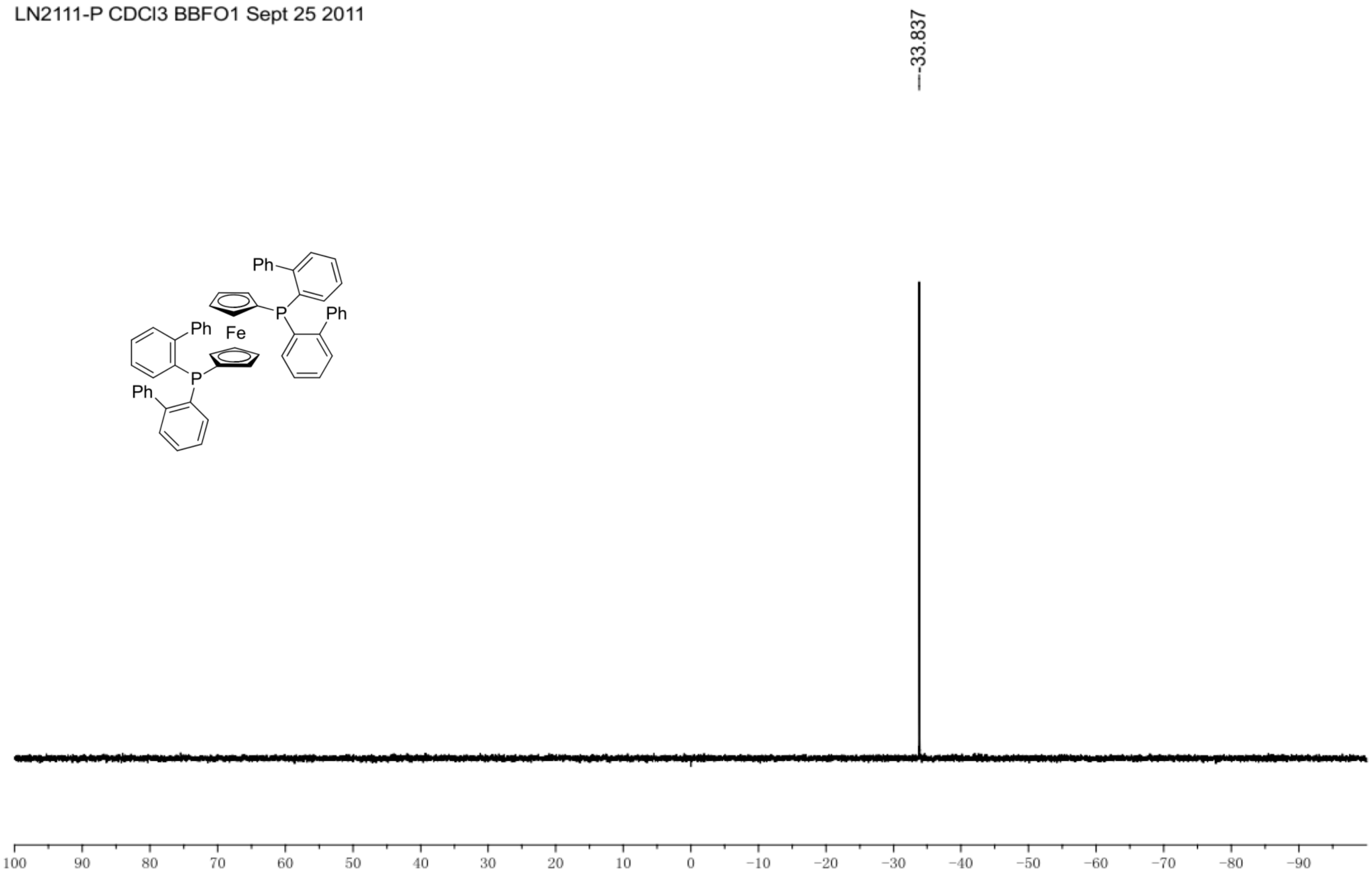
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
ppm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P
Ph
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20
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−40
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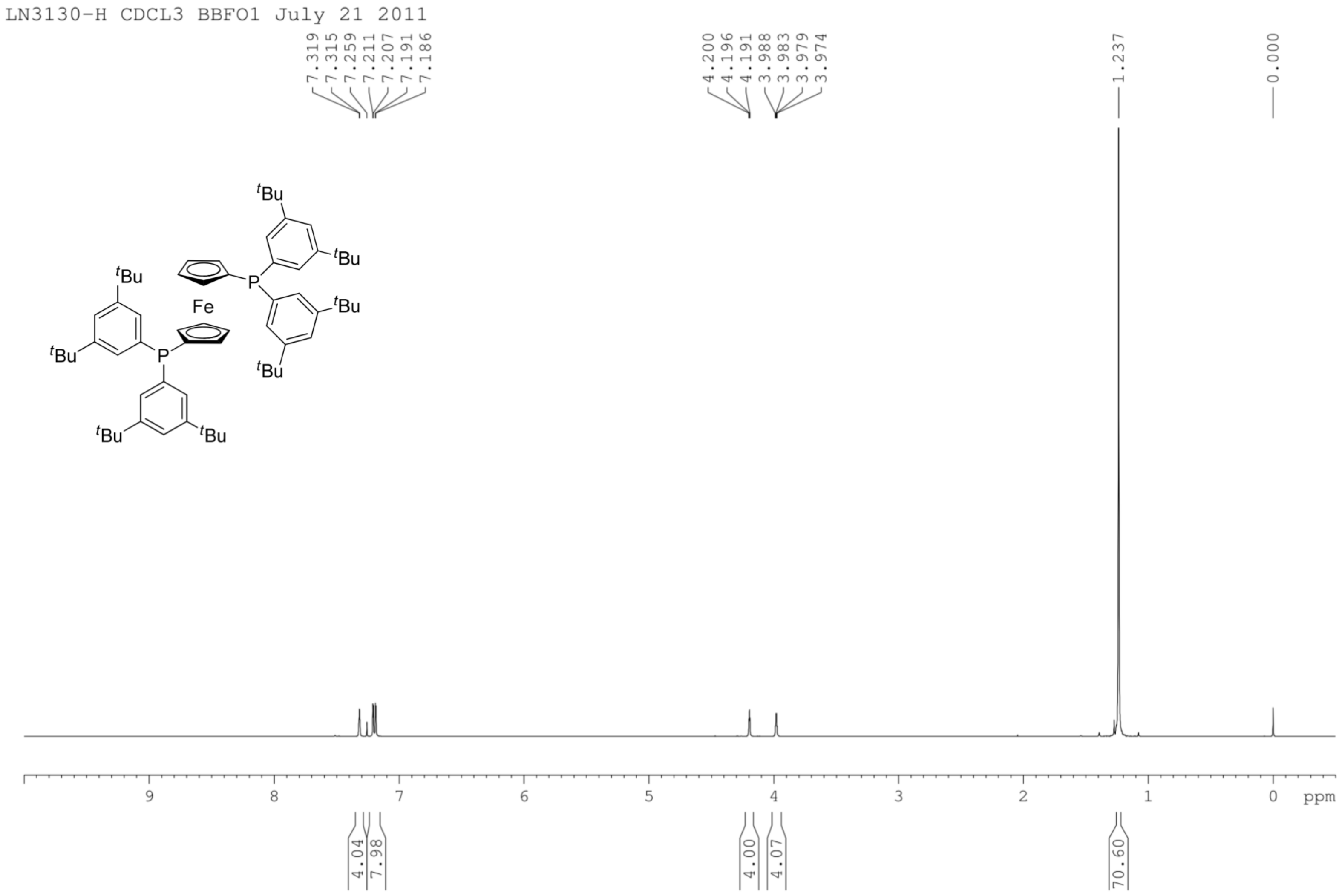
−70
−80
−90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7.186
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4.191
3.988
3.983
3.979
3.974
1.237
0.000
tBu
P
Fe
9
8
7
6
5
4
3
2
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ppm
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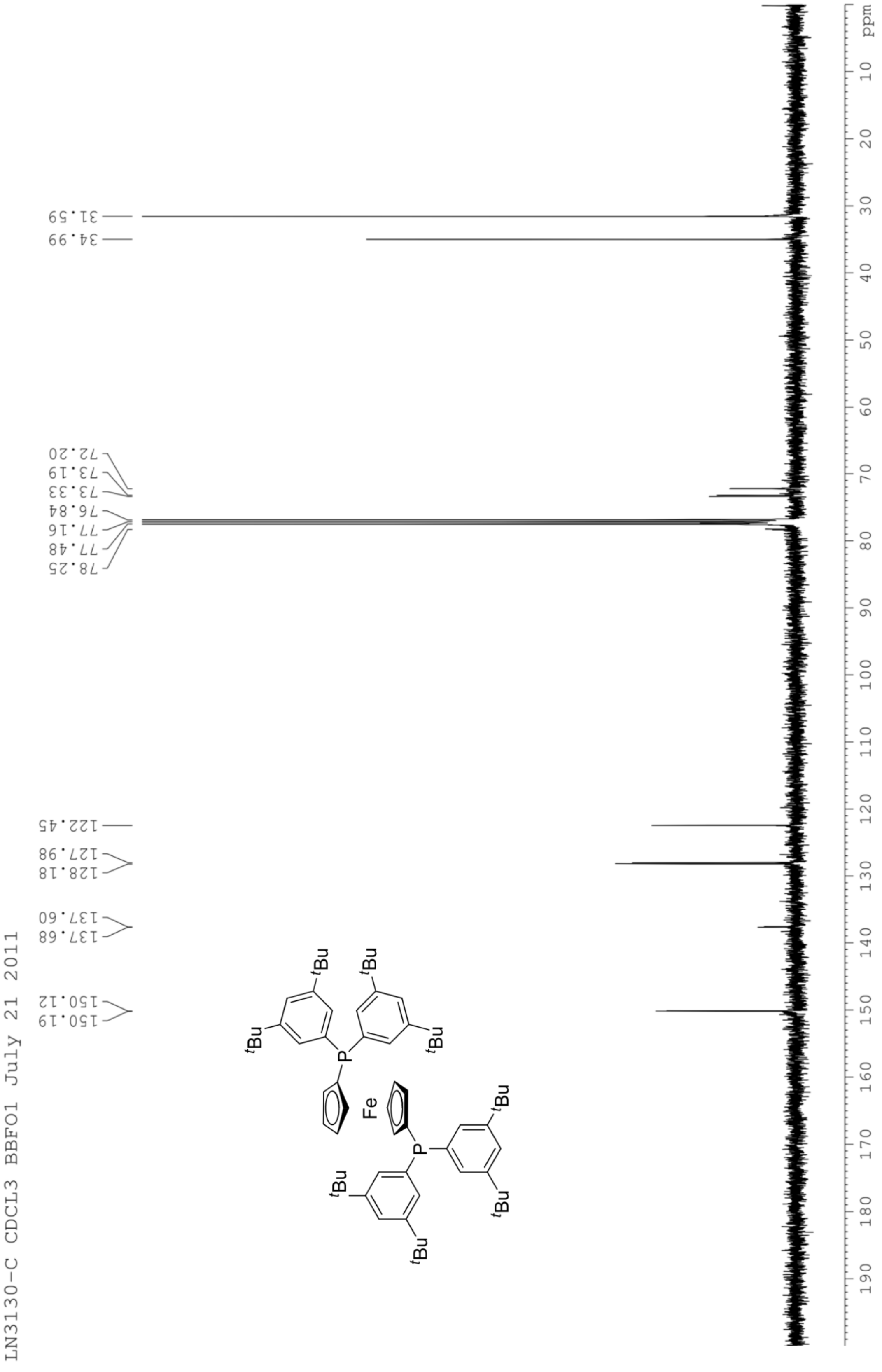
4.00
4.07
70.60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122.45
127.98
128.18
137.60
137.68
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150.19
ppm
10
20
30
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90
100
110
120
130
140
150
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170
180
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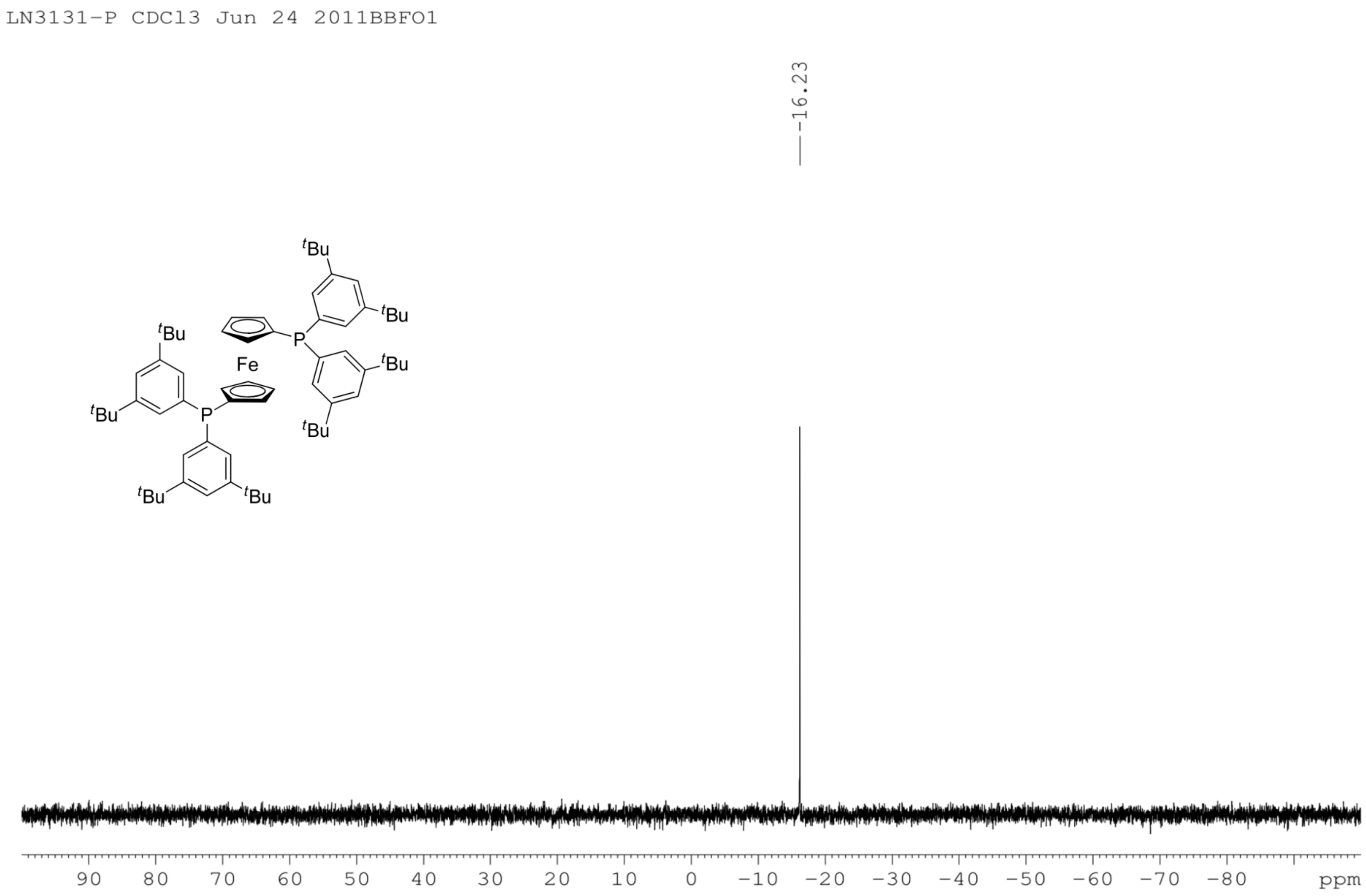
Fe
P
P
^{t}Bu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P
^{t}Bu
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20
10
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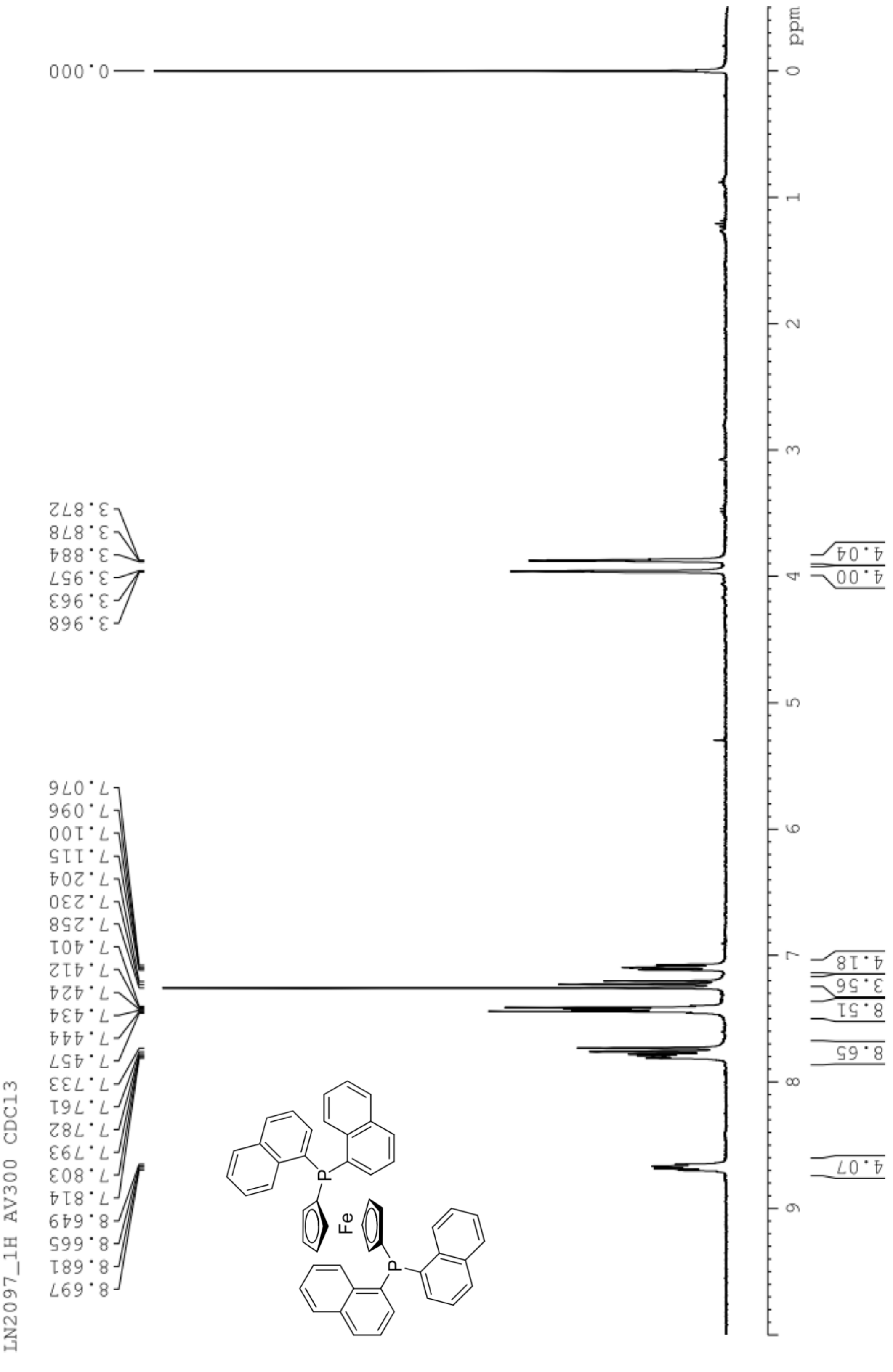
−30
−40
−50
−60
−70
−80
ppm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7.100
7.115
7.204
7.230
7.258
7.401
7.412
7.424
7.434
7.444
7.457
7.733
7.761
7.782
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8.649
8.665
8.681
8.697
P
Fe
P
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8.65
4.07
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2
3
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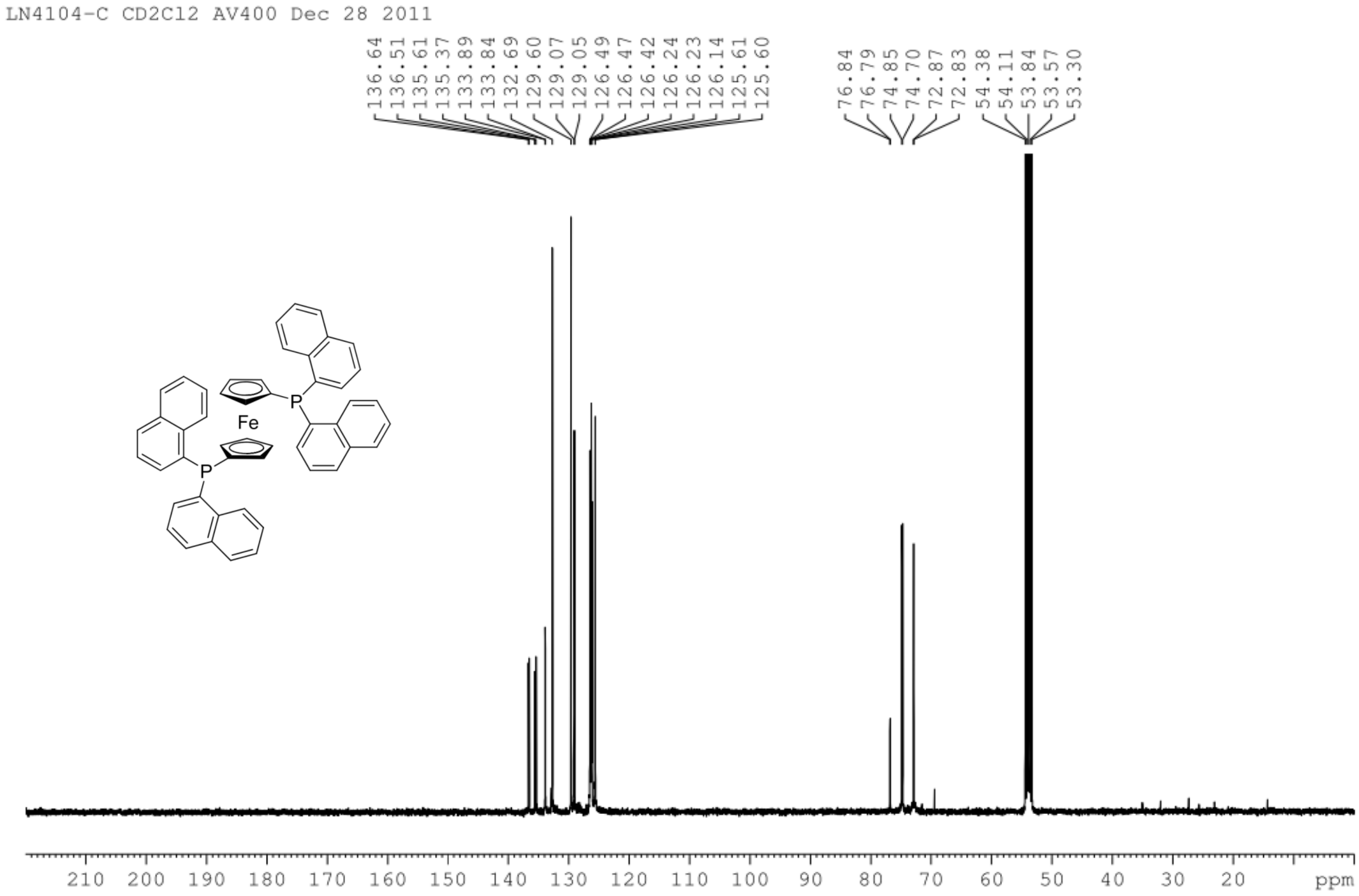
5
6
7
8
9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126.49
126.47
126.42
126.24
126.23
126.14
125.61
125.60
76.84
76.79
74.85
74.70
72.87
72.83
54.38
54.11
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53.30
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P
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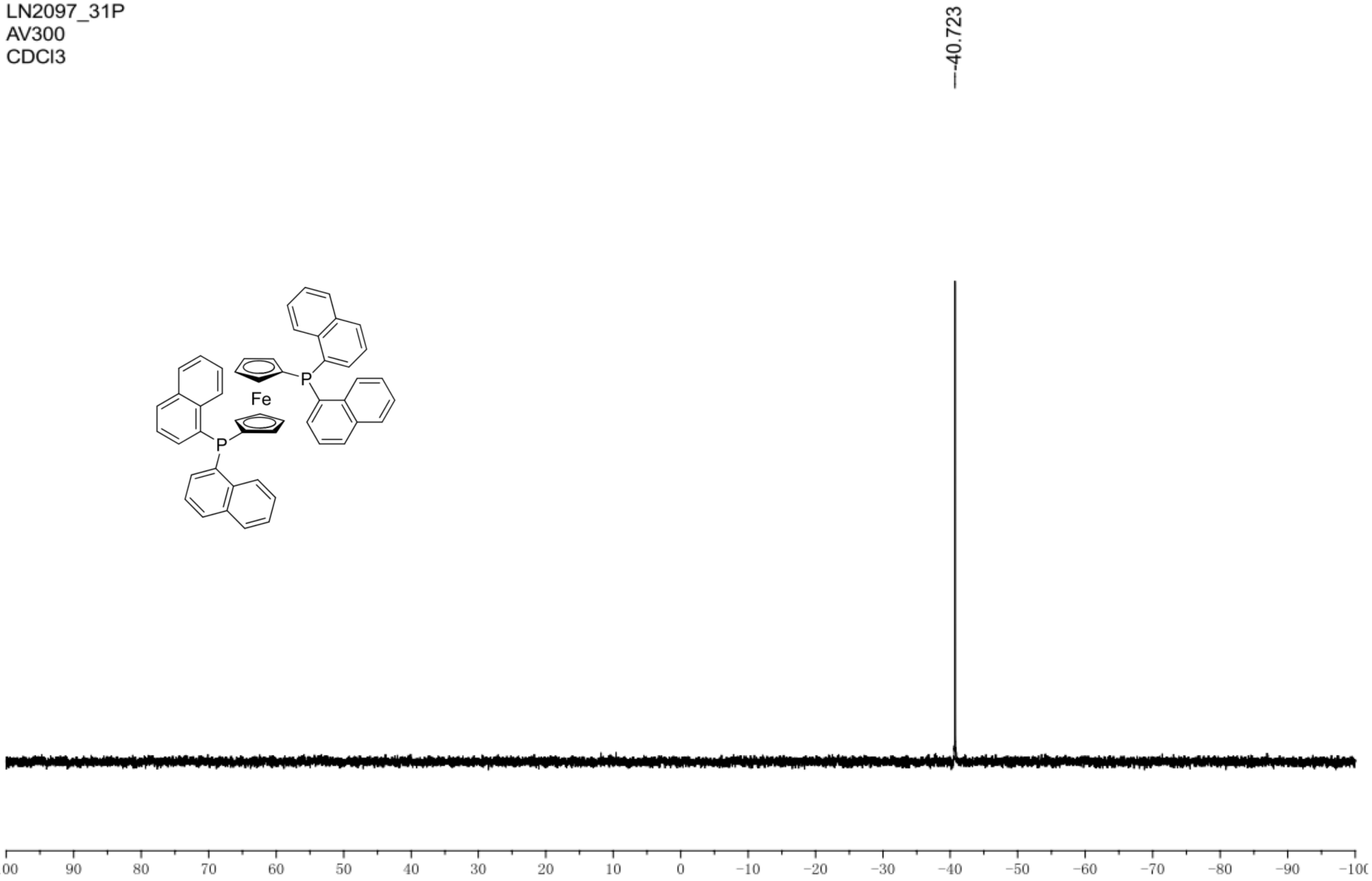
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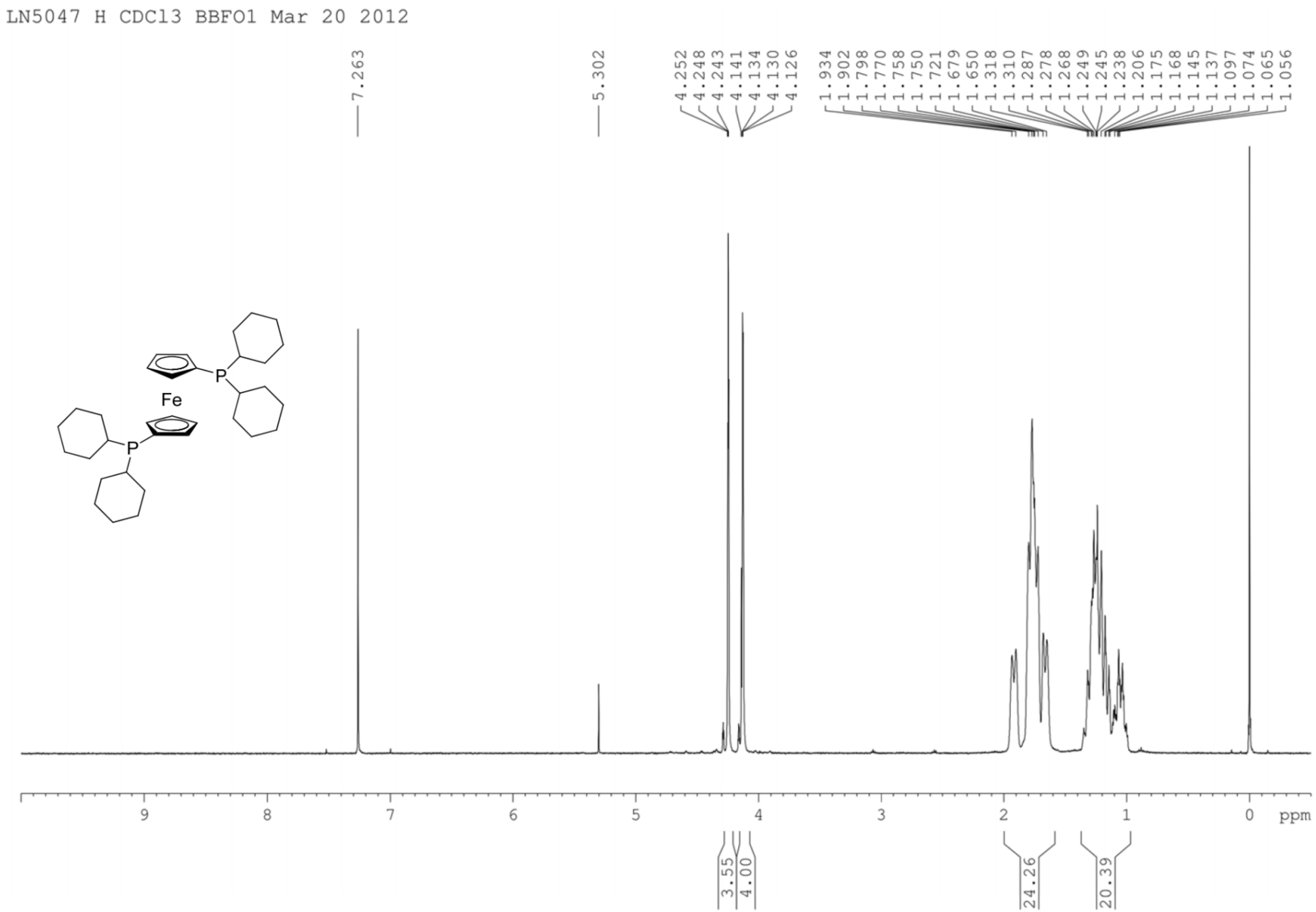
−80
−90
−100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1.758
1.750
1.721
1.679
1.650
1.318
1.310
1.287
1.278
1.268
1.249
1.245
1.238
1.206
1.175
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1.137
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1.065
1.056
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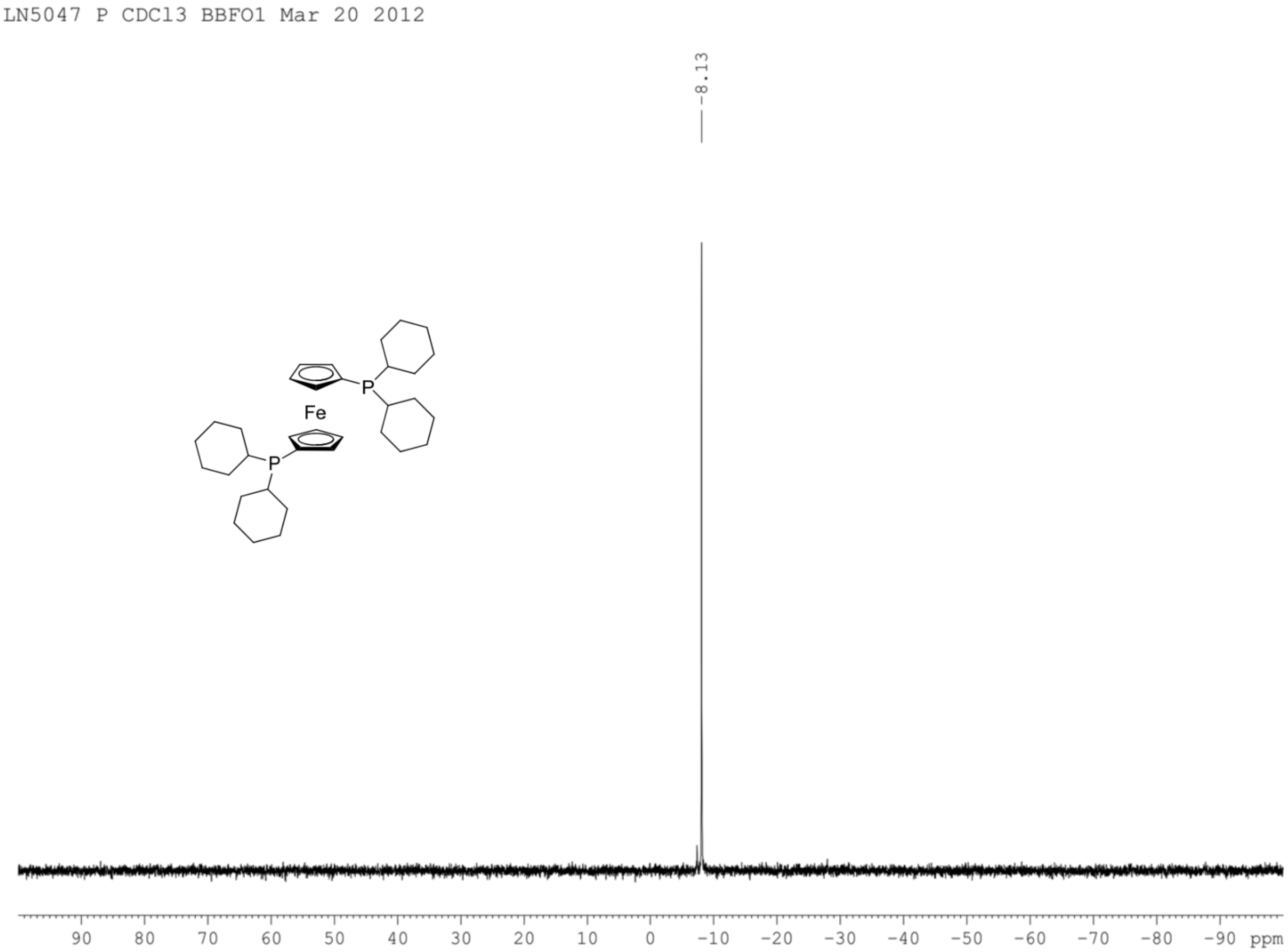
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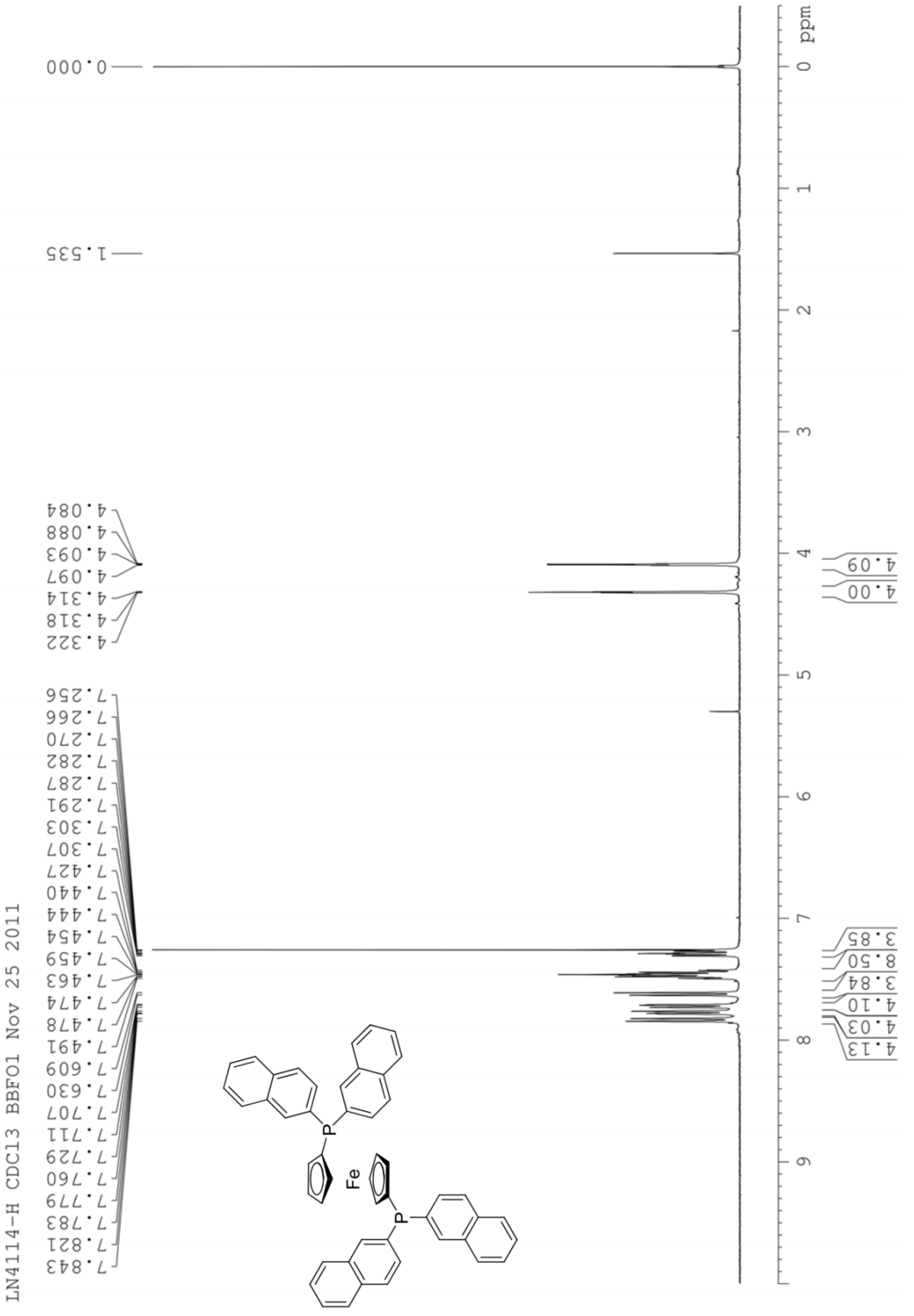
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7.266
7.270
7.282
7.287
7.291
7.303
7.307
7.427
7.440
7.444
7.454
7.459
7.463
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7.478
7.491
7.609
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7.729
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7.783
7.821
7.843
Fe
P
P
ppm
0
1
2
3
4
5
6
7
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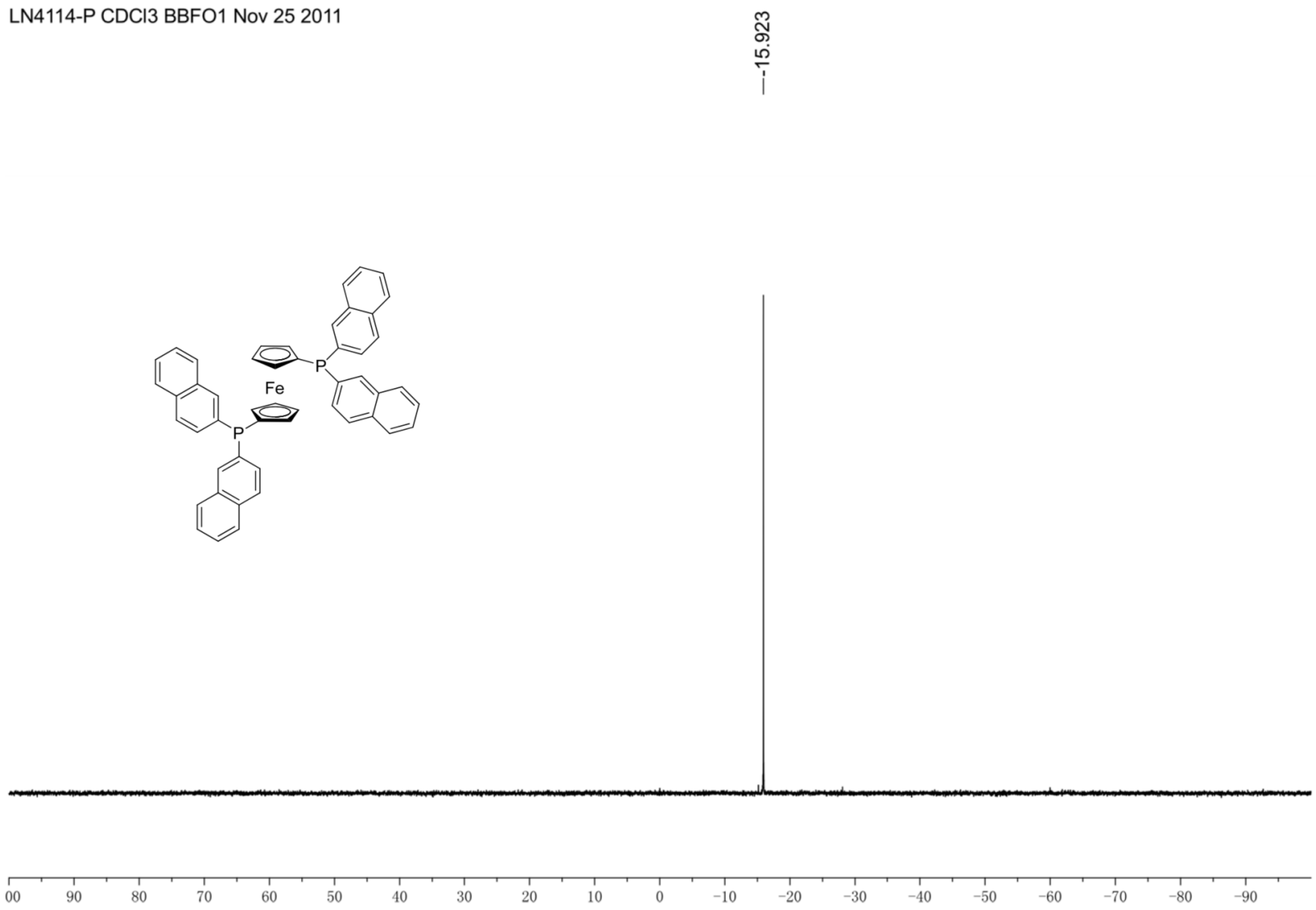

