Synthesis of Organoboron Compounds via a Palladium-Induced 1,2-Metallate Shift Mechanism:

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SYNTHESIS OF ORGANOBORON COMPOUNDS VIA A PALLADIUM-INDUCED 1,2-METALLATE SHIFT MECHANISM

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A dissertation

submitted to the Faculty of

the department of Chemistry

in partial fulfillment

of the requirements for the degree of

Doctor of Philosophy

Boston College
Morrissey College of Arts and Sciences
Graduate School

June 2020

SYNTHESIS OF ORGANOBORON COMPOUNDS VIA A PALLADIUM-INDUCED 1,2-METALLATE SHIFT MECHANISM

Mark Docto Aparece

Advisor: Professor James P. Morken, Ph.D.

Abstract: This dissertation describes the development of various palladium-catalyzed syntheses of organoboron compounds with the 1,2-metallate shift of organoboron "ate" complexes as a common mechanistic feature. Chapter one discusses the history of the 1,2-metallate shift with a focus on reactions promoted by transition metals, followed by my work on the palladium-catalyzed, enantioselective, halide-tolerant conjunctive cross-coupling reaction to enable the use of Grignard reagents and arylbromides. Chapter two discusses the attempt to engage allylic electrophiles in the conjunctive cross-coupling reaction and the discovery and optimization of the vinylidenation reaction to access 1,1-disubstituted boryl alkenes. Unlike other palladium-catalyzed reactions that proceed by a 1,2-metallate shift, the vinylidenation proceeds by a β-hydride elimination rather than a reductive elimination as the final step in the catalytic cycle. Chapter three discusses the development of the enantioselective conjunctive cross-coupling of propargylic electrophiles to access enantioenriched β-boryl allenes. Methanol additive was found to improve both the yield and enantioselectivity of the reaction. ^{1}H NMR studies show that methanol exchanges with the pinacol ligand on the boron "ate" complex.

ACKNOWLEDGEMENTS

First and foremost, I would like to thank my advisor, Professor James P. Morken, for his mentorship, guidance, and patience during my doctoral studies. Jim's passion for science and knowledge of chemistry is an inspiration to all who know him. I would also like to express my gratitude to him for cultivating a friendly and collaborative work environment and for encouraging us to pursue our own careers and livelihoods based on our individual interests and talents.

The work in this dissertation would not have been possible without the help of fellow Morken group members. Collaborating with Gabriel Lovinger, Chenpeng Gao, and Weipeng Hu in each of our respective projects was extremely rewarding and crucial to the success of these projects. I would also like to thank Morken group members at large and members of other research groups for their discussions, ideas, and insights about chemistry, as well as for the friendship and support when the morale is low. I would also like to thank the faculty in the chemistry department from whom I have learned so much during my time at Boston College, as well as the staff who run the analytical instruments and who work in administration for their help and for keeping things running behind the scenes.

Finally, I would like to thank my friends and family for their unfailing love and support: Jon and Suzanne, Ashlyn, Becca, Cali, Courtney, Craig, Dave, Erica, Jackie, Joe, Keisuke, Kevin, Laura, Mark, Natali, Nina, Rob, Ryan, and Wills; my parents, my aunts and uncles, my cousins (especially Karen), and my grandmother.

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LIST OF ABBREVIATIONS

Å: Ångstroms

Ac: acetyl

acac: acetylacetonate

atm: atmospheres

$B_2(pin)_2$: bis(pinacolato)diboron

9-BBN: 9-borabicyclo[3.3.1]nonane

BINAP: 2,2'-bis(diphenylphosphino)-1,1'-binaphthyl

Bn: benzyl

BQ: benzoquinone

BrettPhos: 2-(dicyclohexylphosphino)-3,6-dimethoxy-2′,4′,6′-triisopropyl-1,1′-biphenyl

Bz: benzoyl

cod: 1,5-cyclooctadiene

conv: conversion

Cy: cyclohexyl

CyJohnPhos: (2-biphenyl)dicyclohexyl phosphine

DABCO: 1,4-diazabicyclo[2.2.2]octane

dba: dibenzylideneacetone

DCE: 1,2-dichloroethane

DCM: dichloromethane

dcypf: 1,1'-bis(dicyclohexylphosphino) ferrocene

DFT: density functional theory

DIBAL: diisobutylaluminum hydride

DMAP: 4-dimethylaminopyridine

DME: 1,2-dimethoxyethane

DMF: *N*,*N*-dimethylformamide

DMSO: dimethylsulfoxide

DPEphos: bis[(2-diphenylphosphino) phenyl] ether,

dppb: 1,4-bis(diphenylphosphino)butane

dppe: 1,2-bis(diphenylphosphino)ethane

dppf: 1,2-bis(diphenylphosphino) ferrocene

dppm: bis(diphenylphosphino)methane

dr: diastereomeric ratio

ee: enantiomeric excess

er: enantiomeric ratio

es: enantiospecificity

EtOAc: ethyl acetate

Eq: equation

equiv: equivalents

h: hour(s)

HRMS: high-resolution mass spectrometry

Hz: hertz

IPA: isopropyl alcohol

IR: infrared spectroscopy

JohnPhos: (2-biphenyl)di-*t*-butyl phosphine

LDA: lithium diisopropylamide

LiTMP: lithium 2,2,6,6-tetrmethylpiperidine

M: molar

MandyPhos: (S_P,S'_P)-1,1′-bis[bis(4-methoxy-3,5-dimethylphenyl) phosphino]-2,2′-bis[(*R*)-α-(dimethylamino)benzyl]ferrocene

MeCN: acetonitrile

MIDA: *N*-methyliminodiacetic acid

min: minutes

MS: molecular sieves

MTBE: methyl *t*-butyl ether

nbd: norbornadiene

NBS: *N*-bromosuccinimide

NCS: *N*-chlorosuccinimide

neo: neopentyl glycol

NHC: *N*-heterocyclic carbene

NMMO: *N*-methylmorpholine *N*-oxide

NMR: nuclear magnetic resonance

N.R.: no reaction

OTf: trifluoromethanesulfonate

PCy_3: tricyclohexylphosphine

$Pd(OAc)_2$: palladium(II) acetate

pin: pinacol

PMB: *p*-methoxybenzyl

PMP: *p*-methoxyphenyl

ppm: parts per million

PyBox: pyridine bis(oxazoline)

rac: racemic

rt: room temperature

SFC: supercritical fluid chromatography

SPhos: 2-dicyclohexylphosphino-2',6'-dimethoxybiphenyl

TBDPS: *t*-butyldiphenylsilyl

TBHP: *t*-butyl hydroperoxide

TBS: *t*-butyldimethylsilyl

THF: tetrahydrofuran

TMEDA: *N*,*N*,*N*',*N*'-tetramethylethylenediamine

TMS: trimethylsilyl

XantPhos: 4,5-bis(diphenylphosphino)-9,9-dimethylxanthene

CHAPTER ONE

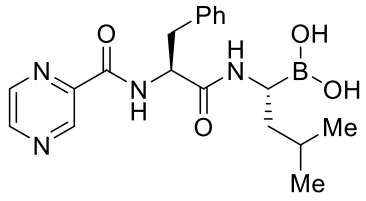
The Halide-Tolerant Conjunctive Cross-Coupling Reaction

1.1. Introduction

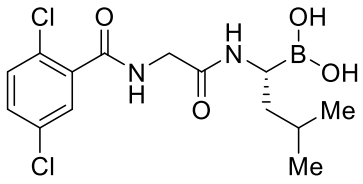
1.1.1. The Structure and Utility of Organoboron Compounds

Organoboron compounds are valuable reagents in modern organic chemistry. Recent research efforts have been made investigating their roles in Brønsted and Lewis acid catalysis,[1] optoelectronics,[2] and chemical biology and medicinal chemistry,[3] including

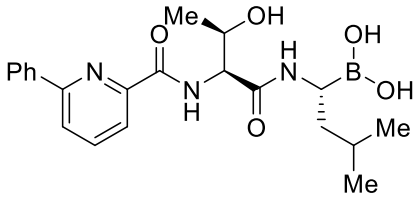
Scheme 1.1. Boron-containing anti-cancer drugs



Velcade (bortezomib)
1.1



Ninlaro (ixazomib)
1.2



delanzomib
1.3

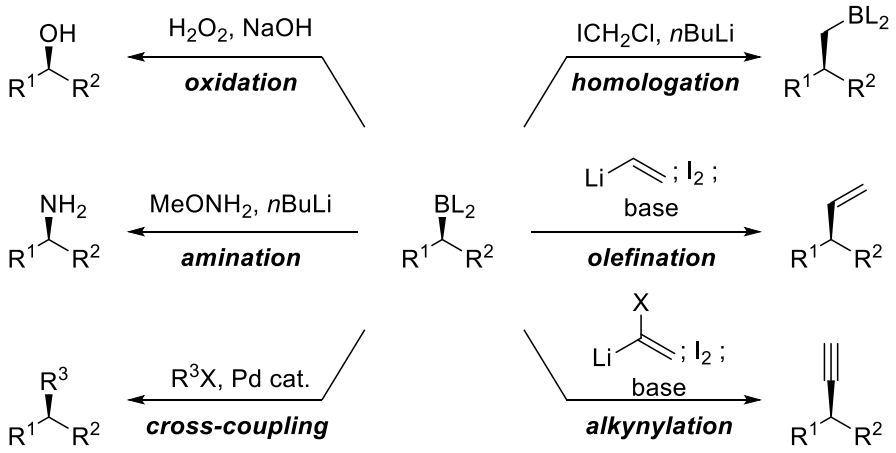
[1] (a) Stephan, D. W.; Erker, G. *Angew. Chem. Int. Ed.* **2015**, *54*, 6400. (b) Stephan, D. W. *Science* **2016**, *354*, aaf7229. (c) Hall, D. G. *Chem. Soc. Rev.* **2019**, *48*, 3475.

[2] (a) von Grotthuss, E.; John, A.; Kaese, T.; Wagner, M. *Asian J. Org. Chem.* **2018**, *7*, 37. (b) Mellerup, S. K.; Wang, S. *Trends in Chemistry* **2019**, *1*, 77.

[3] (a) Baker, S. J.; Tomsho, J. W.; Benkovic, S. J. *Chem. Soc. Rev.* **2011**, *40*, 4279. (b) Touchet, S.; Carreaux, F.; Carboni, B.; Bouillon, A.; Boucher, J.-L. *Chem. Soc. Rev.* **2011**, *40*, 3895. (c) Smoum, R.; Rubinstein, A.; Dembitsky, V. M.; Srebnik, M. *Chem. Rev.* **2012**, *112*, 4156. (d) Adamczyk-Woźniak, A.; Borys, K. M.; Sporzyński, A. *Chem. Rev.* **2015**, *115*, 5224.

the anticancer drugs Velcade (bortezomib),[4] Ninlaro (ixazomib),[5] and delanzomib[6] (Scheme 1.1). However, organoboron compounds in synthetic organic chemistry serve mainly as intermediates to access a variety of other compounds via stereospecific transformations. These transformations include carbon–heteroatom bond-forming reactions such as oxidation,[7] amination,[8] and halogenation,[9] as well as carbon–carbon bond-forming reactions such as the Suzuki–Miyaura cross-coupling,[10] the Zweifel–Evans–

Scheme 1.2. Transformations of organoboron compounds



[4] Bross, P. F. Kane, R.; Farrell, A. T.; Abraham, S.; Benson, K.; Brower, M. E.; Bradley, S.; Gobburu, J. V.; Goheer, A.; Lee, S.-L.; Leighton, J.; Liang, C. Y.; Lostritto, R. T.; McGuinn, W. D.; Morse, D. E.; Rahman, A.; Rosario, L. A.; Verbois, S. L.; Williams, G.; Wang, Y.-C.; Pazdur, R. *Clin. Cancer Res.* **2004**, *10*, 3954.

[5] Kupperman, E.; Lee, E. C.; Cao, Y.; Bannerman, B.; Fitzgerald, M.; Berger, A.; Yu, J.; Yang, Y.; Hales, P.; Bruzzese, F.; Liu, J.; Blank, J.; Garcia, K.; Tsu, C.; Dick, L.; Fleming, P.; Yu, L.; Manfredi, M.; Rolfe, M.; Bolen, J. *Cancer Res.* **2010**, *70*, 1970.

[6] Gallerani, E.; Zucchetti, M.; Brunelli, D.; Marangon, E.; Noberasco, C.; Hess, D.; Delmonte, A.; Martinelli, G.; Böhm, S.; Driessen, C.; De Braud, F.; Marsoni, S.; Cereda, R.; Sala, F.; D'Incalci, M.; Sessa, C. *Eur. J. Cancer* **2013**, *49*, 290.

[7] Brown, H. C.; Snyder, C.; Rao, B. C. S.; Zweifel, G. *Tetrahedron* **1986**, *42*, 5505.

[8] (a) Mlynarski, S. N.; Karns, A. S.; Morken, J. P. *J. Am. Chem. Soc.* **2012**, *134*, 16449. (b) Edelstein, E. K.; Grote, A. C.; Palkowitz, M. D.; Morken, J. P. *Synlett* **2018**, *29*, 1749.

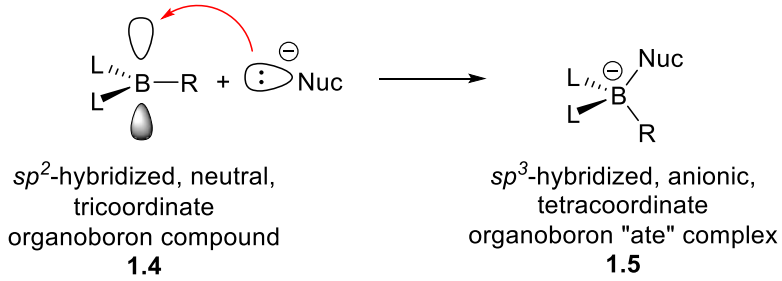
[9] (a) Larouche-Gauthier, R.; Elford, T. G.; Aggarwal, V. K. *J. Am. Chem. Soc.* **2011**, *133*, 16794. (b) Sandford, C.; Rasappan, R.; Aggarwal, V. K. *J. Am. Chem. Soc.* **2015**, *137*, 10100.

[10] (a) Miyaura, N.; Suzuki, A. *Chem. Rev.* **1995**, *95*, 2457. (b) Lennox, A. J. J.; Lloyd-Jones, G. C. *Chem. Soc. Rev.* **2014**, *43*, 412. (c) Cherney, A. H.; Kadunce, N. T.; Reisman, S. E. *Chem. Rev.* **2015**, *115*, 9587. (d) Rygus, J. P. G.; Crudden, C. M. *J. Am. Chem. Soc.* **2017**, *139*, 18124.

Matteson olefination,[11] the Matteson homologation,[12] and recent reports from the Aggarwal group in alkynylation[13] and arylation[14] (Scheme 1.2).

Many reactions of organoboron compounds proceed by nucleophilic attack onto the vacant *p*-orbital of an sp^2-hybridized, neutral, tricoordinate boron center **1.4** to give an sp^3-hybridized, anionic, tetracoordinate organoboron "ate" species **1.5** (Scheme 1.3). In the case of most of the reactions in Scheme 1.2, formation of the "ate" complex is followed by a 1,2-metallate shift of one of the groups on boron onto another, forging a new carbon–carbon or carbon–heteroatom bond while simultaneously reverting boron back to its neutral state.

Scheme 1.3. sp^2-hybridized boron centers and conversion to sp^3-hybridized "ates"



sp^2-hybridized, neutral, tricoordinate organoboron compound **1.4**

sp^3-hybridized, anionic, tetracoordinate organoboron "ate" complex **1.5**

[11] (a) Zweifel, George.; Polston, N. L.; Whitney, C. C. *J. Am. Chem. Soc.* **1968**, *90*, 6243. (b) Matteson, D. S. *Synthesis* **1975**, 147. (c) Matteson, D. S.; Jesthi, P. K. *J. Organomet. Chem.* **1976**, *110*, 25. (d) Evans, D. A.; Thomas, R. C.; Walker, J. A. *Tetrahedron Lett.* **1976**, *18*, 1427. (e) Evans, D. A.; Crawford, T. C.; Thomas, R. C.; Walker, J. A. *J. Org. Chem.* **1976**, *41*, 3947. (f) Armstrong, R. J.; Niwetmarin, W.; Aggarwal, V. K. *Org. Lett.* **2017**, *19*, 2762.

[12] Matteson, D. S.; Sadhu, K. M. *J. Am. Chem. Soc.* **1983**, *105*, 2077.

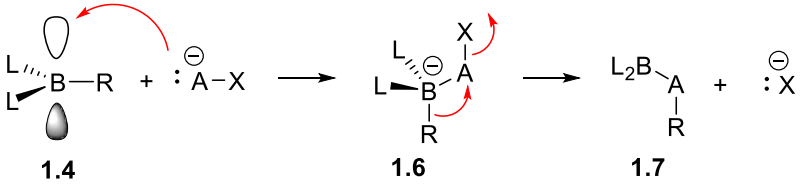
[13] Wang, Y.; Noble, A.; Myers, E. L.; Aggarwal, V. K. *Angew. Chem. Int. Ed.* **2016**, *55*, 4270.

[14] (a) Bonet, A.; Odachowski, M.; Leonori, D.; Essafi, S.; Aggarwal, V. K. *Nature Chem.* **2014**, *6*, 584. (b) Leonori, D.; Aggarwal, V. K. *Angew. Chem. Int. Ed.* **2015**, *54*, 1082. (c) Llaveria, J.; Leonori, D.; Aggarwal, V. K. *J. Am. Chem. Soc.* **2015**, *137*, 10958. (d) Odachowski, M.; Bonet, A.; Essafi, S.; Conti-Ramsden, P.; Harvey, J. N.; Leonori, D.; Aggarwal, V. K. *J. Am. Chem. Soc.* **2016**, *138*, 9521. (e) Aichhorn, S.; Bigler, R.; Myers, E. L.; Aggarwal, V. K. *J. Am. Chem. Soc.* **2017**, *139*, 9519. (f) Ganesh, V.; Odachowski, M.; Aggarwal, V. K. *Angew. Chem. Int. Ed.* **2017**, *56*, 9752. (g) Wang, Y.; Noble, A.; Sandford, C.; Aggarwal, V. K. *Angew. Chem. Int. Ed.* **2017**, *56*, 1810. (h) Wilson, C. M.; Ganesh, V.; Noble, A.; Aggarwal, V. K. *Angew. Chem. Int. Ed.* **2017**, *56*, 16318. (i) Bigler, R.; Aggarwal, V. K. *Angew. Chem. Int. Ed.* **2018**, *57*, 1082.

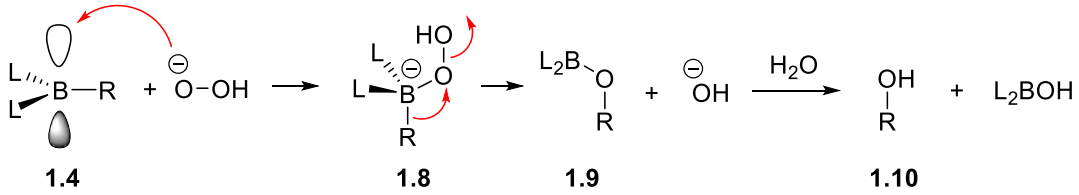
Conceptually, the 1,2-metallate shift can be divided into two main classes depending on the hybridization of the migration terminus. The first class involves migration onto an sp^3-hybridized atom A with concomitant displacement of a pendant leaving group X, forming a new carbon–A bond (**1.6**→**1.7**, Scheme 1.4a). Oxidation with hydrogen peroxide,[7] amination with methoxyamine,[8] and Matteson homologation with chloroiodomethane treated with *n*-butyllithium[12] all proceed by this class of 1,2-metallate shift. With the oxidation reaction, hydroperoxide anion attacks the vacant *p*-orbital on **1.4** to give "ate" complex **1.8**, which triggers a 1,2-metallate shift to displace hydroxide anion

Scheme 1.4. 1,2-metallate shifts onto sp^3-hybridized atoms

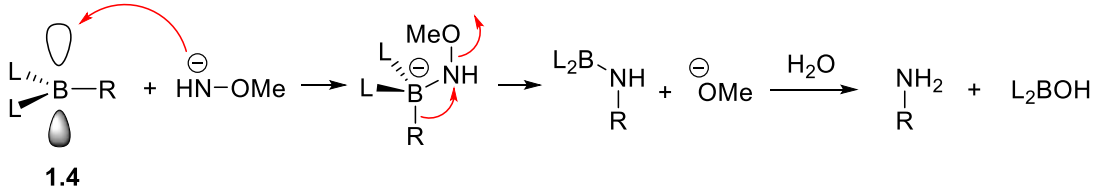
(a) General mechanism: 1,2-metallate and expulsion of pendant leaving group



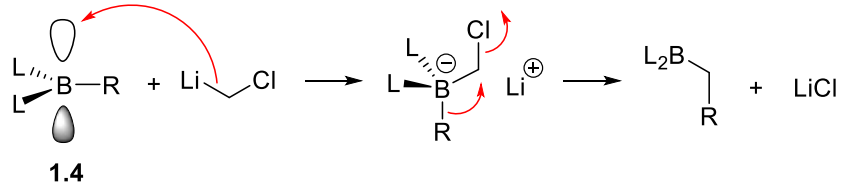
(b) Mechanism of the oxidation of organoboron compounds with hydroperoxy anion



(c) Mechanism of the amination of organoboron compounds with methoxyamide



(d) Mechanism of the homologation of organoboron compounds with lithiochloromethane

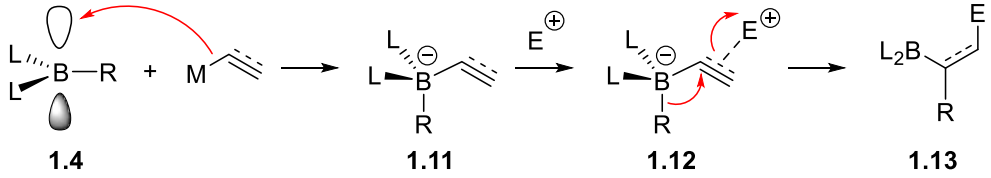


to form a new carbon–oxygen bond (**1.9**); hydrolysis of the boron–oxygen bond gives alcohol **1.10** (Scheme 1.4b). The other reactions proceed via analogous mechanisms (Scheme 1.4c and d).

The second class involves migration onto an sp^2- or *sp*-hybridized center via electrophilic activation of an appended π-system (**1.11**→**1.13**, Scheme 1.5a). The Zweifel–Evans–Matteson olefination,[11] the Aggarwal alkynylation,[13] and the Aggarwal arylation[14] proceed by this type of mechanism. With the olefination and alkynylation mechanisms, electrophilic iodination of the pendant olefin reagent generates a bridged iodonium cation

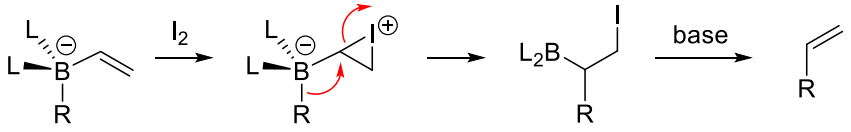
Scheme 1.5. 1,2-metallate shifts onto sp^2- and *sp*-hybridized atoms

(a) General mechanism: electrophilic activation of π-system and 1,2-metallate shift



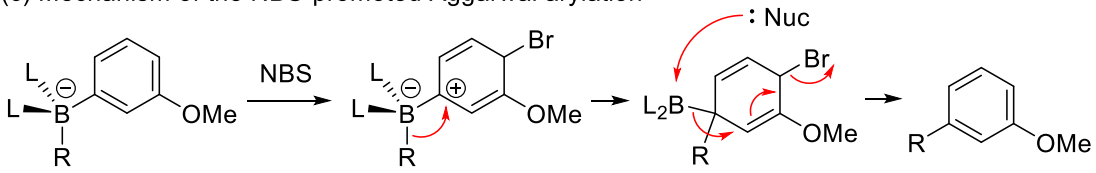
1.4 **1.11** **1.12** **1.13**

(b) Mechanism of the Zweifel-Evans-Matteson olefination[11]



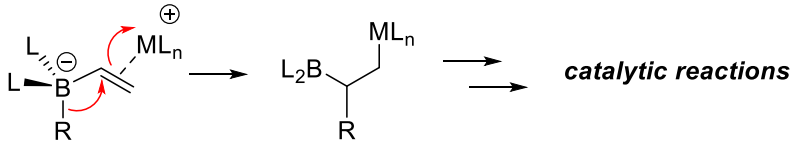
1.11 **1.14** **1.15** **1.16**

(c) Mechanism of the NBS-promoted Aggarwal arylation[14]



1.17 **1.18** **1.19** **1.20**

(d) Proposed π-acidic transition metal-induced 1,2-metallate shift to access catalytic reactions



1.21 **1.22**

1.14, which triggers the 1,2-metallate shift to form a new carbon–carbon bond (**1.15**); subsequent boron–iodine elimination affords the unsaturated product **1.16** (Scheme 1.5b). The Aggarwal arylation reactions involve electrophilic bromination of the pendant aromatic ring on "ate" complex **1.17** to form Wheland intermediate **1.18**, which similarly undergoes 1,2-metallate shift to form the new carbon–carbon bond; boron–bromine elimination (**1.19**) restores aromaticity and gives the arylated product **1.20** (Scheme 1.5c).

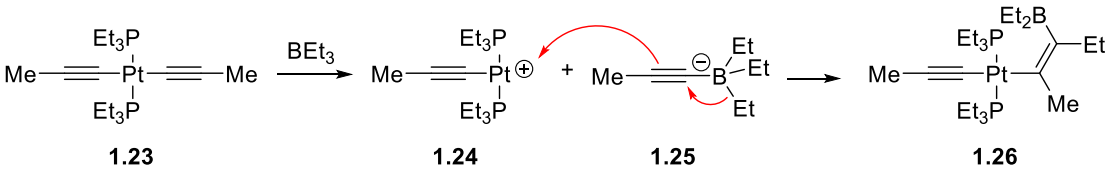
Inspired by this mode of reactivity, the Morken group recently began to explore the possibility of using π-acidic transition metals such as organopalladium or organonickel to activate the pendant π-systems of organoboron "ate" complexes (**1.21**) (Scheme 1.5d). It was hypothesized that rather than undergo boron–metal elimination, the newly formed carbon–metal σ-bond in intermediate **1.22** could undergo catalytic reactions such as cross-coupling with electrophilic organo(pseudo)halides. This proposed three-component *conjunctive cross-coupling reaction* would forge new carbon–carbon bonds between a migrating group, an olefin, and an electrophile with the advantage of retaining the boron atom to serve as a handle for further functionalization. Additionally, appropriate choice of a chiral ligand for the transition metal could render this conjunctive cross-coupling reaction enantioselective, which would further increase the synthetic value of such a transformation.

1.1.2. Transition Metal-Promoted 1,2-Metallate Shifts

Transition metal-promoted 1,2-metallate shifts have some precedence in the literature. One of the earliest examples was reported by the Wrackmeyer group in 1983 in which dialkynylated platinum complex **1.23** reacts with triethylborane to form cationic platinum species **1.24** and trialkylalkynylboron "ate" **1.25**. Electrophilic activation of the π bond of **1.25** by the cationic platinum center triggers a 1,2-metallate shift of one of the

alkyl groups, giving alkenyl platinum complex **1.26** (Scheme 1.6).[15] Although Wrackmeyer and coworkers do not report any synthetic utility of these complexes, this is nonetheless the first demonstration of a late transition metal effecting a 1,2-metallate shift on an unsaturated boron "ate" complex.