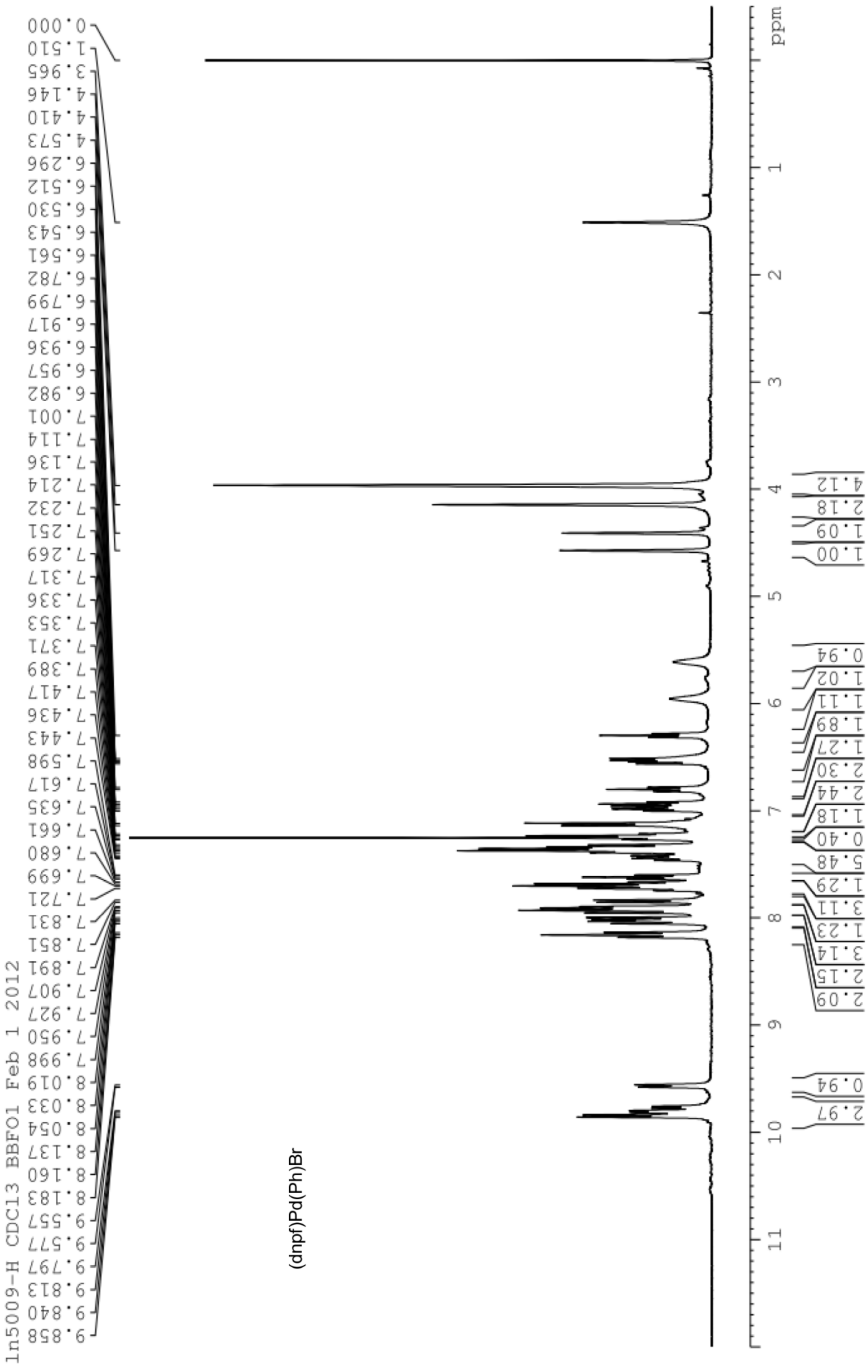
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6.957
6.982
7.001
7.114
7.136
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7.927
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7.998
8.019
8.033
8.054
8.137
8.160
8.183
9.557
9.577
9.797
9.813
9.840
9.858
(dnpf)Pd(Ph)Br
4.12
2.18
1.09
1.00
0.94
1.02
1.11
1.89
1.27
2.30
2.44
1.18
0.40
5.48
1.29
3.11
1.23
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ppm
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2
3
4
5
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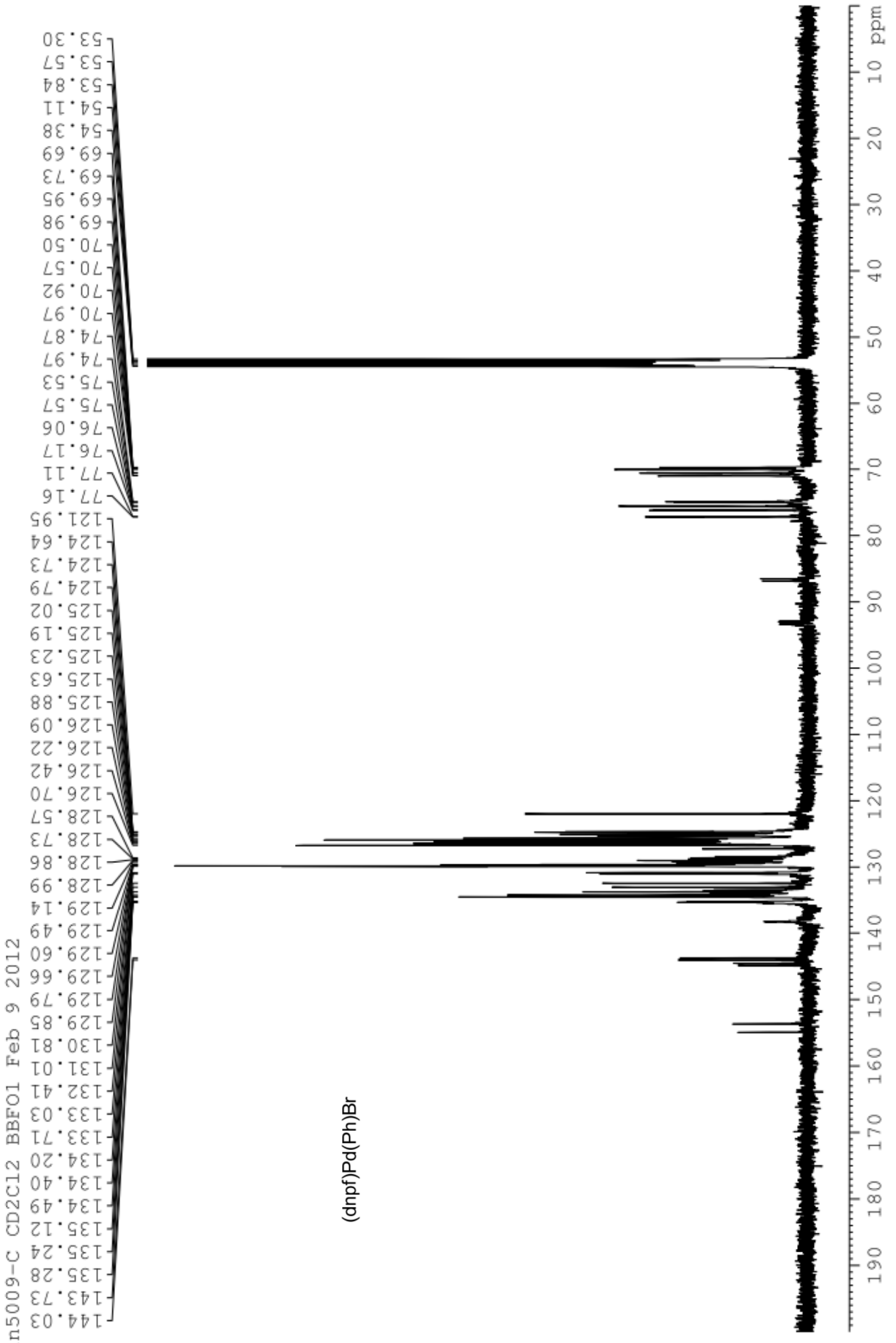
7
8
9
10
11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133.71
133.03
132.41
131.01
130.81
129.85
129.79
129.66
129.60
129.49
129.14
128.99
128.86
128.73
128.57
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125.19
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76.06
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70.92
70.57
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69.95
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69.69
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53.57
53.30
190
180
170
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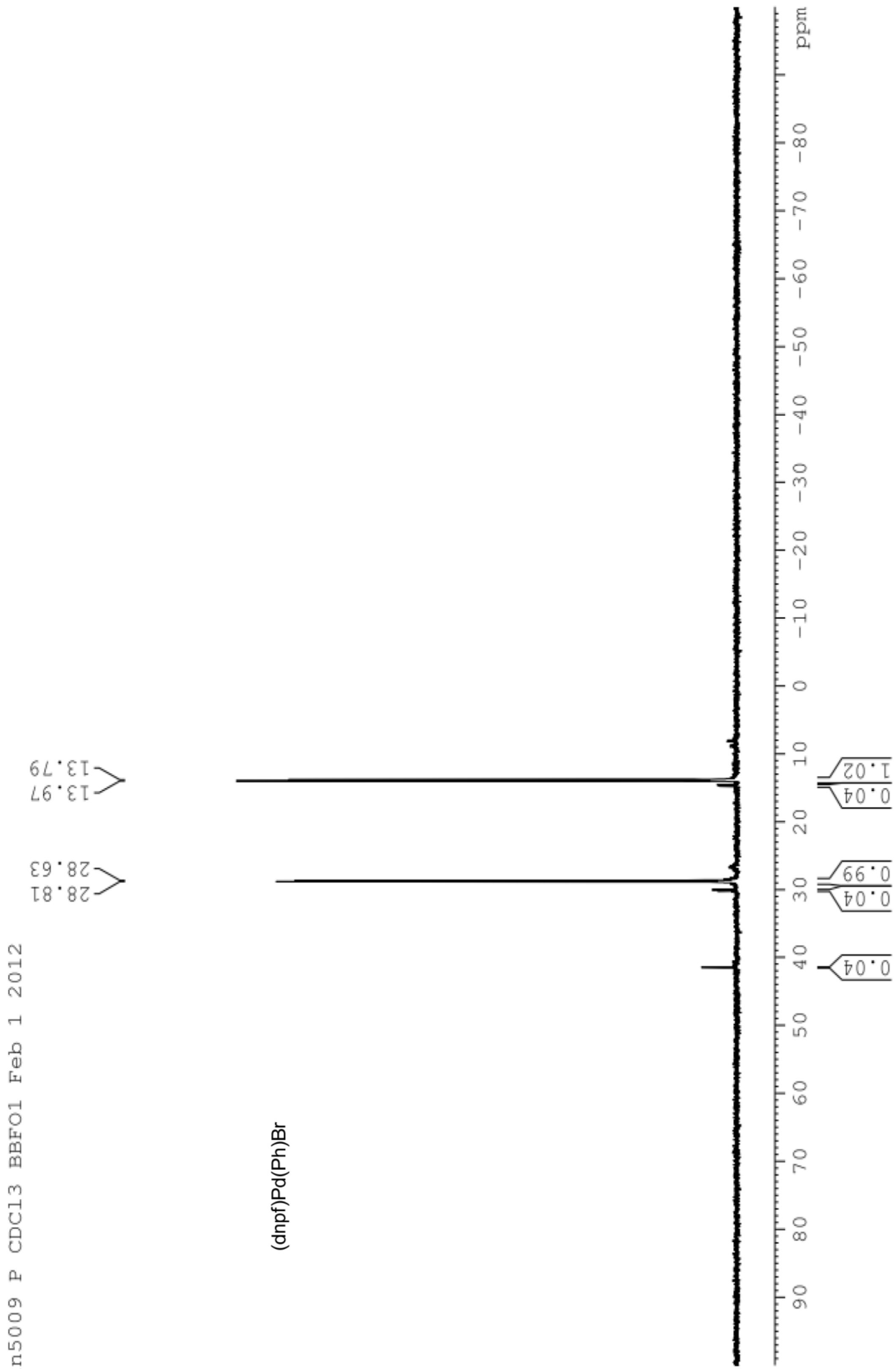
ppm

(dnpf)Pd(Ph)Br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40
30
20
10
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-50
-60
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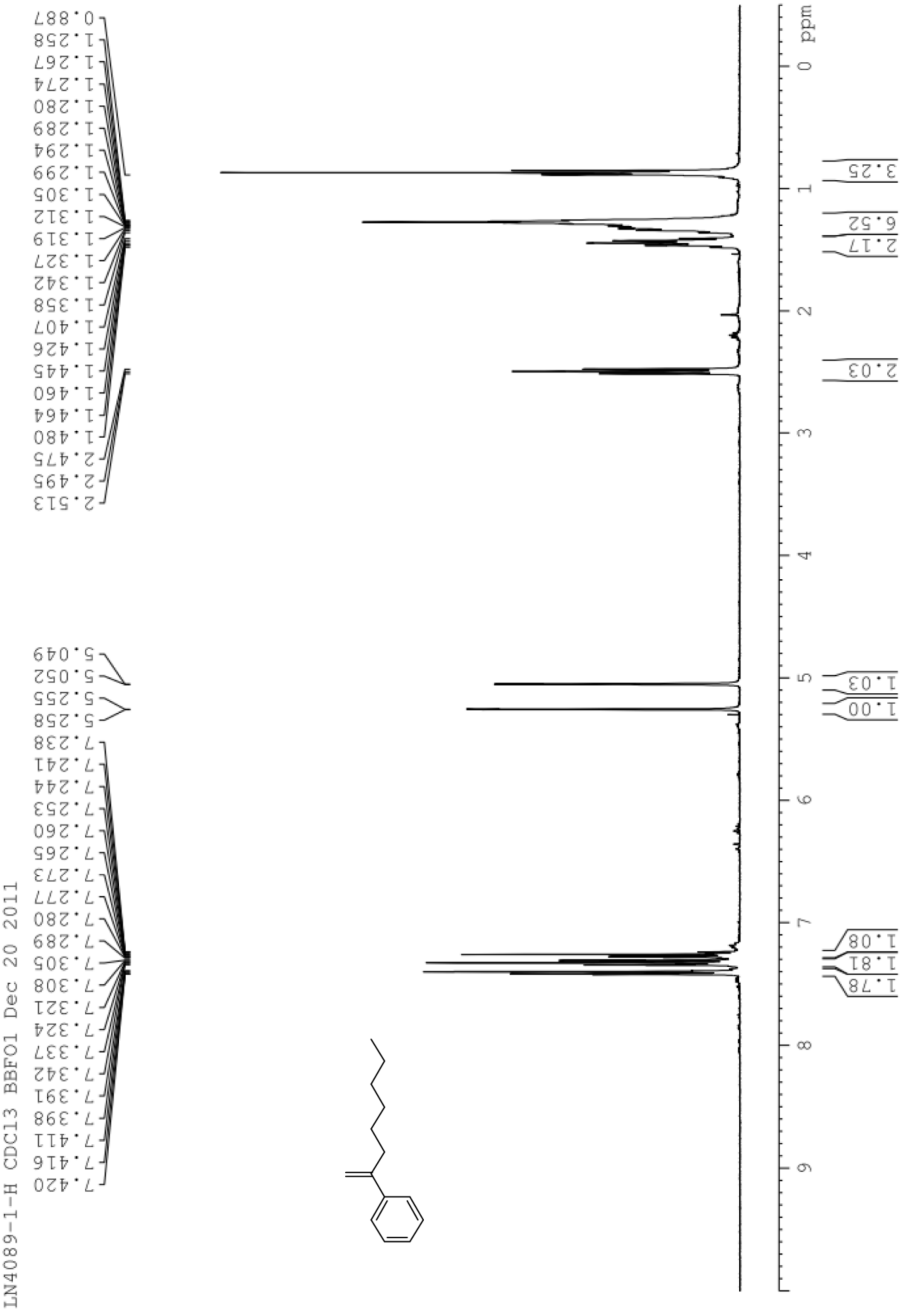
0.04
0.04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7.260
7.253
7.244
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5.049
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2.495
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1.464
1.460
1.445
1.426
1.407
1.358
1.342
1.327
1.319
1.312
1.305
1.299
1.294
1.289
1.280
1.274
1.267
1.258
0.887
1.78
1.81
1.08
1.00
1.03
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6
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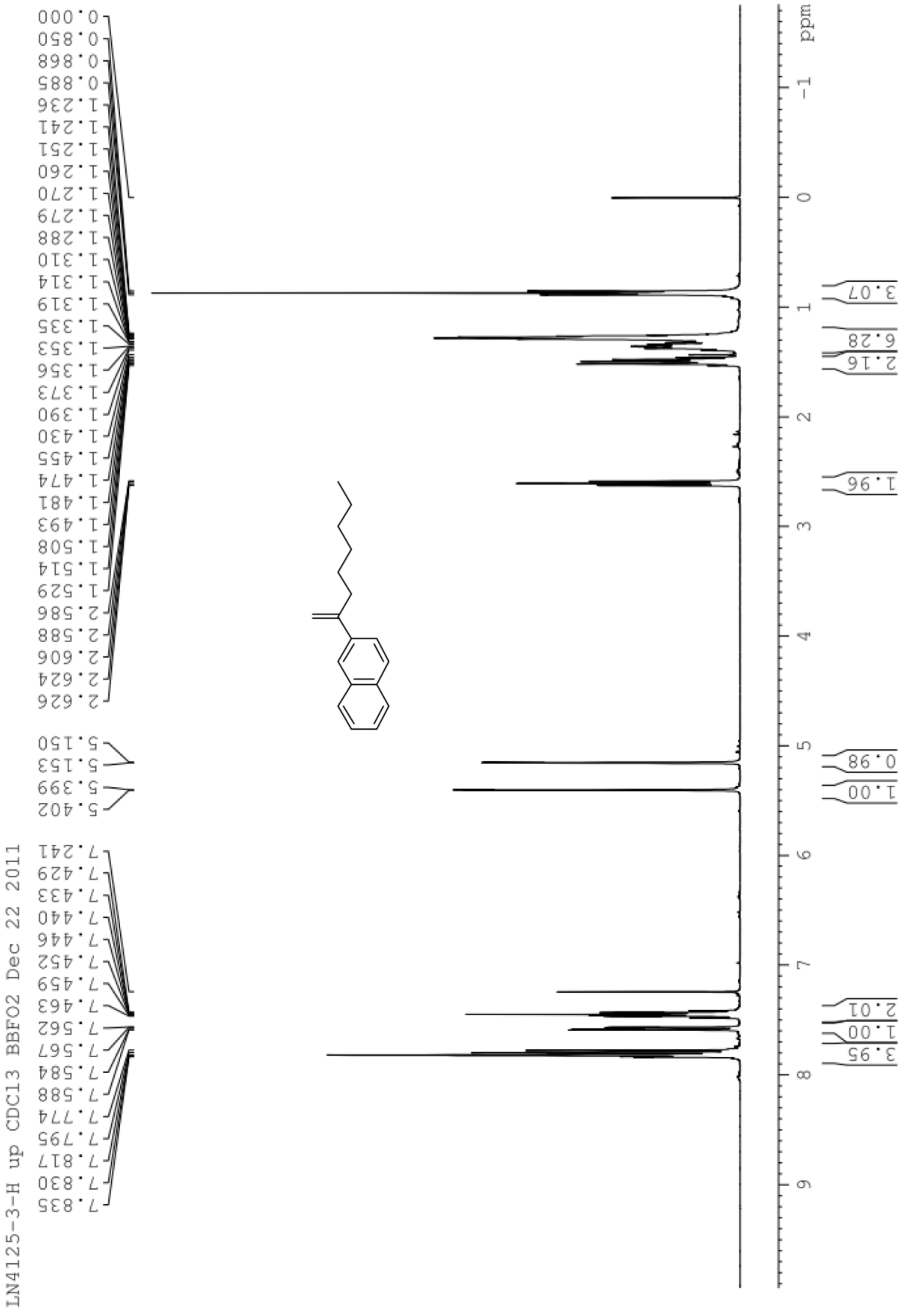
ppm


LN4125-3-H up CDCl3 BBFO2 Dec 22 2011
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7.830
7.817
7.795
7.774
7.588
7.584
7.567
7.562
7.463
7.459
7.452
7.446
7.440
7.433
7.429
7.241
5.402
5.399
5.153
5.150
2.626
2.624
2.606
2.588
2.586
1.529
1.514
1.508
1.493
1.481
1.474
1.455
1.430
1.390
1.373
1.356
1.353
1.335
1.319
1.314
1.310
1.288
1.279
1.270
1.260
1.251
1.241
1.236
0.885
0.868
0.850
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1.00
2.01
1.00
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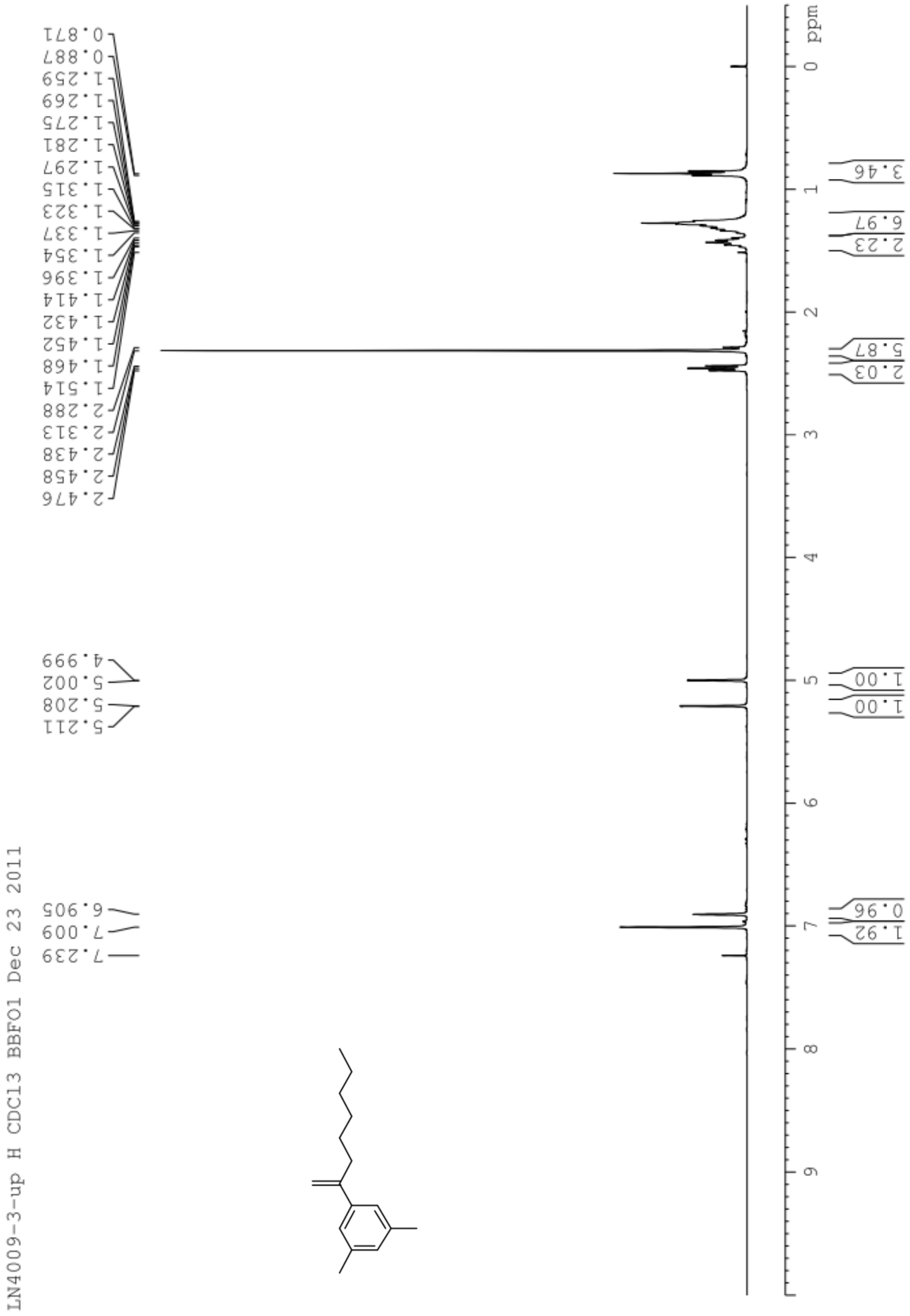
LN4009-3-up H CDCl3 BBFO1 Dec 23 2011
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0.887
1.259
1.269
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1.281
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1.323
1.337
1.354
1.396
1.414
1.432
1.452
1.468
1.514
2.288
2.313
2.438
2.458
2.476
4.999
5.002
5.208
5.211
6.905
7.009
7.239
3.46
6.97
2.23
5.87
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1.00
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ppm
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2
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8
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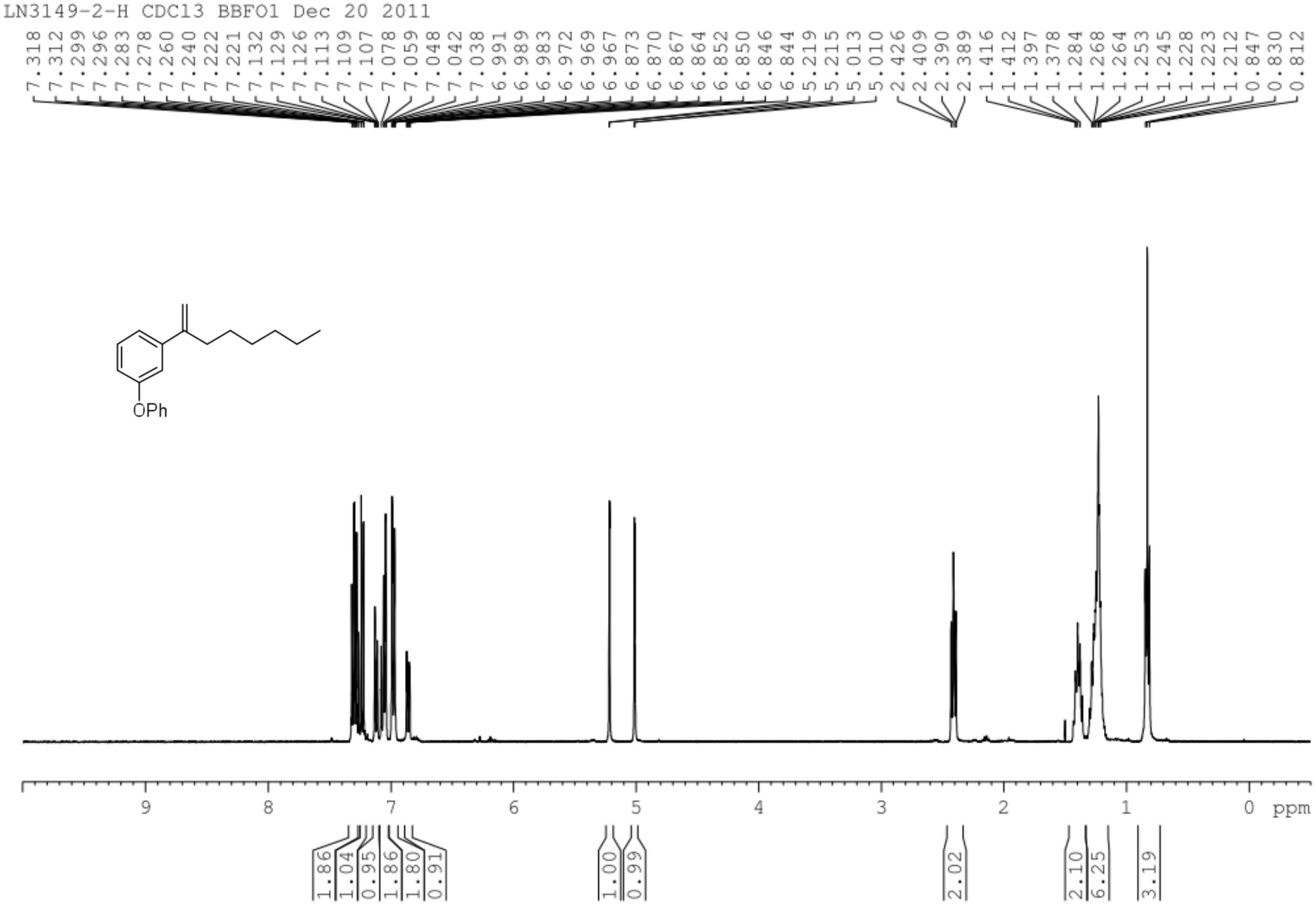
LN3149-2-H CDCl3 BBFO1 Dec 20 2011
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7.312
7.299
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7.283
7.278
7.260
7.240
7.222
7.221
7.132
7.129
7.126
7.113
7.109
7.107
7.078
7.059
7.048
7.042
7.038
6.991
6.989
6.983
6.972
6.969
6.967
6.873
6.870
6.867
6.864
6.852
6.850
6.846
6.844
5.219
5.215
5.013
5.010
2.426
2.409
2.390
2.389
1.416
1.412
1.397
1.378
1.284
1.268
1.264
1.253
1.245
1.228
1.223
1.212
0.847
0.830
0.812
OPh
9
8
7
6
5
4
3
2
1
0 ppm
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0.95
1.86
1.80
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0.99
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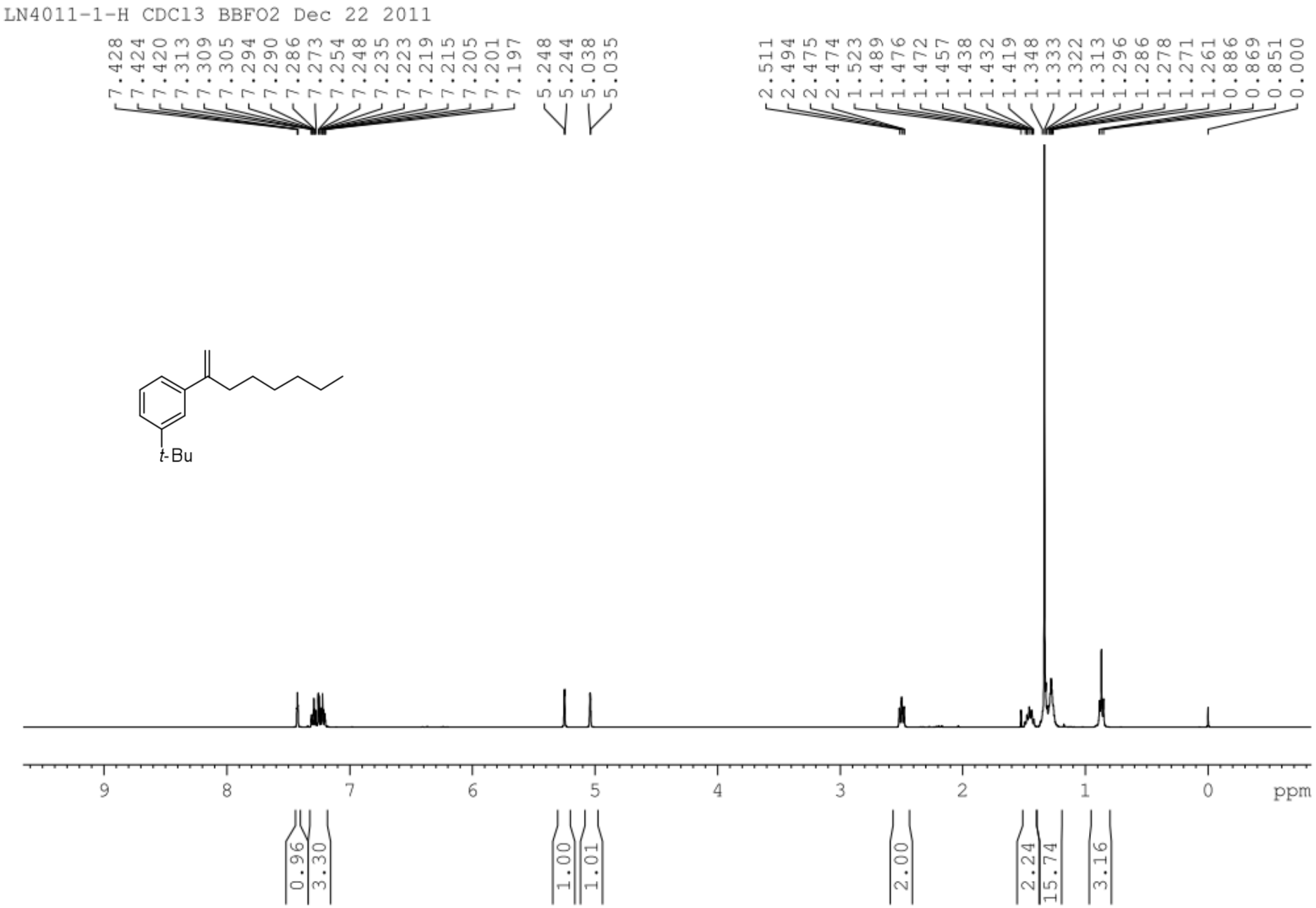
2.10
6.25
3.19


LN4011-1-H CDCl3 BBFO2 Dec 22 2011
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7.424
7.420
7.313
7.309
7.305
7.294
7.290
7.286
7.273
7.254
7.248
7.235
7.223
7.219
7.215
7.205
7.201
7.197
5.248
5.244
5.038
5.035
2.511
2.494
2.475
2.474
1.523
1.489
1.476
1.472
1.457
1.438
1.432
1.419
1.348
1.333
1.322
1.313
1.296
1.286
1.278
1.271
1.261
0.886
0.869
0.851
0.000
t-Bu
9
8
7
6
5
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ppm
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3.30
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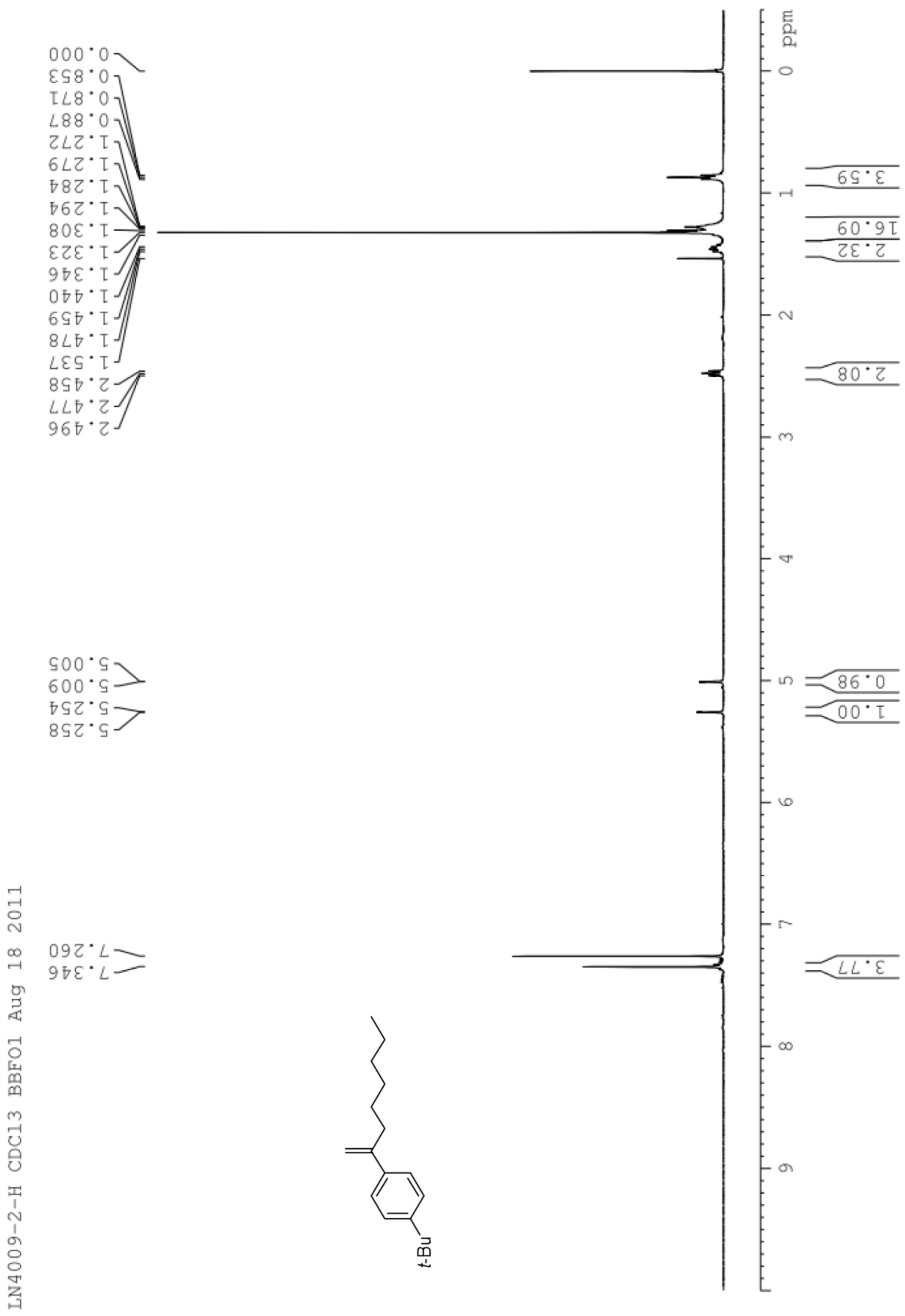
1.01
2.00
2.24
15.74
3.16



LN4009-2-H CDCl3 BBFO1 Aug 18 2011
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1.272
1.279
1.284
1.294
1.308
1.323
1.346
1.440
1.459
1.478
1.537
2.458
2.477
2.496
5.005
5.009
5.254
5.258
7.260
7.346
t-Bu
3.59
16.09
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2.08
0.98
1.00
3.77
ppm
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2
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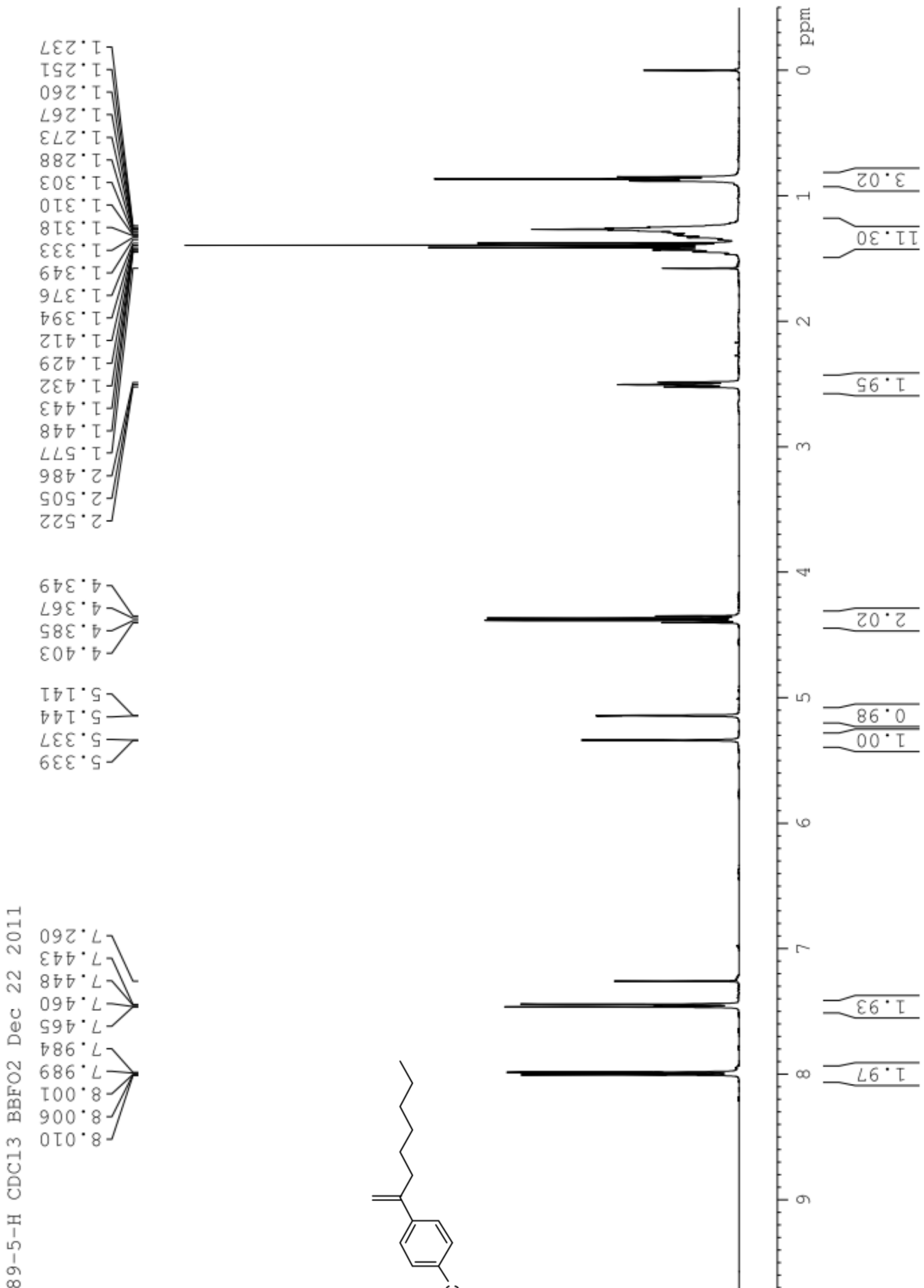
5
6
7
8
9


LN4089-5-H CDCl3 BBFO2 Dec 22 2011
EtO2C
1.237
1.251
1.260
1.267
1.273
1.288
1.303
1.310
1.318
1.333
1.349
1.376
1.394
1.412
1.429
1.432
1.443
1.448
1.577
2.486
2.505
2.522
4.349
4.367
4.385
4.403
5.141
5.144
5.337
5.339
7.260
7.443
7.448
7.460
7.465
7.984
7.989
8.001
8.006
8.010
3.02
11.30
1.95
2.02
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1.00
1.93
1.97
ppm
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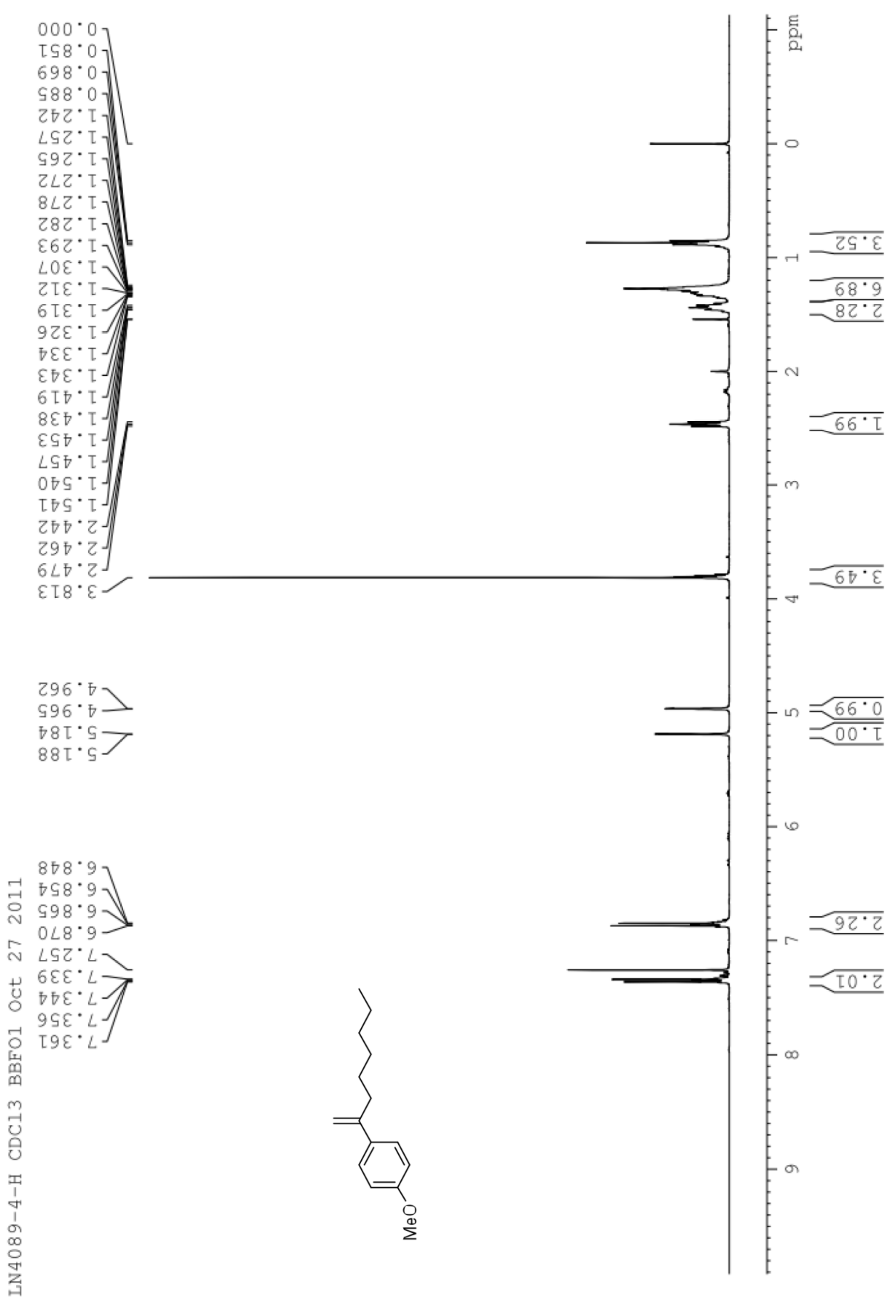
1
2
3
4
5
6
7
8
9


LN4089-4-H CDCl3 BBFO1 Oct 27 2011
0.000
0.851
0.869
0.885
1.242
1.257
1.265
1.272
1.278
1.282
1.293
1.307
1.312
1.319
1.326
1.334
1.343
1.419
1.438
1.453
1.457
1.540
1.541
2.442
2.462
2.479
3.813
4.962
4.965
5.184
5.188
6.848
6.854
6.865
6.870
7.257
7.339
7.344
7.356
7.361
MeO
ppm
0
1
2
3
4
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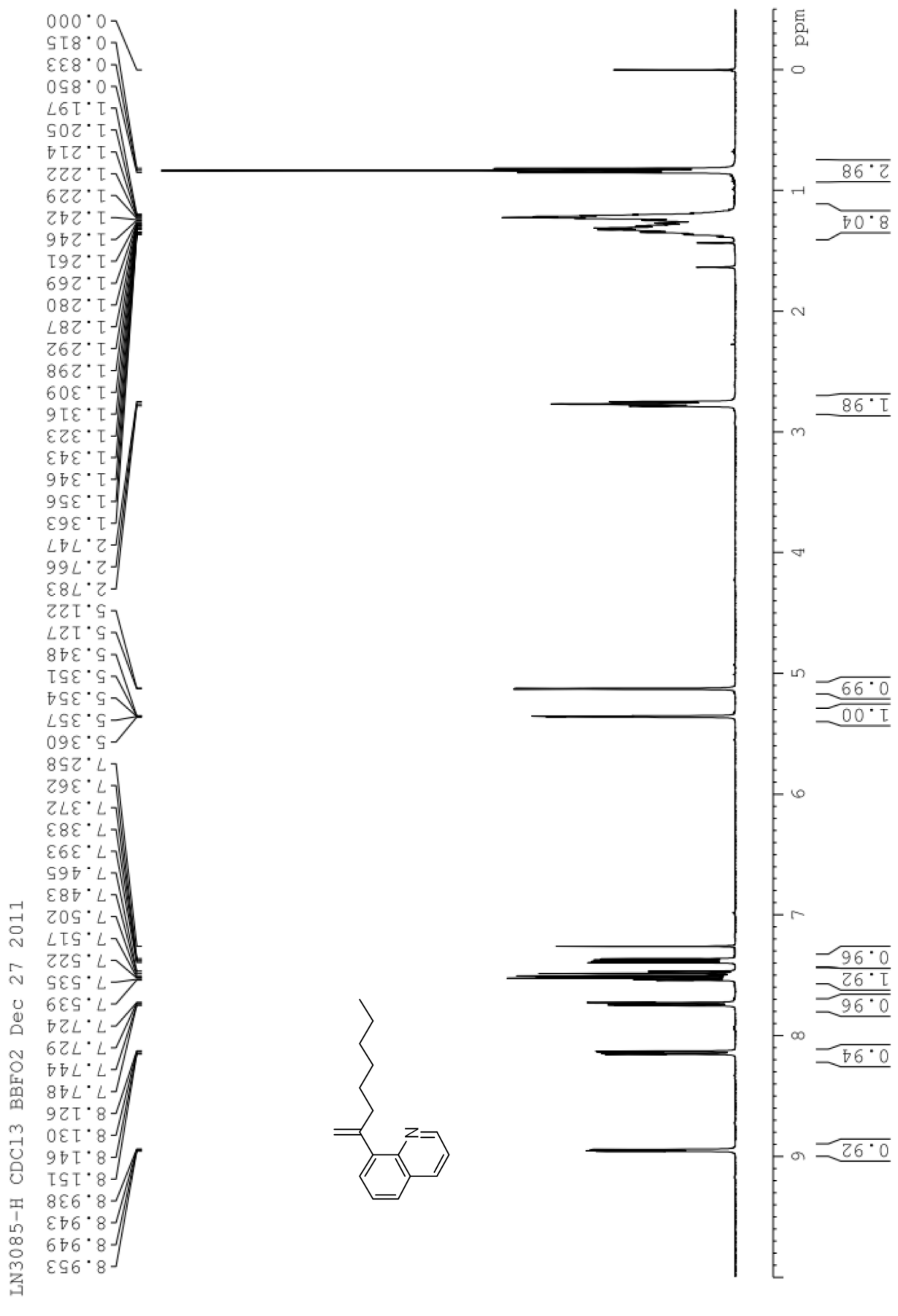
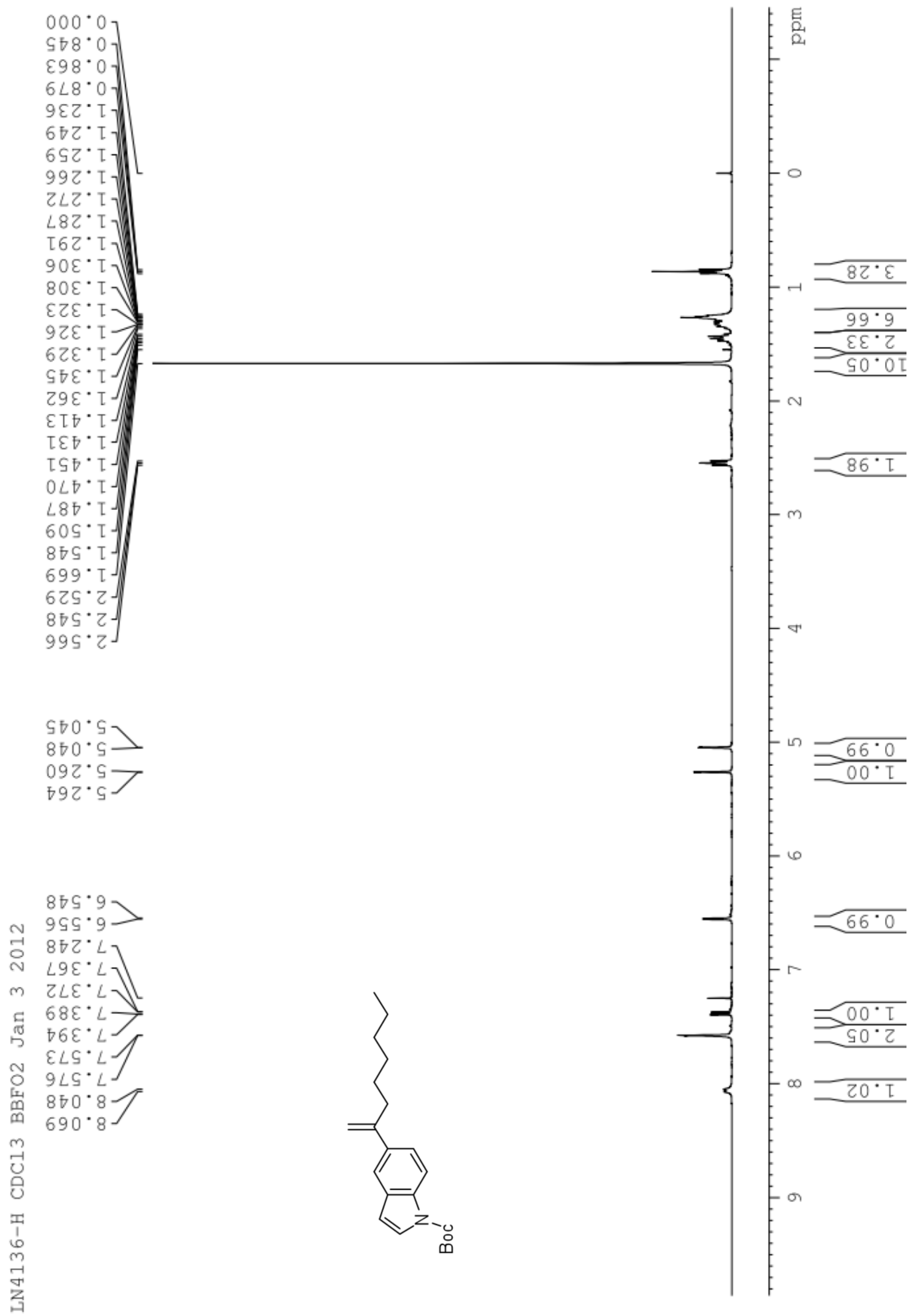
9
3.52
6.89
2.28
1.99
3.49
0.99
1.00
2.26
2.01


LN3085-H CDCl3 BBFO2 Dec 27 2011
0.000
0.815
0.833
0.850
1.197
1.205
1.214
1.222
1.229
1.242
1.246
1.261
1.269
1.280
1.287
1.292
1.298
1.309
1.316
1.323
1.343
1.346
1.356
1.363
2.747
2.766
2.783
5.122
5.127
5.348
5.351
5.354
5.357
5.360
7.258
7.362
7.372
7.383
7.393
7.465
7.483
7.502
7.517
7.522
7.535
7.539
7.724
7.729
7.744
7.748
8.126
8.130
8.146
8.151
8.938
8.943
8.949
8.953
N
2.98
8.04
1.98
0.99
1.00
0.96
1.92
0.96
0.94
0.92
0
1
2
3
4
5
6
7
8
9
ppm


LN4136-H CDCl3 BBFO2 Jan 3 2012
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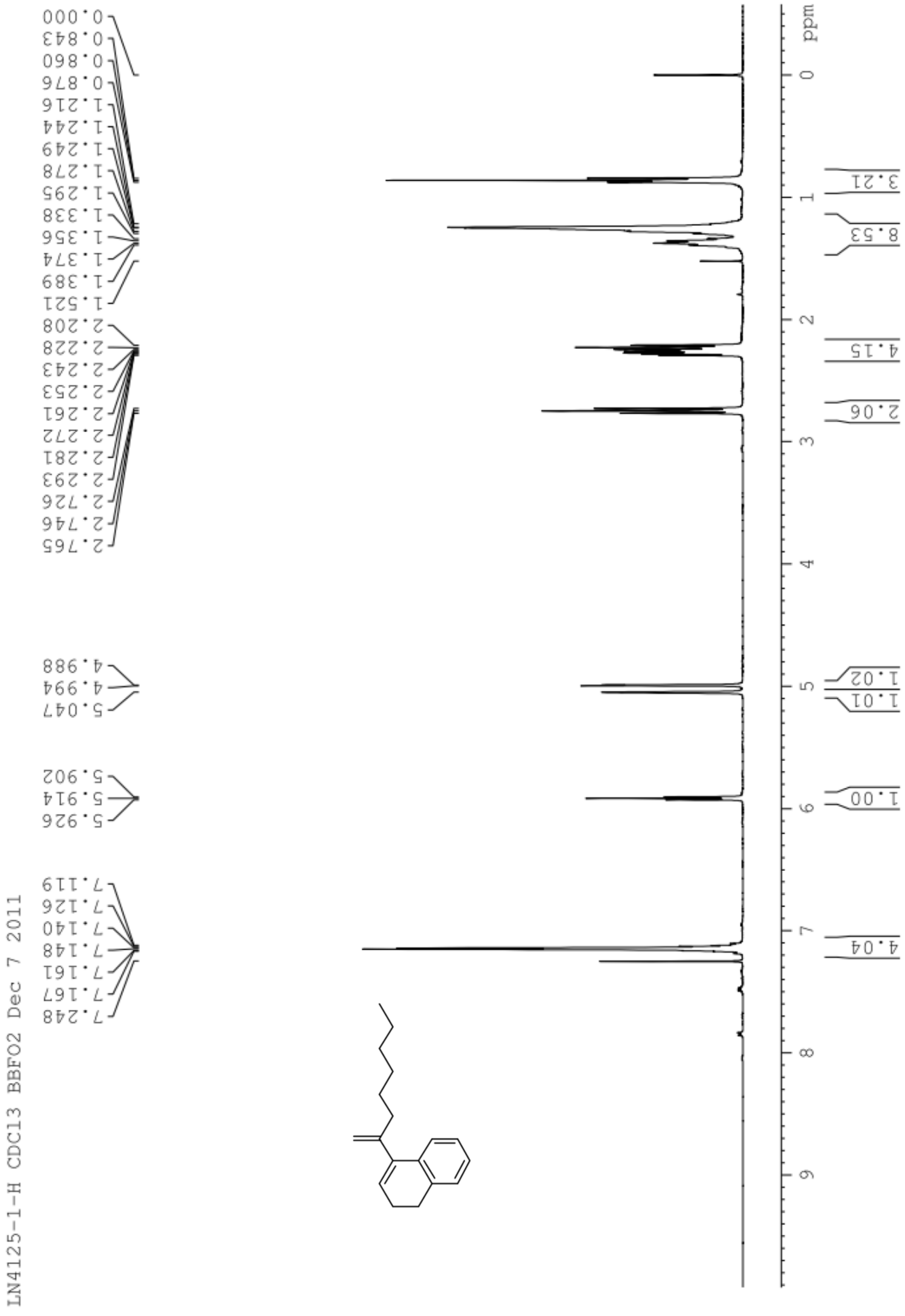
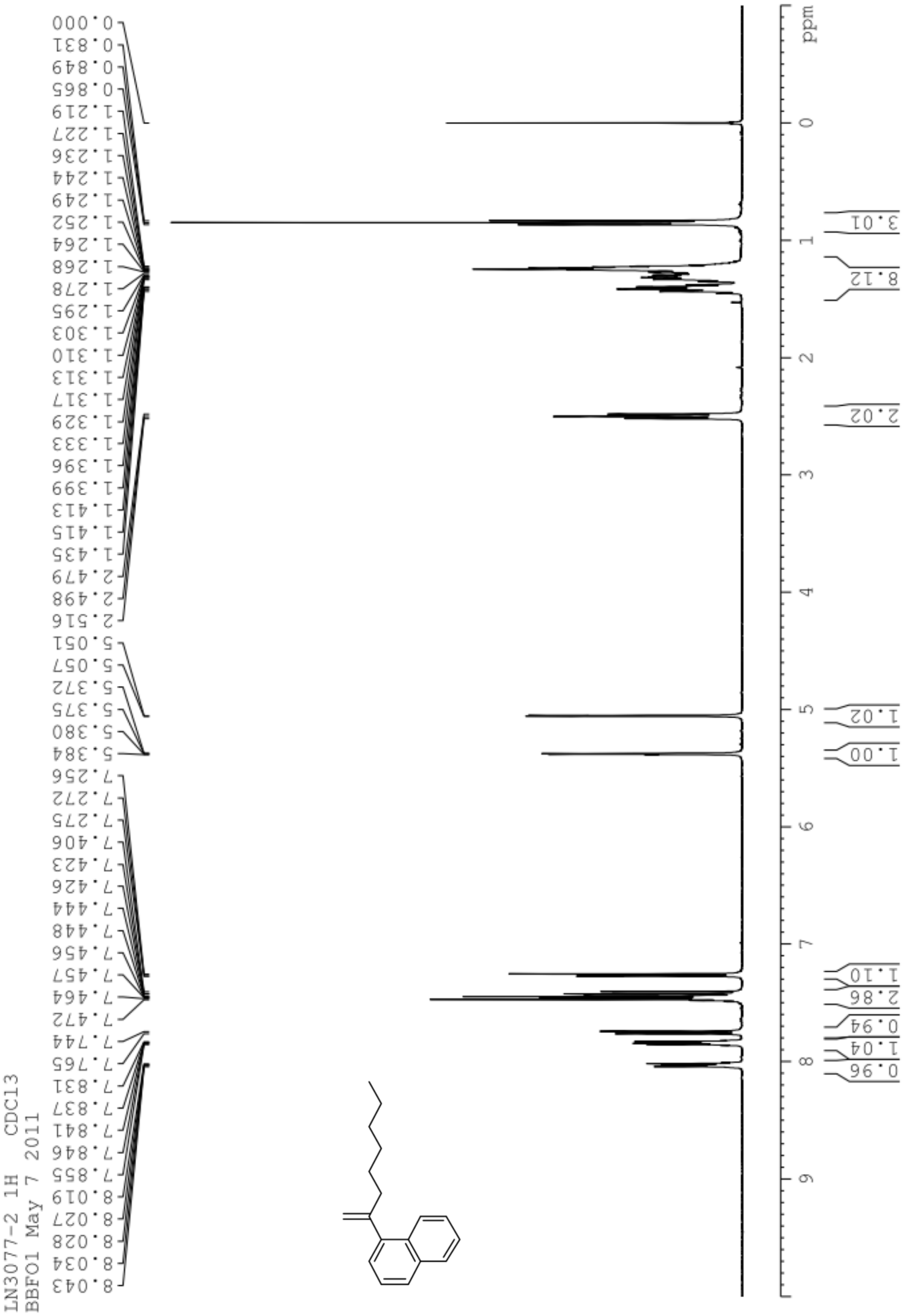
0.845
0.863
0.879
1.236
1.249
1.259
1.266
1.272
1.287
1.291
1.306
1.308
1.323
1.326
1.329
1.345
1.362
1.413
1.431
1.451
1.470
1.487
1.509
1.548
1.669
2.529
2.548
2.566
5.045
5.048
5.260
5.264
6.548
6.556
7.248
7.367
7.372
7.389
7.394
7.573
7.576
8.048
8.069
N
Boc
3.28
6.66
2.33
10.05
1.98
0.99
1.00
0.99
1.00
2.05
1.02
ppm
0
1
2
3
4
5
6
7
8
9


LN4125-1-H CDCl3 BBFO2 Dec 7 2011
0.000
0.843
0.860
0.876
1.216
1.244
1.249
1.278
1.295
1.338
1.356
1.374
1.389
1.521
2.208
2.228
2.243
2.253
2.261
2.272
2.281
2.293
2.726
2.746
2.765
4.988
4.994
5.047
5.902
5.914
5.926
7.119
7.126
7.140
7.148
7.161
7.167
7.248
ppm
0
1
2
3
4
5
6
7
8
9
3.21
8.53
4.15
2.06
1.02
1.01
1.00
4.04


LN3077-2 1H CDCl3
BBFO1 May 7 2011
8.043
8.034
8.028
8.027
8.019
7.855
7.846
7.841
7.837
7.831
7.765
7.744
7.472
7.464
7.457
7.456
7.448
7.444
7.426
7.423
7.406
7.275
7.272
7.256
5.384
5.380
5.375
5.372
5.057
5.051
2.516
2.498
2.479
1.435
1.415
1.413
1.399
1.396
1.333
1.329
1.317
1.313
1.310
1.303
1.295
1.278
1.268
1.264
1.252
1.249
1.244
1.236
1.227
1.219
0.865
0.849
0.831
0.000
0.96
1.04
0.94
2.86
1.10
1.00
1.02
2.02
8.12
3.01
9
8
7
6
5
4
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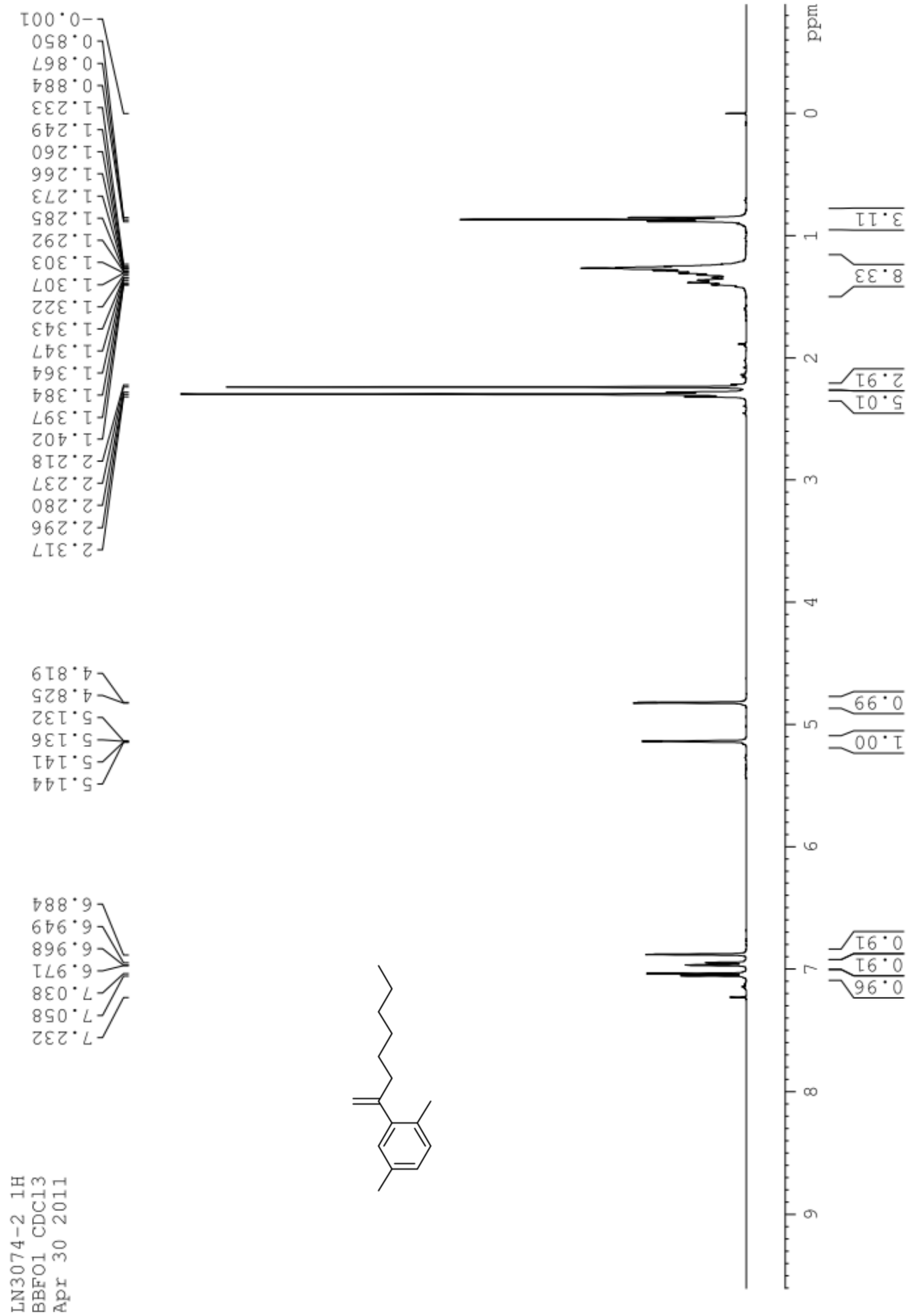
2
1
0
ppm


LN3074-2 1H
BBFO1 CDCl3
Apr 30 2011
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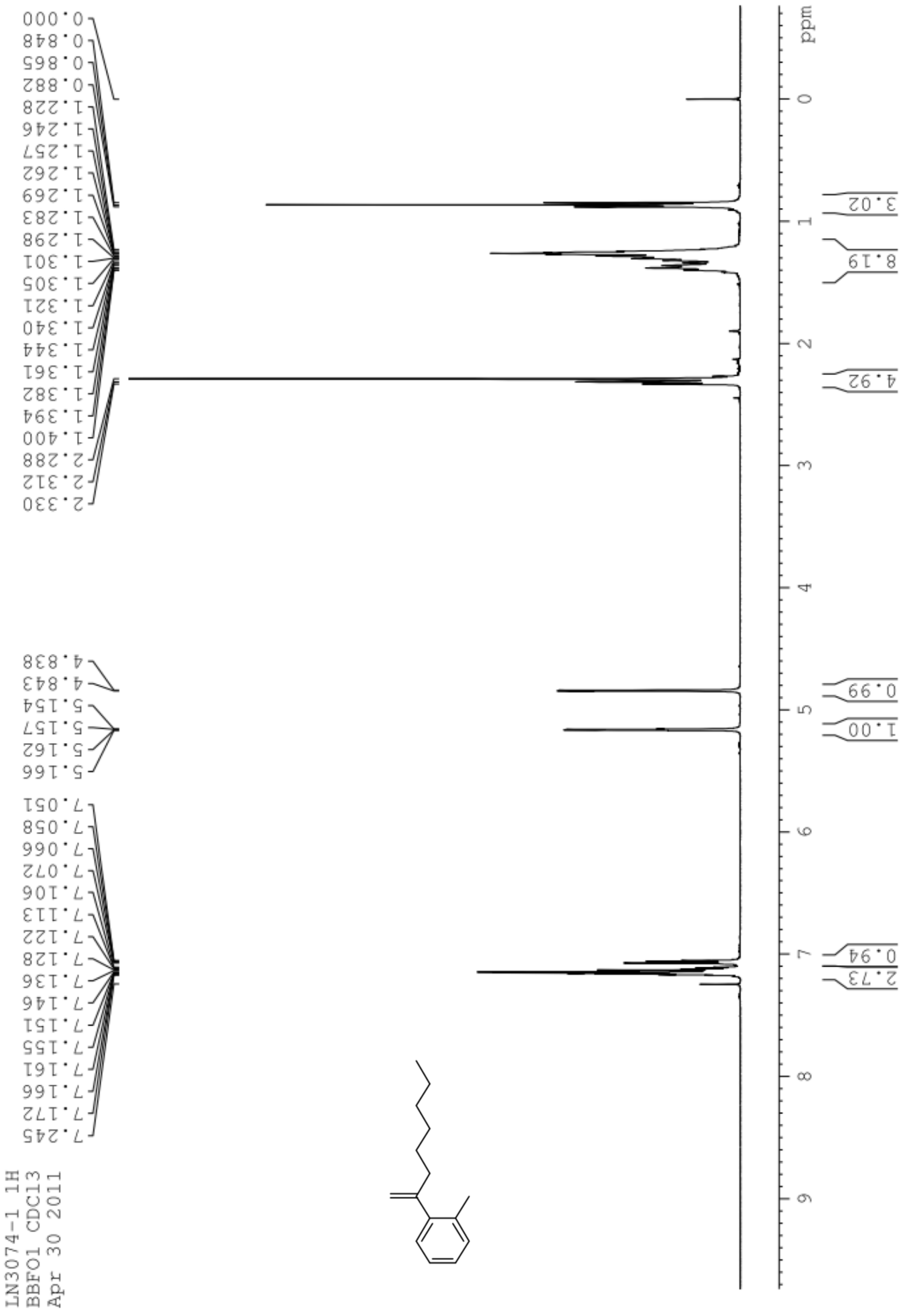
0.850
0.867
0.884
1.233
1.249
1.260
1.266
1.273
1.285
1.292
1.303
1.307
1.322
1.343
1.347
1.364
1.384
1.397
1.402
2.218
2.237
2.280
2.296
2.317
4.819
4.825
5.132
5.136
5.141
5.144
6.884
6.949
6.968
6.971
7.038
7.058
7.232
3.11
8.33
2.91
5.01
0.99
1.00
0.91
0.91
0.96
9
8
7
6
5
4
3
2
1
0
ppm


LN3074-1 1H
BBFO1 CDCl3
Apr 30 2011
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0.865
0.882
1.228
1.246
1.257
1.262
1.269
1.283
1.298
1.301
1.305
1.321
1.340
1.344
1.361
1.382
1.394
1.400
2.288
2.312
2.330
4.838
4.843
5.154
5.157
5.162
5.166
7.051
7.058
7.066
7.072
7.106
7.113
7.122
7.128
7.136
7.146
7.151
7.155
7.161
7.166
7.172
7.245
3.02
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8
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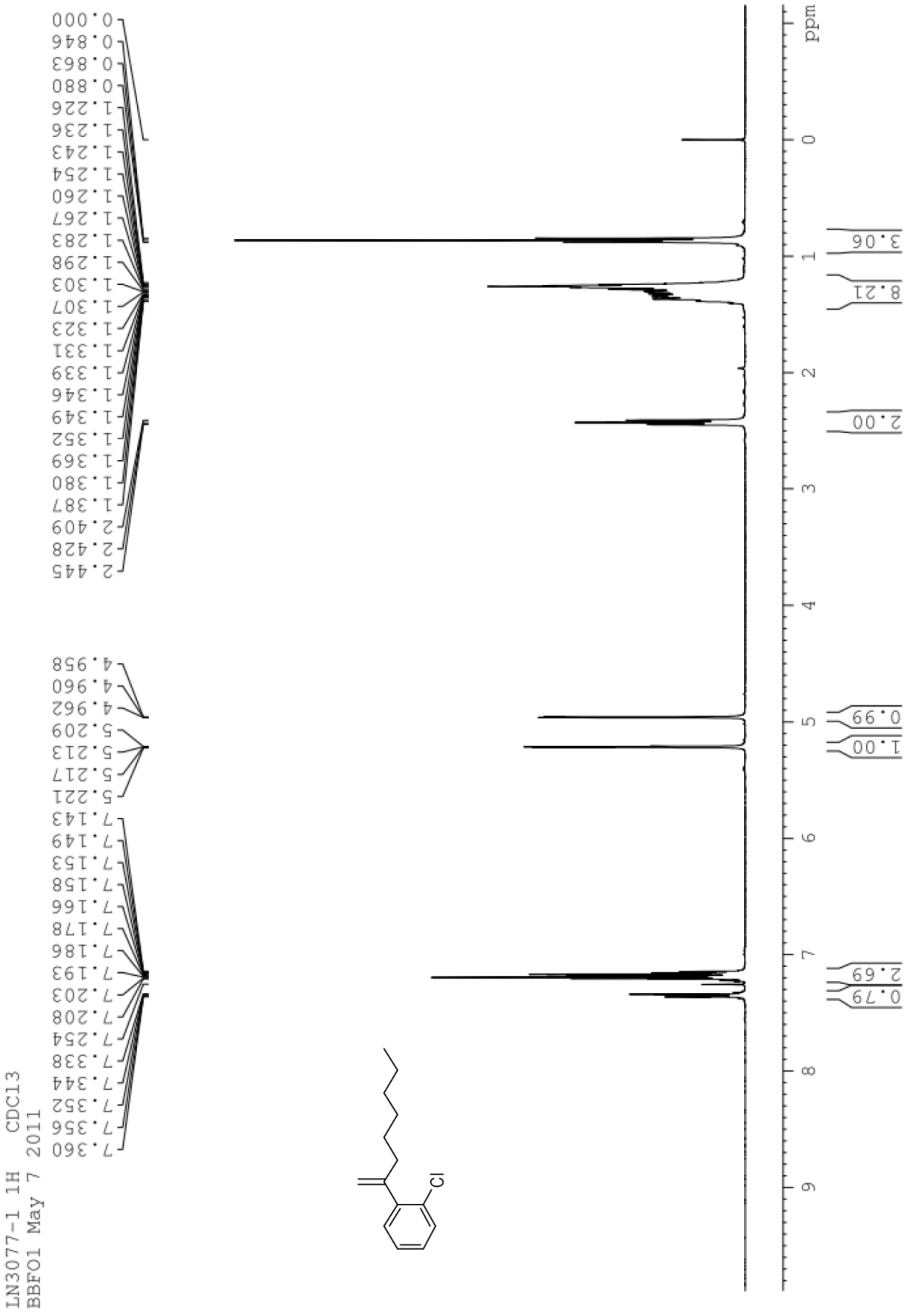
LN3077-1 1H CDCl3
BBFO1 May 7 2011
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0.880
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1.236
1.243
1.254
1.260
1.267
1.283
1.298
1.303
1.307
1.323
1.331
1.339
1.346
1.349
1.352
1.369
1.380
1.387
2.409
2.428
2.445
4.958
4.960
4.962
5.209
5.213
5.217
5.221
7.143
7.149
7.153
7.158
7.166
7.178
7.186
7.193
7.203
7.208
7.254
7.338
7.344
7.352
7.356
7.360
Cl
3.06
8.21
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1.00
2.69
0.79
ppm
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1
2
3
4
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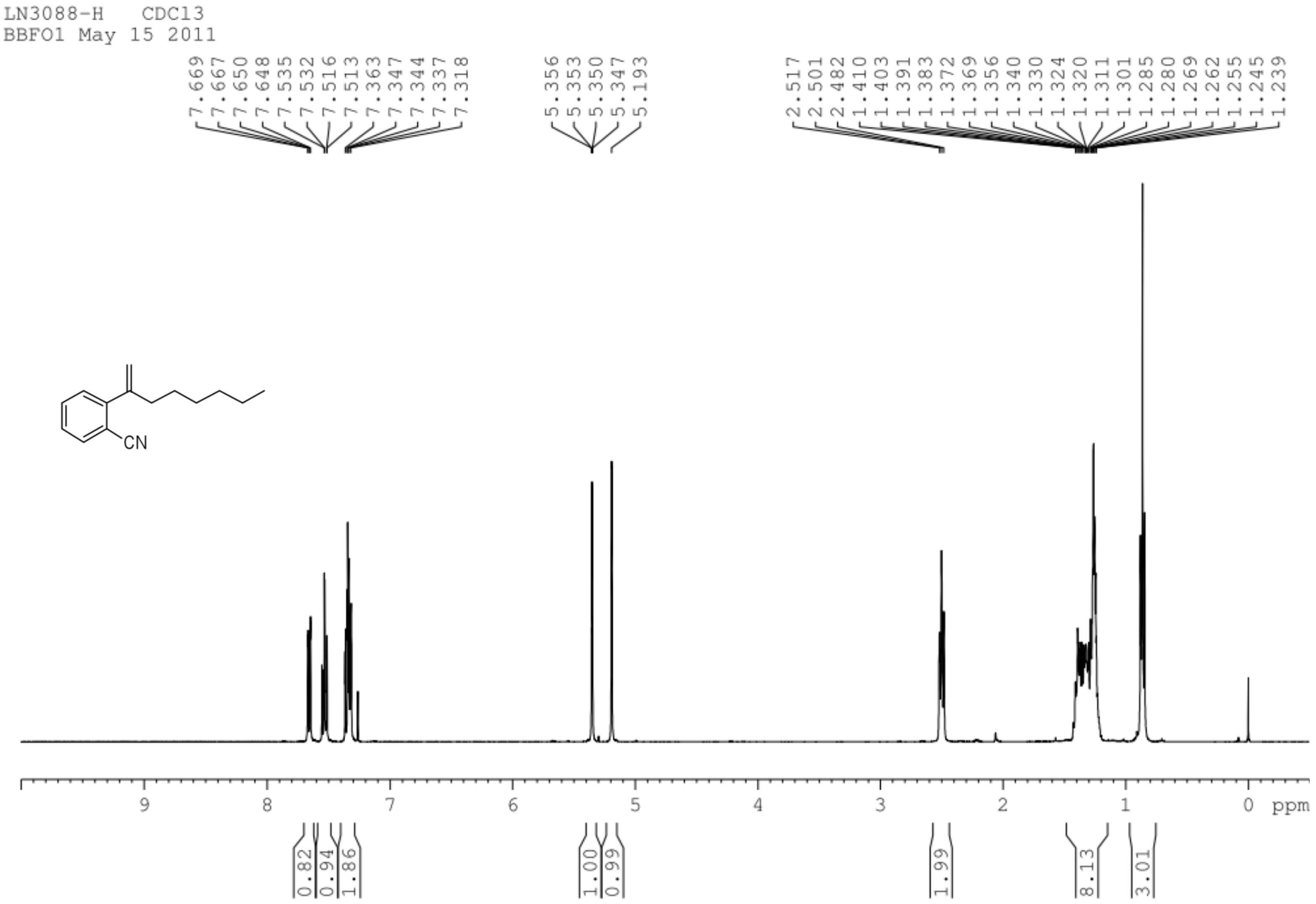
6
7
8
9


LN3088-H CDCl3
BBFO1 May 15 2011
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7.667
7.650
7.648
7.535
7.532
7.516
7.513
7.363
7.347
7.344
7.337
7.318
5.356
5.353
5.350
5.347
5.193
2.517
2.501
2.482
1.410
1.403
1.391
1.383
1.372
1.369
1.356
1.340
1.330
1.324
1.320
1.311
1.301
1.285
1.280
1.269
1.262
1.255
1.245
1.239
CN
9
8
7
6
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0
ppm
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1.00
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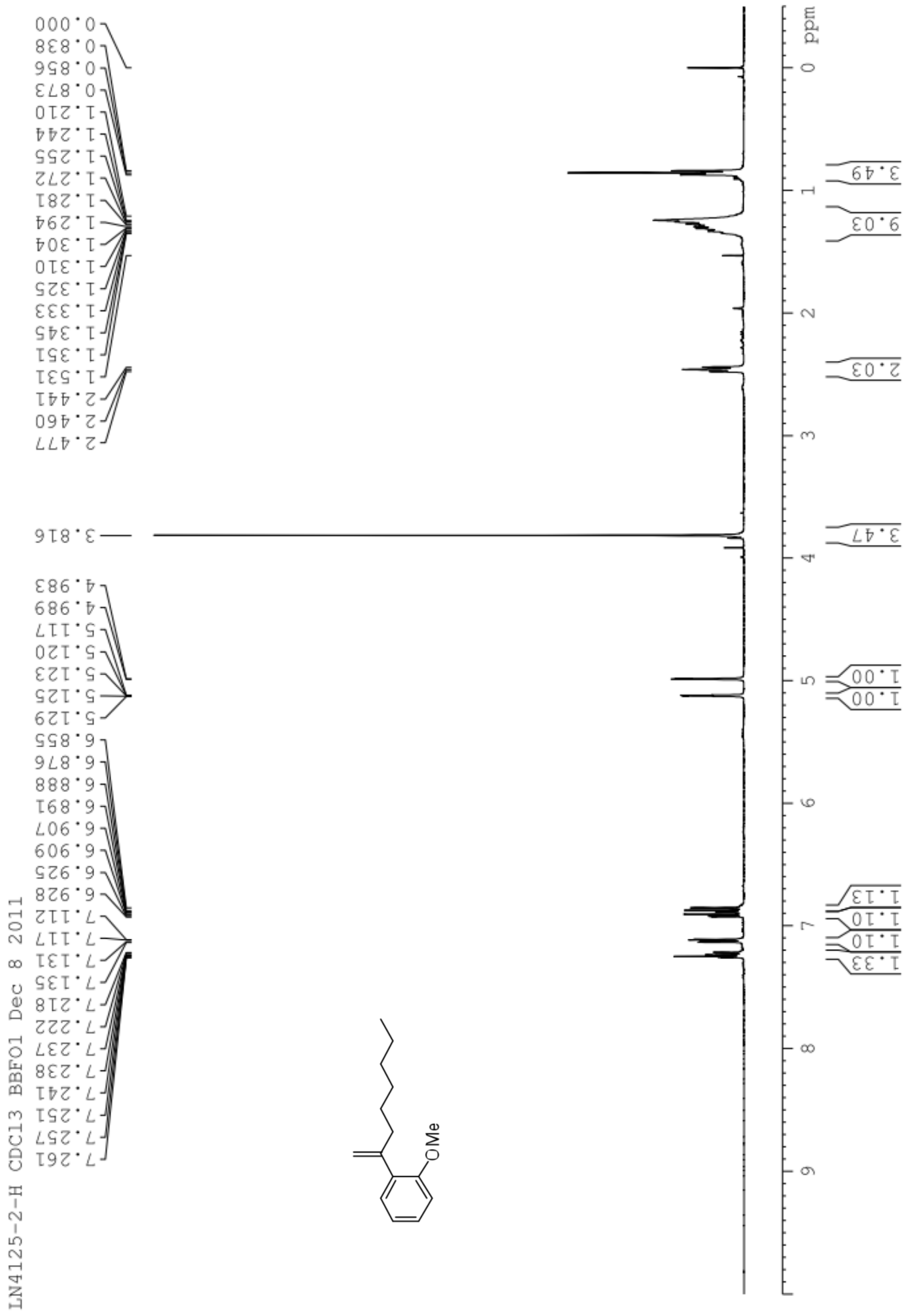
1.99
8.13
3.01