Scheme 1.6. Wrackmeyer's Pt-induced 1,2-metallate shift of trialkylalkynylboron "ate" complexes[15]



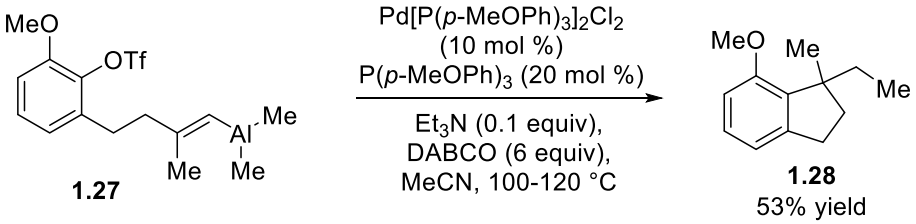
1.23 **1.24** **1.25** **1.26**

In 2004, the Fillion group reported the Pd-catalyzed intramolecular arylation of alkenylalanes **1.27** to form fused carbocycles **1.28** (Scheme 1.7a).[16] They propose that after **1.27** undergoes oxidative addition, intermediate **1.29** undergoes an intramolecular migratory insertion to give **1.30**, which is followed by reductive displacement of palladium via 1,2-methyl shift from aluminum to the α carbon (Scheme 1.7b, left). Compound **1.31** then undergoes protodemetallation to give product **1.28**. While their proposed mechanism is reasonable, this reaction could conceivably operate by an alternative pathway involving Pd-induced 1,2-metallate shift to form **1.32**, which would undergo reductive elimination to give **1.31** (Scheme 1.7b, right). Fillion and coworkers observe that 2,6-disubstituted aryltriflates give superior yields to monosubstituted aryltriflates, which lends support for their *5-exo-dig* migratory insertion–reductive displacement mechanism. Regardless, without extensive mechanistic studies, the alternative Pd-induced 1,2-metallate shift pathway remains a possibility.

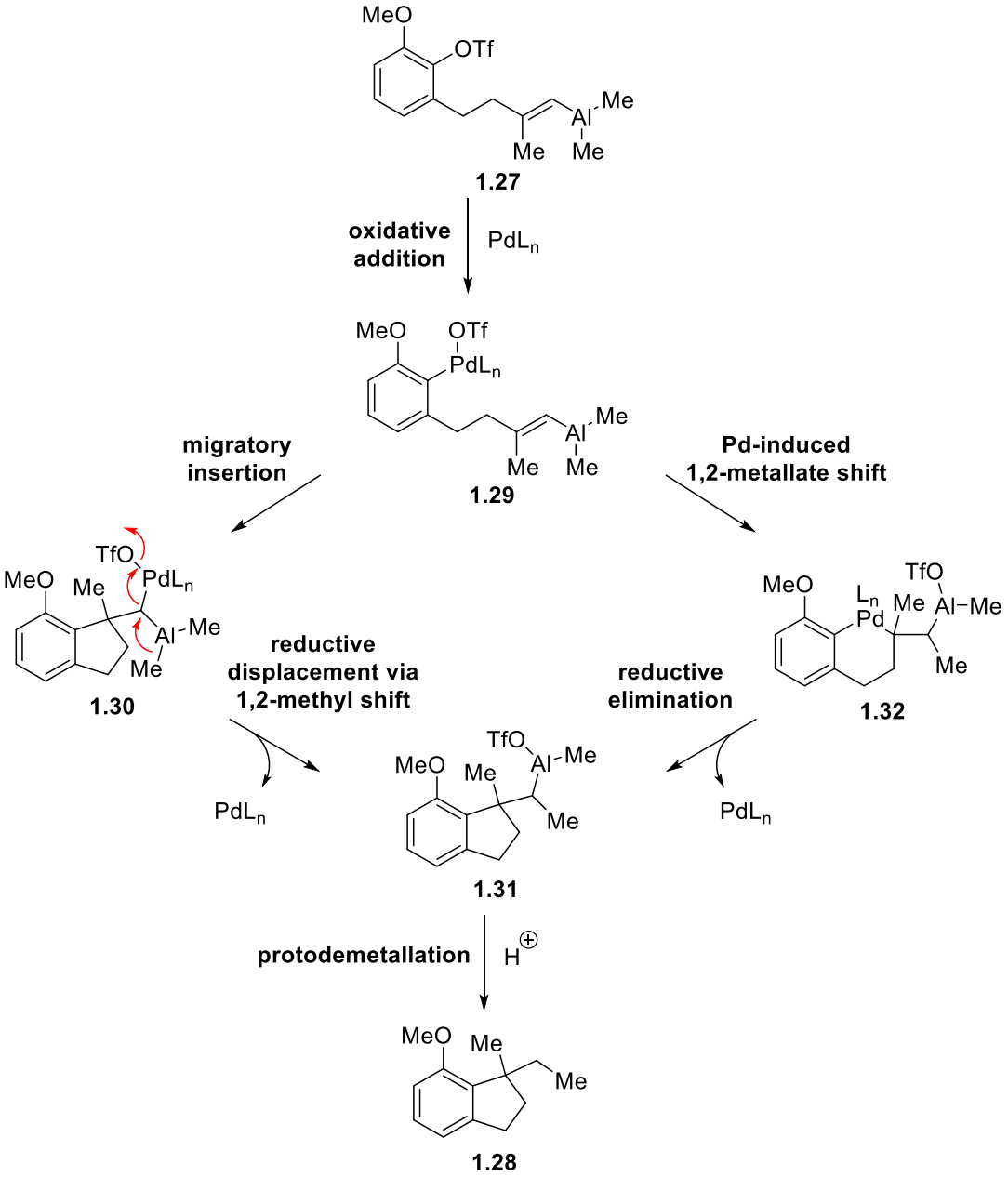
[15] Sebald, A.; Wrackmeyer, B. *J. Chem. Soc., Chem. Commun.* **1983**, *12*, 309.
[16] Fillion, E.; Carson, R. J.; Trépanier, V. E.; Goll, J. M.; Remorova, A. A. *J. Am. Chem. Soc.* **2004**, *126*, 15354.

Scheme 1.7. Fillion's Pd-catalyzed intramolecular arylation of alkenylalanes[16]

(a)



(b) Possible mechanisms



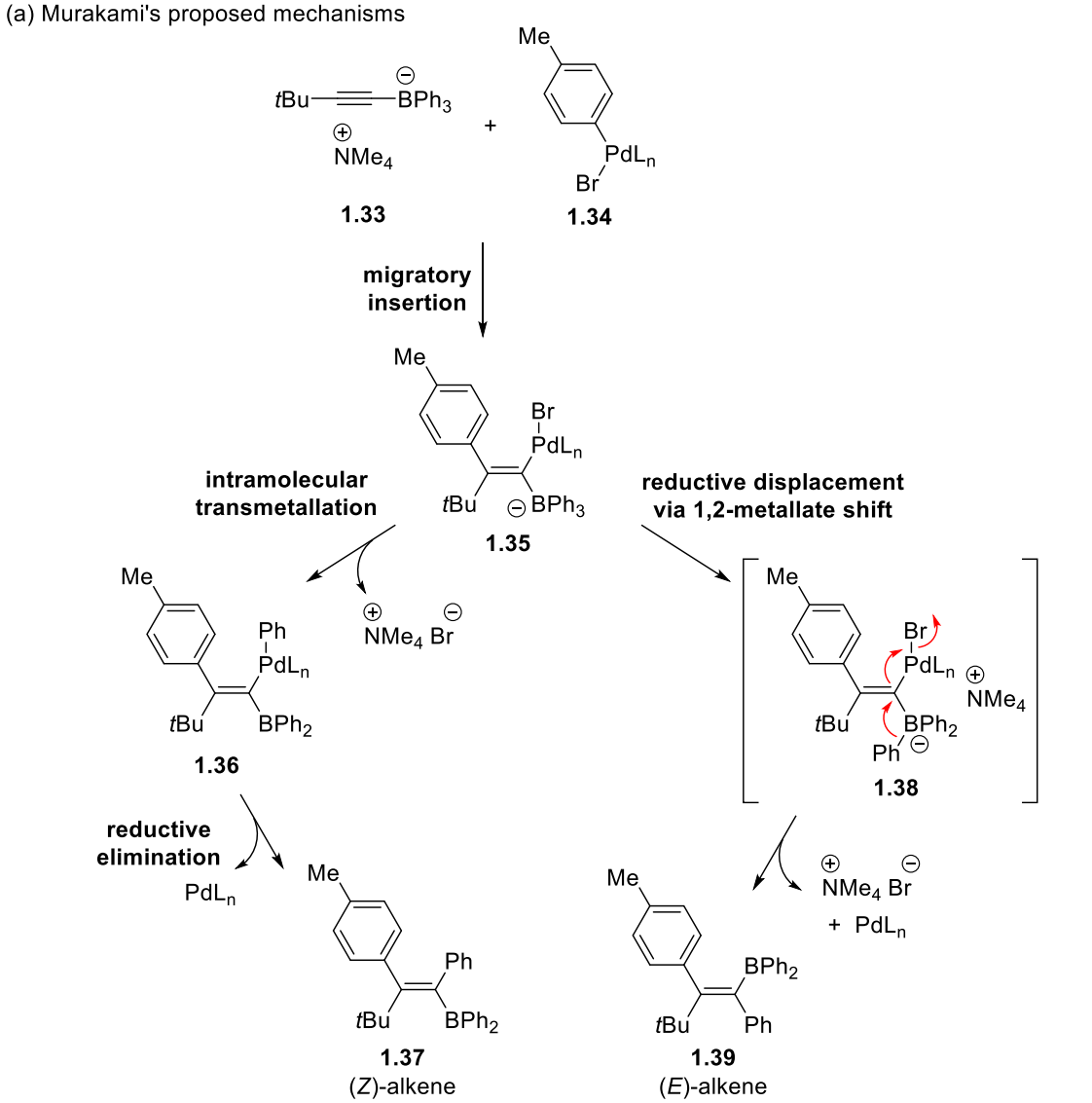
In 2007, the laboratory of Murakami reported the Pd-catalyzed arylation of tetramethylammonium trialkylalkynylboron "ate" complexes **1.33**.[17] They proposed that (aryl)Pd species **1.34** undergoes migratory insertion with **1.33** to give (alkenyl)Pd species **1.35**. This species could then undergo an intramolecular transmetallation of one of the phenyl groups on boron to palladium to give **1.36**, which furnishes (*Z*)-alkenylboronate **1.37** as the major diastereomer of the reaction following reductive elimination (Scheme 1.8a, left). To rationalize the formation of the minor *E* diastereomer **1.39**, they propose a reductive displacement of the palladium atom via a 1,2-metallate shift of one of the boron "ate" phenyl groups (**1.38**, Scheme 1.8a, right). This reductive displacement is similar to Fillion's proposal in his Pd-catalyzed intramolecular arylation of alkenylalanes (*vide supra*).

Like Fillion, Murakami and coworkers do not conduct mechanistic studies to support their proposed pathways. It is possible that two alternative mechanisms could be operative in which the cationic (aryl)Pd species activates the alkynylboron "ate" complex to undergo either a *syn*- (**1.40**→**1.41**) or an *anti*-1,2-metallate shift (**1.42**→**1.43**), followed by reductive elimination to give **1.37** and **1.39**, respectively (Scheme 1.7b). Although they do not propose these alternate pathways for this reaction, they do invoke them in a later study involving the Pd-catalyzed allylation of the same boron "ate" species **1.33**.[18]

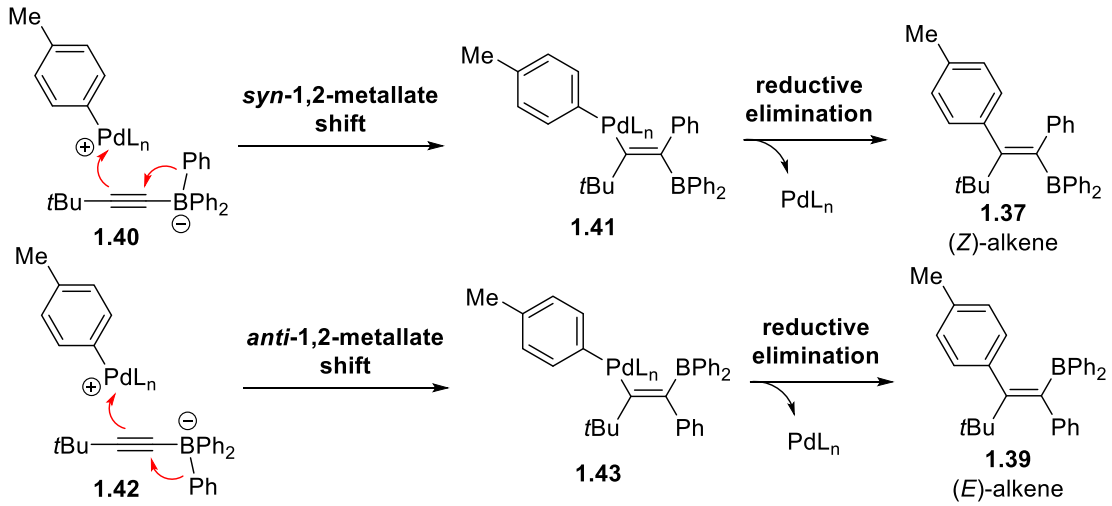
[17] Ishida, N.; Miura, T.; Murakami, M. *Chem. Commun.* **2007**, *42*, 4381.
[18] Ishida, N.; Shinmoto, T.; Sawano, S.; Miura, T.; Murakami, M. *Bull. Chem. Soc. Jpn.* **2010**, *83*, 1380.

Scheme 1.8. Murakami's Pd-catalyzed arylation of trialkylalkynylboron "ate" complexes[17]

(a) Murakami's proposed mechanisms

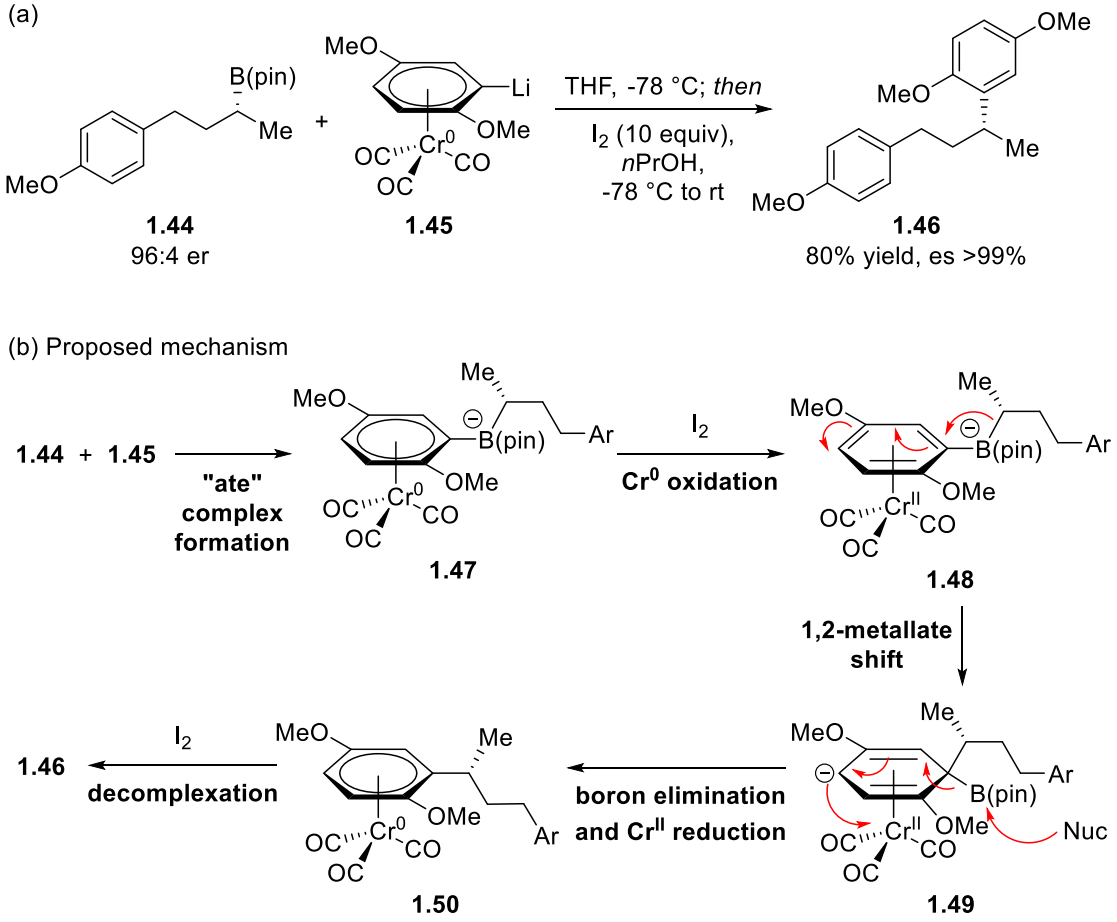


(b) Possible alternative mechanisms



In 2018, the Aggarwal lab reported the coupling of enantioenriched organoboronates **1.44** with a variety of lithiated chromium–arene complexes **1.45** to access enantioenriched arylalkanes **1.46** (Scheme 1.9a).[14i] Following formation of the organoboron "ate" complex **1.47**, treatment with molecular iodine oxidizes chromium(0) to chromium(II) (**1.48**). The chromium in the higher oxidation state triggers the 1,2-metallate shift to give Meisenheimer complex **1.49**, whose negative charge is stabilized by complexation with the chromium(II) center. Elimination of boron restores aromaticity while simultaneously reducing chromium(II) to chromium(0) (**1.50**). Intermediate **1.50** undergoes decomplexation upon reaction with another equivalent of iodine to give product **1.46** (Scheme 1.9b).

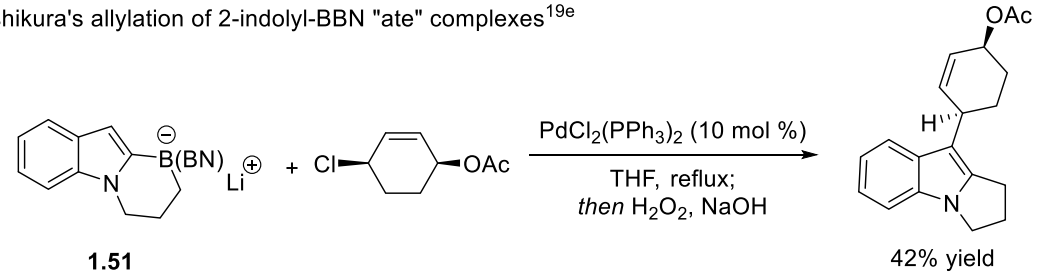
Scheme 1.9. Aggarwal's Cr-induced 1,2-metallate shift of boron "ate" complexes[14i]



It is worth mentioning that Pd-catalyzed allylation reactions of 2-indolylboron "ate" complexes such as **1.51** have also been developed (Scheme 1.10a).[19] However, as a recent mechanistic study by Ready revealed, this class of boron "ate" first undergoes electrophilic alkylation of the C3 position of the indole moiety (**1.52**) independent of the subsequent 1,2-metallate shift onto the iminium cation (**1.53**, Scheme 1.10b).[19g] Furthermore, these reactions are believed to proceed via an outer sphere attack of the allyl ligand on palladium rather than an inner sphere attack of the metal center. Because of these mechanistic differences, Pd-catalyzed allylation reactions of boron "ate" complexes will not be discussed further and will instead be elaborated upon in the following chapter.

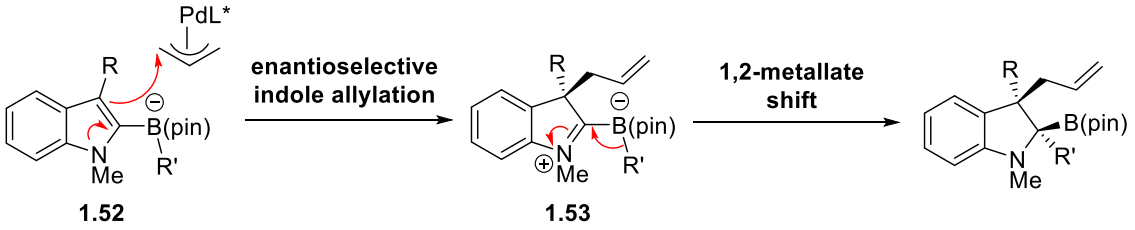
Scheme 1.10. Pd-catalyzed allylation of 2-indolylboron "ate" complexes

(a) Ishikura's allylation of 2-indolyl-BBN "ate" complexes[19e]



1.51 42% yield

(b) Ready's proposed stepwise mechanism: a highly enantioselective allylation followed by 1,2-migration[19g]



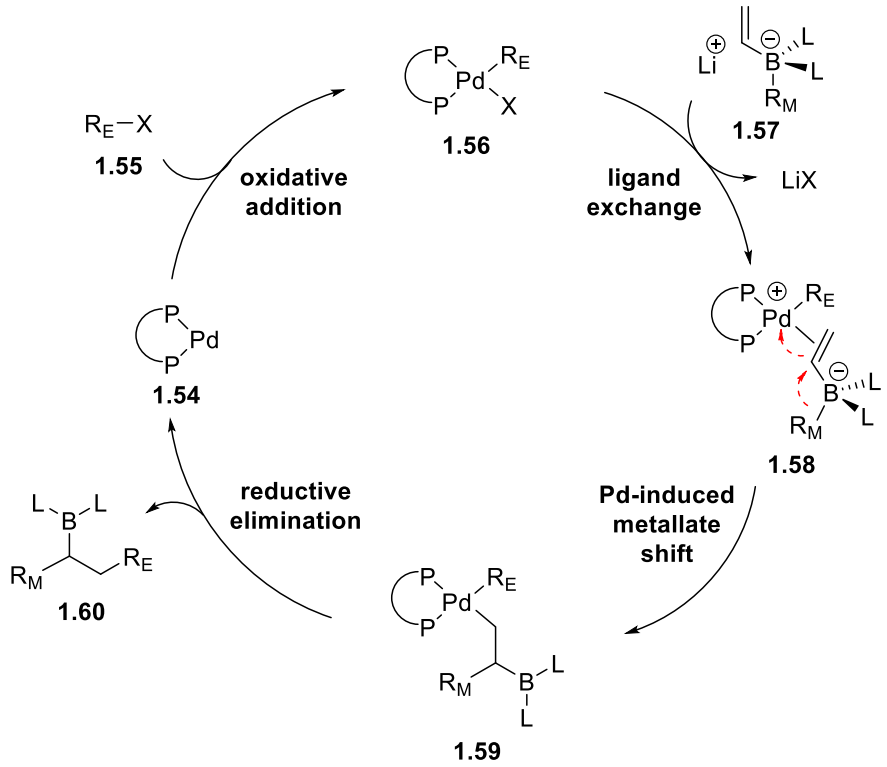
1.52 **1.53**

[19] (a) Ishida, N.; Shinmoto, T.; Sawano, S.; Miura, T.; Murakami, M. *Bull. Chem. Soc. Jpn.* **2010**, *83*, 1380. (b) Ishikura, M.; Terashima, M.; Okamura, K.; Date, T. *J. Chem. Soc., Chem. Commun.* **1991**, *20*, 1219. (c) Ishikura, M.; Agata, I. *Heterocycles* **1996**, *43*, 1591. (d) Ishikura, M.; Kato, H. *Tetrahedron* **2002**, *58*, 9827. (e) Ishikura, M.; Ida, W.; Yanada, K. *Tetrahedron* **2006**, *62*, 1015. (f) Panda, S.; Ready, J. M. *J. Am. Chem. Soc.* **2017**, *139*, 6038. (g) Panda, S.; Ready, J. M. *J. Am. Chem. Soc.* **2018**, *140*, 13242.

1.2. The First-Generation Conjunctive Cross-Coupling Reaction

The proposed catalytic cycle for the conjunctive cross-coupling reaction is shown in Scheme 1.11. Like the Suzuki–Miyaura cross coupling reaction, the cycle begins with an oxidative addition between palladium(0) species **1.54** and an electrophile R_E–X **1.55** to give intermediate **1.56**. A ligand exchange between the X group and the olefin moiety on organoboron "ate" complex **1.57** would give complex **1.58**. The migrating group R_M would then undergo a 1,2-metallate shift to give intermediate **1.59**, which would undergo reductive elimination to furnish the conjunctive cross-coupling product **1.60** and close the catalytic cycle.

Scheme 1.11. Proposed catalytic cycle for the conjunctive cross-coupling reaction

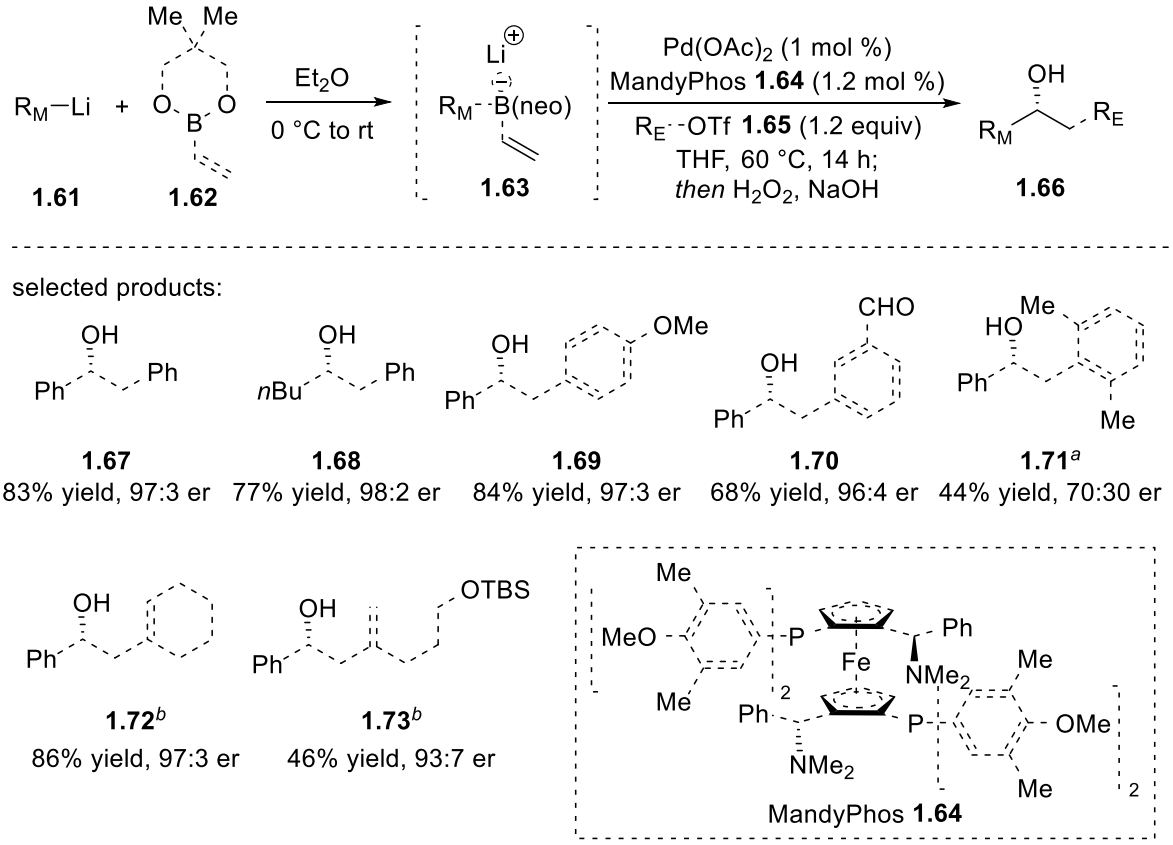


The success of the proposed reaction depends on the careful choice of the electrophile: the X group on **1.55** must be labile enough to dissociate from palladium complex **1.56** to form a cationic metal center with an open coordination site in order for the boron "ate" complex to bind. To this end, organotriflates were chosen as the electrophile in the first-generation conjunctive cross-coupling reaction. Furthermore, the appropriate ligand must be chosen which would stabilize cationic palladium and favor reductive elimination over β-hydride elimination for complex **1.59**. It was hypothesized that electron-rich, bidentate ligands with wide bite angles would fulfill all of these requirements. A ligand survey revealed that the chiral bidentate bisphosphine ligand MandyPhos **1.64** (*vide infra*) was the most effective at giving conjunctive cross-coupling products in good yields with generally high levels of enantioselectivity.