LN4125-2-H CDCl3 BBFO1 Dec 8 2011
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0.856
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1.210
1.244
1.255
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1.281
1.294
1.304
1.310
1.325
1.333
1.345
1.351
1.531
2.441
2.460
2.477
3.816
4.983
4.989
5.117
5.120
5.123
5.125
5.129
6.855
6.876
6.888
6.891
6.907
6.909
6.925
6.928
7.112
7.117
7.131
7.135
7.218
7.222
7.237
7.238
7.241
7.251
7.257
7.261
OMe
3.49
9.03
2.03
3.47
1.00
1.00
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1.10
1.33
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8
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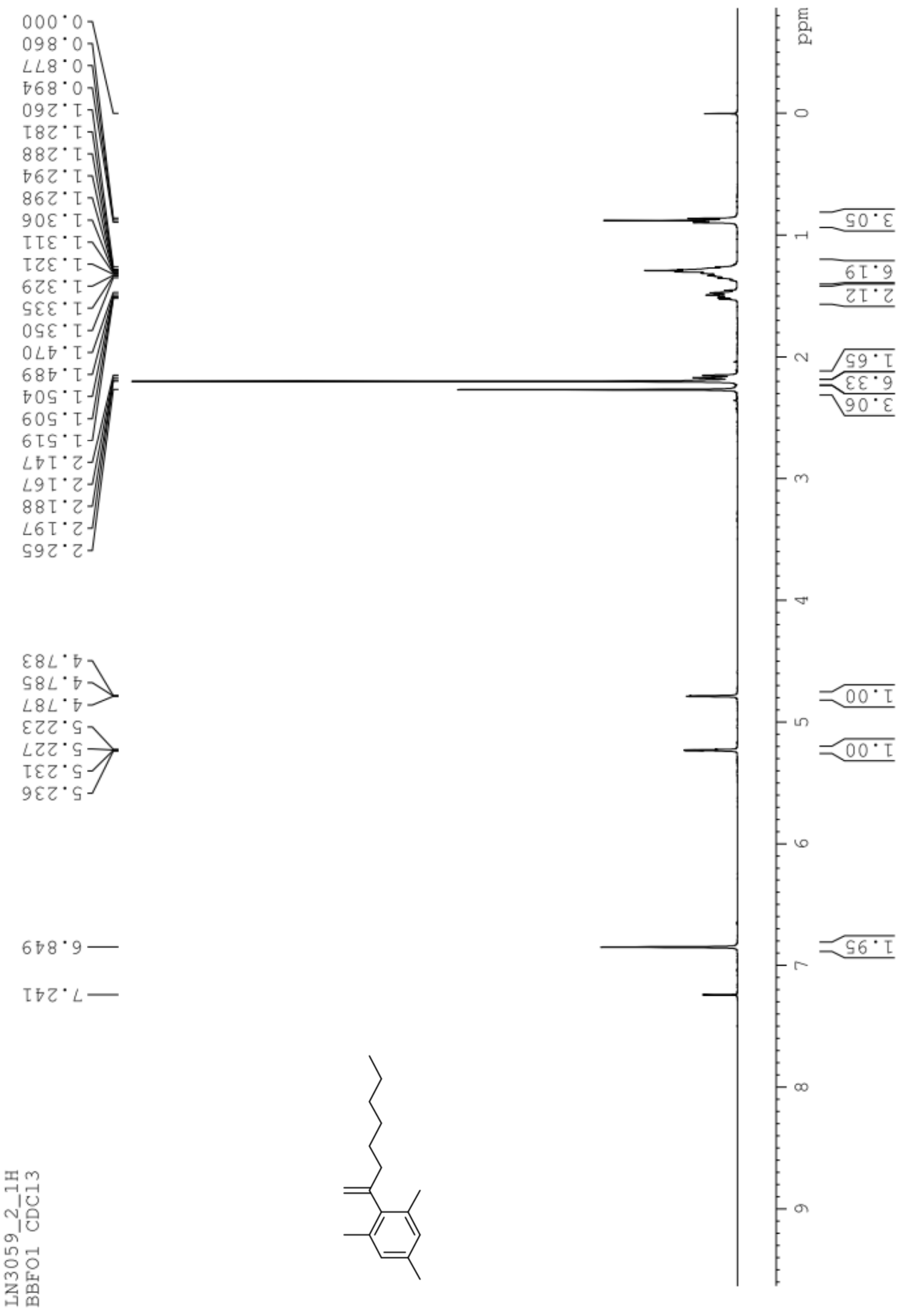
LN3059_2_1H
BBFO1 CDCl3
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1.288
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1.298
1.306
1.311
1.321
1.329
1.335
1.350
1.470
1.489
1.504
1.509
1.519
2.147
2.167
2.188
2.197
2.265
4.783
4.785
4.787
5.223
5.227
5.231
5.236
6.849
7.241
3.05
6.19
2.12
1.65
6.33
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1.00
1.00
1.95
ppm
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2
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4
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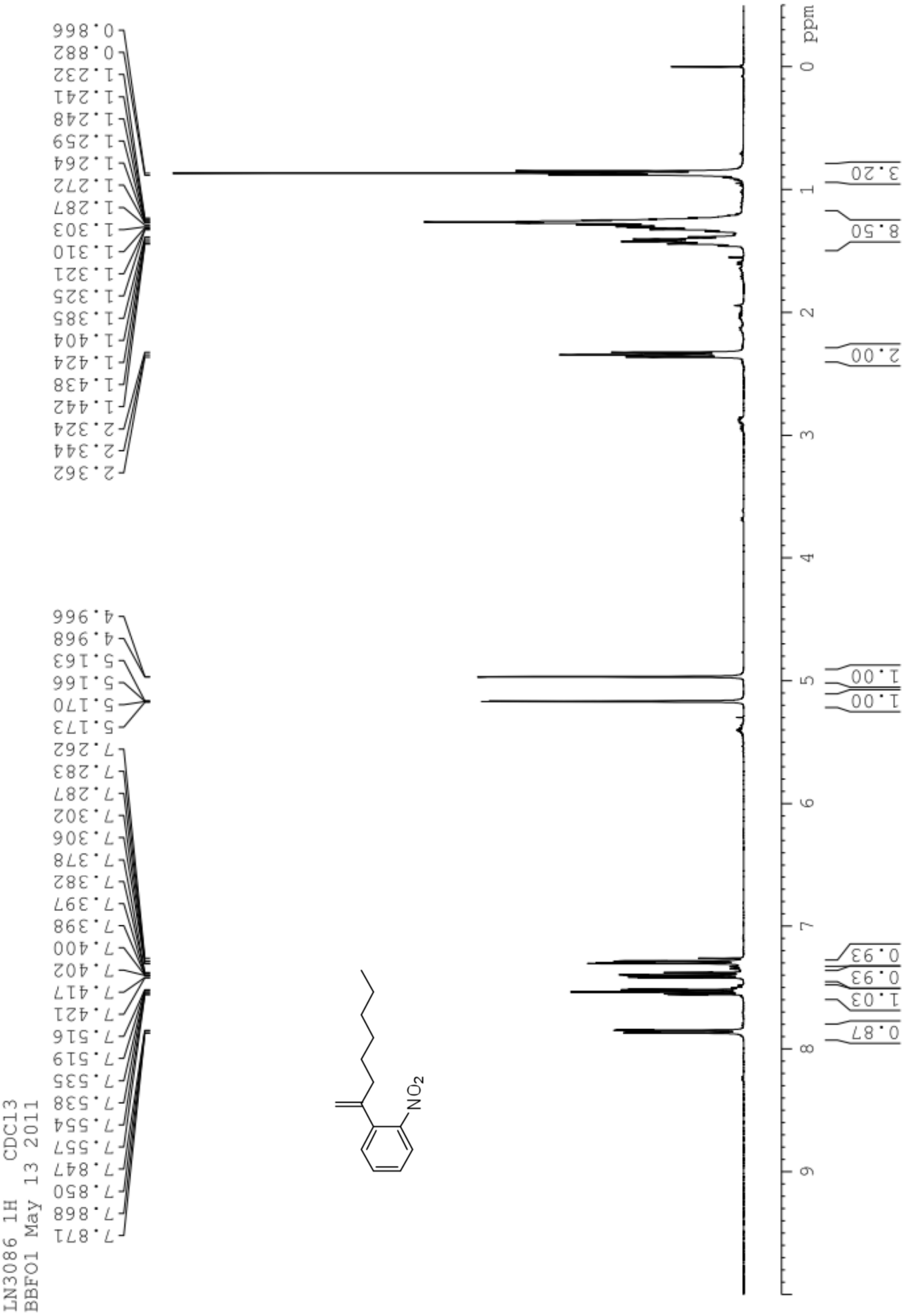
6
7
8
9


LN3086 1H CDCl3
BBFO1 May 13 2011
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0.882
1.232
1.241
1.248
1.259
1.264
1.272
1.287
1.303
1.310
1.321
1.325
1.385
1.404
1.424
1.438
1.442
2.324
2.344
2.362
4.966
4.968
5.163
5.166
5.170
5.173
7.262
7.283
7.287
7.302
7.306
7.378
7.382
7.397
7.398
7.400
7.402
7.417
7.421
7.516
7.519
7.535
7.538
7.554
7.557
7.847
7.850
7.868
7.871
NO2
3.20
8.50
2.00
1.00
1.00
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0.93
1.03
0.87
0
1
2
3
4
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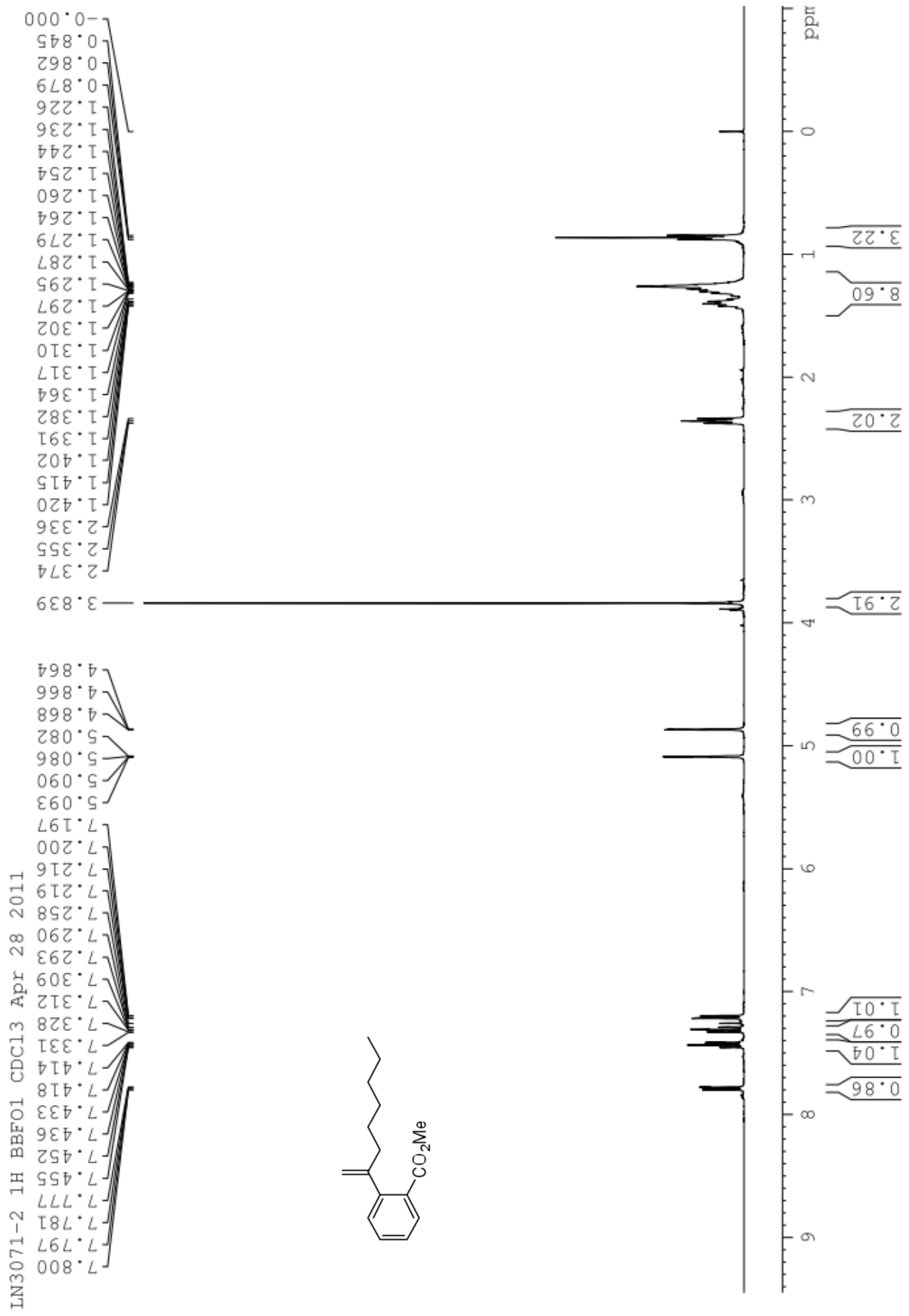
6
7
8
9
ppm


LN3071-2 1H BBFO1 CDCl3 Apr 28 2011
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0.879
1.226
1.236
1.244
1.254
1.260
1.264
1.279
1.287
1.295
1.297
1.302
1.310
1.317
1.364
1.382
1.391
1.402
1.415
1.420
2.336
2.355
2.374
3.839
4.864
4.866
4.868
5.082
5.086
5.090
5.093
7.197
7.200
7.216
7.219
7.258
7.290
7.293
7.309
7.312
7.328
7.331
7.414
7.418
7.433
7.436
7.452
7.455
7.777
7.781
7.797
7.800
CO2Me
3.22
8.60
2.02
2.91
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1.01
0.97
1.04
0.86
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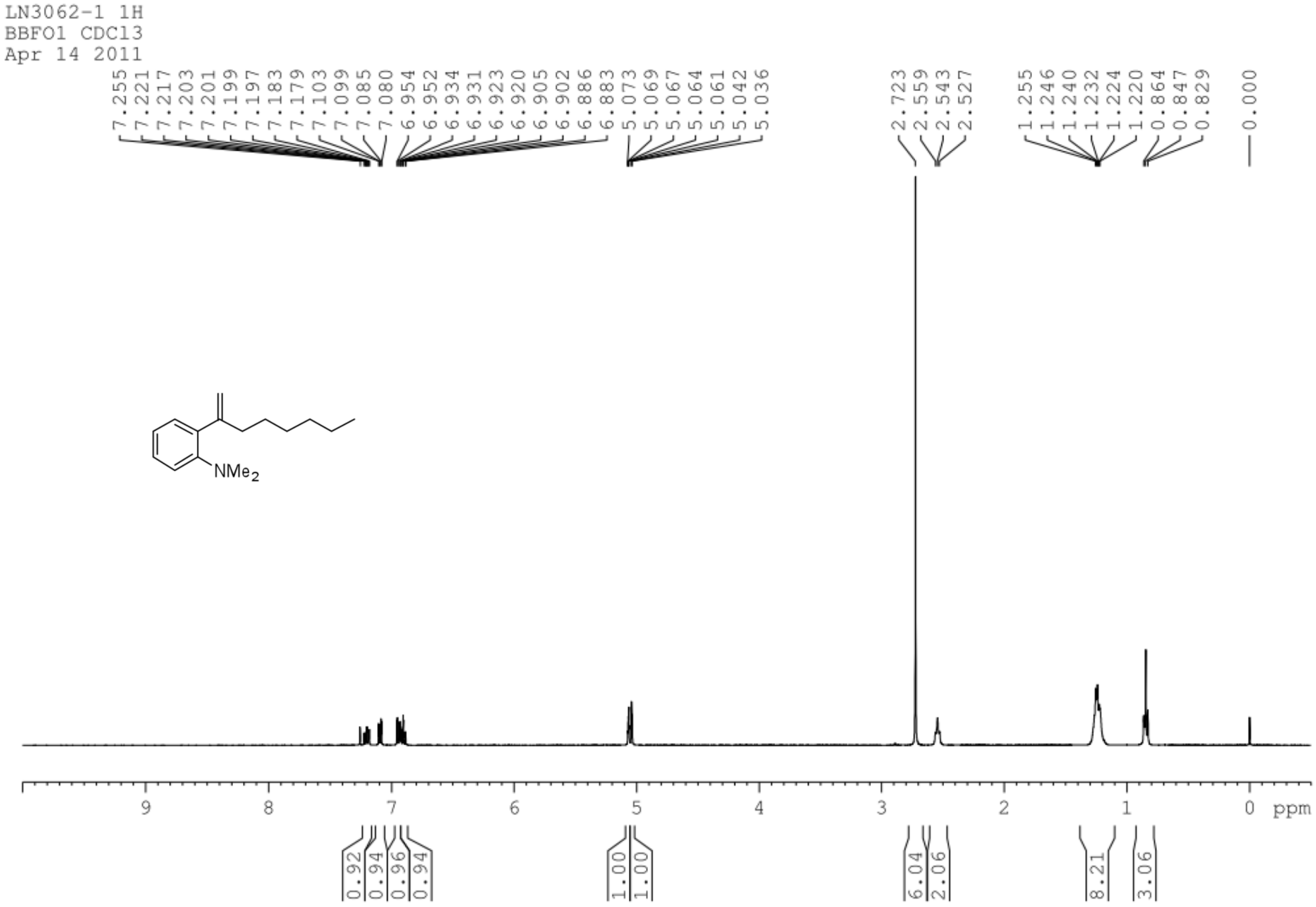
LN3062-1 1H
BBFO1 CDCl3
Apr 14 2011
7.255
7.221
7.217
7.203
7.201
7.199
7.197
7.183
7.179
7.103
7.099
7.085
7.080
6.954
6.952
6.934
6.931
6.923
6.920
6.905
6.902
6.886
6.883
5.073
5.069
5.067
5.064
5.061
5.042
5.036
2.723
2.559
2.543
2.527
1.255
1.246
1.240
1.232
1.224
1.220
0.864
0.847
0.829
0.000
NMe2
9
8
7
6
5
4
3
2
1
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ppm
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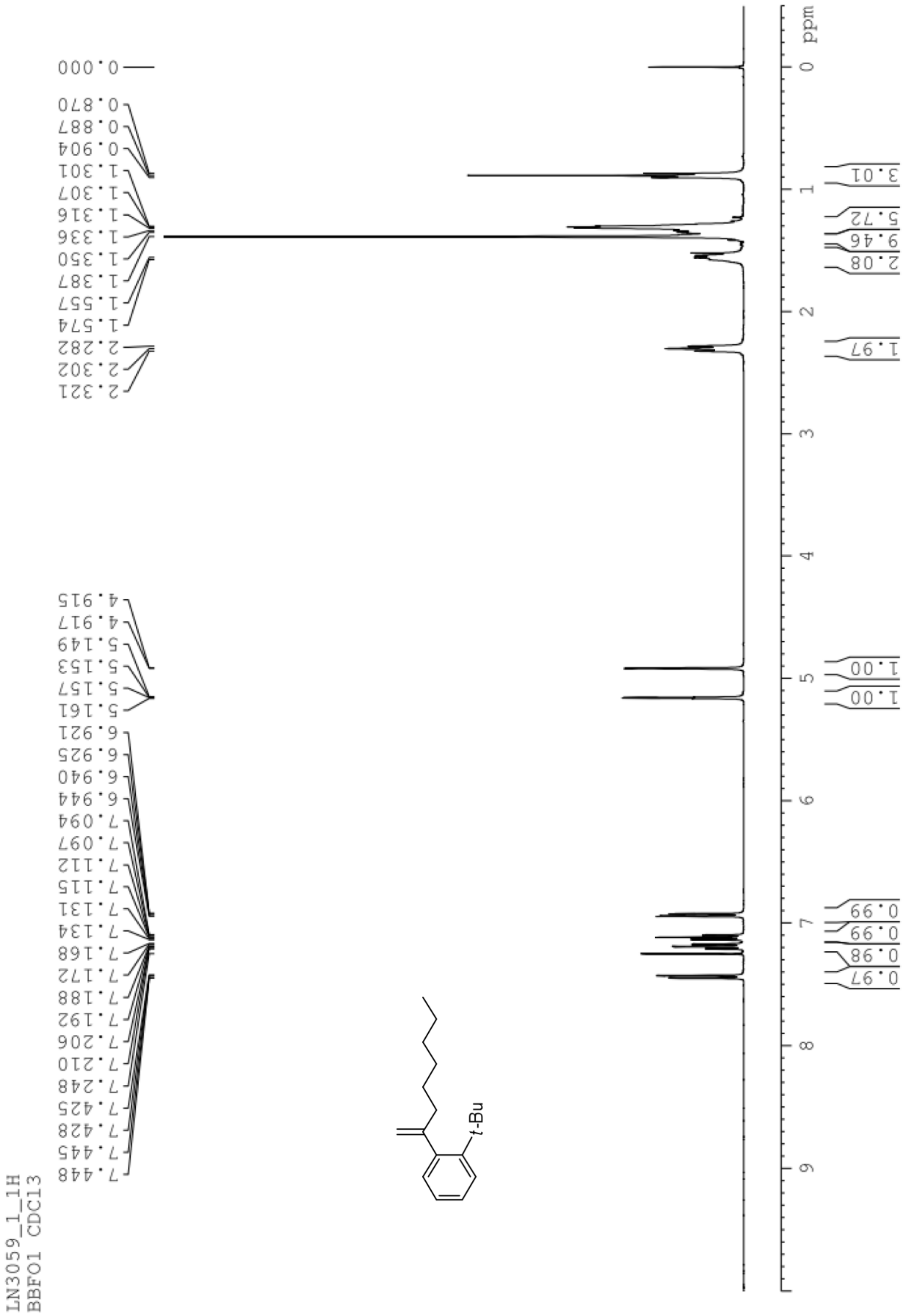
0.94
0.96
0.94
1.00
1.00
6.04
2.06
8.21
3.06


LN3059_1_1H
BBFO1 CDCl3
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0.887
0.904
1.301
1.307
1.316
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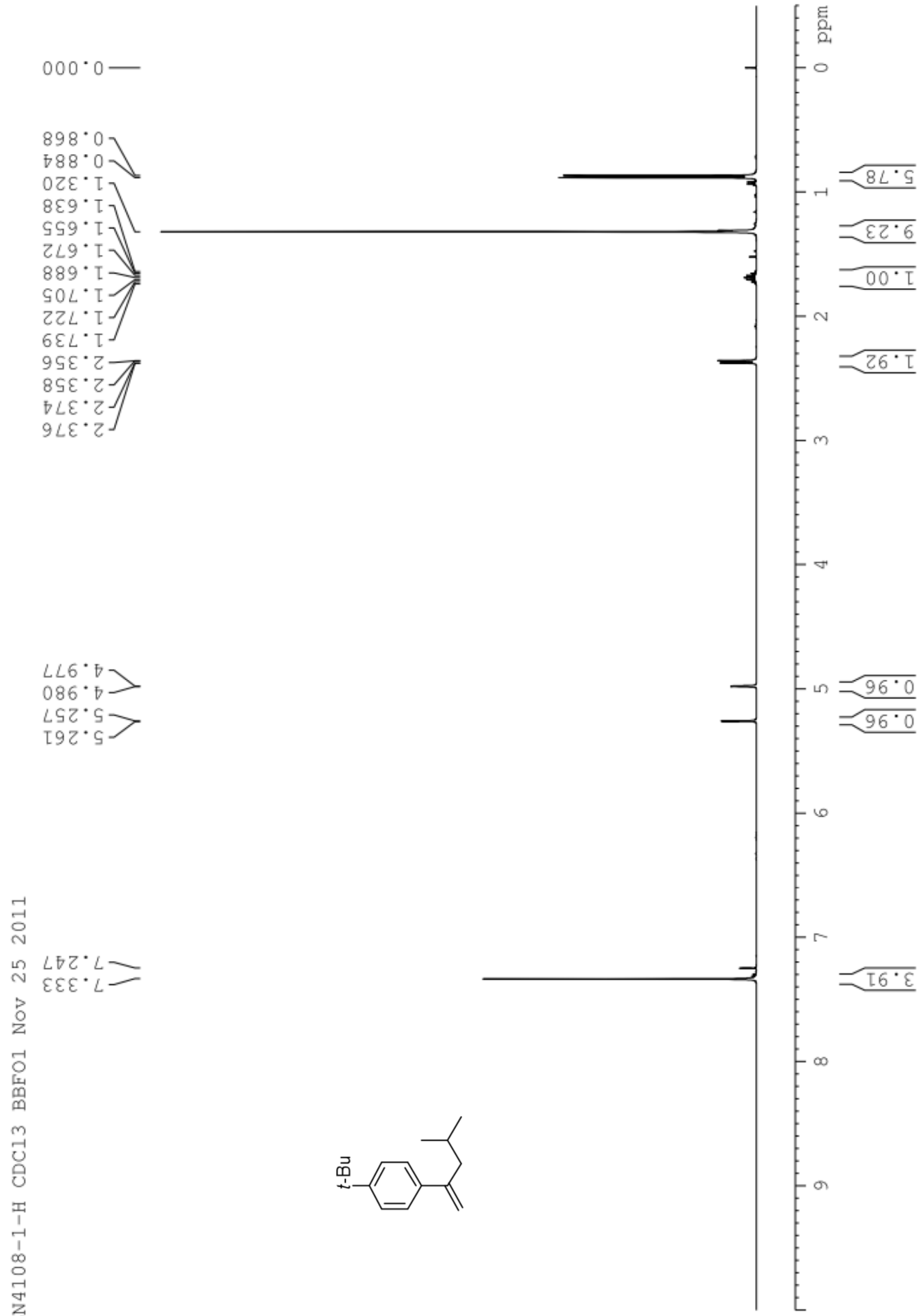
1.350
1.387
1.557
1.574
2.282
2.302
2.321
4.915
4.917
5.149
5.153
5.157
5.161
6.921
6.925
6.940
6.944
7.094
7.097
7.112
7.115
7.131
7.134
7.168
7.172
7.188
7.192
7.206
7.210
7.248
7.425
7.428
7.445
7.448
t-Bu
3.01
5.72
9.46
2.08
1.97
1.00
1.00
0.99
0.99
0.98
0.97
0
1
2
3
4
5
6
7
8
9
ppm


LN4108-1-H CDCl3 BBFO1 Nov 25 2011
t-Bu
0.000
0.868
0.884
1.320
1.638
1.655
1.672
1.688
1.705
1.722
1.739
2.356
2.358
2.374
2.376
4.977
4.980
5.257
5.261
7.247
7.333
5.78
9.23
1.00
1.92
0.96
0.96
3.91
ppm
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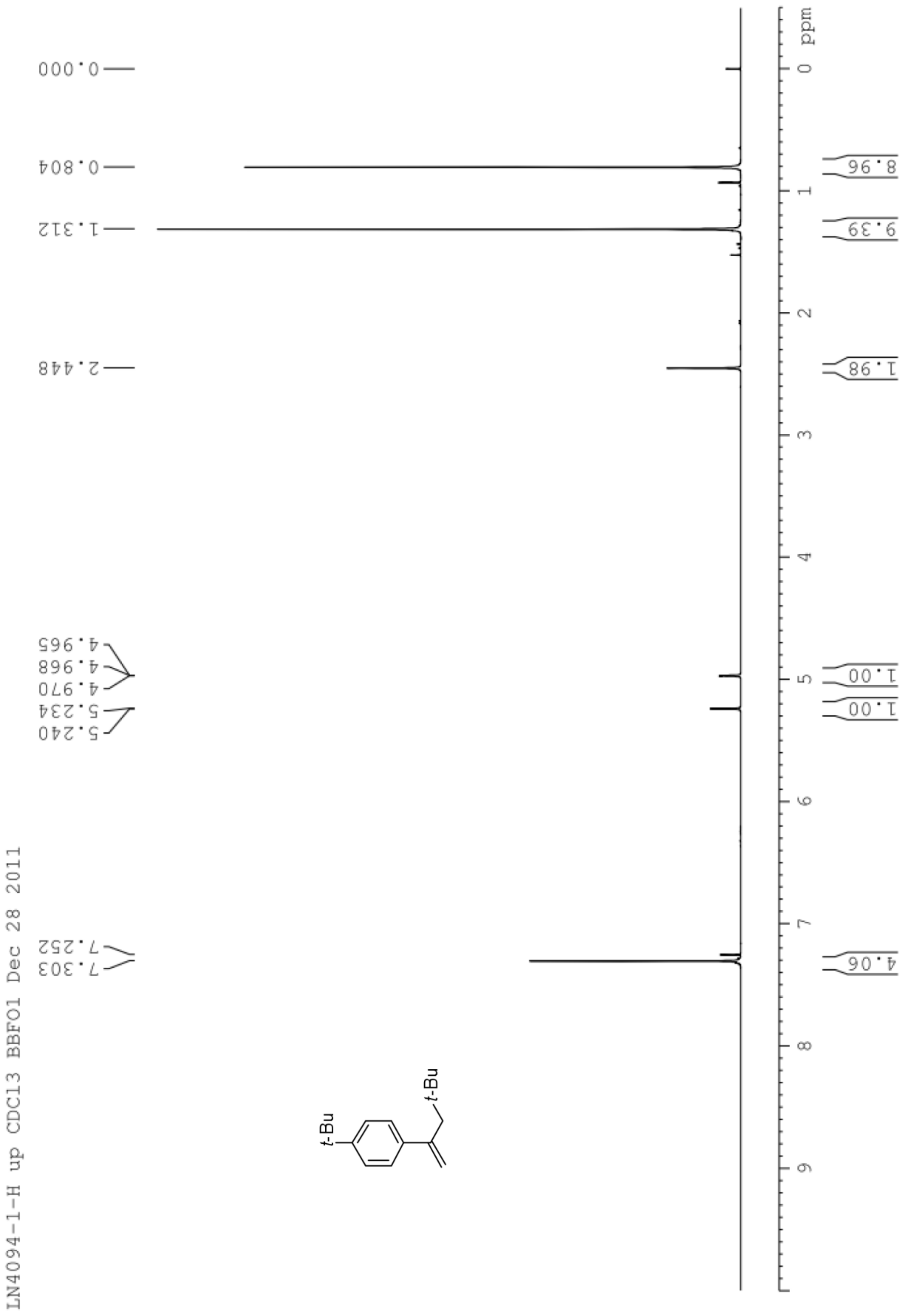
1
2
3
4
5
6
7
8
9


LN4094-1-H up CDCl3 BBFO1 Dec 28 2011
7.303
7.252
5.240
5.234
4.970
4.968
4.965
2.448
1.312
0.804
0.000
4.06
1.00
1.00
1.98
9.39
8.96
ppm
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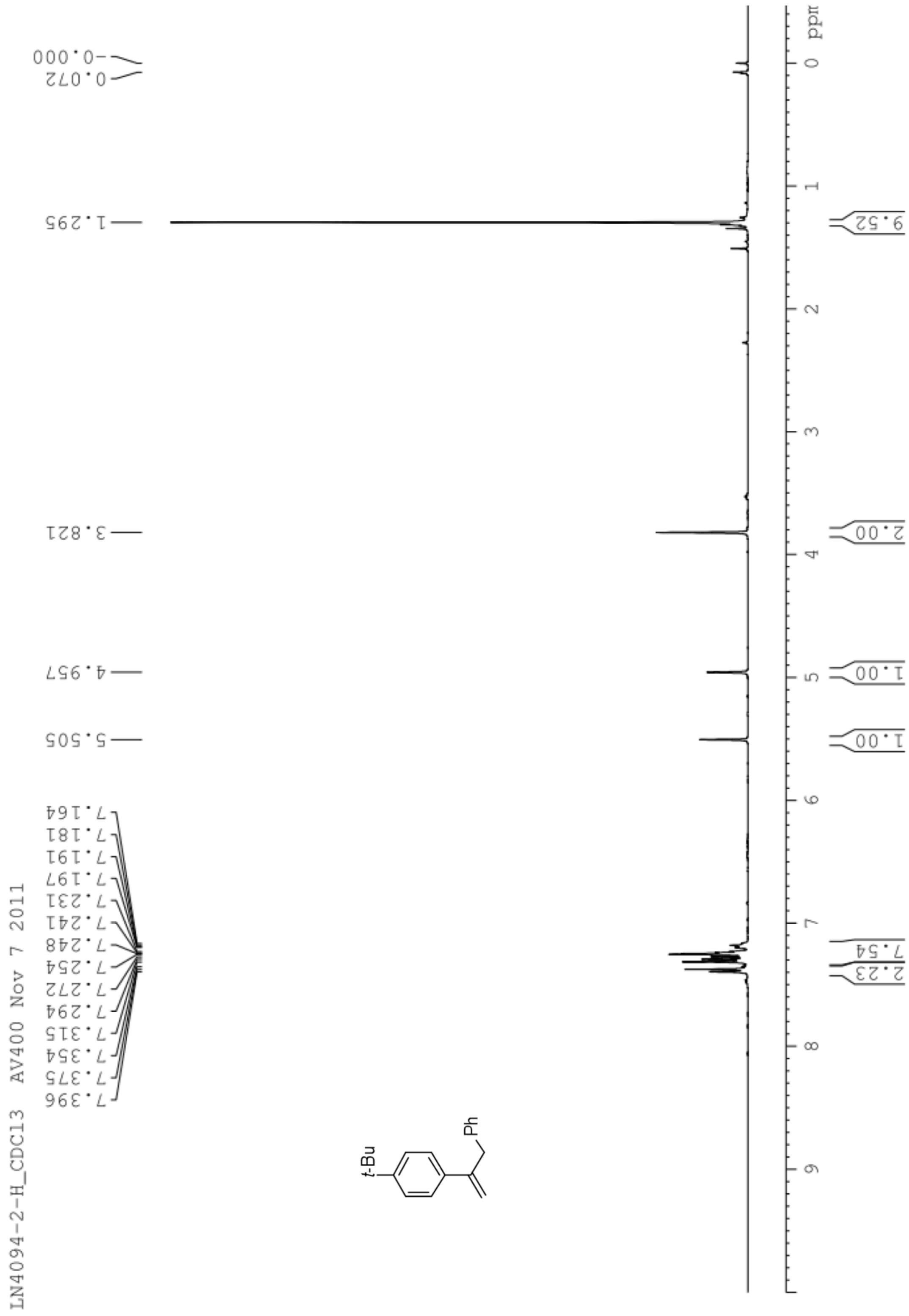
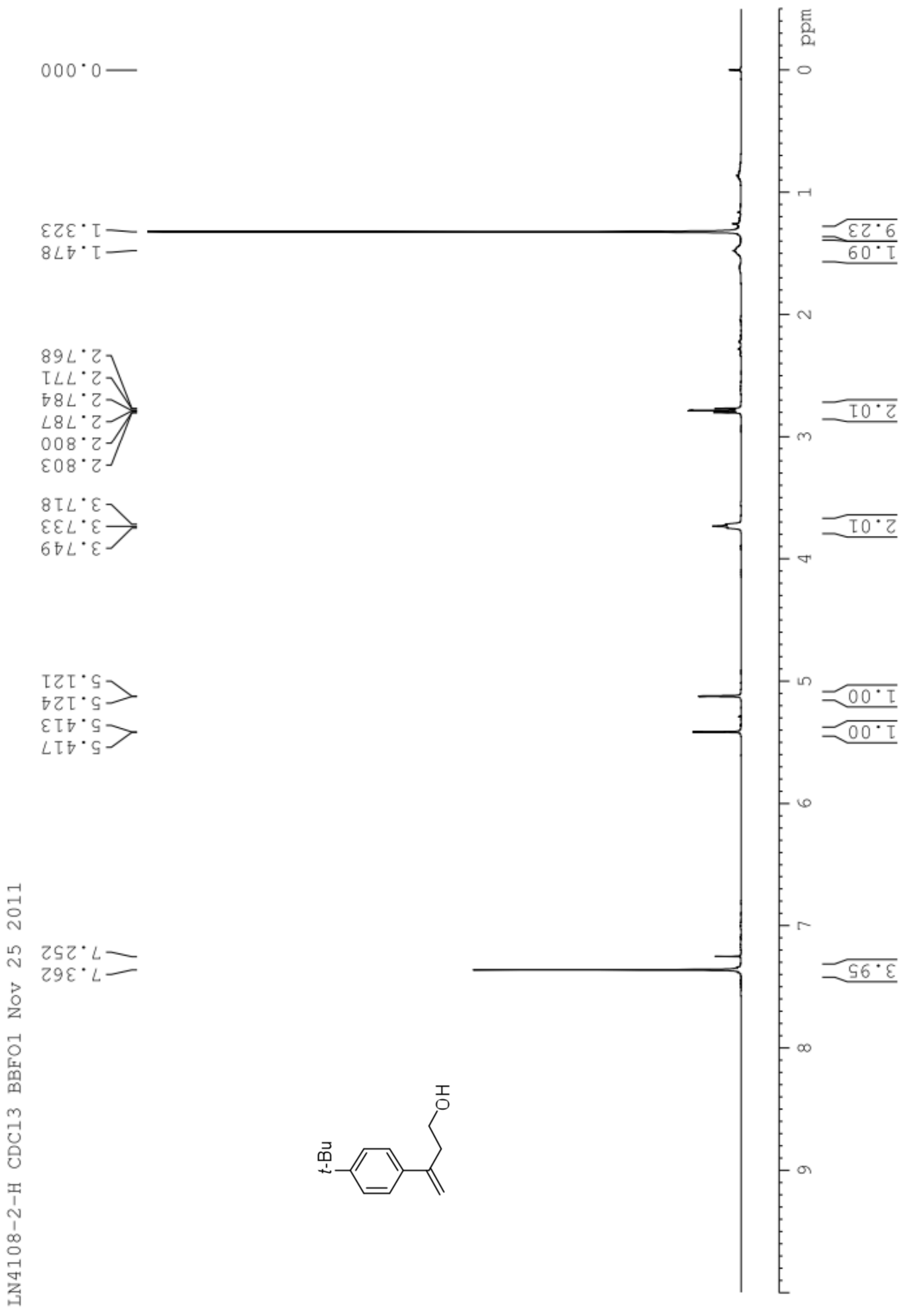
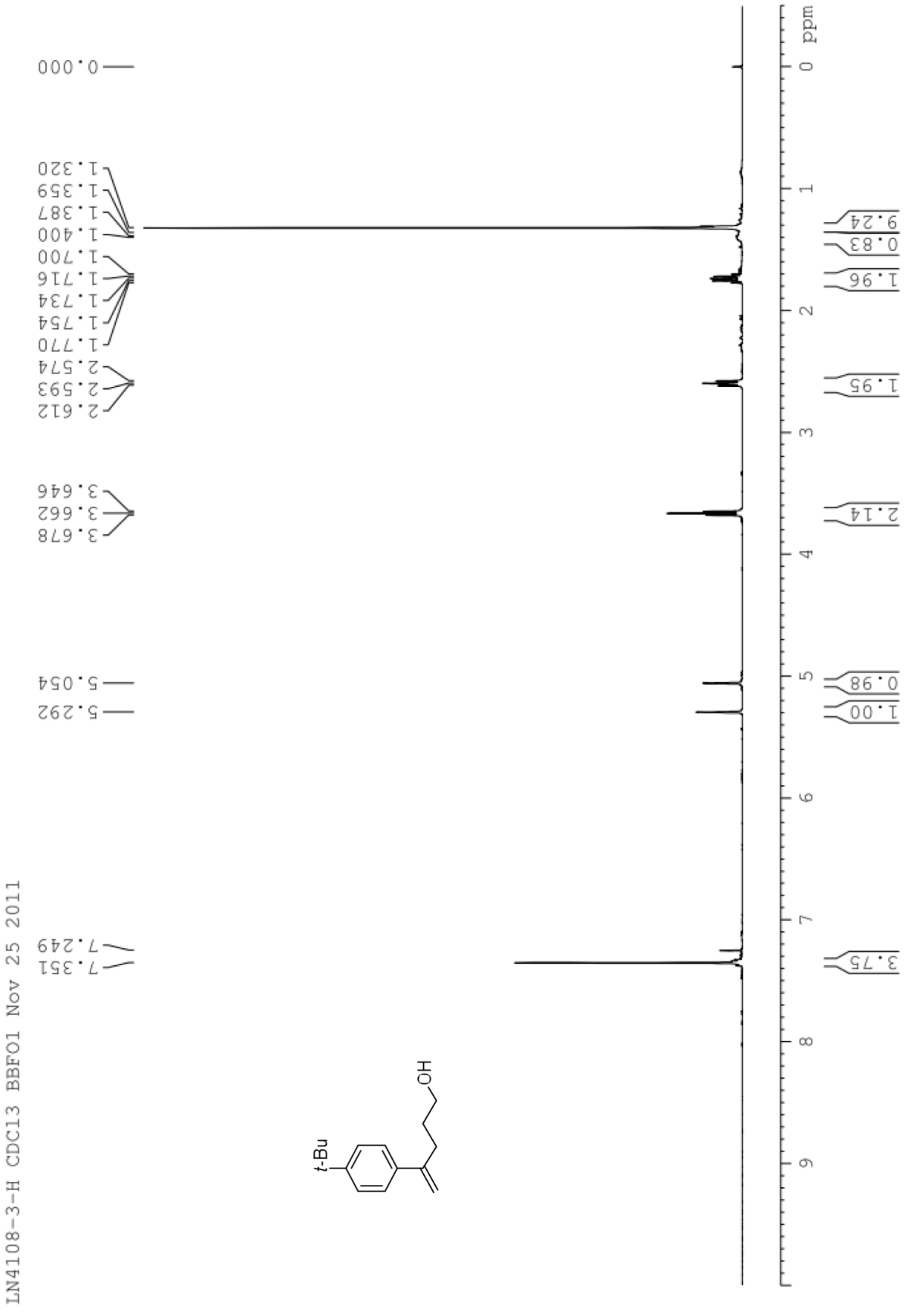
1
2
3
4
5
6
7
8
9
t-Bu
t-Bu


LN4094-2-H_CDCl3 AV400 Nov 7 2011
-0.000
0.072
1.295
3.821
4.957
5.505
7.164
7.181
7.191
7.197
7.231
7.241
7.248
7.254
7.272
7.294
7.315
7.354
7.375
7.396
t-Bu
Ph
9.52
2.00
1.00
1.00
7.54
2.23
ppm
0
1
2
3
4
5
6
7
8
9


LN4108-2-H CDCl3 BBFO1 Nov 25 2011
0.000
1.323
1.478
2.768
2.771
2.784
2.787
2.800
2.803
3.718
3.733
3.749
5.121
5.124
5.413
5.417
7.252
7.362
9.23
1.09
2.01
2.01
1.00
1.00
3.95
ppm
0
1
2
3
4
5
6
7
8
9
t-Bu
OH


LN4108-3-H CDCl3 BBFO1 Nov 25 2011
0.000
1.320
1.359
1.387
1.400
1.700
1.716
1.734
1.754
1.770
2.574
2.593
2.612
3.646
3.662
3.678
5.054
5.292
7.249
7.351
t-Bu
OH
9.24
0.83
1.96
1.95
2.14
0.98
1.00
3.75
0 ppm
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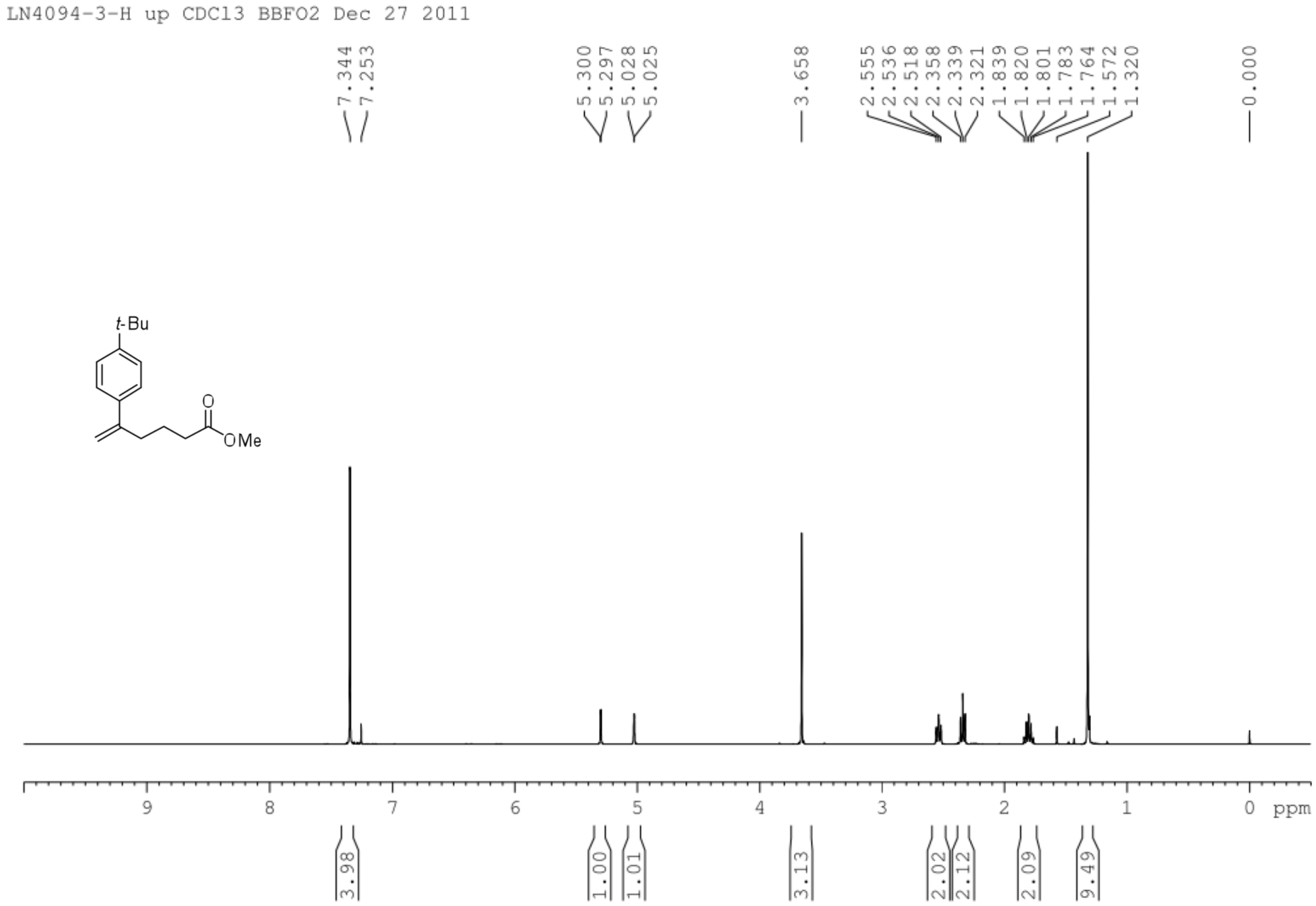
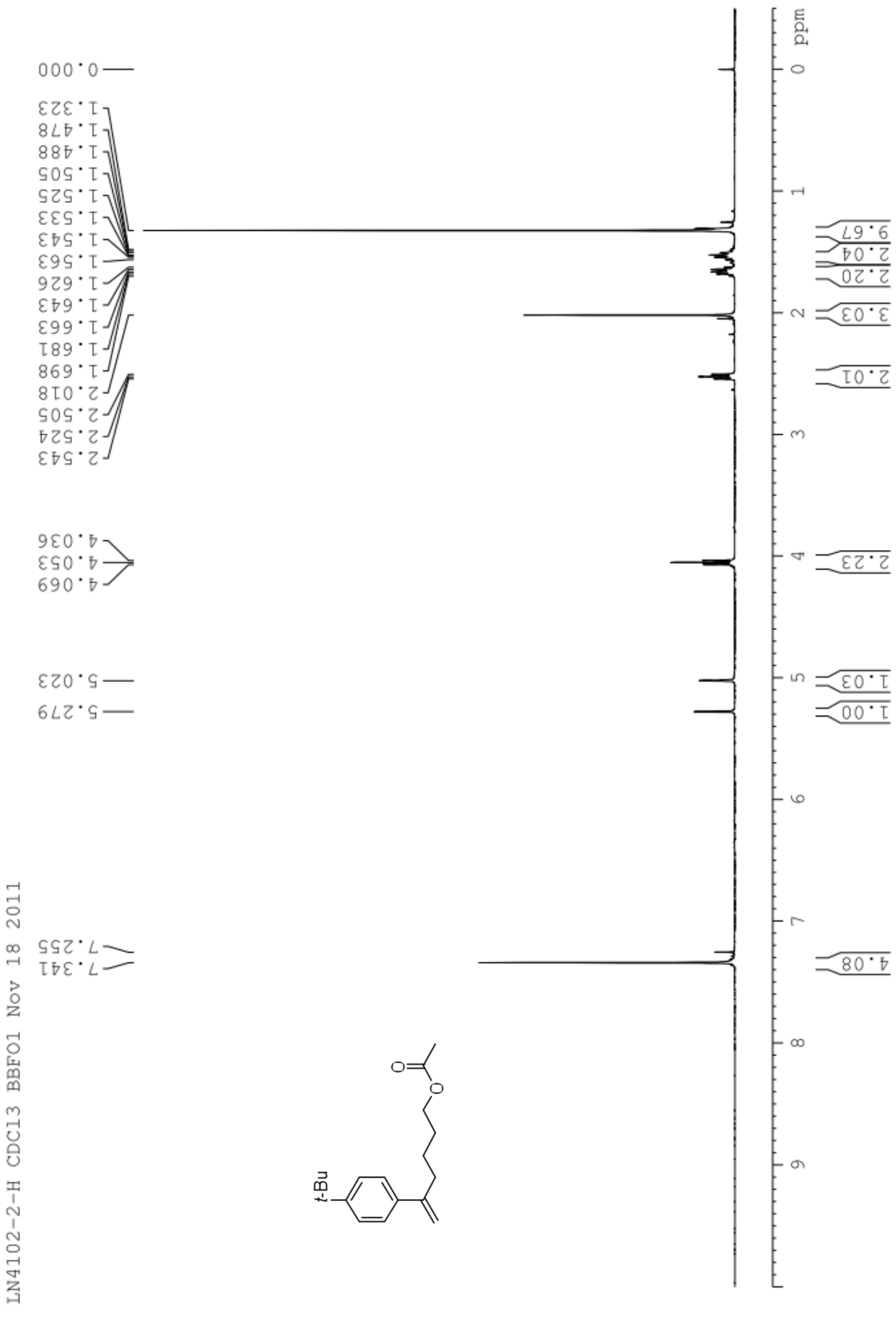
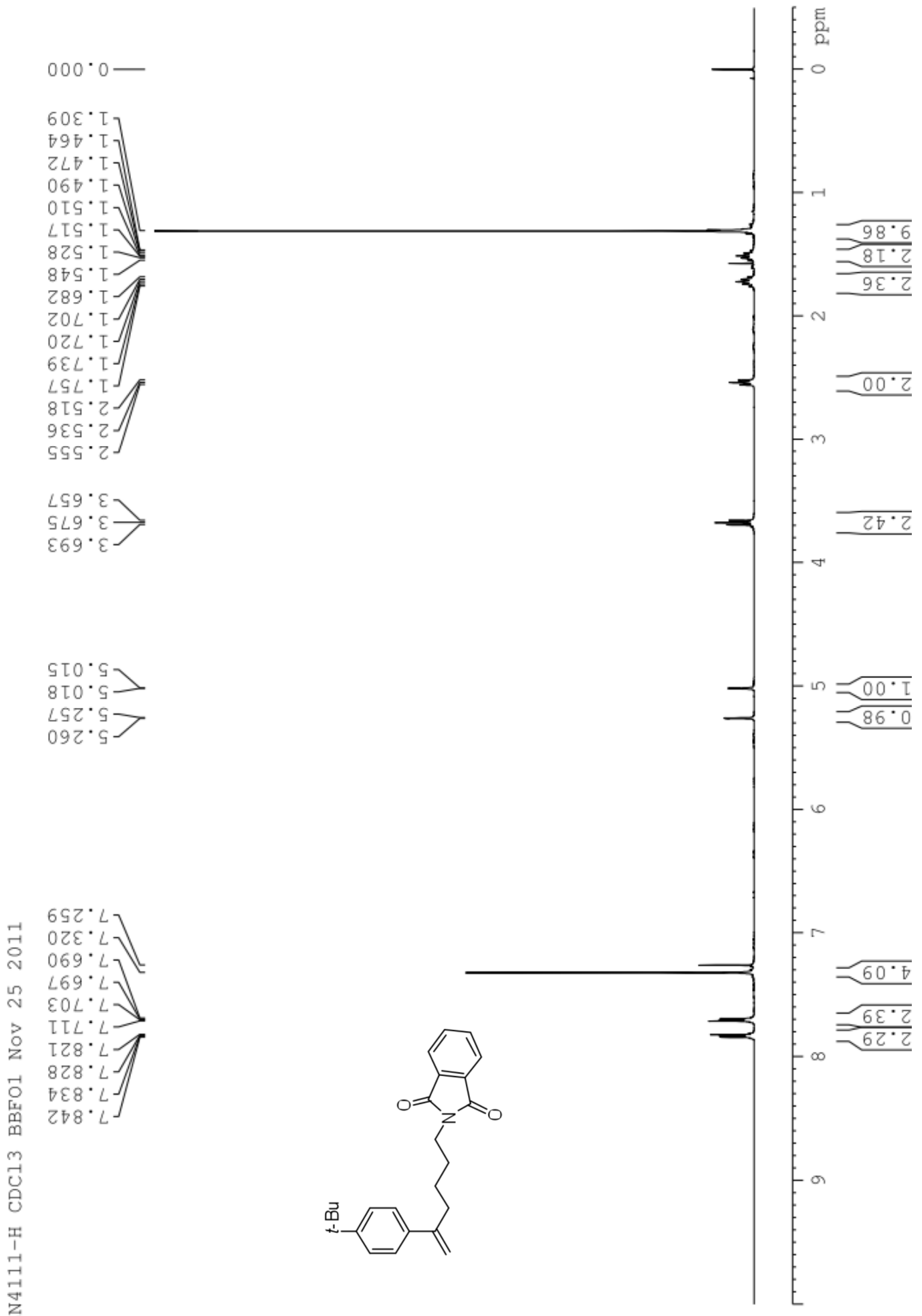
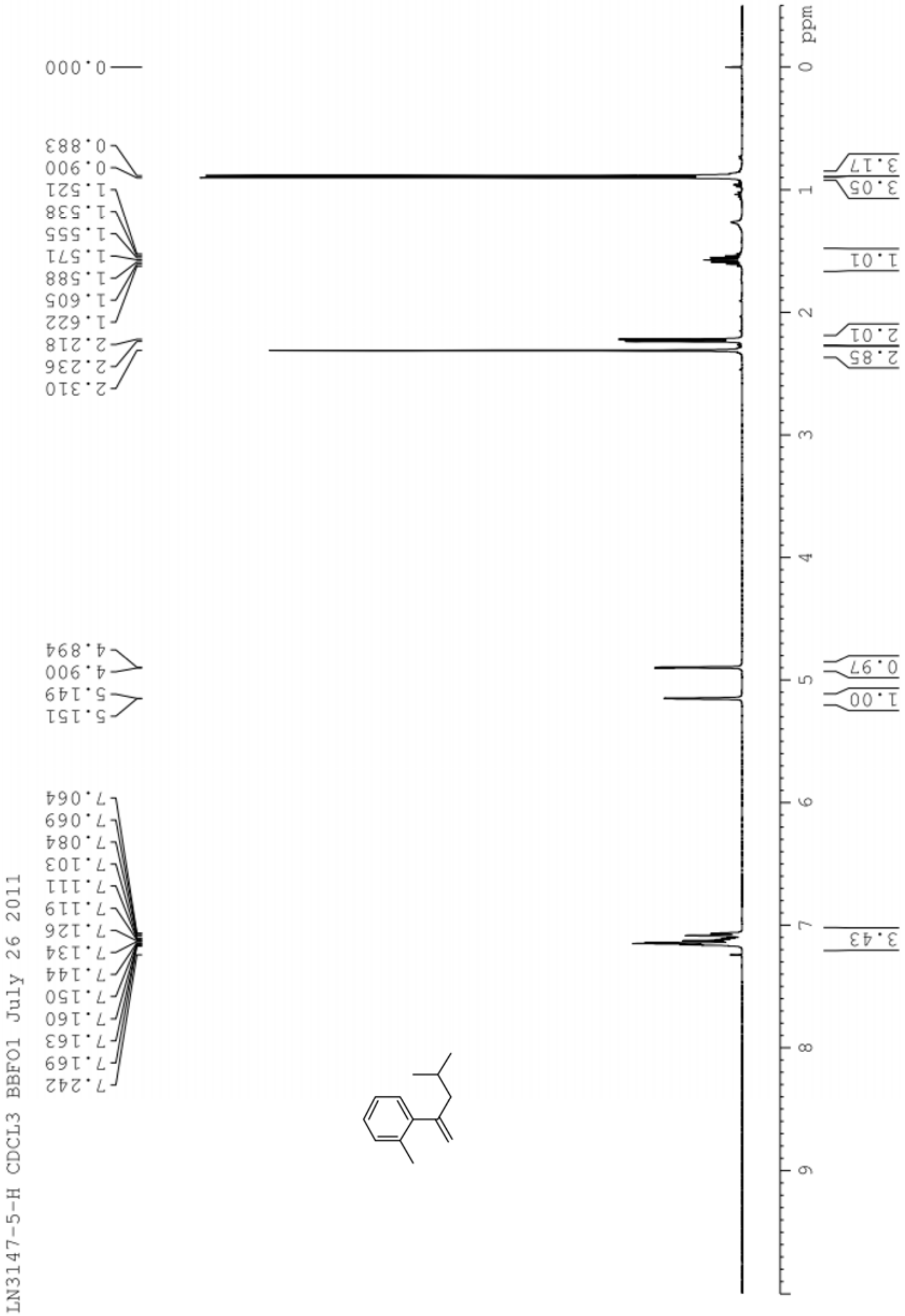
2
3
4
5
6
7
8
9


LN4094-3-H up CDCl3 BBFO2 Dec 27 2011
7.344
7.253
5.300
5.297
5.028
5.025
3.658
2.555
2.536
2.518
2.358
2.339
2.321
1.839
1.820
1.801
1.783
1.764
1.572
1.320
0.000
t-Bu
O
OMe
9
8
7
6
5
4
3
2
1
0
ppm
3.98
1.00
1.01
3.13
2.02
2.12
2.09
9.49


LN4102-2-H CDCl3 BBFO1 Nov 18 2011
0.000
1.323
1.478
1.488
1.505
1.525
1.533
1.543
1.563
1.626
1.643
1.663
1.681
1.698
2.018
2.505
2.524
2.543
4.036
4.053
4.069
5.023
5.279
7.255
7.341
9.67
2.04
2.20
3.03
2.01
2.23
1.03
1.00
4.08
0
1
2
3
4
5
6
7
8
9
ppm
O
O
t-Bu


LN4111-H CDCl3 BBFO1 Nov 25 2011
0.000
1.309
1.464
1.472
1.490
1.510
1.517
1.528
1.548
1.682
1.702
1.720
1.739
1.757
2.518
2.536
2.555
3.657
3.675
3.693
5.015
5.018
5.257
5.260
7.259
7.320
7.690
7.697
7.703
7.711
7.821
7.828
7.834
7.842
9.86
2.18
2.36
2.00
2.42
1.00
0.98
4.09
2.39
2.29
ppm
0
1
2
3
4
5
6
7
8
9
O
N
O
t-Bu


LN3147-5-H CDCL3 BBFO1 July 26 2011
0.000
0.883
0.900
1.521
1.538
1.555
1.571
1.588
1.605
1.622
2.218
2.236
2.310
4.894
4.900
5.149
5.151
7.064
7.069
7.084
7.103
7.111
7.119
7.126
7.134
7.144
7.150
7.160
7.163
7.169
7.242
3.17
3.05
1.01
2.01
2.85
0.97
1.00
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ppm
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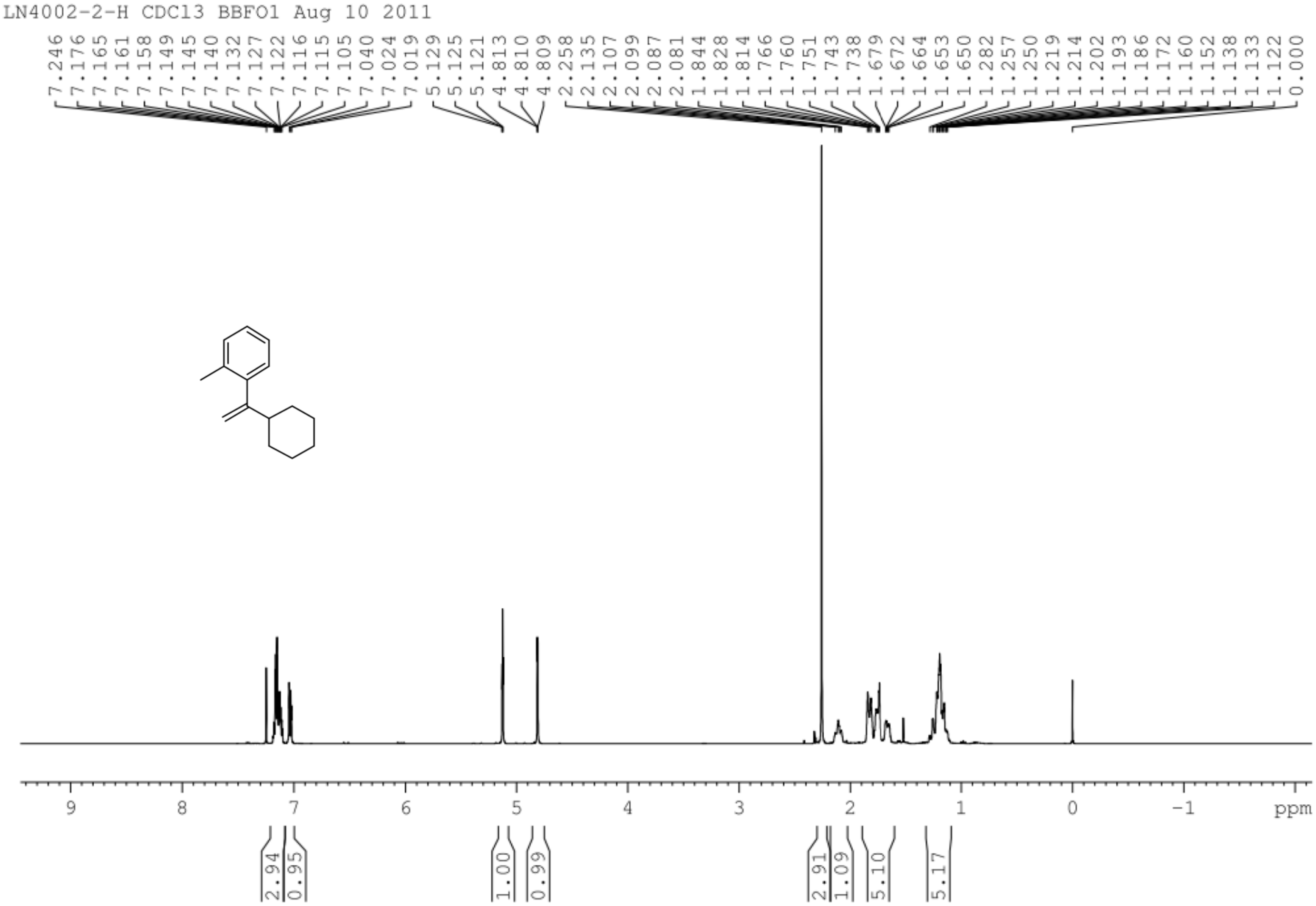
1
2
3
4
5
6
7
8
9


LN4002-2-H CDCl3 BBFO1 Aug 10 2011
7.246
7.176
7.165
7.161
7.158
7.149
7.145
7.140
7.132
7.127
7.122
7.116
7.115
7.105
7.040
7.024
7.019
5.129
5.125
5.121
4.813
4.810
4.809
2.258
2.135
2.107
2.099
2.087
2.081
1.844
1.828
1.814
1.766
1.760
1.751
1.743
1.738
1.679
1.672
1.664
1.653
1.650
1.282
1.257
1.250
1.219
1.214
1.202
1.193
1.186
1.172
1.160
1.152
1.138
1.133
1.122
0.000
9
8
7
6
5
4
3
2
1
0
−1
ppm
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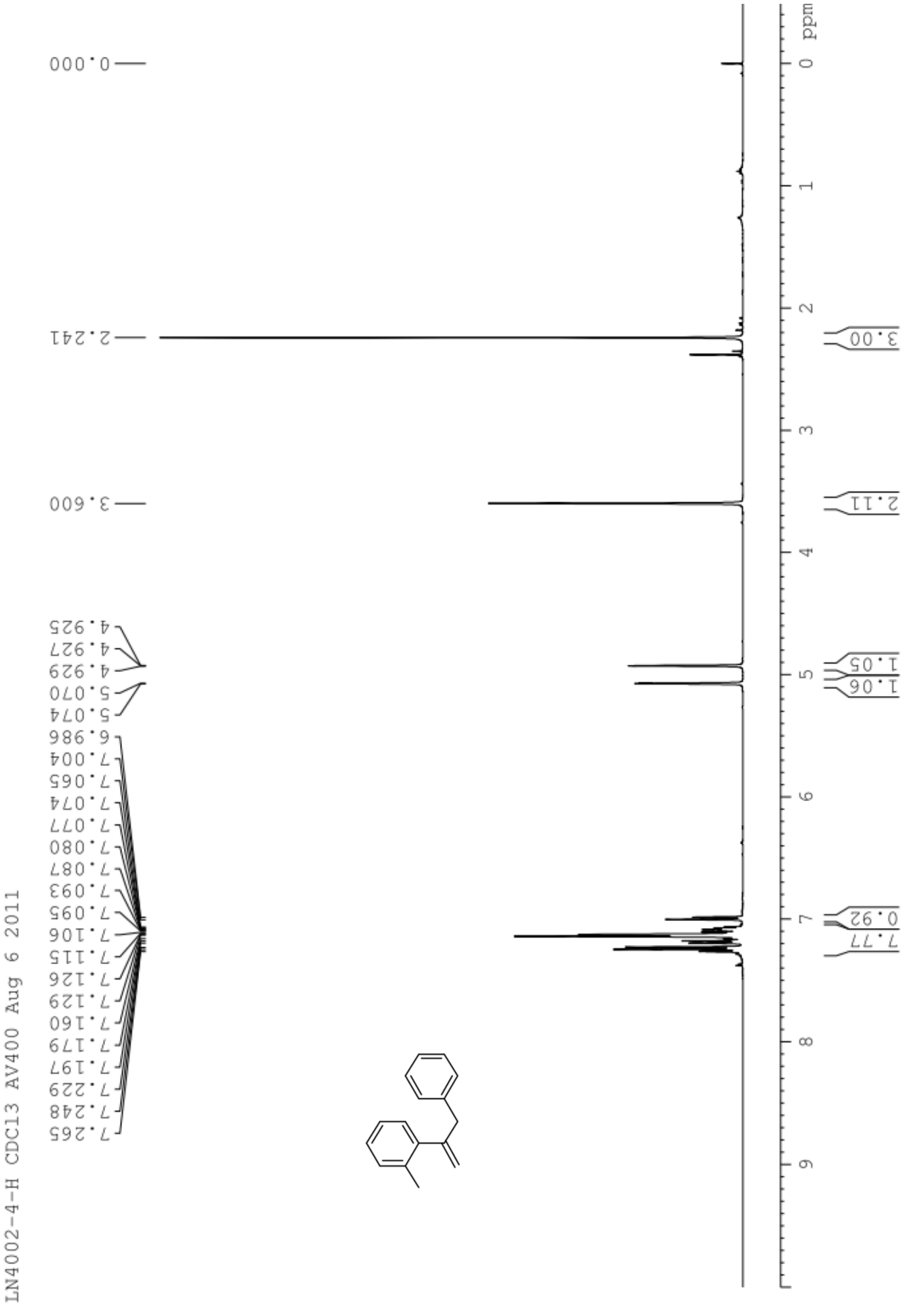
0.95
1.00
0.99
2.91
1.09
5.10
5.17


LN4002-4-H CDCl3 AV400 Aug 6 2011
0.000
2.241
3.600
4.925
4.927
4.929
5.070
5.074
6.986
7.004
7.065
7.074
7.077
7.080
7.087
7.093
7.095
7.106
7.115
7.126
7.129
7.160
7.179
7.197
7.229
7.248
7.265
3.00
2.11
1.05
1.06
0.92
7.77
ppm
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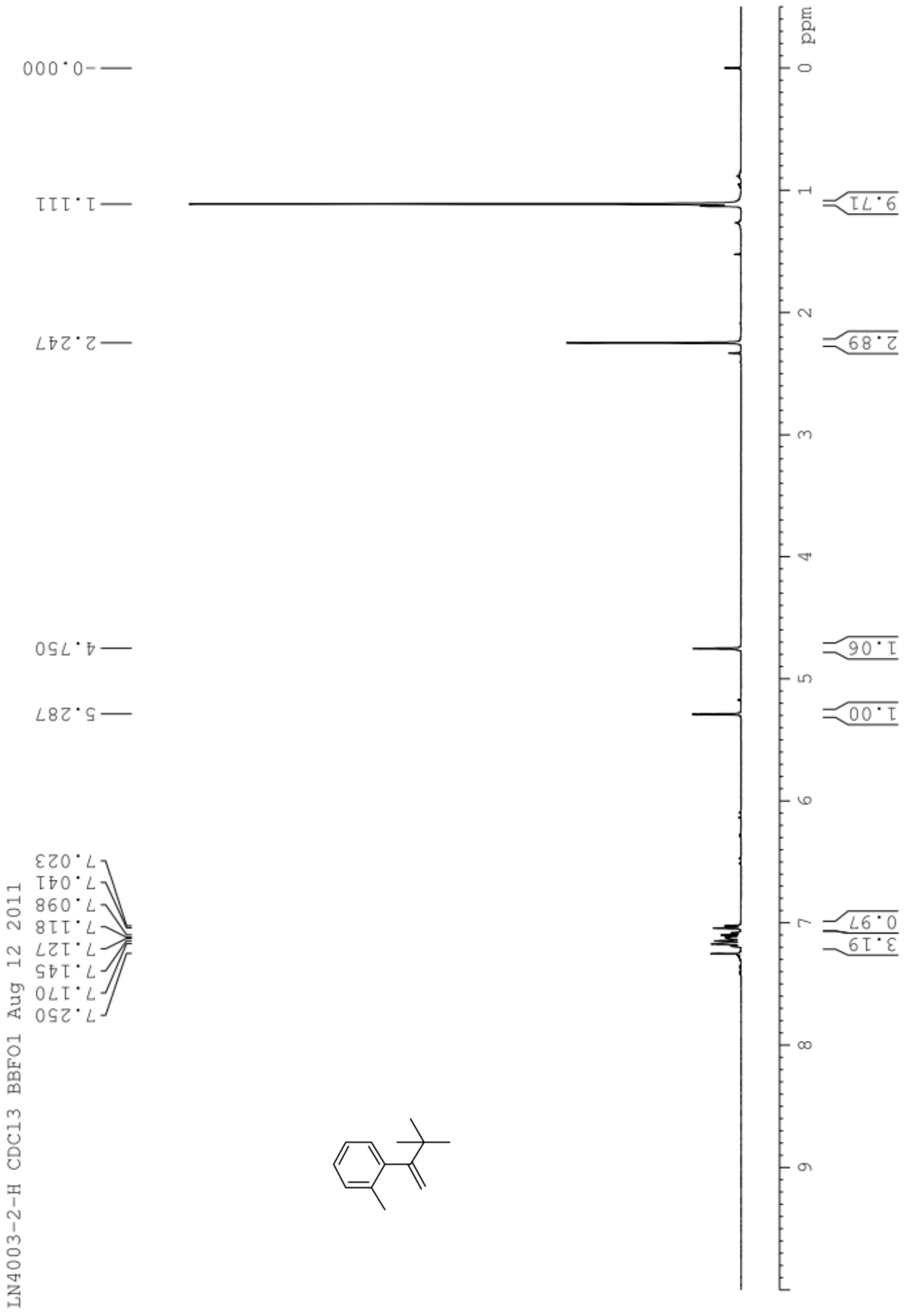
1
2
3
4
5
6
7
8
9


LN4003-2-H CDCl3 BBFO1 Aug 12 2011
-0.000
1.111
2.247
4.750
5.287
7.023
7.041
7.098
7.118
7.127
7.145
7.170
7.250
9.71
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1.06
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0.97
3.19
ppm
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2
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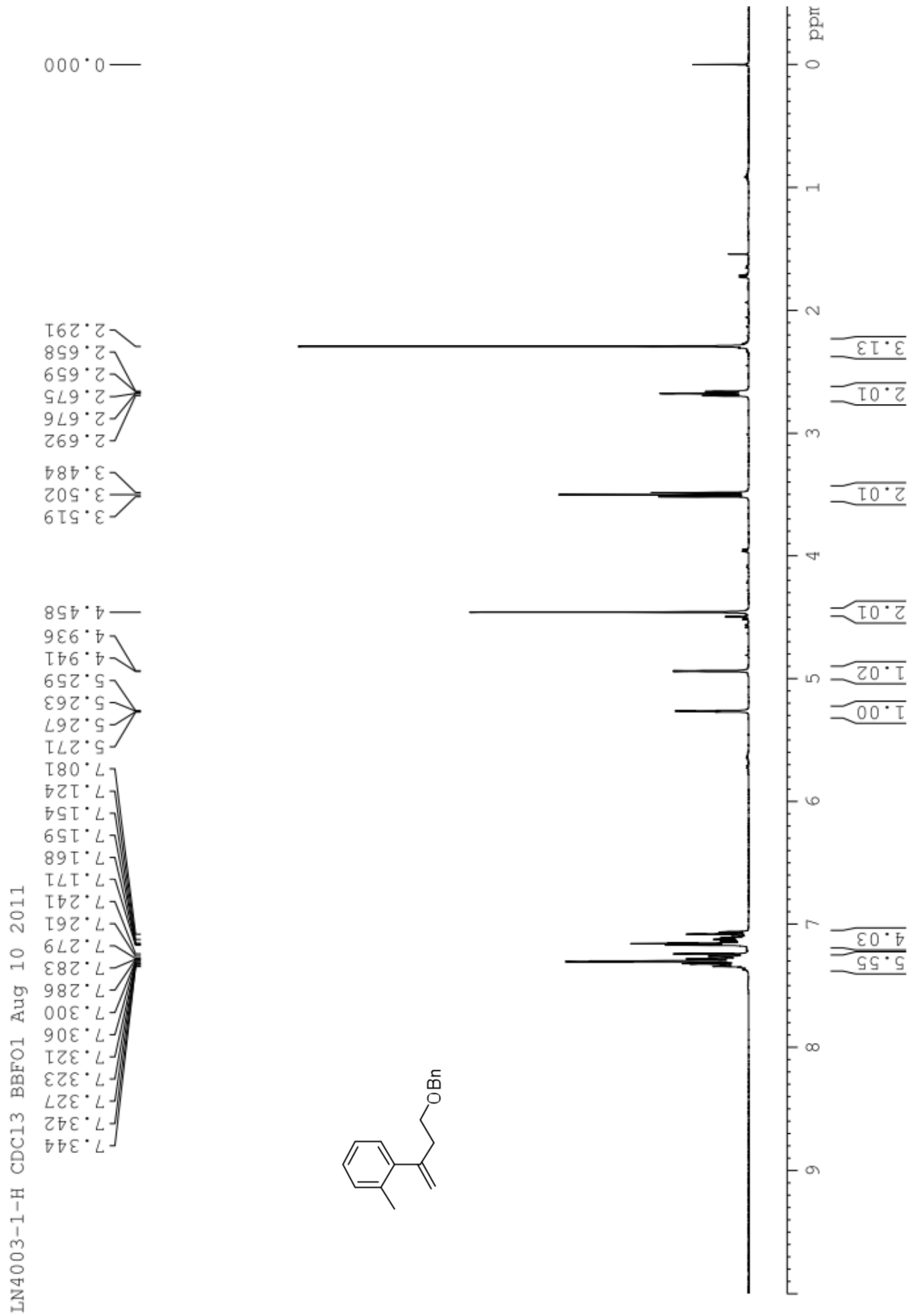
5
6
7
8
9


LN4003-1-H CDCl3 BBFO1 Aug 10 2011
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2.291
2.658
2.659
2.675
2.676
2.692
3.484
3.502
3.519
4.458
4.936
4.941
5.259
5.263
5.267
5.271
7.081
7.124
7.154
7.159
7.168
7.171
7.241
7.261
7.279
7.283
7.286
7.300
7.306
7.321
7.323
7.327
7.342
7.344
OBn
3.13
2.01
2.01
2.01
1.02
1.00
4.03
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2
3
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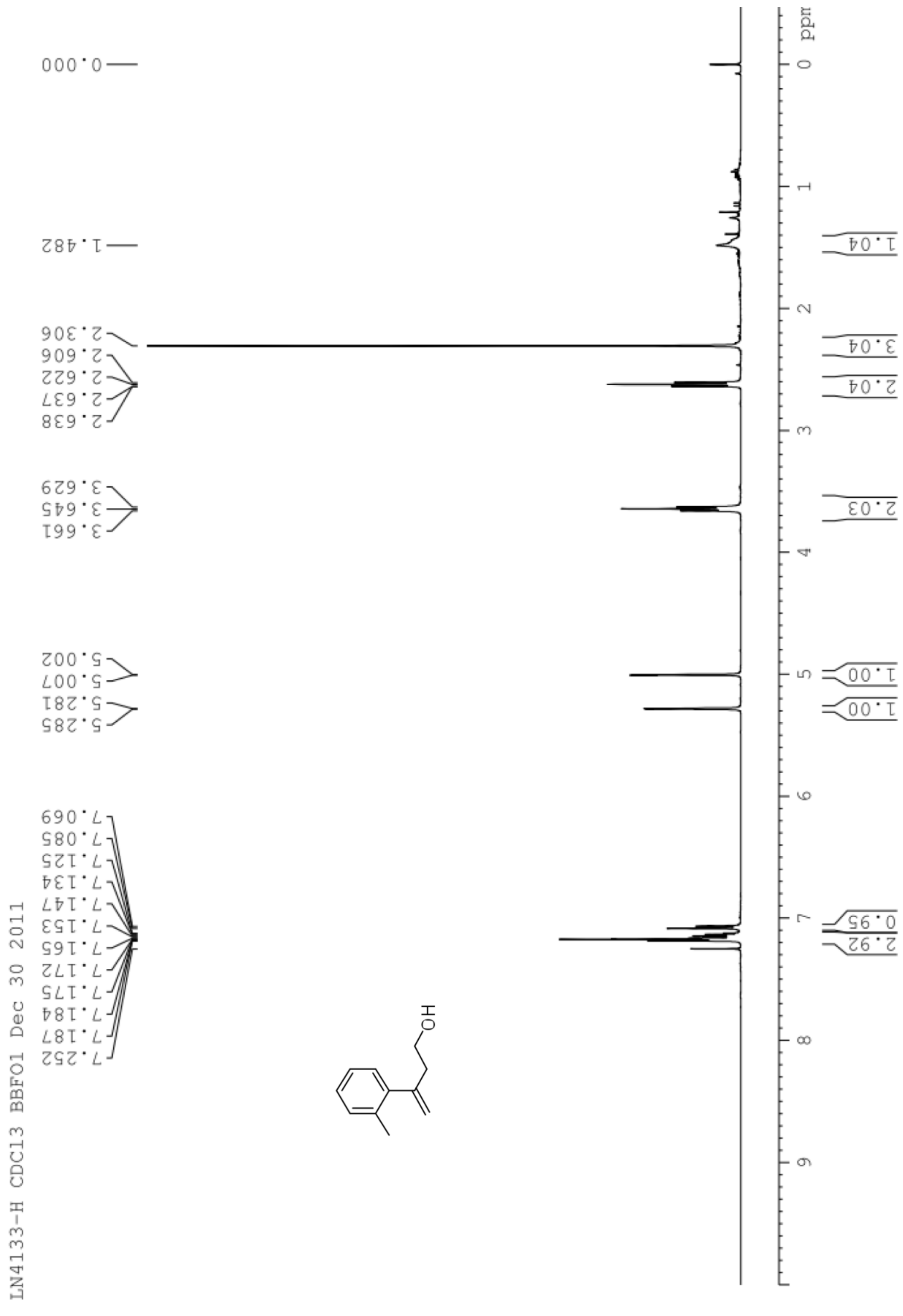
8
9


LN4133-H CDCl3 BBFO1 Dec 30 2011
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1.482
2.306
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2.622
2.637
2.638
3.629
3.645
3.661
5.002
5.007
5.281
5.285
7.069
7.085
7.125
7.134
7.147
7.153
7.165
7.172
7.175
7.184
7.187
7.252
HO
1.04
3.04
2.04
2.03
1.00
1.00
0.95
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ppm
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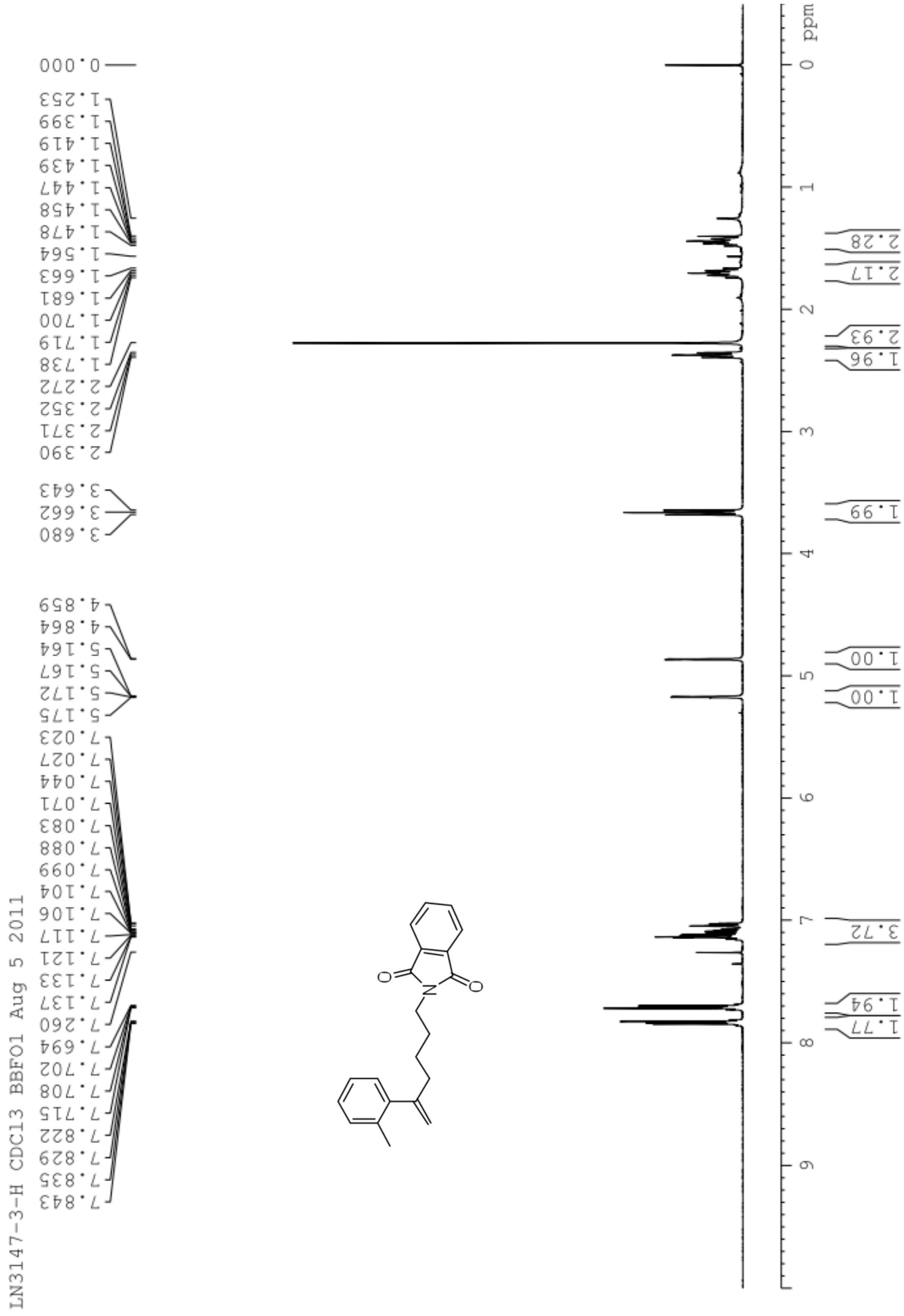
1
2
3
4
5
6
7
8
9


LN3147-3-H CDCl3 BBFO1 Aug 5 2011
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1.253
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1.419
1.439
1.447
1.458
1.478
1.564
1.663
1.681
1.700
1.719
1.738
2.272
2.352
2.371
2.390
3.643
3.662
3.680
4.859
4.864
5.164
5.167
5.172
5.175
7.023
7.027
7.044
7.071
7.083
7.088
7.099
7.104
7.106
7.117
7.121
7.133
7.137
7.260
7.694
7.702
7.708
7.715
7.822
7.829
7.835
7.843
2.28
2.17
2.93
1.96
1.99
1.00
1.00
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5
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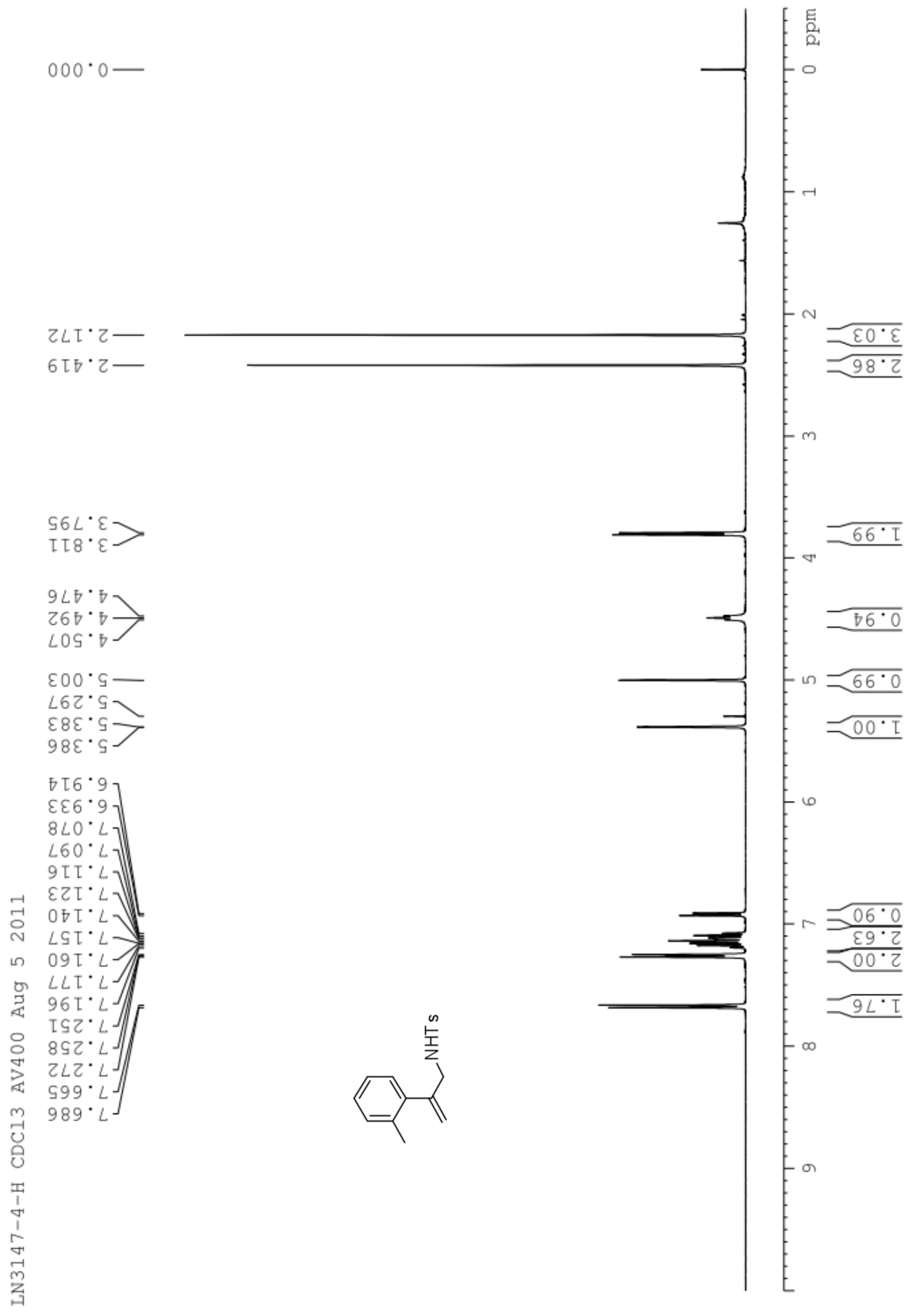
7
8
9
O
N
O