In 2016, the Morken group reported the first conjunctive cross-coupling reaction in which vinyl boron "ate" complexes **1.63**—generated from C(sp^3)- or C(sp^2)-hybridized organolithium reagents **1.61** and vinylboronic acid, neopentyl glycol ester (vinylB(neo) **1.62**)—are coupled to C(sp^2)-hybridized organotriflate electrophiles **1.65** catalyzed by $Pd(OAc)_2$ and MandyPhos **1.64** at 60 °C for 14 hours.[20] After oxidation with alkaline hydrogen peroxide, the secondary alcohol products **1.66** are isolated in modest to good yields with generally excellent levels of enantioselectivity (Scheme 1.12). Electrophiles bearing sensitive functional groups such as aldehydes (**1.70**) were found to participate well in the reaction. Electrophiles bearing di-*ortho*-substitution also worked well, but due to the increased steric congestion, the reaction required 80 °C for full conversion and the enantioselectivity was diminished (**1.71**). Alkenyltriflates also worked (**1.72** and **1.73**),

[20] Zhang, L.; Lovinger, G. J.; Edelstein, E. K.; Szymaniak, A. A.; Chierchia, M. P.; Morken, J. P. *Science* **2016**, *351*, 70.

Scheme 1.12. First generation conjunctive cross-coupling reaction using organolithium reagents and vinylB(neo)



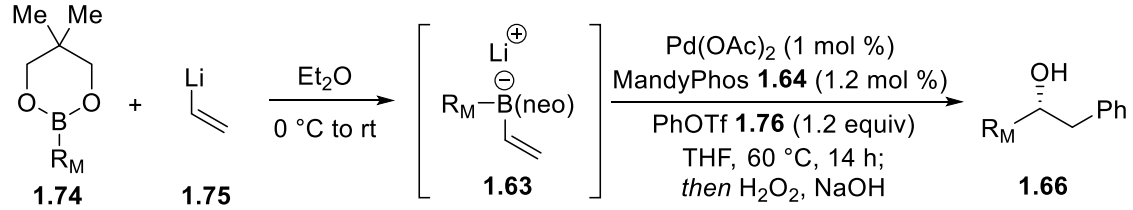
[a]Reaction conducted at 80 °C. [b]VinylB(pin) was used instead of vinylB(neo).

although employing pinacolato rather than neopentyl glycolato "ate" complexes resulted in markedly enhanced yields and enantioselectivities; for instance, **1.72** was isolated in 53% yield and 82:18 er when vinylB(neo) was used instead of vinylB(pin).

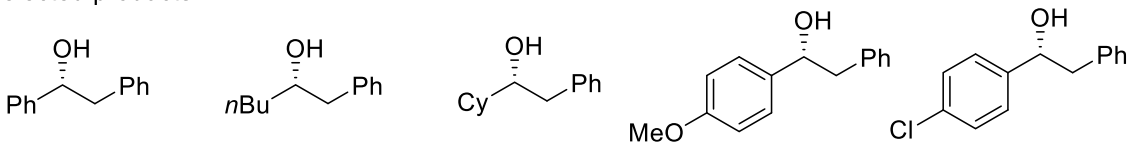
A wider array of organoboron compounds are commercially-available or are readily synthesized compared to organolithium reagents. Thus, seeking to expand the scope of migrating groups in the conjunctive cross-coupling reaction, boron "ate" complexes **1.63** derived from C(sp^3)- or C(sp^2)-hybridized B(neo) compounds **1.74** and vinyllithium **1.75** were subjected to the same reaction conditions shown in Scheme 1.12 using phenyltriflate **1.76** as the electrophile (Scheme 1.13). Employing phenylB(neo) and *n*-butylB(neo) gave

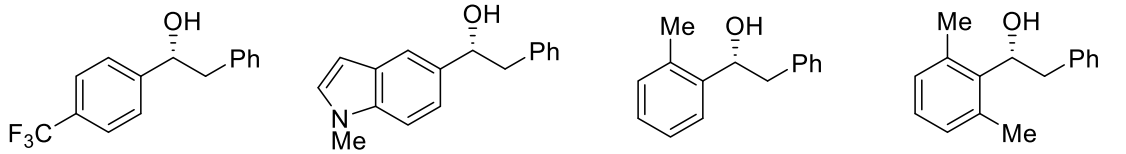
their respective conjunctive cross-coupling products **1.67** and **1.68** with virtually identical yields and enantioselectivities compared to using phenyllithium and *n*-butyllithium with vinylB(neo) (Scheme 1.12, *vide supra*), showing that the same "ate" complex **1.63** is formed regardless of how it is generated. Electron-rich (**1.78**) and electron-deficient (**1.79**) aryl groups were found to participate in the reaction, although an arene bearing a strongly deactivating trifluoromethyl group gave trace product (**1.80**). Heterocycles were found to migrate (**1.81**), as were groups bearing *ortho* substitution (**1.82**). As demonstrated in Scheme 1.12 with a di-*ortho*-substituted aryltriflate (**1.71**), a di-*ortho*-substituted arylB(neo) gave product with diminished levels of enantioselectivity (**1.83**).

Scheme 1.13. First generation conjunctive cross-coupling reaction using organo B(neo) compounds and vinyllithium



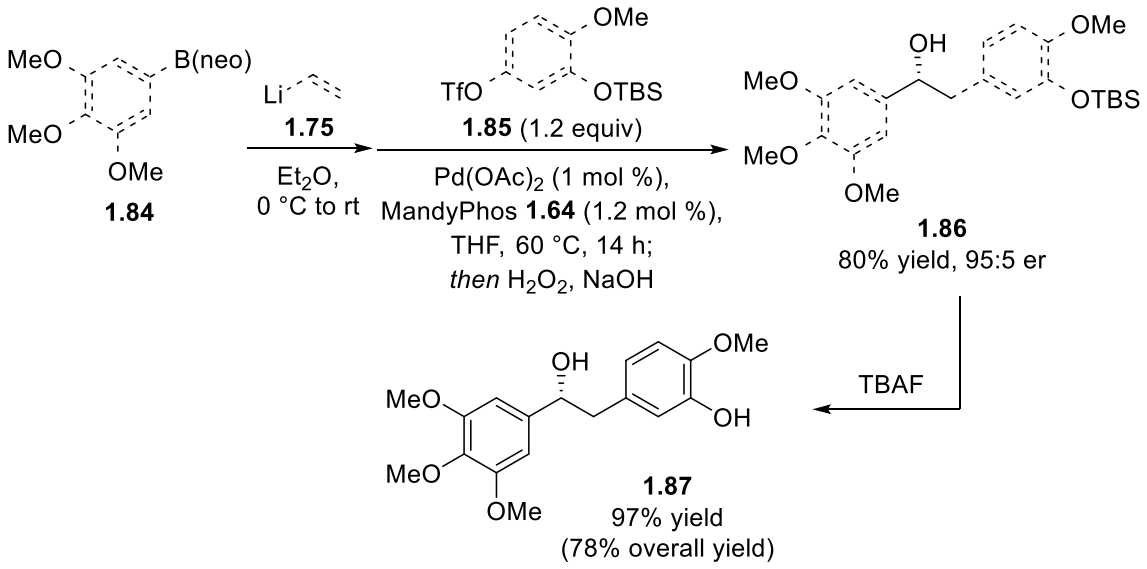
selected products:





In order to demonstrate the synthetic utility of the conjunctive cross-coupling reaction, the natural product (–)-combretastatin[21] **1.87** was synthesized in a rapid and efficient manner in high yield and enantioselectivity. The "ate" complex derived from 3,4,5-trimethoxyphenylB(neo) **1.84** and vinyllithium **1.75** was subjected to conjunctive cross-coupling conditions with aryltriflate **1.85**, giving enantioenriched secondary alcohol **1.86** in high yield. Removal of the TBS group with TBAF afforded (–)-combretastatin **1.87** in 78% overall yield (Scheme 1.14).

Scheme 1.14. Total synthesis of (-)-combretastatin



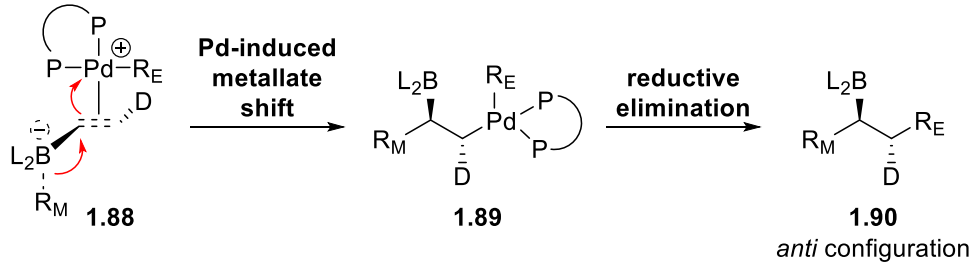
Although this reaction was proposed to proceed through a Pd-induced 1,2-metallate rearrangement followed by reductive elimination (Scheme 1.15a), other mechanistic possibilities could not be ignored. One alternative mechanism is similar to Murakami's proposal for his Pd-catalyzed arylation of trialkylalkynylboron "ate" complexes (Scheme 1.8, left, *vide supra*) involving a migratory insertion mechanism to give α-palladated

[21] Pettit, G. R.; Cragg, G. M.; Herald, D. L.; Schmidt, J. M.; Lohavanijaya, P. *Can. J. Chem.* **1982**, *60*, 1374.

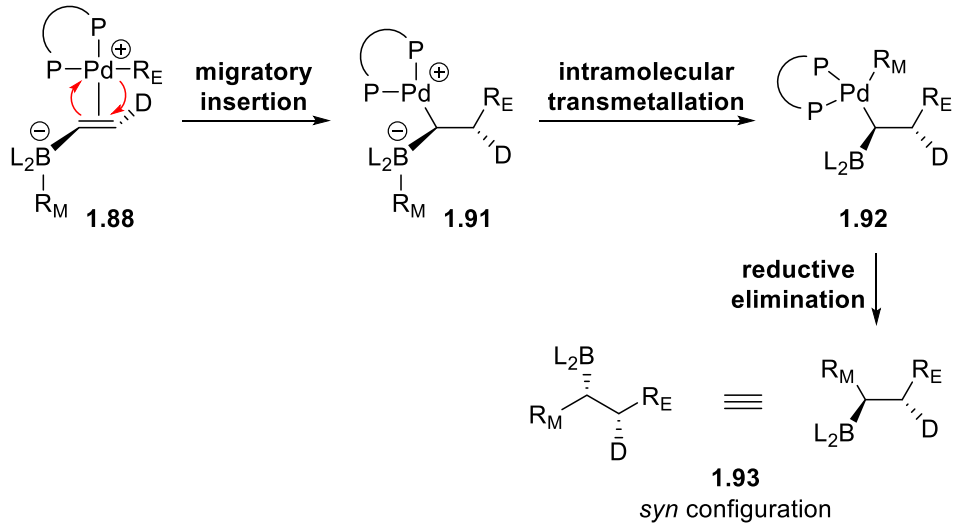
species **1.91**, which could undergo intramolecular transmetallation and reductive elimination to give **1.93** (Scheme 1.15b). Another plausible mechanism similar to Murakami's proposal (Scheme 1.8, right) involves the same α-palladated species **1.91**, which could trigger a 1,2-metallate shift from boron to reductively displace palladium (Scheme 1.15c).