LN3147-4-H CDCl3 AV400 Aug 5 2011
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2.419
3.795
3.811
4.476
4.492
4.507
5.003
5.297
5.383
5.386
6.914
6.933
7.078
7.097
7.116
7.123
7.140
7.157
7.160
7.177
7.196
7.251
7.258
7.272
7.665
7.686
NHTs
3.03
2.86
1.99
0.94
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0.90
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2.00
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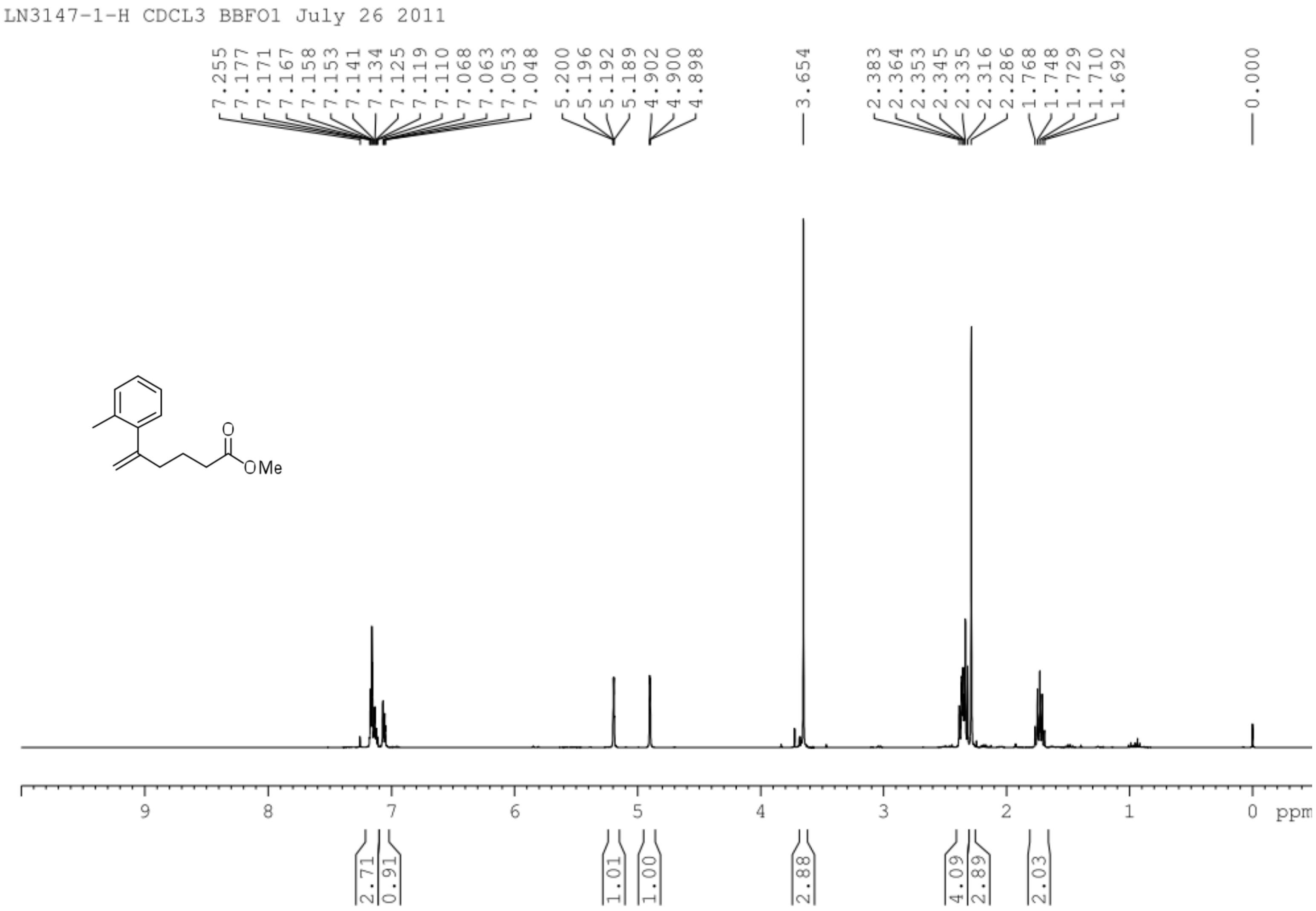
1
2
3
4
5
6
7
8
9
ppm


LN3147-1-H CDCL3 BBFO1 July 26 2011
7.255
7.177
7.171
7.167
7.158
7.153
7.141
7.134
7.125
7.119
7.110
7.068
7.063
7.053
7.048
5.200
5.196
5.192
5.189
4.902
4.900
4.898
3.654
2.383
2.364
2.353
2.345
2.335
2.316
2.286
1.768
1.748
1.729
1.710
1.692
0.000
O
OMe
9
8
7
6
5
4
3
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1
0
ppm
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1.00
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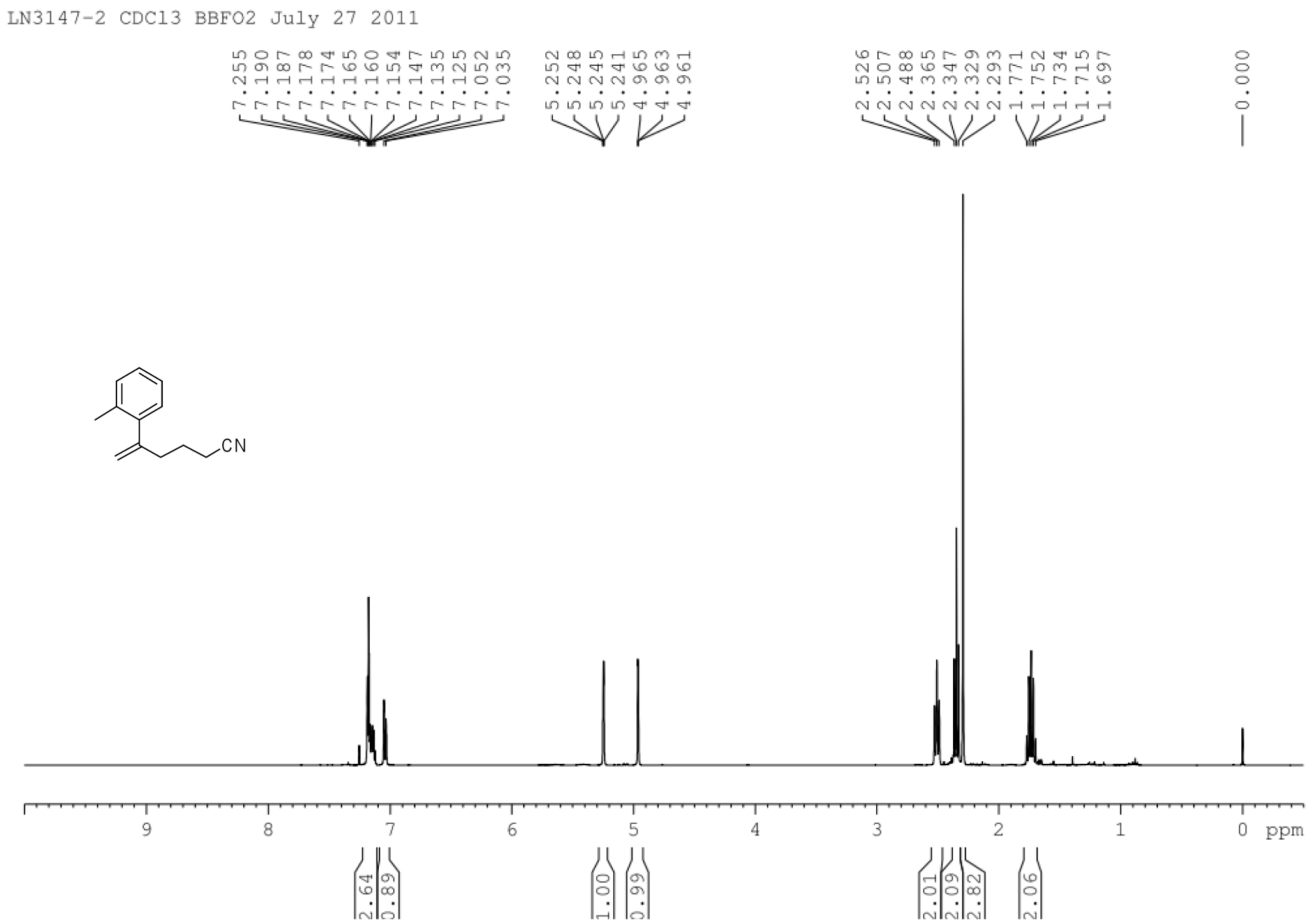
4.09
2.89
2.03


LN3147-2 CDCl3 BBFO2 July 27 2011
7.255
7.190
7.187
7.178
7.174
7.165
7.160
7.154
7.147
7.135
7.125
7.052
7.035
5.252
5.248
5.245
5.241
4.965
4.963
4.961
2.526
2.507
2.488
2.365
2.347
2.329
2.293
1.771
1.752
1.734
1.715
1.697
0.000
CN
9
8
7
6
5
4
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2
1
0 ppm
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0.99
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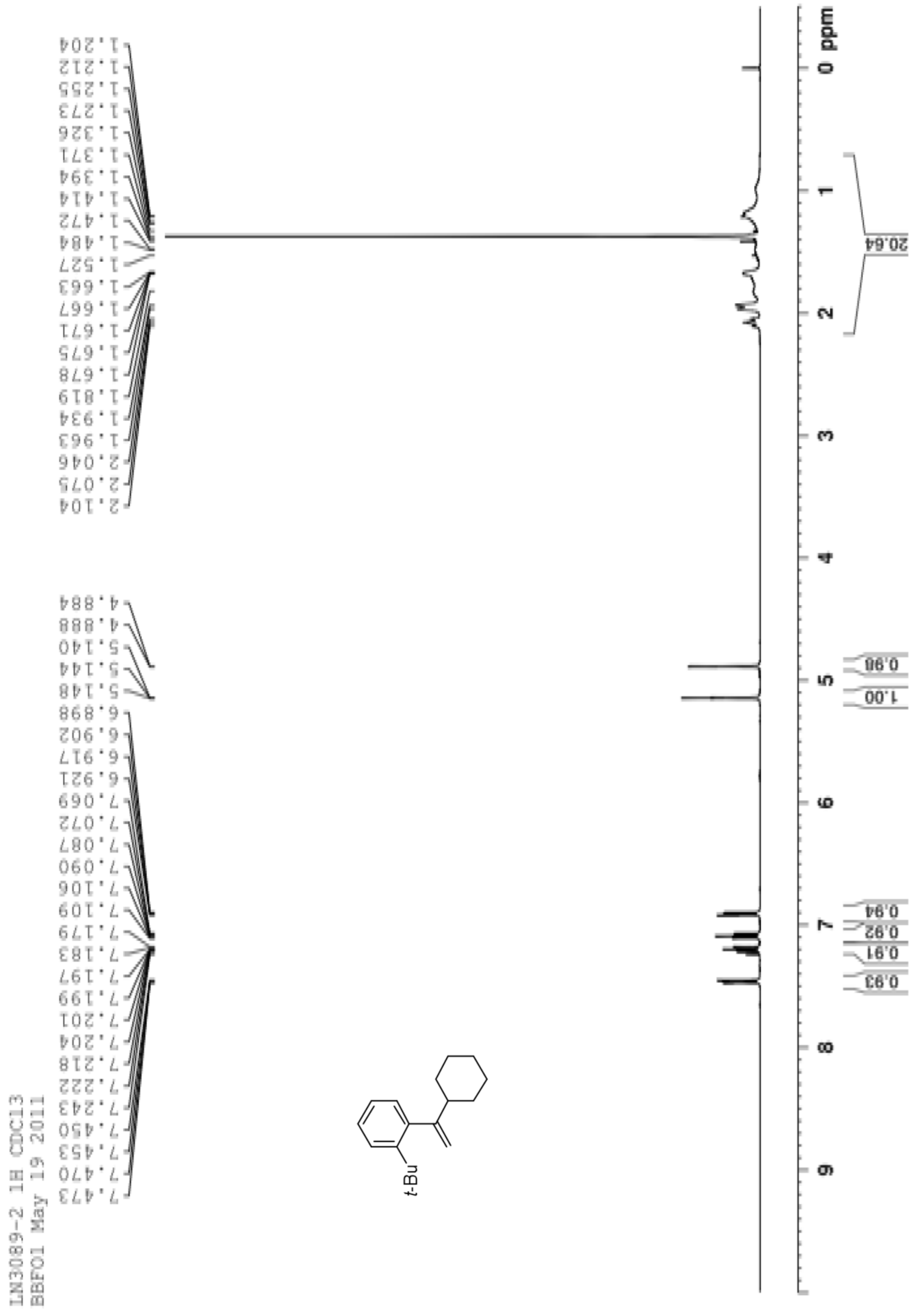
2.09
2.82
2.06


LN3089-2 1H CDCl3
BBFO1 May 19 2011
7.473
7.470
7.453
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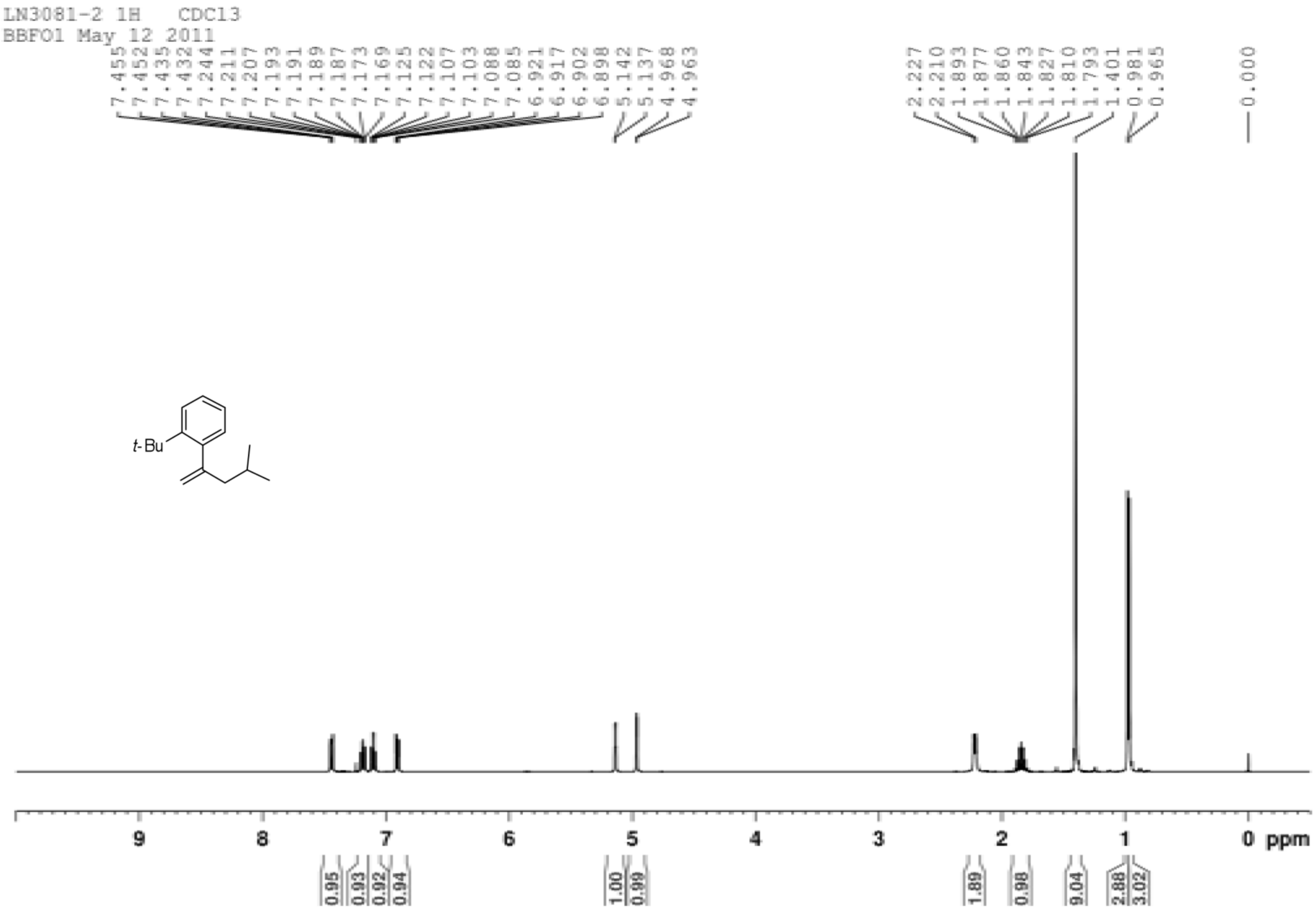
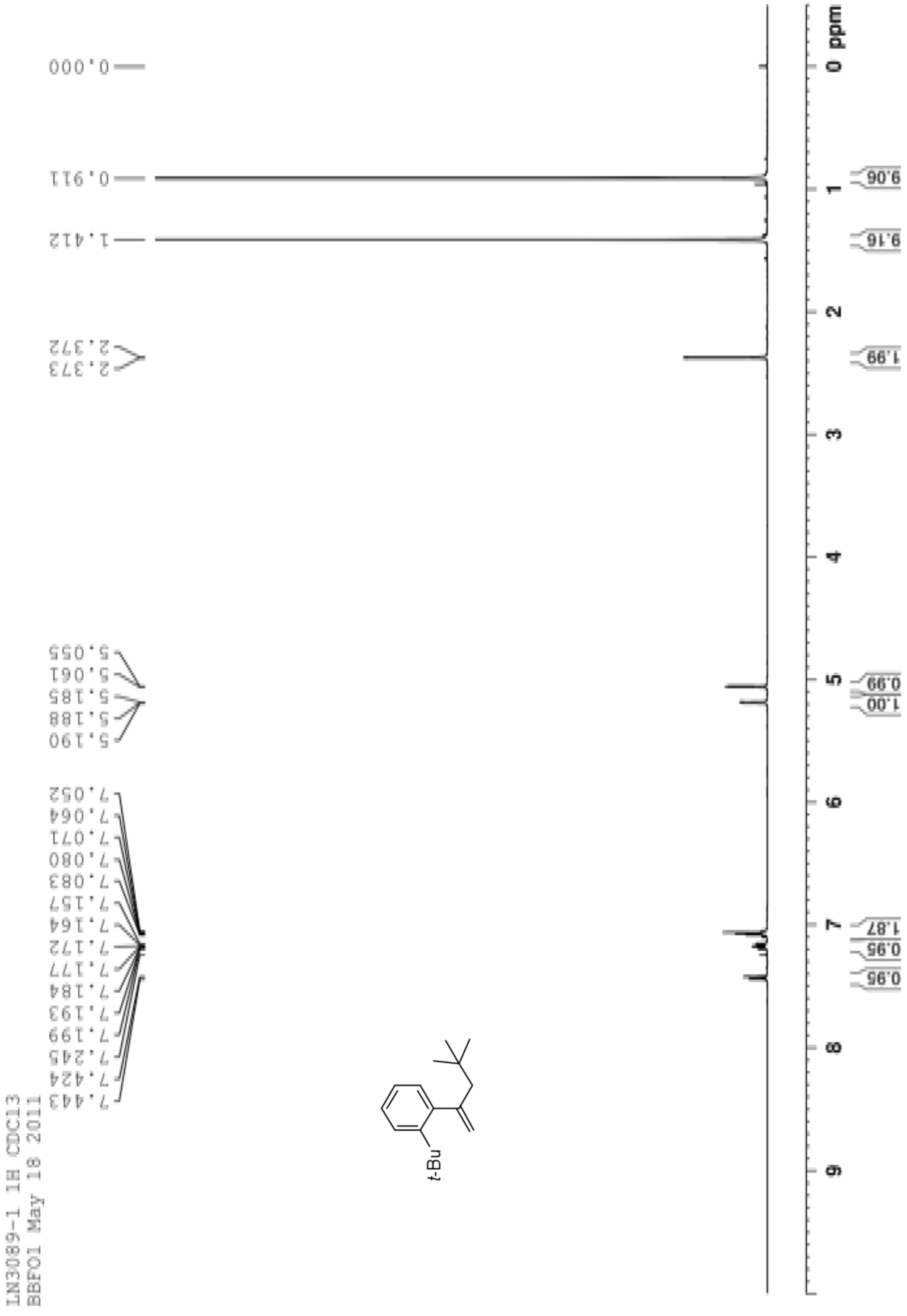
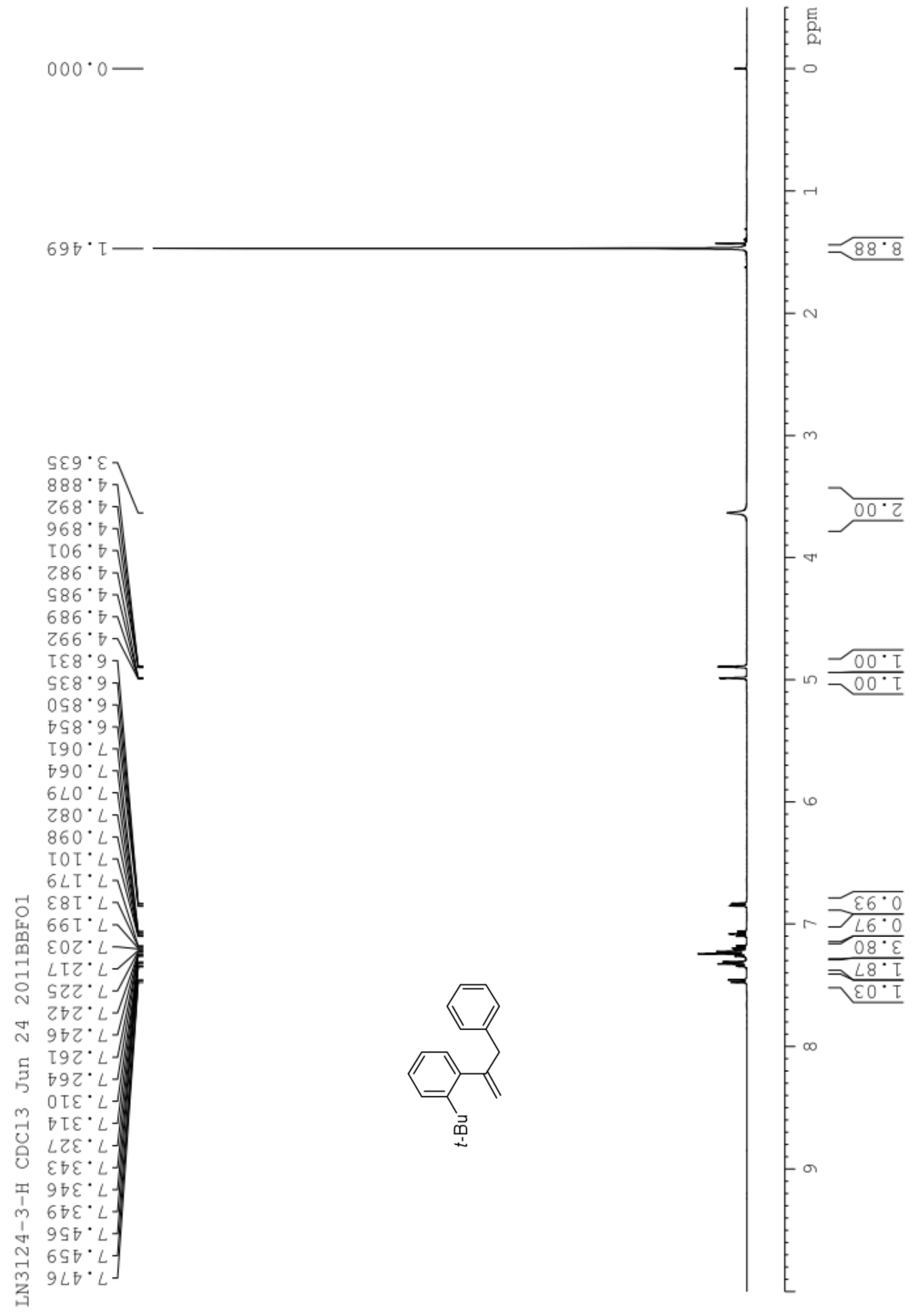
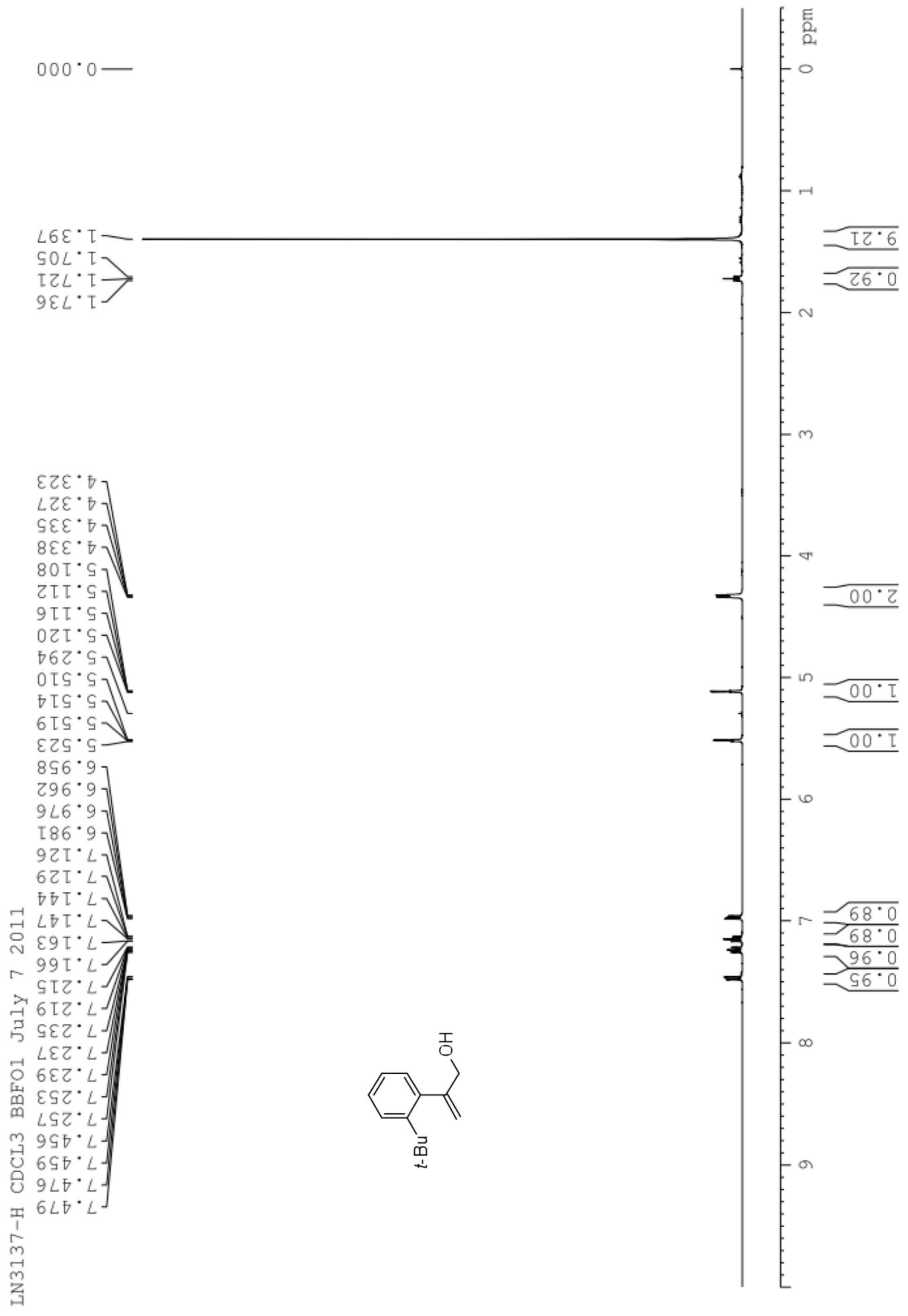
7.243
7.222
7.218
7.204
7.201
7.199
7.197
7.183
7.179
7.109
7.106
7.090
7.087
7.072
7.069
6.921
6.917
6.902
6.898
5.148
5.144
5.140
4.888
4.884
2.104
2.075
2.046
1.963
1.934
1.819
1.678
1.675
1.671
1.667
1.663
1.527
1.484
1.472
1.414
1.394
1.371
1.326
1.273
1.255
1.212
1.204
t-Bu
0.93
0.91
0.92
0.94
1.00
0.98
20.64
9
8
7
6
5
4
3
2
1
0 ppm

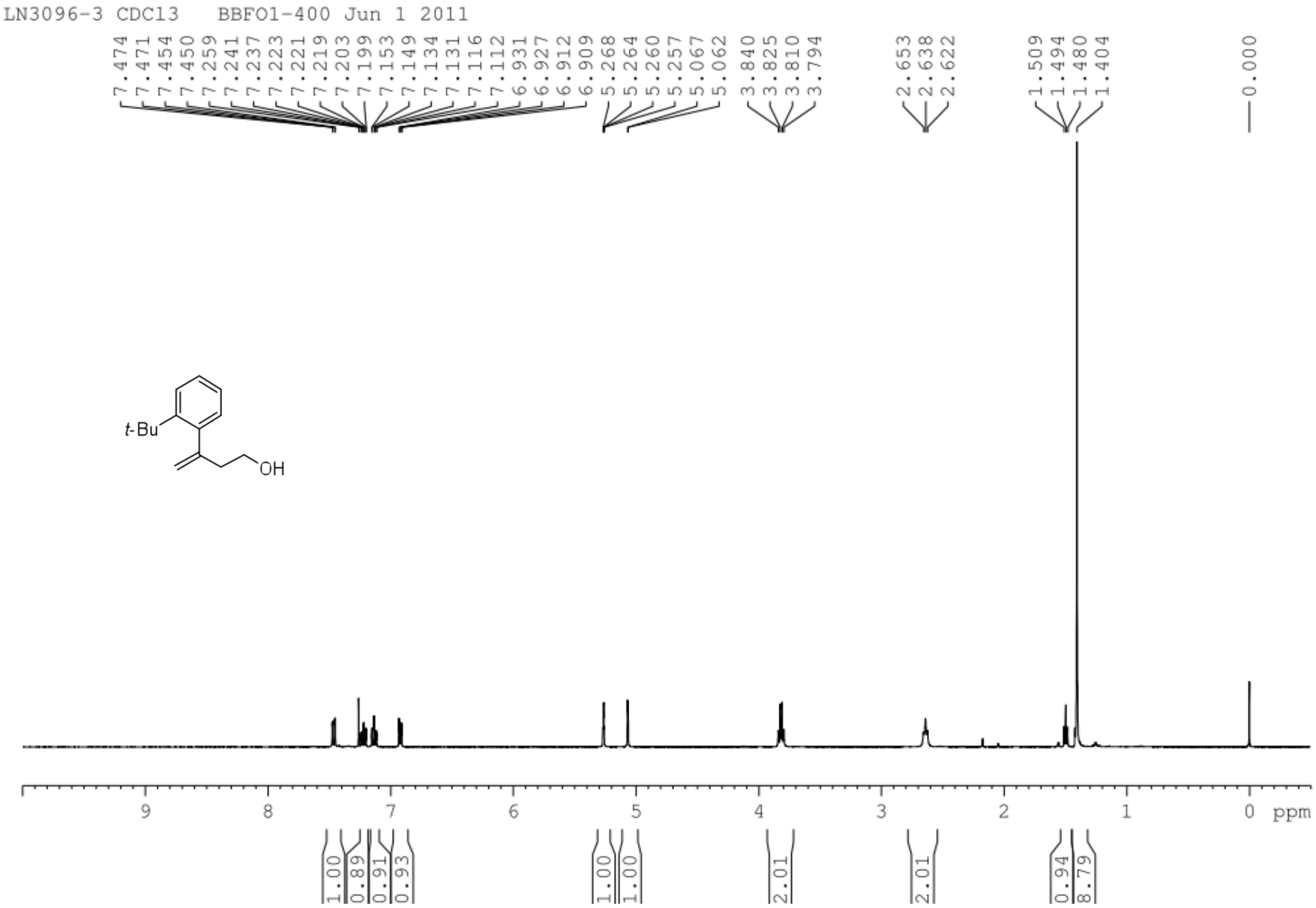

LN3081-2 1H CDCl3
BBFO1 May 12 2011
7.455
7.452
7.435
7.432
7.244
7.211
7.207
7.193
7.191
7.189
7.187
7.173
7.169
7.125
7.122
7.107
7.103
7.088
7.085
6.921
6.917
6.902
6.898
5.142
5.137
4.968
4.963
2.227
2.210
1.893
1.877
1.860
1.843
1.827
1.810
1.793
1.401
0.981
0.965
0.000
t-Bu
9
8
7
6
5
4
3
2
1
0 ppm
0.95
0.93
0.92
0.94
1.00
0.99
1.89
0.98
9.04
2.88
3.02

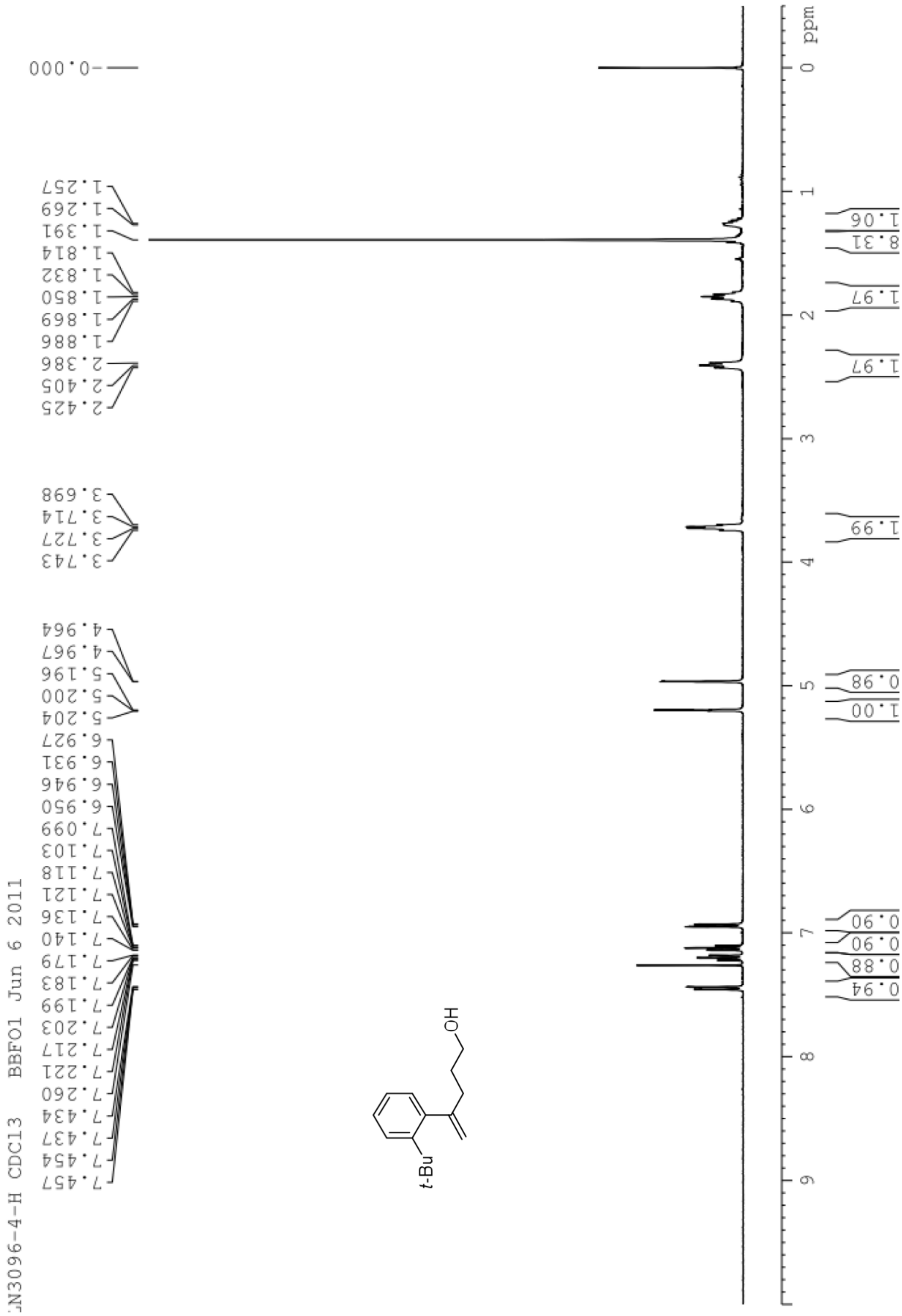

1N3089-1 1H CDCl3
BBFO1 May 18 2011
0.000
0.911
1.412
2.372
2.373
5.055
5.061
5.185
5.188
5.190
7.052
7.064
7.071
7.080
7.083
7.157
7.164
7.172
7.177
7.184
7.193
7.199
7.245
7.424
7.443
t-Bu
9.06
9.16
1.99
0.99
1.00
1.87
0.95
0.95
0
1
2
3
4
5
6
7
8
9
ppm

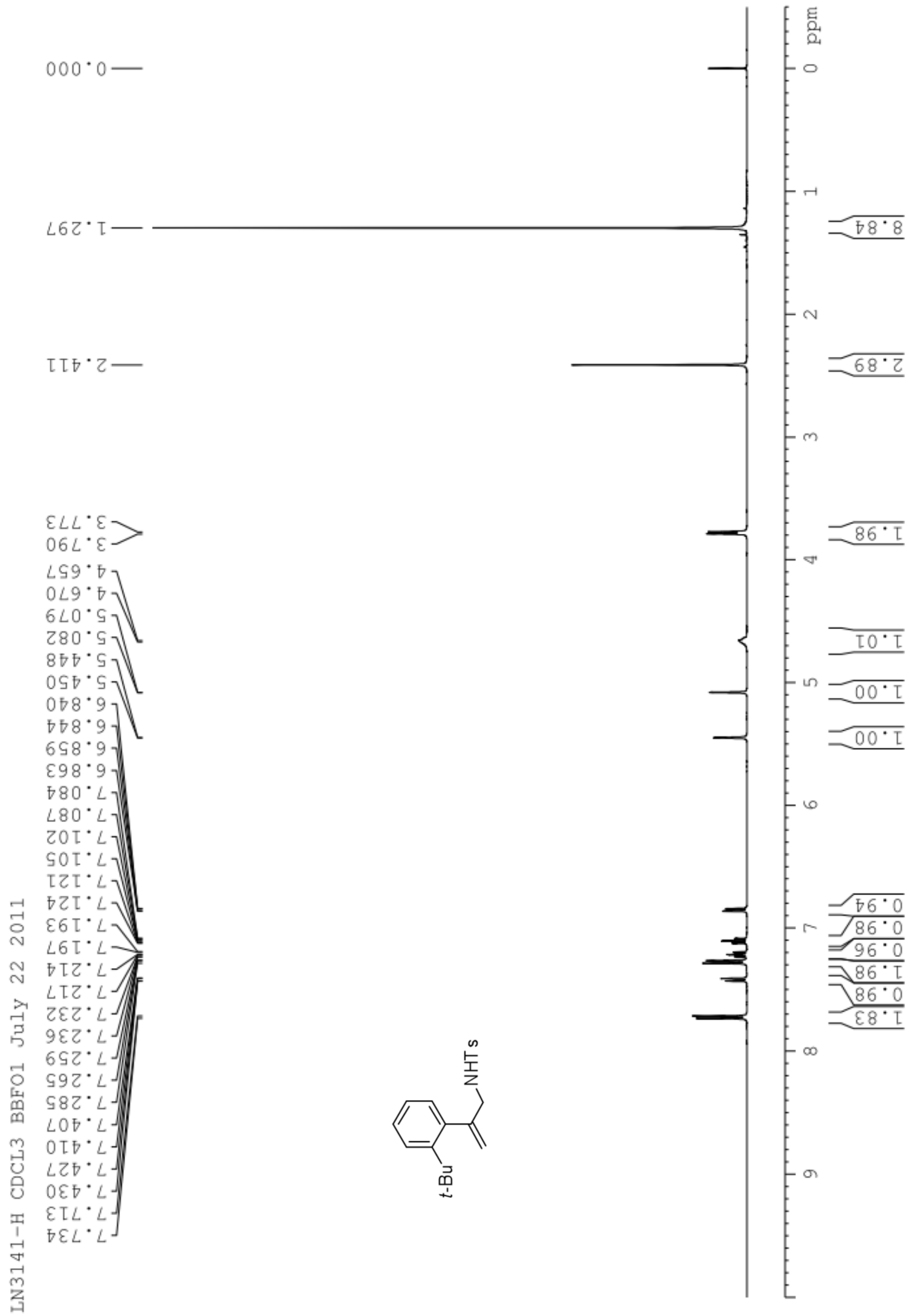


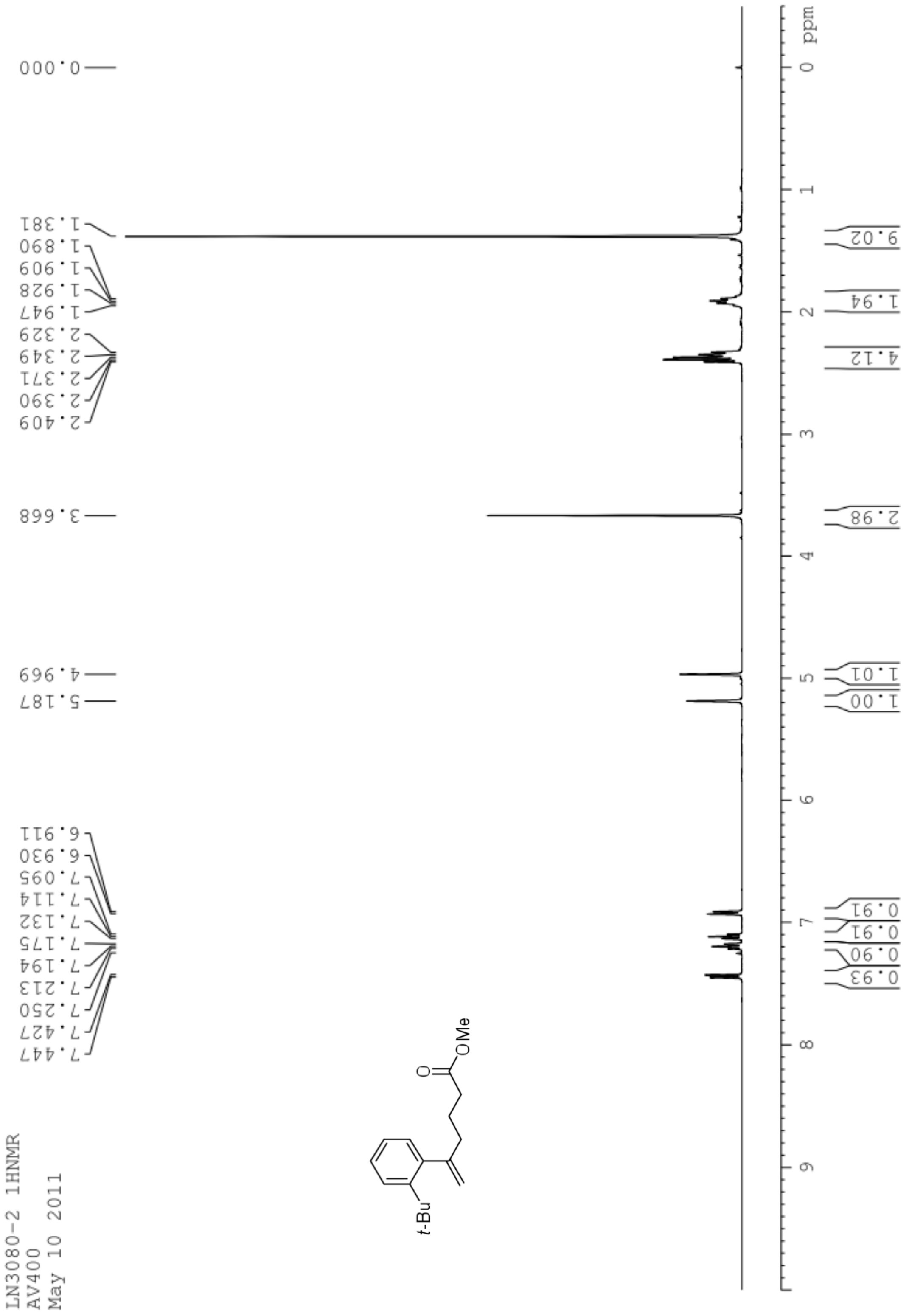
LN3124-3-H CDCl3 Jun 24 2011BBFO1
0.000
1.469
3.635
4.888
4.892
4.896
4.901
4.982
4.985
4.989
4.992
6.831
6.835
6.850
6.854
7.061
7.064
7.079
7.082
7.098
7.101
7.179
7.183
7.199
7.203
7.217
7.225
7.242
7.246
7.261
7.264
7.310
7.314
7.327
7.343
7.346
7.349
7.456
7.459
7.476
t-Bu
8.88
2.00
1.00
1.00
0.93
0.97
3.80
1.87
1.03
0
1
2
3
4
5
6
7
8
9
ppm

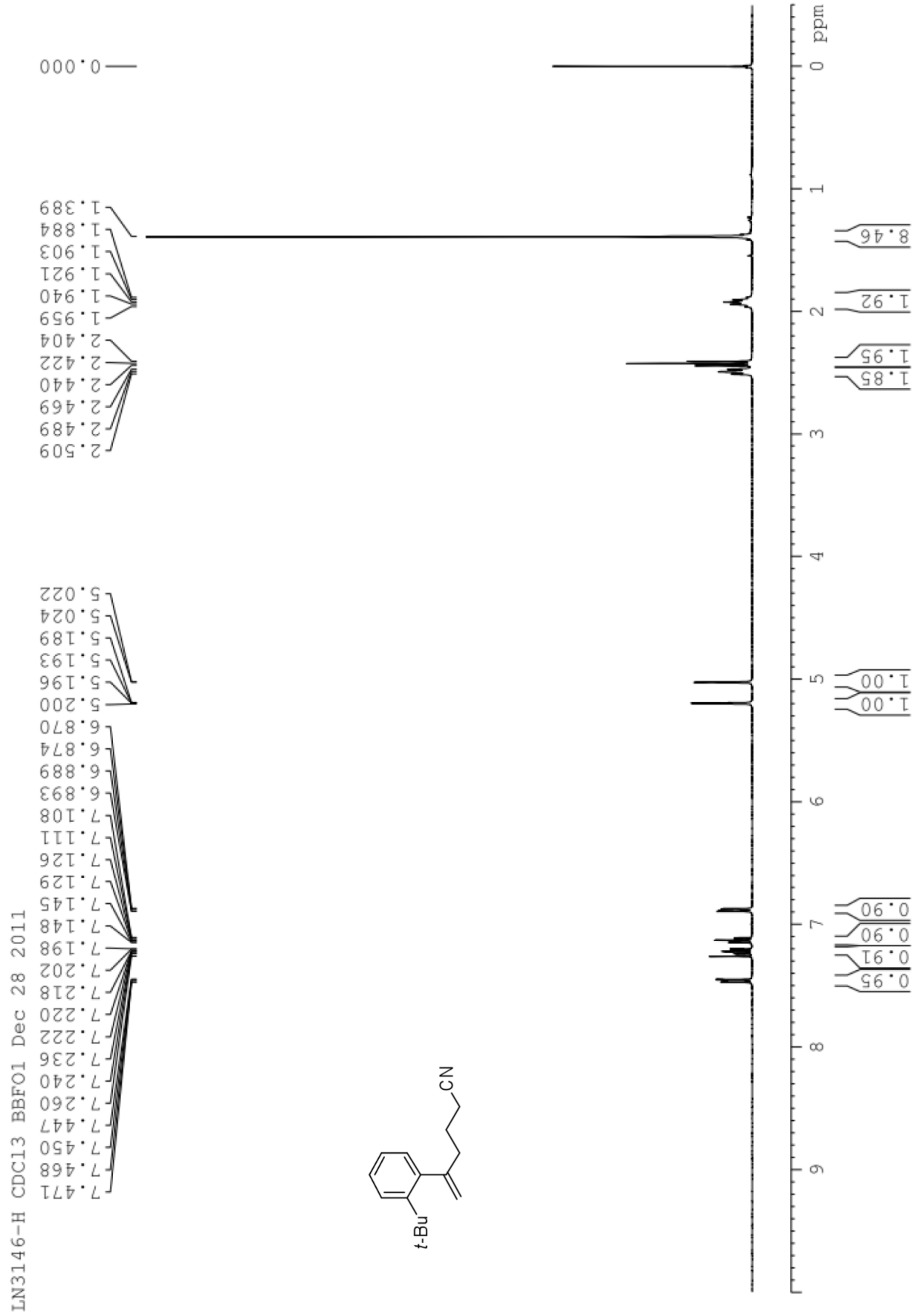

LN3137-H CDCL3 BBFO1 July 7 2011
7.479
7.476
7.459
7.456
7.257
7.253
7.239
7.237
7.235
7.219
7.215
7.166
7.163
7.147
7.144
7.129
7.126
6.981
6.976
6.962
6.958
5.523
5.519
5.514
5.510
5.294
5.120
5.116
5.112
5.108
4.338
4.335
4.327
4.323
1.736
1.721
1.705
1.397
0.000
t-Bu
OH
0.95
0.96
0.89
0.89
1.00
1.00
2.00
0.92
9.21
9
8
7
6
5
4
3
2
1
0
ppm

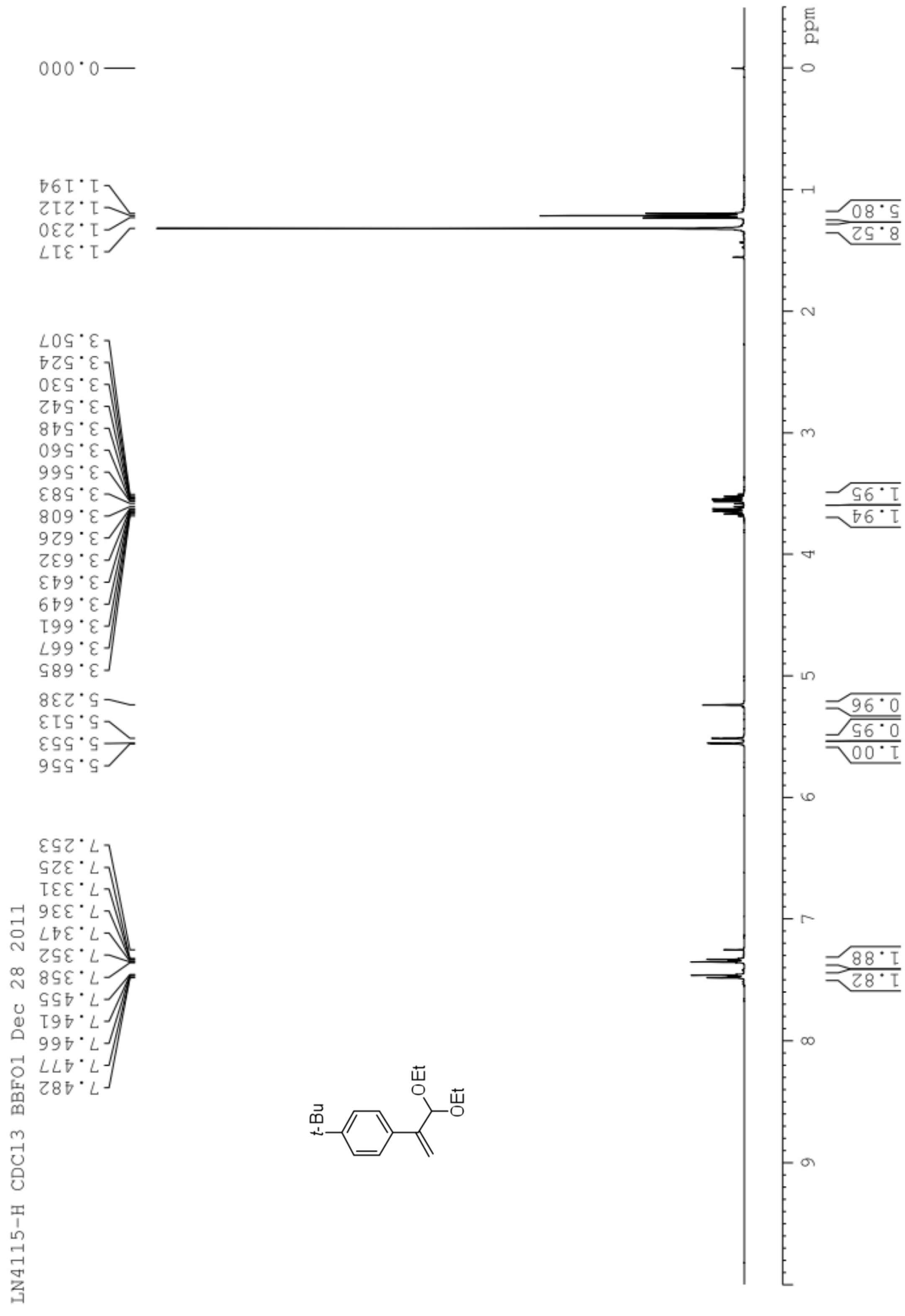

LN3096-3 CDCl3 BBFO1-400 Jun 1 2011
7.474
7.471
7.454
7.450
7.259
7.241
7.237
7.223
7.221
7.219
7.203
7.199
7.153
7.149
7.134
7.131
7.116
7.112
6.931
6.927
6.912
6.909
5.268
5.264
5.260
5.257
5.067
5.062
3.840
3.825
3.810
3.794
2.653
2.638
2.622
1.509
1.494
1.480
1.404
0.000
t-Bu
OH
9
8
7
6
5
4
3
2
1
0
ppm
1.00
0.89
0.91
0.93
1.00
1.00
2.01
2.01
0.94
8.79

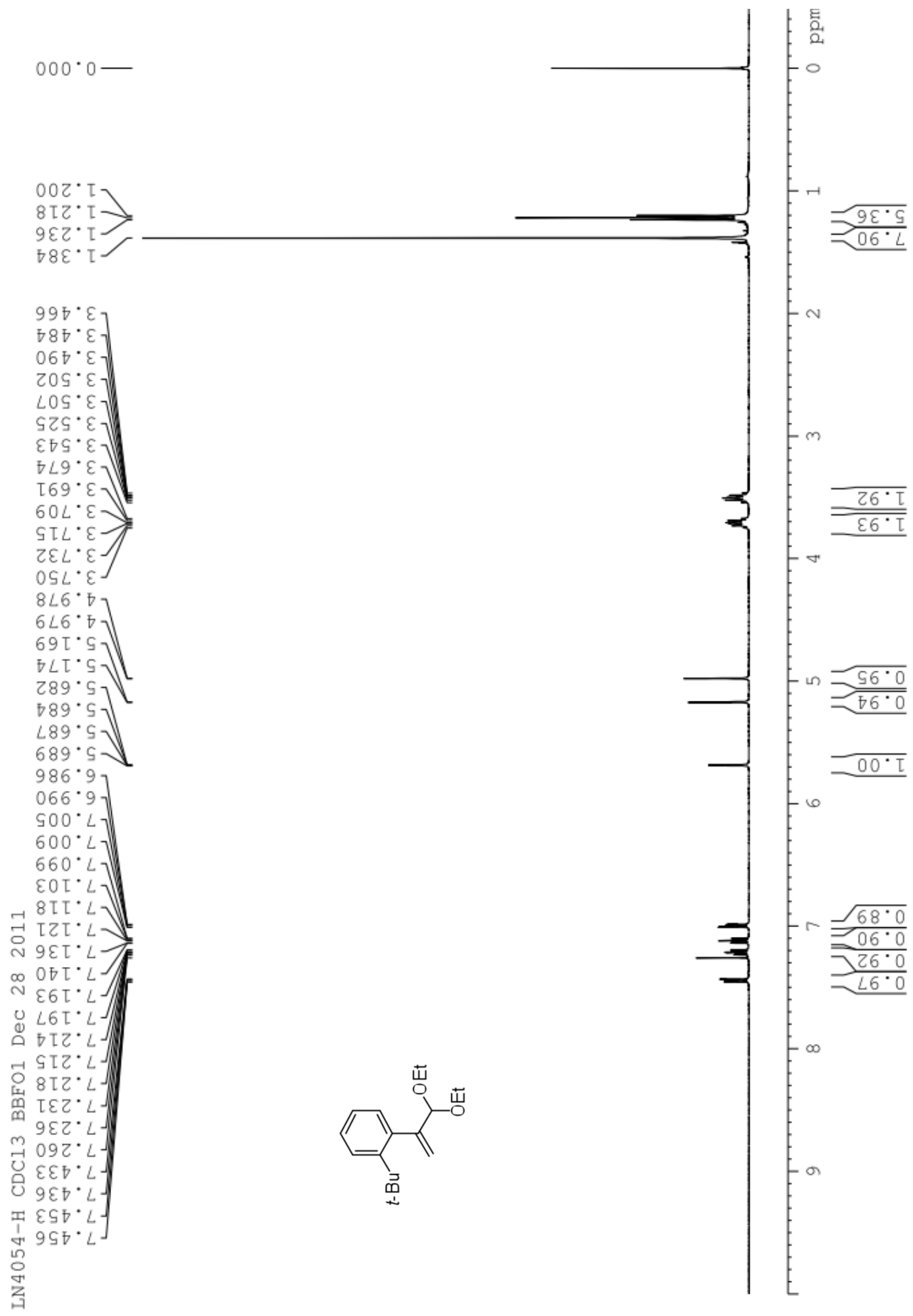

N3096-4-H CDCl3 BBFO1 Jun 6 2011
0.000
1.257
1.269
1.391
1.814
1.832
1.850
1.869
1.886
2.386
2.405
2.425
3.698
3.714
3.727
3.743
4.964
4.967
5.196
5.200
5.204
6.927
6.931
6.946
6.950
7.099
7.103
7.118
7.121
7.136
7.140
7.179
7.183
7.199
7.203
7.217
7.221
7.260
7.434
7.437
7.454
7.457
t-Bu
OH
1.06
8.31
1.97
1.97
1.99
0.98
1.00
0.90
0.90
0.88
0.94
9
8
7
6
5
4
3
2
1
0
ppm


LN3141-H CDCL3 BBFO1 July 22 2011
0.000
1.297
2.411
3.773
3.790
4.657
4.670
5.079
5.082
5.448
5.450
6.840
6.844
6.859
6.863
7.084
7.087
7.102
7.105
7.121
7.124
7.193
7.197
7.214
7.217
7.232
7.236
7.259
7.265
7.285
7.407
7.410
7.427
7.430
7.713
7.734
t-Bu
NHTs
8.84
2.89
1.98
1.01
1.00
1.00
0.94
0.98
0.96
1.98
0.98
1.83
ppm
0
1
2
3
4
5
6
7
8
9

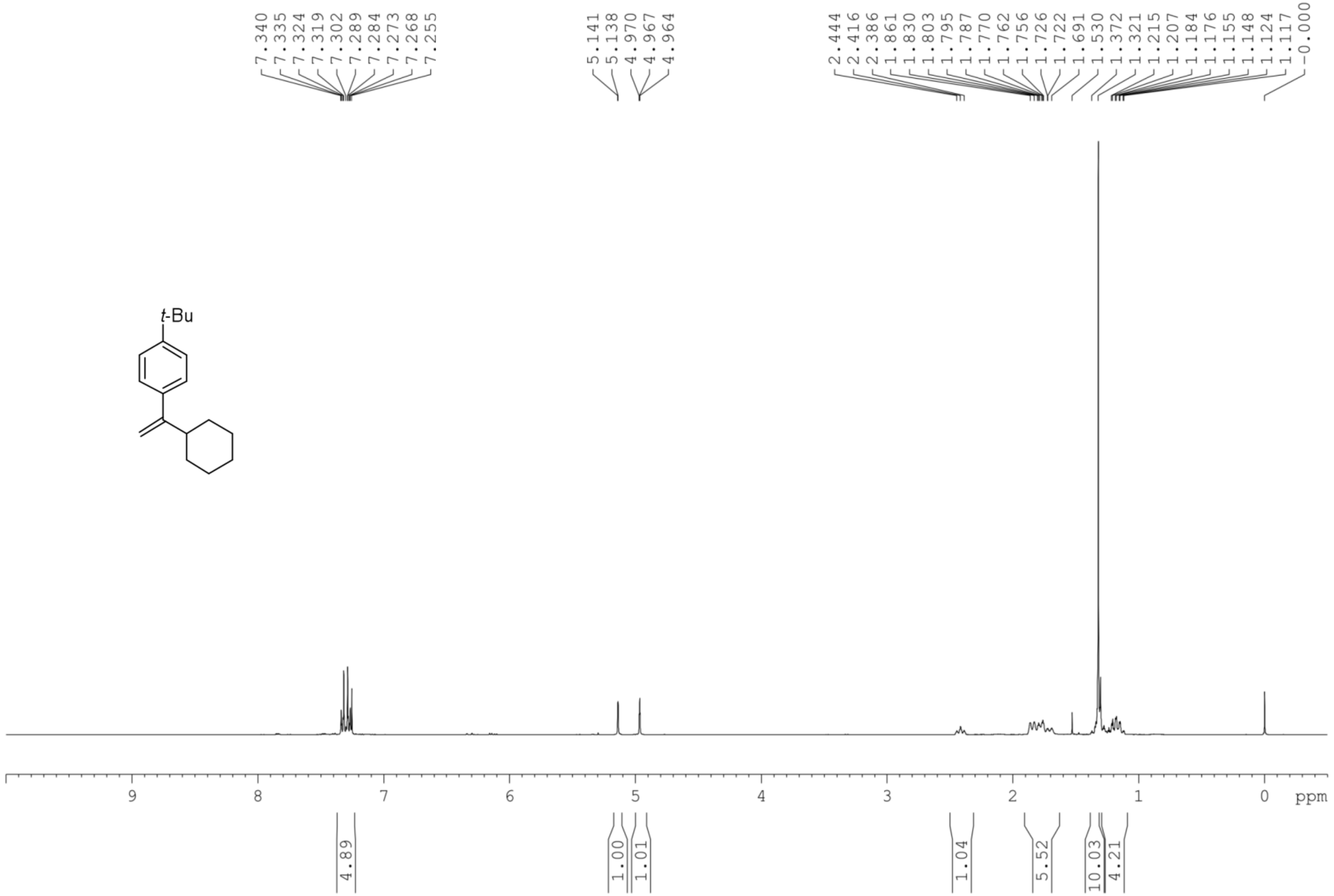

LN3080-2 1HNMR
AV400
May 10 2011
0.000
1.381
1.890
1.909
1.928
1.947
2.329
2.349
2.371
2.390
2.409
3.668
4.969
5.187
6.911
6.930
7.095
7.114
7.132
7.175
7.194
7.213
7.250
7.427
7.447
9.02
1.94
4.12
2.98
1.01
1.00
0.91
0.91
0.90
0.93
ppm
0
1
2
3
4
5
6
7
8
9
O
OMe
t-Bu

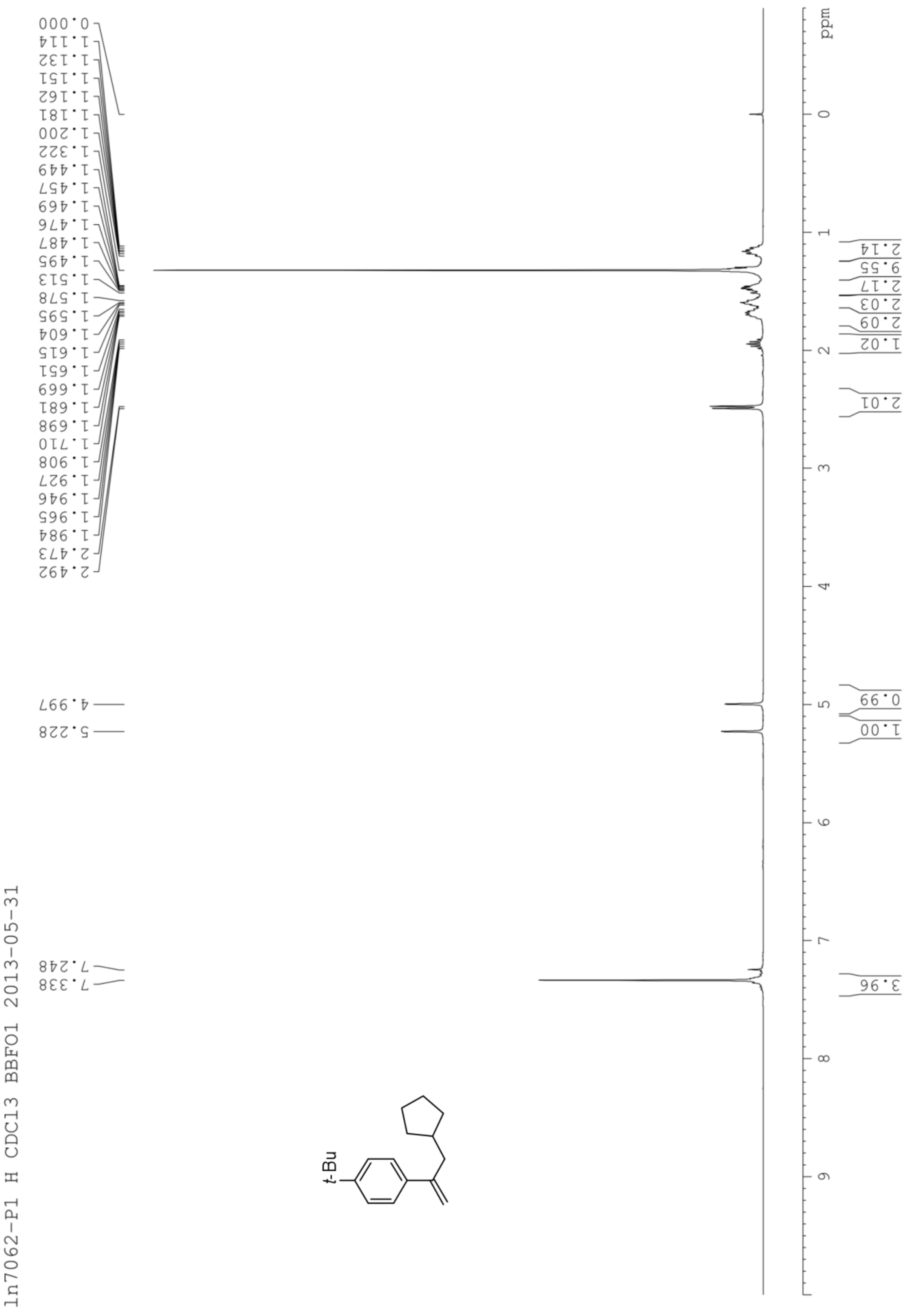

LN3146-H CDCl3 BBFO1 Dec 28 2011
7.471
7.468
7.450
7.447
7.260
7.240
7.236
7.222
7.220
7.218
7.202
7.198
7.148
7.145
7.129
7.126
7.111
7.108
6.893
6.889
6.874
6.870
5.200
5.196
5.193
5.189
5.024
5.022
2.509
2.489
2.469
2.440
2.422
2.404
1.959
1.940
1.921
1.903
1.884
1.389
0.000
t-Bu
CN
0.95
0.91
0.90
0.90
1.00
1.00
1.85
1.95
1.92
8.46
9
8
7
6
5
4
3
2
1
0
ppm

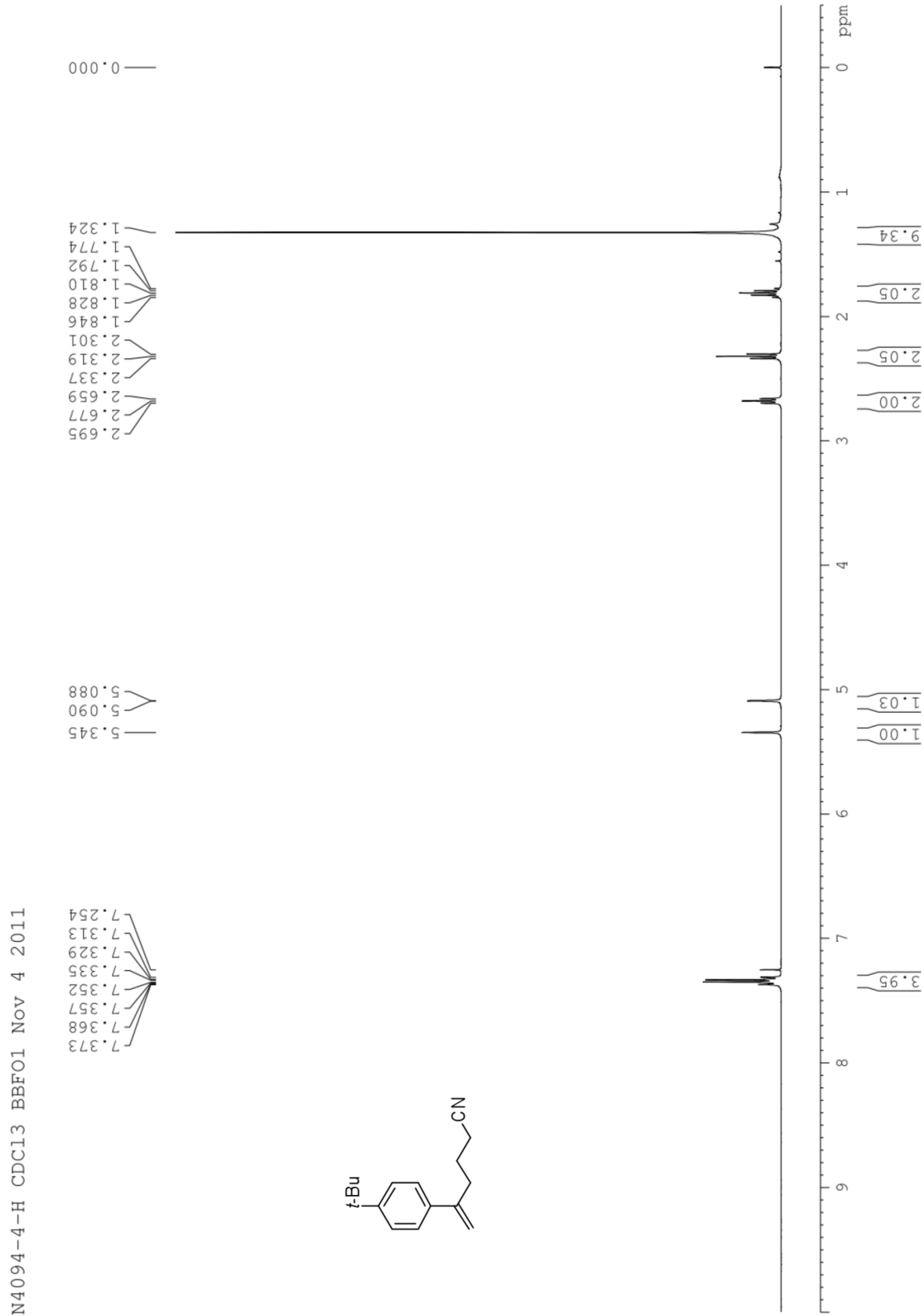

LN4115-H CDCl3 BBFO1 Dec 28 2011
0.000
1.194
1.212
1.230
1.317
3.507
3.524
3.530
3.542
3.548
3.560
3.566
3.583
3.608
3.626
3.632
3.643
3.649
3.661
3.667
3.685
5.238
5.513
5.553
5.556
7.253
7.325
7.331
7.336
7.347
7.352
7.358
7.455
7.461
7.466
7.477
7.482
t-Bu
OEt
OEt
5.80
8.52
1.95
1.94
0.96
0.95
1.00
1.88
1.82
0
1
2
3
4
5
6
7
8
9
ppm

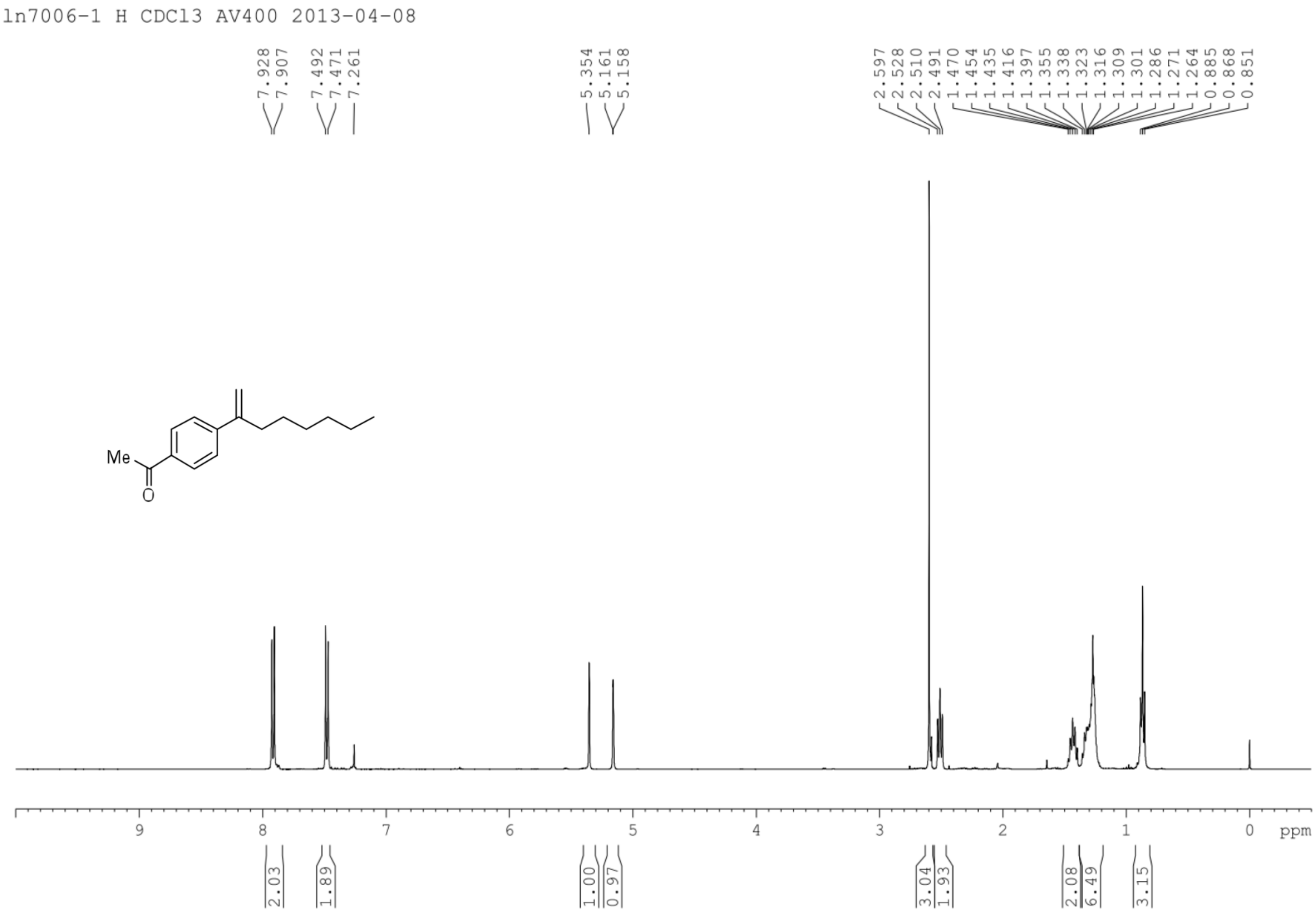

LN4054-H CDCl3 BBFO1 Dec 28 2011
7.456
7.453
7.436
7.433
7.260
7.236
7.231
7.218
7.215
7.214
7.197
7.193
7.140
7.136
7.121
7.118
7.103
7.099
7.009
7.005
6.990
6.986
5.689
5.687
5.684
5.682
5.174
5.169
4.979
4.978
3.750
3.732
3.715
3.709
3.691
3.674
3.543
3.525
3.507
3.502
3.490
3.484
3.466
1.384
1.236
1.218
1.200
0.000
t-Bu
OEt
OEt
0.97
0.92
0.90
0.89
1.00
0.94
0.95
1.93
1.92
7.90
5.36
9
8
7
6
5
4
3
2
1
0
ppm

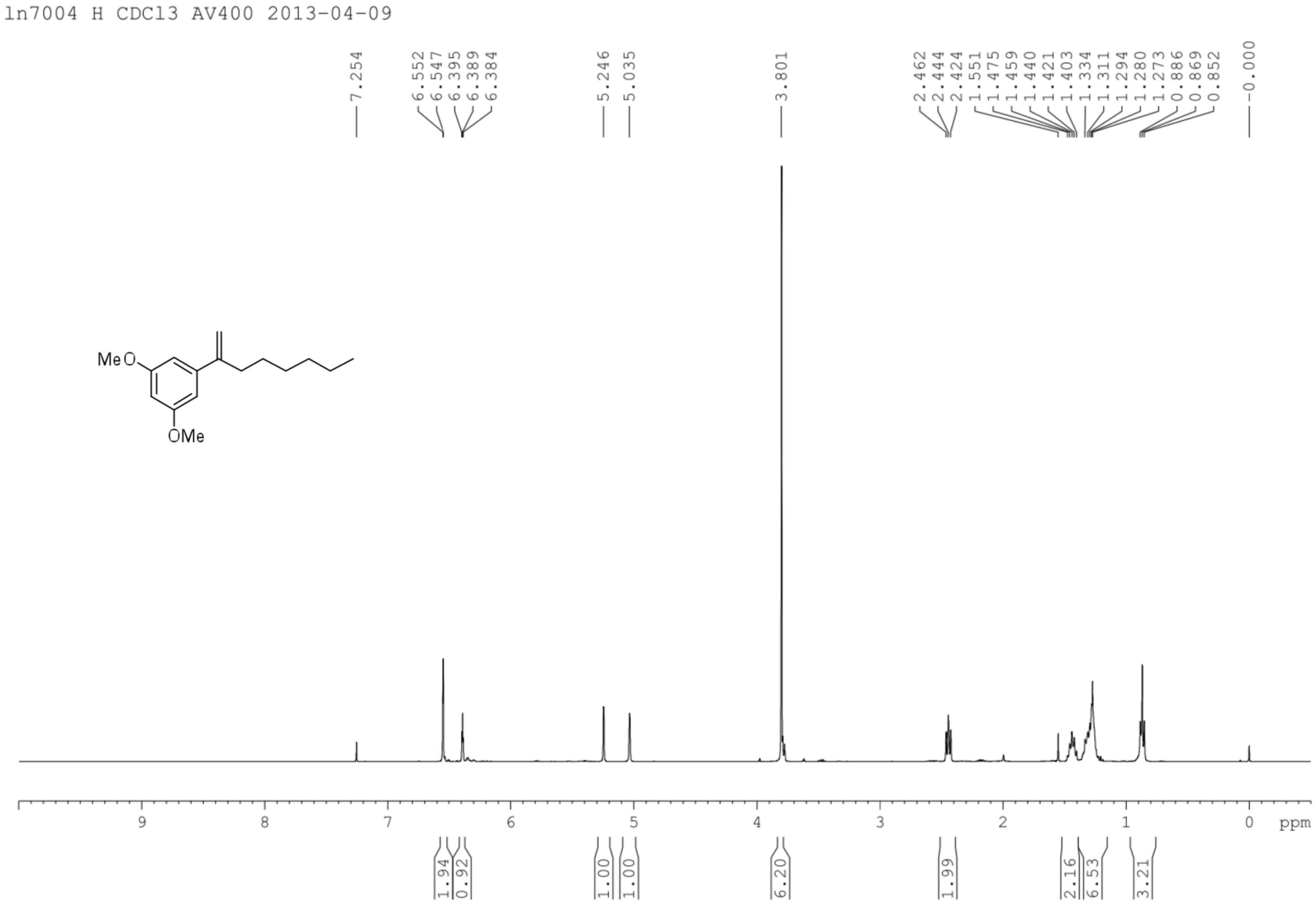
ln6127-4 H CDCl3 BBFO1 2013-3-31



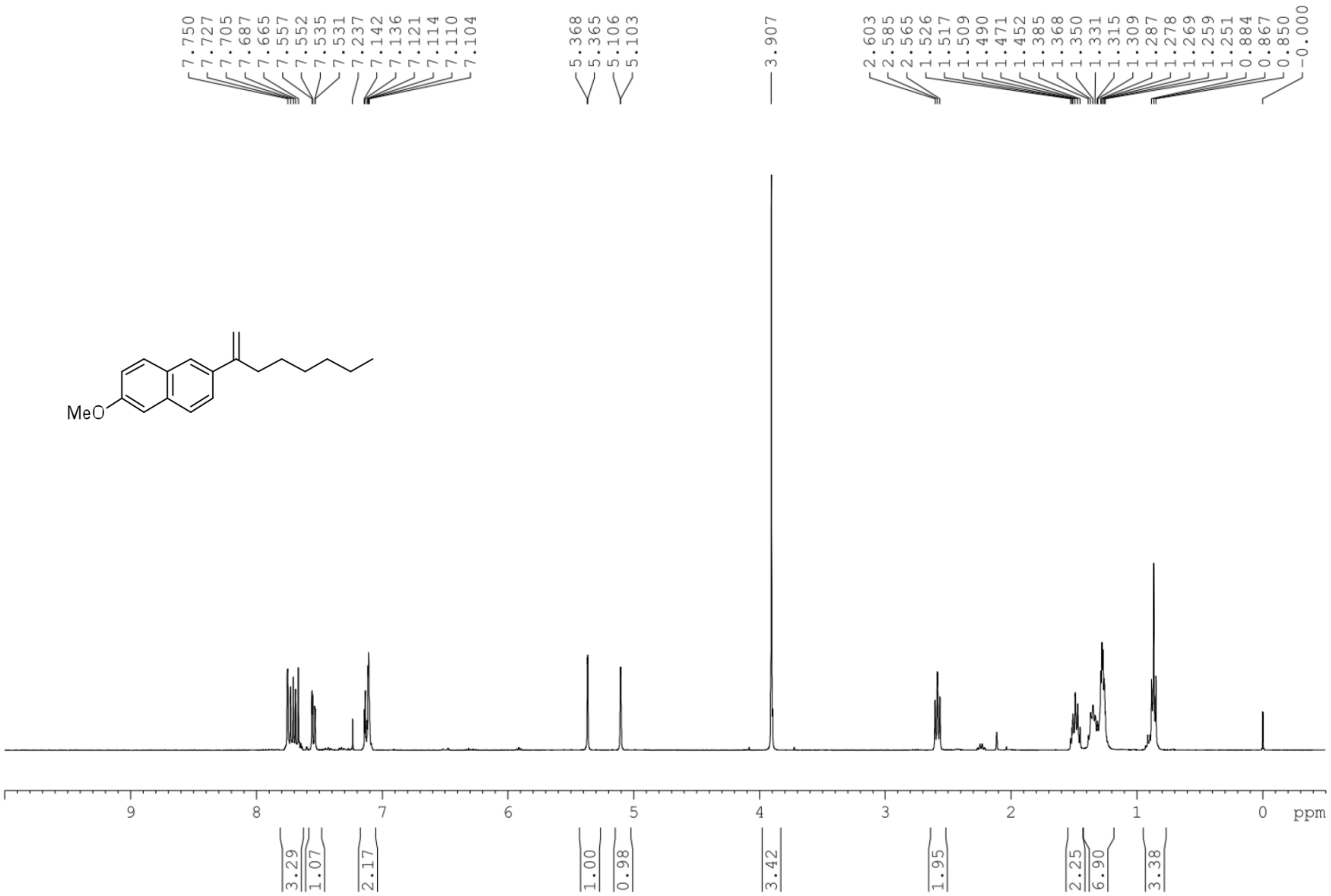

1n7062-P1 H CDCl3 BBFO1 2013-05-31
t-Bu
0.000
1.114
1.132
1.151
1.162
1.181
1.200
1.322
1.449
1.457
1.469
1.476
1.487
1.495
1.513
1.578
1.595
1.604
1.615
1.651
1.669
1.681
1.698
1.710
1.908
1.927
1.946
1.965
1.984
2.473
2.492
4.997
5.228
7.248
7.338
2.14
9.55
2.17
2.03
2.09
1.02
2.01
0.99
1.00
3.96
ppm
0
1
2
3
4
5
6
7
8
9