Scheme 1.15. Possible mechanisms for the conjunctive cross-coupling reaction

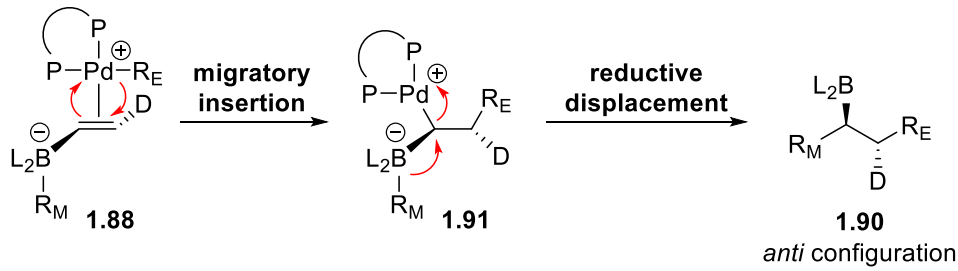
(a) Pd-induced 1,2-metallate shift-reductive elimination



(b) Migratory insertion-intramolecular transmetallation-reductive elimination

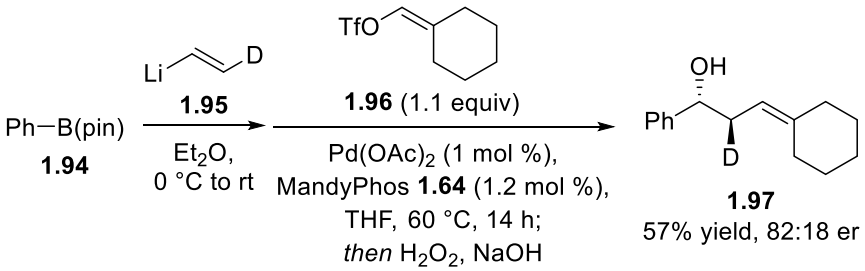


(c) Migratory insertion-reductive displacement



In order to ascertain which in the likely pathway, *trans*-deuterium-labeled vinyllithium **1.95** was employed in the conjunctive cross-coupling reaction with phenylB(pin) **1.94** and alkenyltriflate electrophile **1.96** to give deuterium-labeled secondary alcohol **1.97**. ^{1}H NMR analysis shows that the hydroxyl group and the deuterium atom are *anti* to each other (Scheme 1.16), ruling out the intramolecular transmetallation mechanism in Scheme 1.15b which would result in a *syn* configuration.

Scheme 1.16. Deuterium-labeling experiment to determine relative stereochemistry

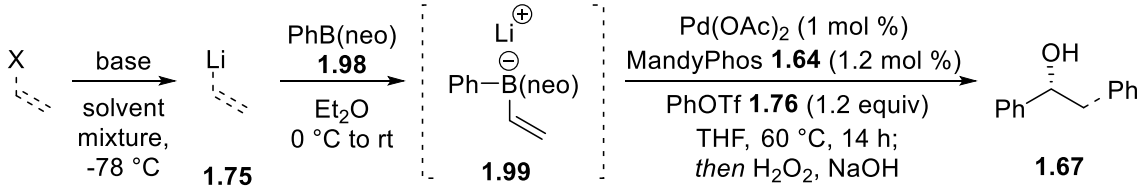


Although this labeling experiment does not distinguish between the other two mechanistic possibilities, both of which would result in an *anti*-configuration, unpublished DFT calculations conducted in our group suggest a prohibitively high energy barrier associated with aligning the palladium–carbon σ-bond parallel to the carbon–carbon π-bond on the boron "ate" complex, the configuration required for migratory insertion (Scheme 1.15c). This high barrier arises from steric repulsion between the ligand set on boron and the large MandyPhos ligand on palladium.

1.3. The Halide-Tolerant Conjunctive Cross-Coupling Reaction

The conjunctive cross-coupling reaction was shown to be a modular and efficient method to construct enantioenriched organoboronic esters. However, the first-generation reaction suffers from limitations that prevent this reaction from being more general, limitations that my research efforts aimed to address. Firstly, the reaction requires the use of vinyllithium free from halide impurities. Lithium-halogen exchange between either vinyl halides and either *n*-butyllithium or *t*-butyllithium to generate vinyllithium *in situ* led to greatly diminished yields (Table 1.1, entries 1–4). Preparing vinyllithium by lithium-halogen exchange and then conducting the conjunctive cross-coupling reaction with 5 mol % catalyst loading rather than 1 mol % led to enhanced yield (Table 1.1, entry 5). Ultimately, vinyllithium that had been recrystallized from pentane and dissolved in Et_2O

Table 1.1. The effect of different vinylltihium sources in the conjunctive cross-coupling reaction



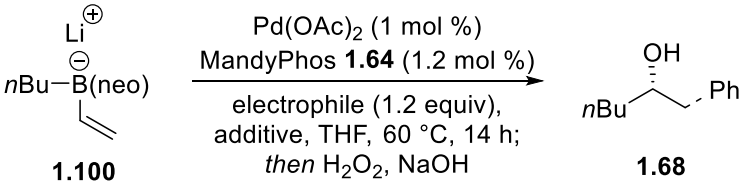
entry	X	base (equiv)	solvent mixture	yield of **1.67** (%)[a]	er of **1.67** (%)[b]
1	Br	*t*BuLi (2)	THF/pentane	<5	N.D.
2	Br	*t*BuLi (2)	Et_2O/pentane	<5	N.D.
3	Br	*n*BuLi (1)	Et_2O/hexane	N.D.[c]	N.D.
4	I	*n*BuLi (1)	Et_2O/hexane	40	N.D.
5[d]	I	*n*BuLi (1)	Et_2O/hexane	69	98:2
6[e]	I	*n*BuLi (1)	Et_2O/hexane	84	97:3

[a]Yields represent isolated yields. [b]Determined by chiral SFC chromatography. [c]Vinyllithium formation was not observed. [d]5 mol % catalyst loading was used. [e]Vinyllithium was recrystallized from pentane and used as an Et_2O solution.

was found to be optimal in the first-generation conjunctive cross-coupling (Table 1.1, entry 6). These data suggest that the presence of halides in the reaction medium was detrimental to the reaction.

In fact, exogenous addition of 1 mol % lithium halide salts to the reaction of *n*-butyl(vinyl)B(neo) "ate" complex **1.100** with phenyltriflate **1.76** using 1 mol % catalyst loading led to a significant drop in yield, although the enantioselectivity is not greatly affected (Table 1.2, entry 1 vs. entries 2–5). Raising the catalyst loading from 1 mol % to 5 mol % in the presence of 1 mol % lithium iodide led to a partial recovery of the yield, although the yield was not as high compared to standard halide-free conditions (Table 1.2, entry 6). Employing iodobenzene **1.101** or bromobenzene **1.102** instead of phenyltriflate **1.76** resulted in greatly diminished yield, although the enantioselectivity was not greatly

Table 1.2. Halide inhibition in the conjunctive cross-coupling reaction



entry	electrophile	additive	yield of **1.68** (%)[a]	er of **1.68** (%)[b]
1	PhOTf **1.76**	none	77	98:2
2	PhOTf **1.76**	LiI (1 mol %)	13	98:2
3	PhOTf **1.76**	LiBr (1 mol %)	41	98:2
4	PhOTf **1.76**	LiCl (1 mol %)	40	98:2
5	PhOTf **1.76**	(nBu)$_4$NCl (1 mol %)	31	98:2
6[c]	PhOTf **1.76**	LiI (1 mol %)	69	98:2
7	PhI **1.101**	none	9	96:4
8	PhBr **1.102**	none	9	96:4
9	PhCl **1.103**	none	<5	N.D.

[a]Yields represent isolated yields. [b]Determined by chiral SFC chromatography. [c]5 mol % catalyst loading was used.

affected (Table 1.2, entries 7 and 8). Chlorobenzene **1.103** gave trace product (Table 1.2, entry 9), presumably due to the higher activation barrier associated with oxidative addition into carbon–chloride bonds.[22] These results show that, in addition to avoiding the time-consuming and cumbersome synthesis of halide-free vinyllithium, solving the problem of halide inhibition would also allow for the use of aryl halide electrophiles. This would greatly expand the generality of this reaction, as aryl halides are more readily available and in greater variety compared to aryl triflates.

In order for the 1,2-metallate shift to occur, the olefin on the "ate" complex **1.57** must bind to the cationic palladium center in species **1.58** (Scheme 1.17). This is favored when the electrophile is an aryl triflate. We hypothesize that in the presence of halide salts in solution, this equilibrium favors neutral palladium species **1.56**; without an open coordination site on the metal center, the catalytic conjunctive cross-coupling reaction is arrested.[23] Although halide additives have been known to accelerate Pd-catalyzed Heck reactions,[24] it is believed that this is due to an acceleration of the rate-determining oxidative addition step. In Heck reactions in which oxidative addition is not the rate-determining step, halides inhibit the reaction.[25]

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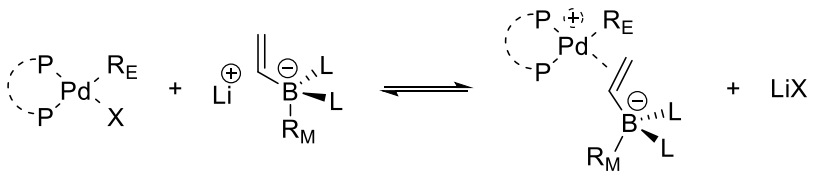
[22] Littke, A. F.; Fu, G. C. *Angew. Chem. Int. Ed.* **2002**, *41*, 4176.

[23] (a) Kawataka, F.; Shimizu, I.; Yamamoto, A. *Bull. Chem. Soc. Jpn.* **1995**, *68*, 654. (b) Kayaki, Y.; Shimizu, I.; Yamamoto, A. *Chem. Lett.* **1995**, *24*, 1089. (c) Amatore, C.; Carre, E.; Jutand, A.; M'Barki, M. A.; Meyer, G. *Organometallics* **1995**, *14*, 5605. (d) Amatore, C.; Godin, B.; Jutand, A.; Lemaître, F. *Organometallics* **2007**, *26*, 1757. (e) Amatore, C.; Godin, B.; Jutand, A.; Lemaître, F. *Chem. Eur. J.* **2007**, *13*, 2002.

[24] (a) Jeffery, T. *J. Chem. Soc., Chem. Commun.* **1984**, *19*, 1287. (b) Jeffery, T. *Tetrahedron Lett.* **1985**, *26*, 2667. (c) Grigg, R.; Stevenson, P.; Worakun, T. *Tetrahedron* **1988**, *44*, 2033. (d) Andersson, C. M.; Hallberg, A. *J. Org. Chem.* **1988**, *53*, 2112

[25] (a) Ozawa, F.; Kubo, A.; Hayashi, T. *J. Am. Chem. Soc.* **1991**, *113*, 1417. (b) Jutand, A. *Appl. Organomet. Chem.* **2004**, *18*, 574.

Scheme 1.17. Hypothesized mechanism of halide inhibition



1.56 neutral Pd, favored if X = halide

1.57

1.58 cationic Pd, favored if X = OTf

We also sought to improve the generality of the conjunctive cross-coupling reaction by being able to employ Grignard reagents in addition to organolithium reagents, particularly commercially-available vinylmagnesium halides. Although it was anticipated that the halides present in Grignard reagents would inhibit catalysis, we discovered that employing these reagents come with their own challenges with respect to reactivity. ^{11}B NMR studies on the reaction between phenylB(pin) **1.94** (δ = 30.9 ppm, Figure 1.1a) and vinyllithium **1.75** showed that organoboron "ate" complex **1.104** was formed cleanly and with full conversion (δ = 5.8 ppm, Figure 1.1b). However, when vinylmagnesium bromide **1.105** was used, "ate" complex **1.104** was only formed in approximately 20% conversion (Figure 1.1c). In line with these findings, a previous report by Blakemore suggests that formation of boron "ate" complexes from Grignard reagents is more difficult compared to the analogous reaction using organolithium reagents, which probably stems from their diminished nucleophilicity.[26] We then explored the use of additives which, in addition to enhancing the formation of "ate" complexes from Grignard reagents, may also serve as halide scavengers to allow for the 1,2-metallate shift to occur.

[26] Blakemore, P. R.; Marsden, S. P.; Vater, H. D. *Org. Lett.* **2006**, *8*, 773.

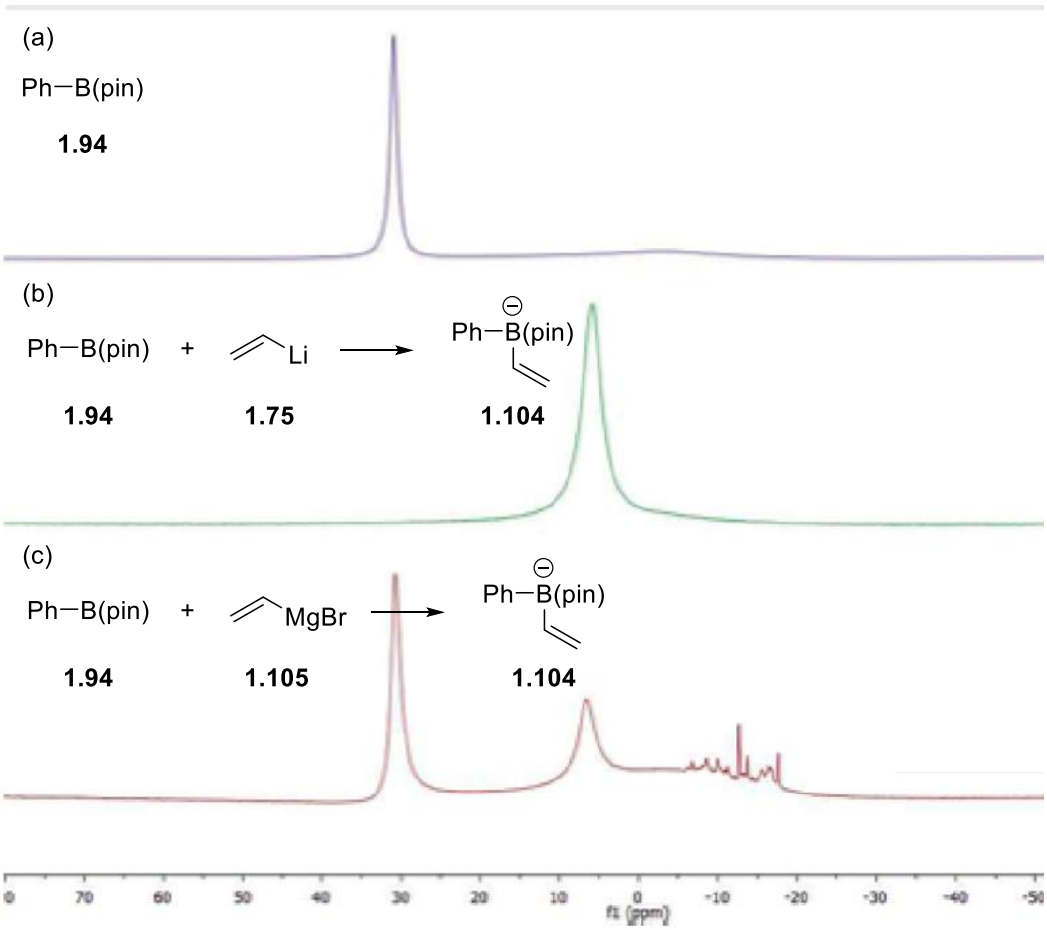


Figure 1.1. ^{11}B NMR studies of the formation of organoboron "ate" complexes with vinylmetal reagents. ^{11}B NMR spectra of (a) phenylB(pin) **1.94**; (b) the reaction of phenylB(pin) **1.94** and vinyllithium **1.75** to form "ate" complex **1.104**; and (c) the reaction of phenylB(pin) **1.94** and vinylmagnesium bromide **1.105** to form "ate" complex **1.104**.

We began our additive survey with lithium chloride, as Knochel and coworkers have shown than lithium chloride enhances the reactivity of Grignard reagents in magnesium-halogen exchange reactions as well as the reactivity of Hauser bases, giving so-called "turbo Grignard reagents"[27] and "turbo Hauser bases,"[28] respectively. Although

[27] (a) Krasovskiy, A.; Knochel, P. *Angew. Chem. Int. Ed.* **2004**, *43*, 3333. (b) Klatt, T.; Markiewicz, J. T.; Sämann, C.; Knochel, P. *J. Org. Chem.* **2014**, *79*, 4253. (c) Tilly, D.; Chevallier, F.; Mongin, F.; Gros, P. C. *Chem. Rev.* **2014**, *114*, 1207. (d) Li-Yuan Bao, R.; Zhao, R.; Shi, L. *Chem. Commun.* **2015**, *51*, 6884.

[28] (a) Krasovskiy, A.; Krasovskaya, V.; Knochel, P. *Angew. Chem. Int. Ed.* **2006**, *45*, 2958. (b) Lin, W.; Baron, O.; Knochel, P. *Org. Lett.* **2006**, *8*, 5673. (c) Neufeld, R.; Teuteberg, T. L.; Herbst-Irmer, R.; Mata, R. A.; Stalke, D. *J. Am. Chem. Soc.* **2016**, *138*, 4796.

lithium chloride would undoubtedly inhibit the subsequent conjunctive cross-coupling reaction, we thought learning about the effect of additives on "ate" complex formation was a good starting point to improve the reaction. Indeed, lithium chloride additive led to full conversion to the "ate" complex as revealed by ^{11}B NMR analysis (Figure 1.2b).

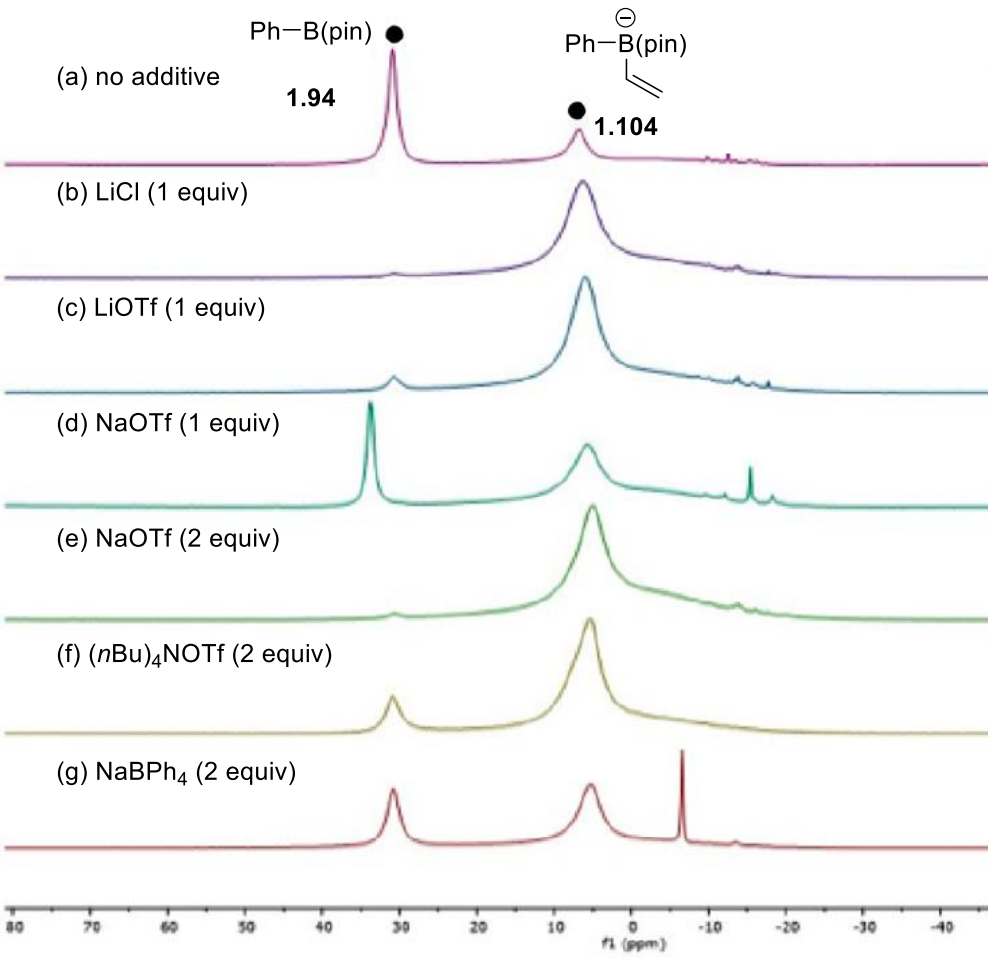


Figure 1.2. ^{11}B NMR studies of the effect of additives on the formation of aryl boron "ate" complexes. ^{11}B NMR spectra of the reaction of phenylB(pin) **1.94** and vinylmagnesium bromide **1.105** to form "ate" complex **1.104** (a) without additive; (b) with one equivalent of lithium chloride; (c) with one equivalent of lithium triflate; (d) with one equivalent of sodium triflate; (e) with two equivalents of sodium triflate; (f) with two equivalents of tetrabutylammonium triflate; and (g) with two equivalents of sodium tetraphenylborate.

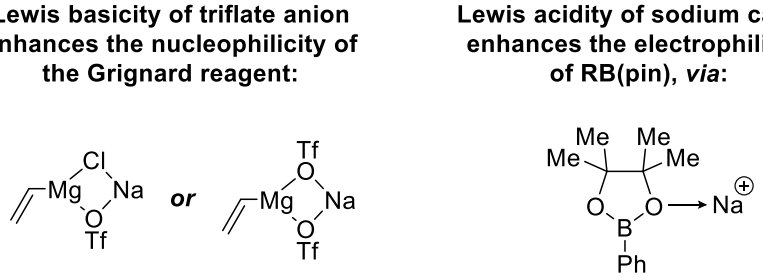
Other weakly basic metal salts were investigated. We found that lithium triflate (Figure 1.2c) can also promote full conversion to the "ate" complex, but under conjunctive cross-coupling conditions, this additive gave low yield of the product. We attribute this to the poor sequestration of halide anions by lithium cation and hypothesized that a larger alkali metal cation would be more effective. In line with this hypothesis, we found that sodium triflate can also promote full conversion to the "ate" complex, although requiring two equivalents to be effective (Figure 1.2d and e). Importantly, this additive gave the conjunctive cross-coupling product in high yield and enantioselectivity (*vide infra*).

We were also eager to ascertain the role of sodium cation and triflate anion in "ate" complex formation. Two equivalents of tetrabutylammonium triflate are able to promote "ate" complex formation in approximately 85% conversion (Figure 1.2f), while sodium tetraphenylborate does so in about 40% conversion (Figure 1.2g). From these two experiments, we hypothesize that sodium triflate facilitates "ate" complex formation from vinylmagnesium bromide **1.105** via both nucleophilic activation of the Grignard reagent by the triflate anion (Scheme 1.18 left)[29] and via electrophilic activation of phenylB(pin) **1.94** by coordination of one of the pinacolato oxygen atoms to sodium cation (Scheme 1.18 right).[30]

[29] (a) Kendall, A. J.; Salazar, C. A.; Martino, P. F.; Tyler, D. R. *Organometallics* **2014**, *33*, 6171. (b) Reetz, M. T.; Harmat, N.; Mahrwald, R. *Angew. Chem., Int. Ed. Engl.* **1992**, *31*, 342.

[30] (a) Corey, E. J.; Barnes-Seeman, D.; Lee, T. W. *Tetrahedron: Asymmetry* **1997**, *8*, 3711. (b) Midland, M. M. *J. Org. Chem.* **1998**, *63*, 914. (c) Rauniyar, V.; Hall, D. G. *J. Am. Chem. Soc.* **2004**, *126*, 4518.

Scheme 1.18. Hypothesized mechanism of NaOTf-promoted "ate" complex formation



Using alkyl boronic esters such as 3-butenylB(pin) **1.106** presents its own problems. When treated with vinyllithium **1.75** in THF, the "ate" complex **1.107** remains stable at room temperature even after 24 hours (Figure 1.3a). As demonstrated above with phenylB(pin) **1.94**, treating **1.106** with Grignard reagent **1.108** without an additive led to poor conversion to the "ate" complex (Figure 1.3b). Unfortunately, the presence of two equivalents of sodium triflate gave only about 50% conversion in THF after one hour (Figure 1.3c), and after 24 hours, the "ate" complex had reverted to **1.106** (Figure 1.3d), indicating that alkyl boron "ate" complexes derived from Grignard reagents are unstable in THF. We found that a 1:1 THF:DMSO solvent mixture allowed for high conversion to **1.107**, which was stable to decomposition after 24 hours at 40 °C (Figure 1.3e).

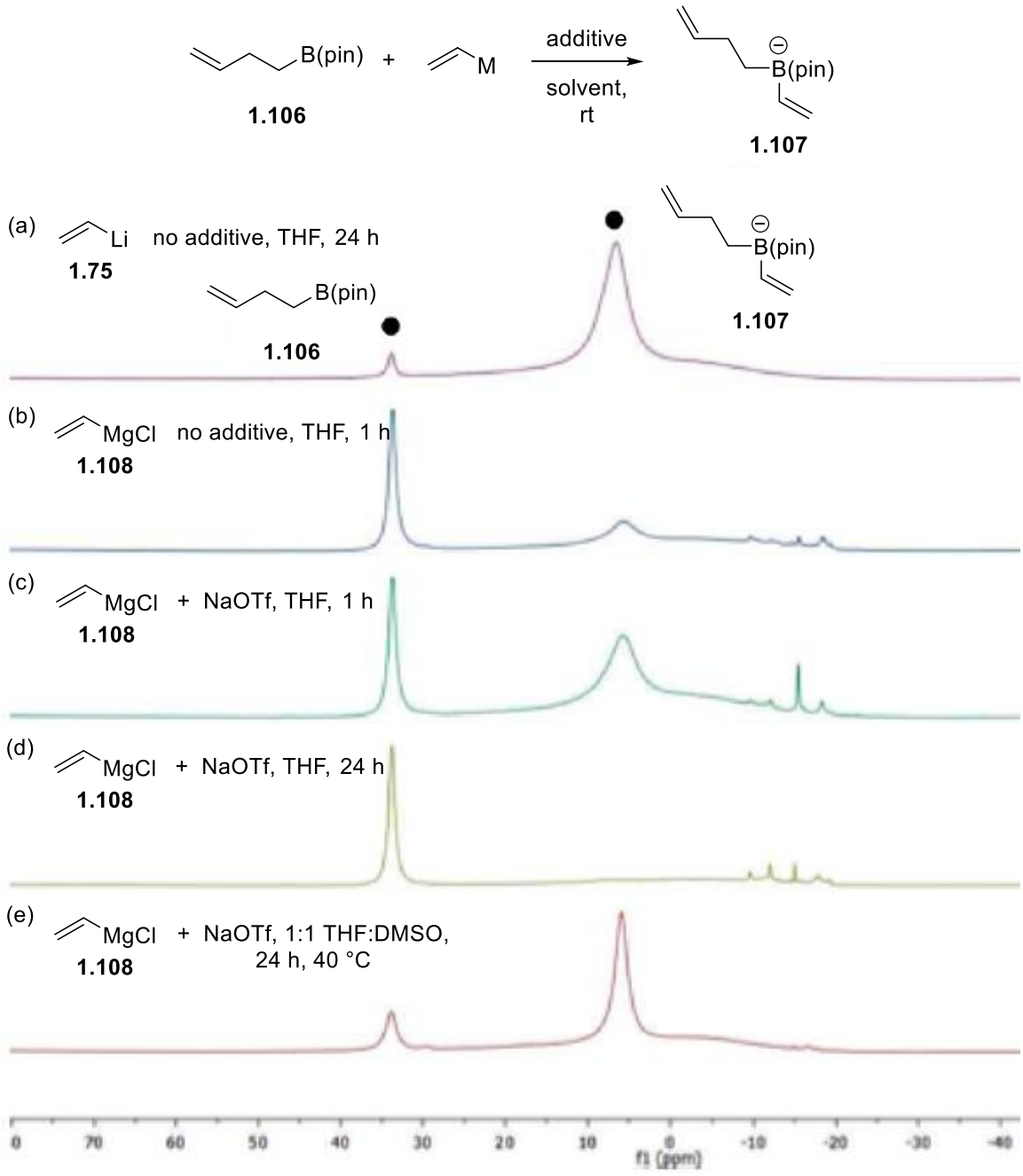
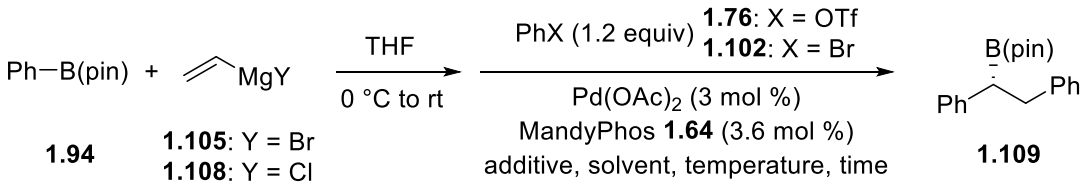


Figure 1.3. ^{11}B NMR studies of the effect of additives on the formation of alkyl boron "ate" complexes. ^{11}B NMR spectra of the conversion of 3-butenylB(pin) **1.106** to "ate" complex **1.107** (a) with vinyllithium **1.75** in THF for 24 hours without additive; (b) with vinylmagnesium chloride **1.108** in THF for one hour without additive; (c) with vinylmagnesium chloride **1.108** in THF for one hour with two equivalents of sodium triflate; (d) with vinylmagnesium chloride **1.108** in THF for 24 hours with two equivalents of sodium triflate; and (e) with vinylmagnesium chloride **1.108** in 1:1 THF:DMSO for 24 hours at 40 °C with two equivalents of sodium triflate.