LN4094-4-H CDCl3 BBFO1 Nov 4 2011
0.000
1.324
1.774
1.792
1.810
1.828
1.846
2.301
2.319
2.337
2.659
2.677
2.695
5.088
5.090
5.345
7.254
7.313
7.329
7.335
7.352
7.357
7.368
7.373
t-Bu
CN
9.34
2.05
2.05
2.00
1.03
1.00
3.95
ppm
0
1
2
3
4
5
6
7
8
9

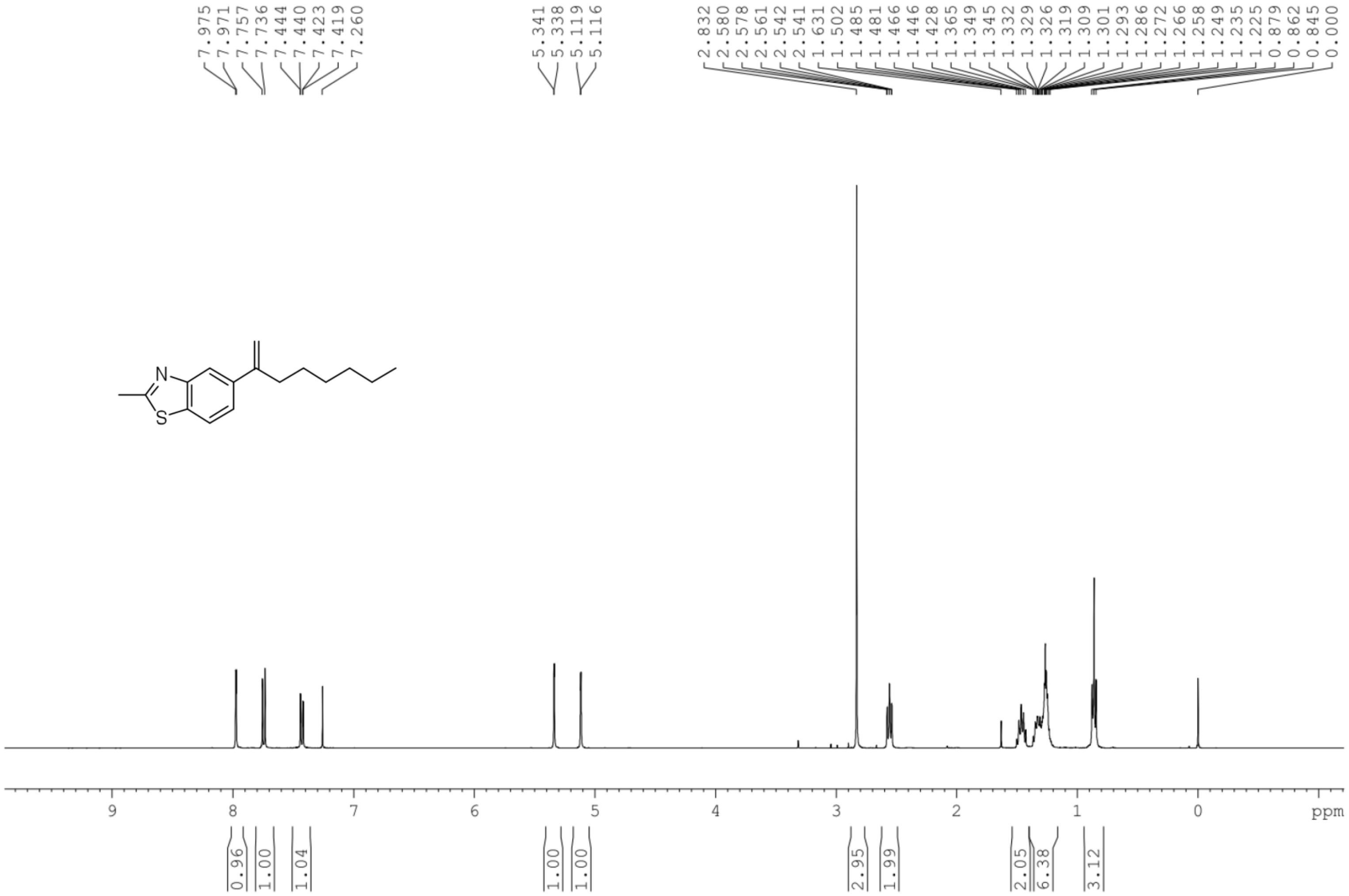

ln7006-1 H CDCl3 AV400 2013-04-08
7.928
7.907
7.492
7.471
7.261
5.354
5.161
5.158
2.597
2.528
2.510
2.491
1.470
1.454
1.435
1.416
1.397
1.355
1.338
1.323
1.316
1.309
1.301
1.286
1.271
1.264
0.885
0.868
0.851
Me
O
9
8
7
6
5
4
3
2
1
0
ppm
2.03
1.89
1.00
0.97
3.04
1.93
2.08
6.49
3.15

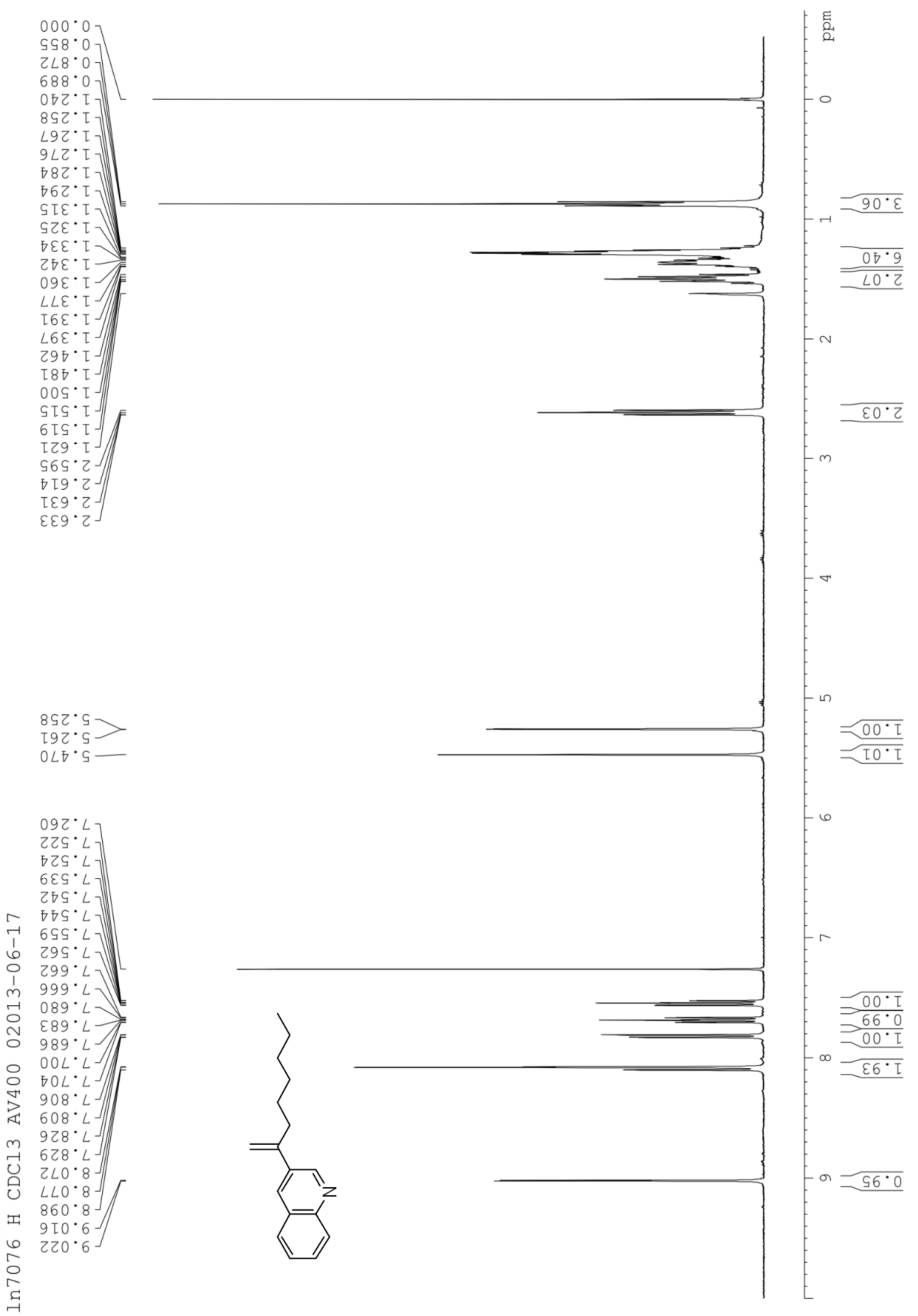

1n7004 H CDCl3 AV400 2013-04-09
7.254
6.552
6.547
6.395
6.389
6.384
5.246
5.035
3.801
2.462
2.444
2.424
1.551
1.475
1.459
1.440
1.421
1.403
1.334
1.311
1.294
1.280
1.273
0.886
0.869
0.852
-0.000
MeO
OMe
9
8
7
6
5
4
3
2
1
0
ppm
1.94
0.92
1.00
1.00
6.20
1.99
2.16
6.53
3.21

ln7006-2 H CDCl3 AV400 2013-04-08

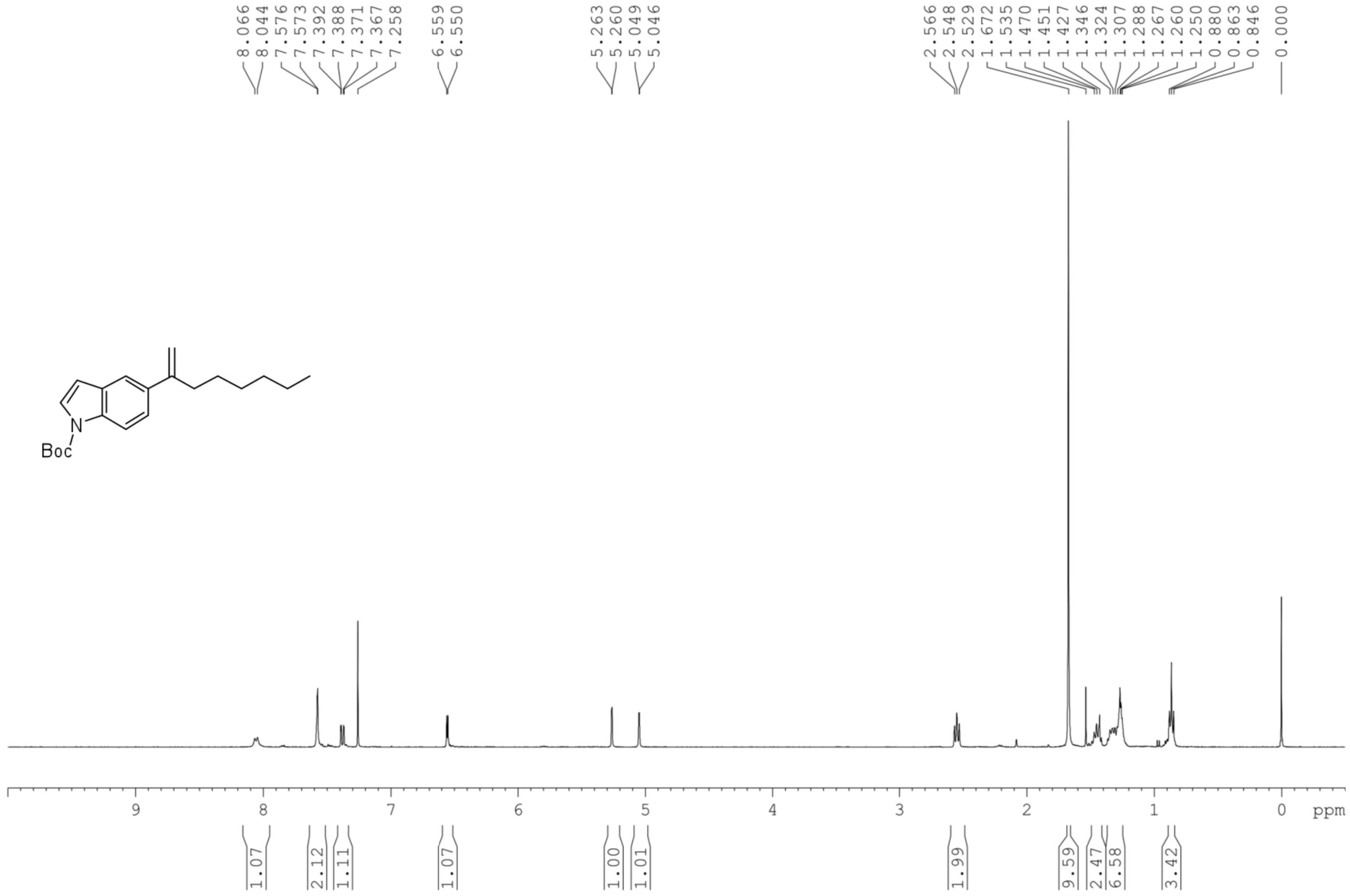


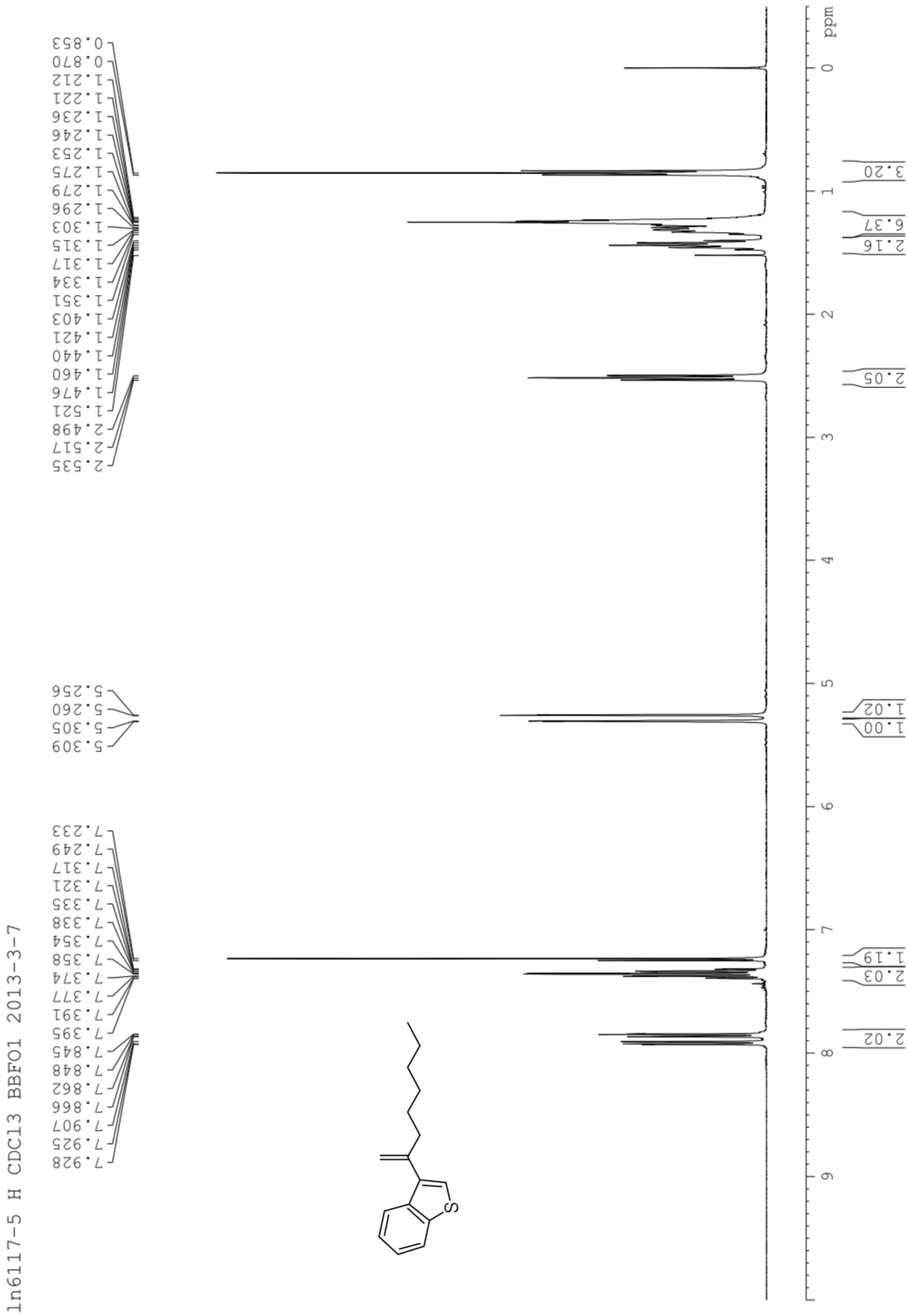
LN7015-2 H CDCl3 BBFO1 2013-04-15

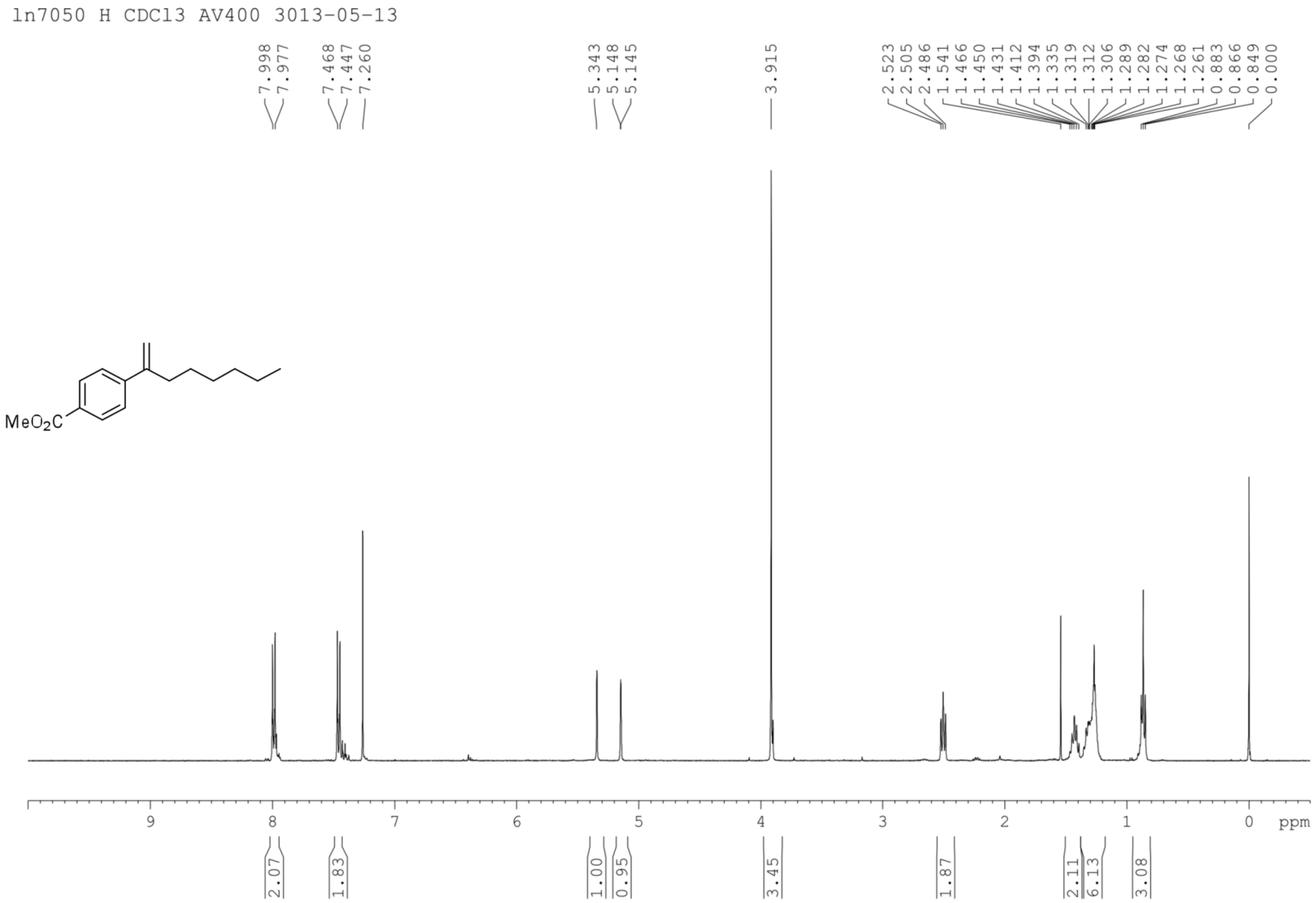


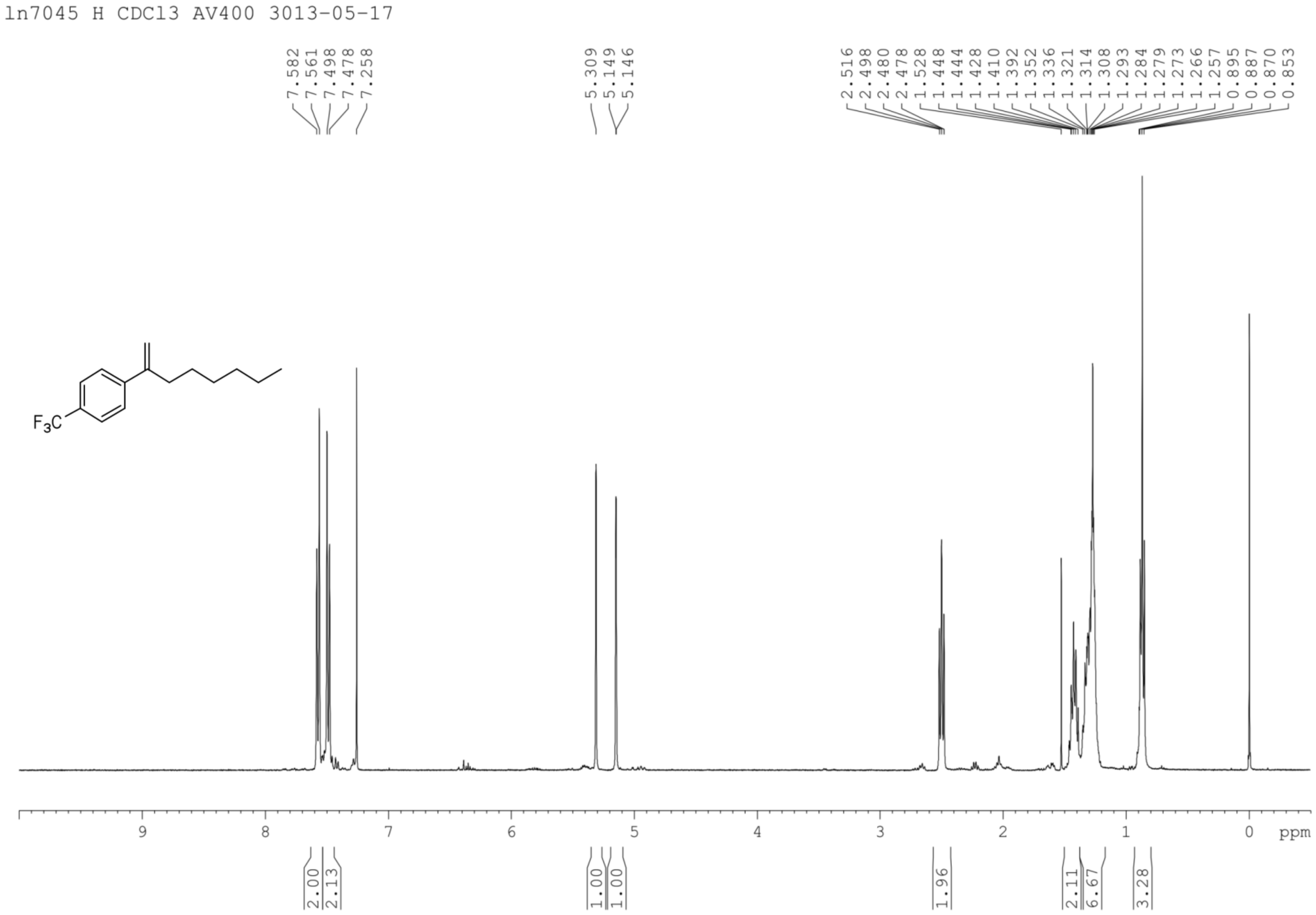

1n7076 H CDCl3 AV400 02013-06-17
0.000
0.855
0.872
0.889
1.240
1.258
1.267
1.276
1.284
1.294
1.315
1.325
1.334
1.342
1.360
1.377
1.391
1.397
1.462
1.481
1.500
1.515
1.519
1.621
2.595
2.614
2.631
2.633
5.258
5.261
5.470
7.260
7.522
7.524
7.539
7.542
7.544
7.559
7.562
7.662
7.666
7.680
7.683
7.686
7.700
7.704
7.806
7.809
7.826
7.829
8.072
8.077
8.098
9.016
9.022
N
3.06
6.40
2.07
2.03
1.00
1.01
1.00
0.99
1.00
1.93
0.95
ppm
0
1
2
3
4
5
6
7
8
9

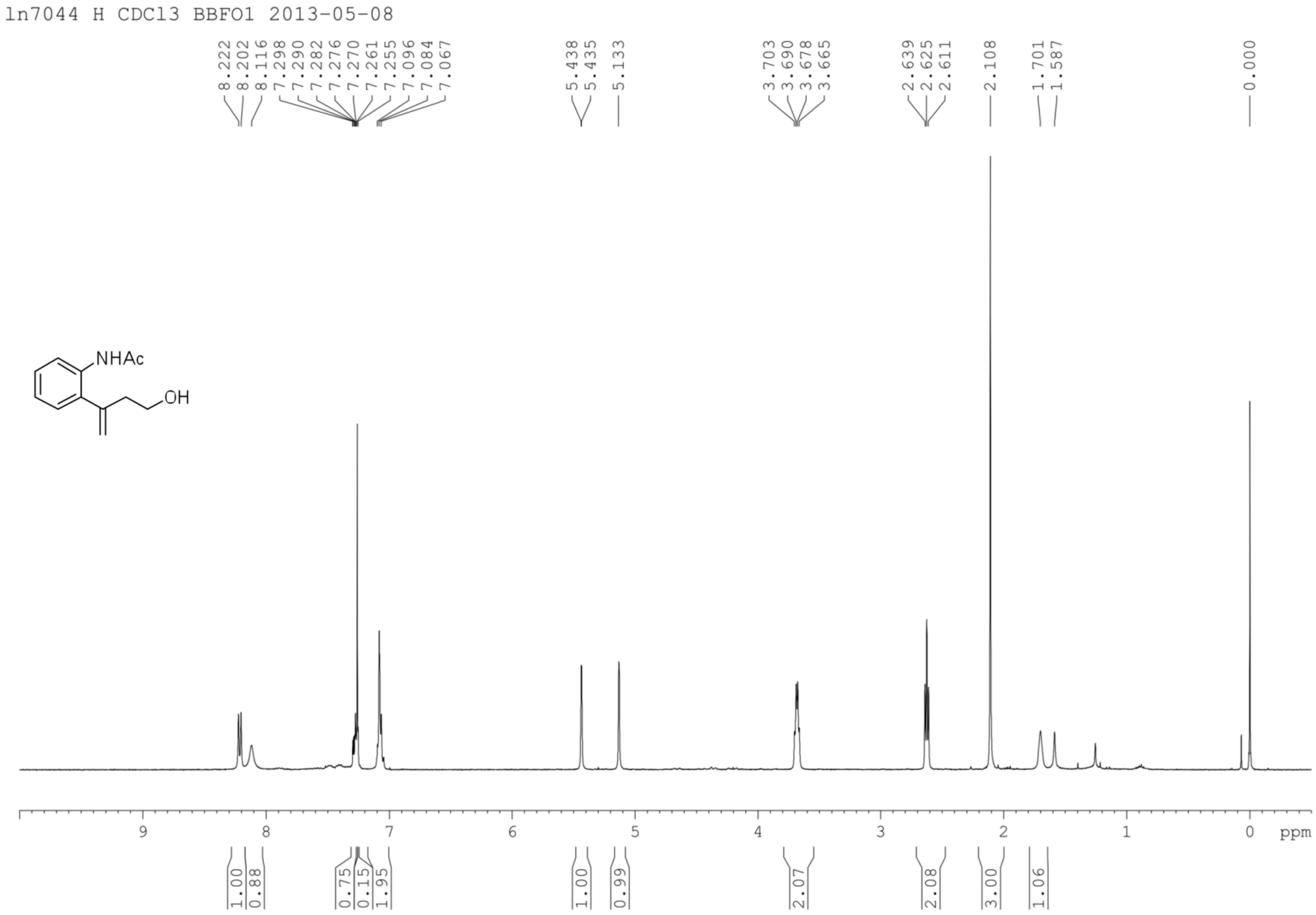
1n7074 H CDCl3 BBFO1 2013-06-09



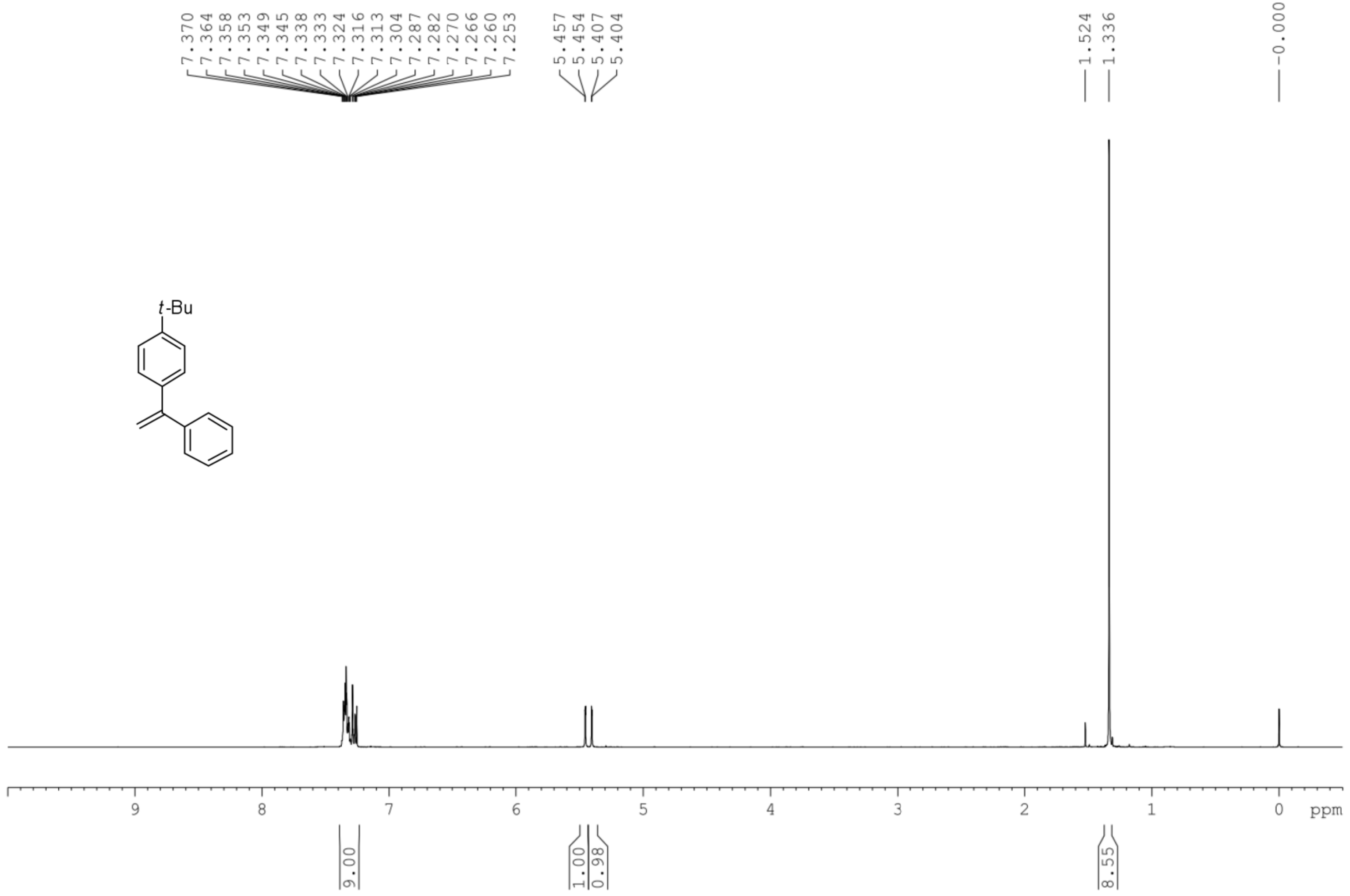

ln6117-5 H CDCl3 BBFO1 2013-3-7
0.853
0.870
1.212
1.221
1.236
1.246
1.253
1.275
1.279
1.296
1.303
1.315
1.317
1.334
1.351
1.403
1.421
1.440
1.460
1.476
1.521
2.498
2.517
2.535
5.256
5.260
5.305
5.309
7.233
7.249
7.317
7.321
7.335
7.338
7.354
7.358
7.374
7.377
7.391
7.395
7.845
7.848
7.862
7.866
7.907
7.925
7.928
S
3.20
6.37
2.16
2.05
1.02
1.00
1.16
2.03
2.02
ppm
0
1
2
3
4
5
6
7
8
9

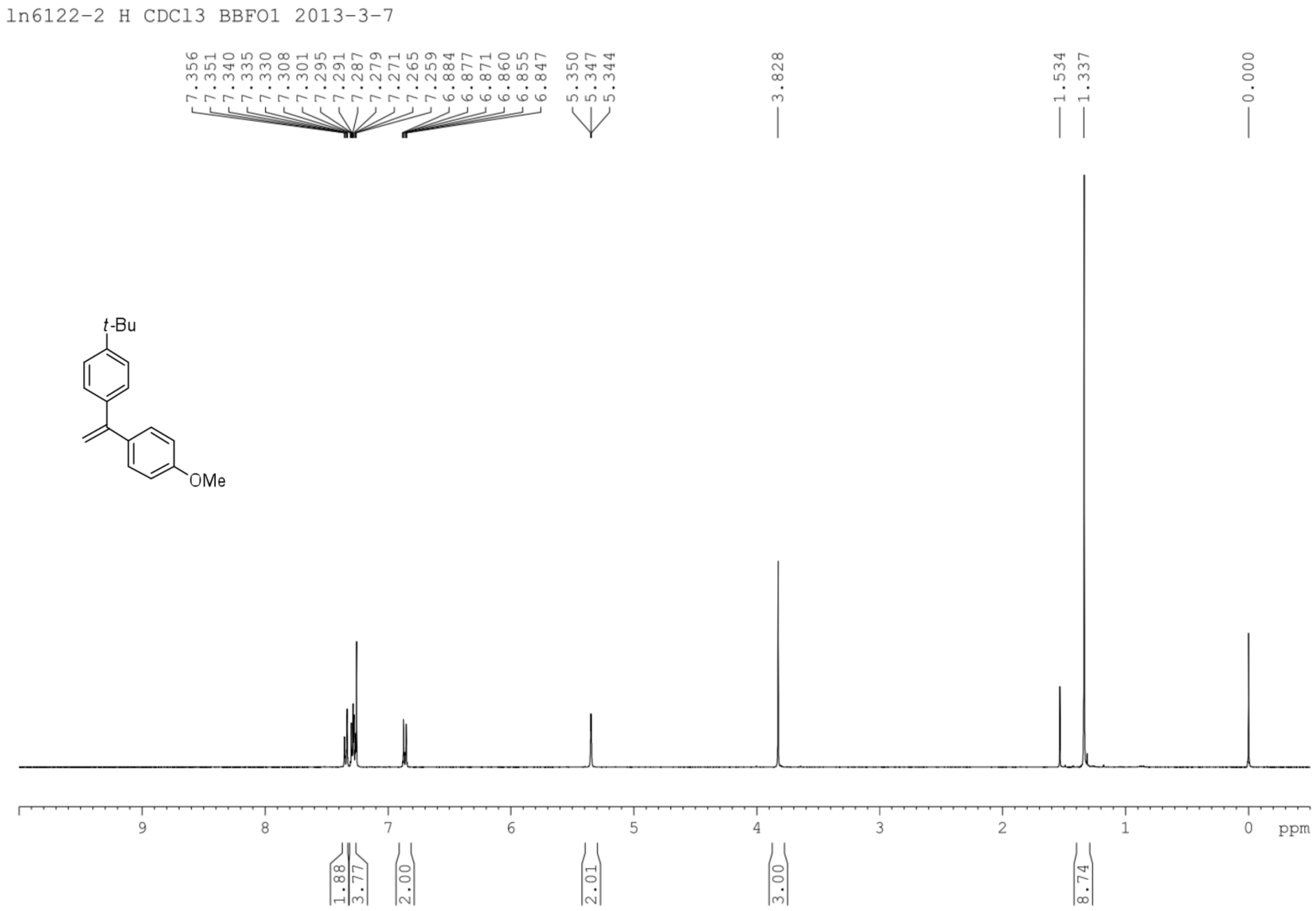

ln7050 H CDCl3 AV400 3013-05-13
7.998
7.977
7.468
7.447
7.260
5.343
5.148
5.145
3.915
2.523
2.505
2.486
1.541
1.466
1.450
1.431
1.412
1.394
1.335
1.319
1.312
1.306
1.289
1.282
1.274
1.268
1.261
0.883
0.866
0.849
0.000
MeO2C
9
8
7
6
5
4
3
2
1
0
ppm
2.07
1.83
1.00
0.95
3.45
1.87
2.11
6.13
3.08

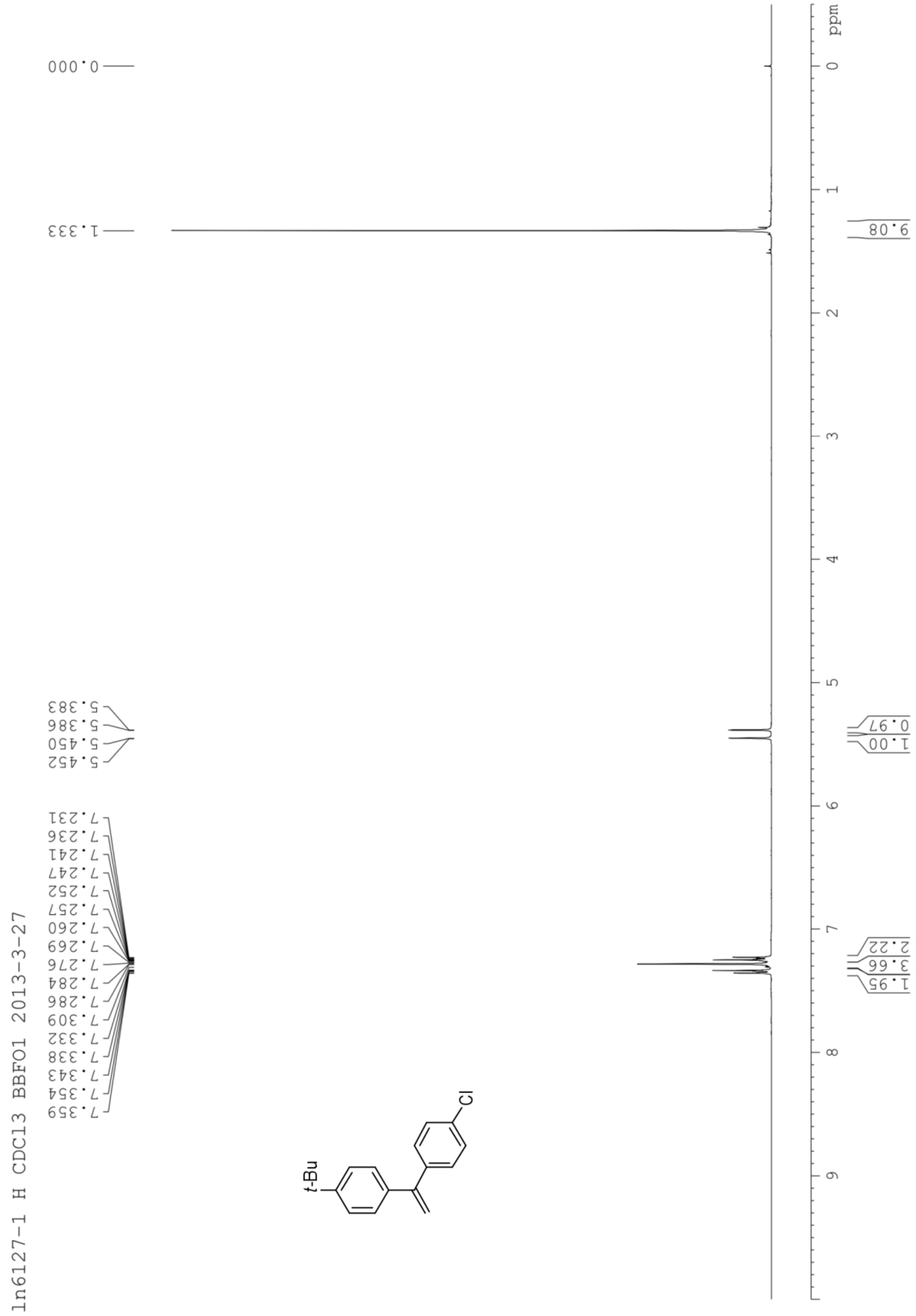

1n7045 H CDCl3 AV400 3013-05-17
7.582
7.561
7.498
7.478
7.258
5.309
5.149
5.146
2.516
2.498
2.480
2.478
1.528
1.448
1.444
1.428
1.410
1.392
1.352
1.336
1.321
1.314
1.308
1.293
1.284
1.279
1.273
1.266
1.257
0.895
0.887
0.870
0.853
F_3C
9
8
7
6
5
4
3
2
1
0
ppm
2.00
2.13
1.00
1.00
1.96
2.11
6.67
3.28


ln7044 H CDCl3 BBFO1 2013-05-08
8.222
8.202
8.116
7.298
7.290
7.282
7.276
7.270
7.261
7.255
7.096
7.084
7.067
5.438
5.435
5.133
3.703
3.690
3.678
3.665
2.639
2.625
2.611
2.108
1.701
1.587
0.000
NHAc
OH
9
8
7
6
5
4
3
2
1
0
ppm
1.00
0.88
0.75
0.15
1.95
1.00
0.99
2.07
2.08
3.00
1.06

ln6122-1 H CDCl3 BBFO1 2013-3-4




ln6122-2 H CDCl3 BBFO1 2013-3-7
7.356
7.351
7.340
7.335
7.330
7.308
7.301
7.295
7.291
7.287
7.279
7.271
7.265
7.259
6.884
6.877
6.871
6.860
6.855
6.847
5.350
5.347
5.344
3.828
1.534
1.337
0.000
t-Bu
OMe
9
8
7
6
5
4
3
2
1
0
ppm
1.88
3.77
2.00
2.01
3.00
8.74


1n6127-1 H CDCl3 BBFO1 2013-3-27
0.000
1.333
5.383
5.386
5.450
5.452
7.231
7.236
7.241
7.247
7.252
7.257
7.260
7.269
7.276
7.284
7.286
7.309
7.332
7.338
7.343
7.354
7.359
t-Bu
Cl
9.08
0.97
1.00
2.22
3.66
1.95
ppm
0
1
2
3
4
5
6
7
8
9