With these data in hand, we commenced on the optimization studies shown in Table 1.3. Sodium triflate was found to be the optimal additive in the halide-tolerant conjunctive cross-coupling reaction with phenyltriflate **1.76**, which was superior to both lithium and potassium triflate. We attribute this to the tight sodium halide ion pairs that are formed in solution, sequestering halide impurities which would otherwise inhibit catalysis; solubility studies of various salts in THF and THF:DMSO support this hypothesis.[31] Furthermore, we found that using vinylmagnesium chloride **1.108** and a 1:1 mixture of THF:DMSO as

Table 1.3. Optimization of the halide-tolerant conjunctive cross-coupling reaction



1.94 **1.105**: Y = Br **1.108**: Y = Cl **1.109**

entry	additive	Y	X	solvent	temperature	time	yield (%)[a]	e.r.[b]
1	none	Br	OTf	THF	60 °C	14 h	0	N.D.
2	LiCl (1 equiv)	Br	OTf	THF	60 °C	14 h	0	N.D.
3	LiOTf (1 equiv)	Br	OTf	THF	60 °C	14 h	0	N.D.
4	KOTf (1 equiv)	Br	OTf	THF	40 °C	14 h	10	94:6
5	KOTf (2 equiv)	Br	OTf	THF	40 °C	14 h	64	92:8
6	NaOTf (2 equiv)	Br	OTf	THF	40 °C	14 h	58	94:6
7	NaOTf (1 equiv)	Cl	OTf	THF:DMSO 1:1	40 °C	24 h	45	97:3
8	NaOTf (2 equiv)	Cl	OTf	THF:DMSO 1:1	40 °C	24 h	81	96:4
9	none	Cl	OTf	THF:DMSO 1:1	40 °C	24 h	<5	N.D.
10	NaOTf (2 equiv)	Cl	Br	THF	40 °C	14 h	4	94:6
11	NaOTf (2 equiv)	Cl	Br	THF	60 °C	14 h	8	94:6
12	NaOTf (3 equiv)	Cl	Br	THF	60 °C	14 h	30	92:8
13	NaOTf (3 equiv)	Cl	Br	THF:DMSO 1:1	60 °C	24 h	84	97:3
14	NaOTf (3 equiv)	Cl	Br	DMSO	40 °C	14 h	80	94:6

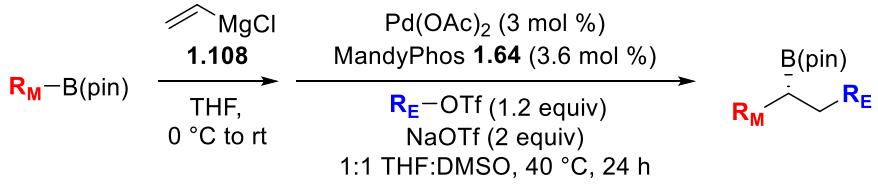
[a]Yields represent isolated yields. [b]Determined by chiral SFC chromatography.

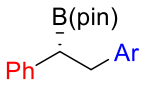
[31] Lovinger, G. J.; Aparece, M. D.; Morken, J. P. *J. Am. Chem. Soc.* **2017**, *139*, 3153.

the solvent system gave optimal yields and enantioselectivities, although reaction times of 24 hours were required for full conversion, as DMSO retards the rate of conjunctive cross-coupling (entry 8). Gratifyingly, we found that we were able to employ bromobenzene **1.102** as the electrophile with the modification that the reaction requires a third equivalent of sodium triflate to sequester bromide ion and a temperature of 60 °C for full conversion (entry 13).

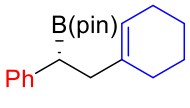
With the optimized conditions in Table 1.3, entry 8, we examined the scope of the conjunctive cross-coupling reaction using vinylmagnesium chloride **1.108** and organotriflates (Scheme 1.19). Several of sp^2-hybridized organotriflate electrophiles were successfully coupled (**1.109**–**1.116**, **1.134**, **1.137**, and **1.138**). We also expanded the scope of aryl migrating groups to encompass boronic esters bearing various electron-donating (**1.117**–**1.119**) groups, electron-withdrawing groups (**1.120**, **1.123**, **1.124**, and **1.133**), and heterocycles (**1.121** and **1.122**). The scope of aliphatic migrating groups was also expanded to include monosubstituted alkenes (**1.126**), silyl ethers (**1.128**), Boc-protected piperidines (**1.129**), amides (**1.130**), esters (**1.131** and **1.138**), primary bromides (**1.132**), and acetals (**1.136**). We were surprised to find that a boronic ester bearing an unprotected alcohol (**1.135**) was able to participate in the reaction, so long as an additional equivalent of vinylmagnesium chloride was used to deprotonate the alcohol prior to formation of the "ate" complex. As in the first-generation conjunctive cross-coupling reaction, we also demonstrated that boron "ate" complexes generated from organomagnesium chlorides and vinylB(pin) **1.139** gave virtually identical results as those generated in Scheme 1.19 (Scheme 1.20).

Scheme 1.19. Enantioselective Pd-catalyzed halide-tolerant conjunctive cross-coupling with vinylmagnesium chloride and organotriflates[a]

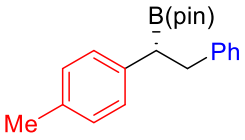




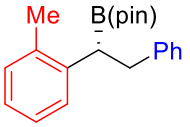
1.109, Ar = Ph: 81% yield, 96:4 er
1.110, Ar = *p*-MeOPh: 90% yield, 98:2 er
1.111, Ar = *p*-CF_3Ph: 85% yield, 95:5 er
1.112, Ar = 2,4-diMePh: 79% yield, 88:12 er[c]
1.113, Ar = *p*-ClPh: 74% yield, 96:4 er
1.114, Ar = *p*-CHOPh: 67% yield, 93:7 er
1.115, Ar = 3-pyridyl: 50% yield, 94:6 er



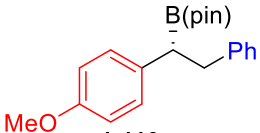
1.116
76% yield, 96:4 er



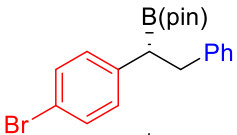
1.117
76% yield, 97:3 er



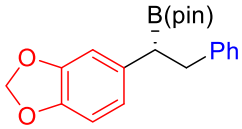
1.118
86% yield, 94:6 er



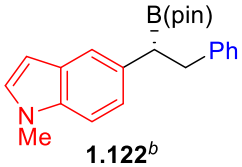
1.119
80% yield, 96:4 er



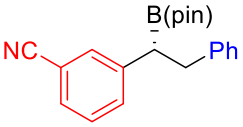
1.120[b]
86% yield, 97:3 er



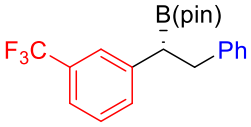
1.121
84% yield, 98:2 er



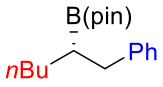
1.122[b]
50% yield, 92:8 er



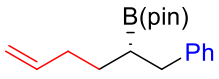
1.123[c]
70% yield, 97:3 er



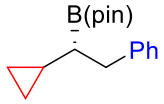
1.124[c]
58% yield, 95:5 er



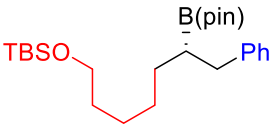
1.125[b]
58% yield, 90:10 er



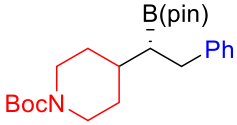
1.126
72% yield, 91:9 er



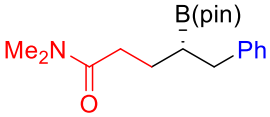
1.127
76% yield, 96:4 er



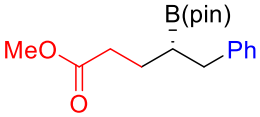
1.128[b]
83% yield, 92:8 er



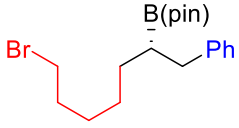
1.129
46% yield, 84:16 er



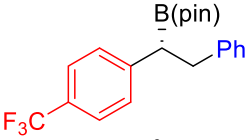
1.130
64% yield, 97:3 er



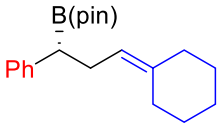
1.131
81% yield, 96:4 er



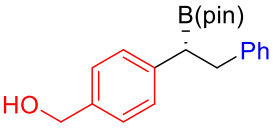
1.132
67% yield, 89:11 er



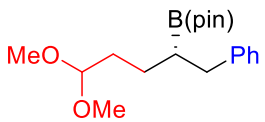
1.133[c]
69% yield, 96:4 er



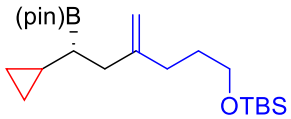
1.134[b]
38% yield, 87:13 er



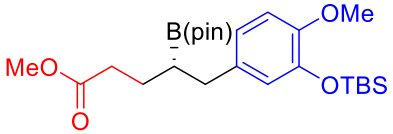
1.135[d]
74% yield, 90:10 er



1.136[b]
69% yield, 91:9 er



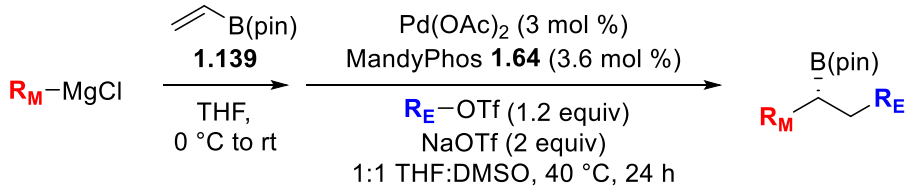
1.137
56% yield, 98:2 er

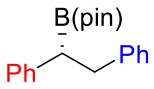


1.138
69% yield, 96:4 er

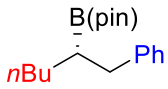
[a]Reactions conducted at 0.17 *M*. Yields and enantioselectivities represent isolated yields and are the average of two trials. [b]Product isolated as the derived alcohol. [c]Reaction conducted at 60 °C. [d]Solvent = THF and 2 equivalents of vinylmagnesium chloride were used.

Scheme 1.20. Enantioselective Pd-catalyzed halide-tolerant conjunctive cross-coupling with organomagnesium chlorides and vinylB(pin)[a]

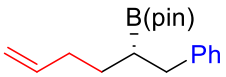




1.109
81% yield, 96:4 er



1.125[b]
43% yield, 85:15 er

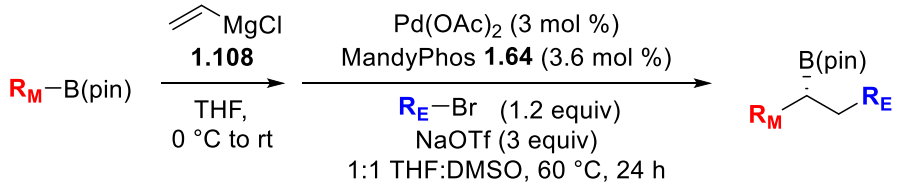


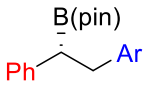
1.126
71% yield, 90:10 er

[a]Reactions conducted at 0.17 *M*. Yields and enantioselectivities represent isolated yields and are the average of two trials. [b]Product isolated as the derived alcohol.

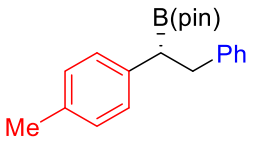
With the optimized conditions in Table 1.3, entry 13, we examined the scope of the conjunctive cross-coupling reaction using vinylmagnesium chloride **1.108** and aryl bromides (Scheme 1.21). Aryl bromides gave similar results as their corresponding triflate counterparts from Scheme 1.19 (**1.109**–**1.111**, **1.113**–**1.115**), as did coupling arylboronates to bromobenzene instead of phenyltriflate (**1.117**, **1.118**, and **1.121**). As mentioned earlier, aryl halides are available in greater variety compared to aryl triflates. Capitalizing on this diversity, we were able to synthesize a wider array of conjunctive cross-coupling products from numerous aryl bromides compared to the first-generation reaction. The scope of electrophiles encompasses nitro groups (**1.140**), ketones (**1.141**, **1.145**, and **1.148**), furans (**1.142** and **1.144**), benzofurans (**1.143**), thiophenes (**1.145** and **1.148**), benzothiazoles (**1.146** and **1.151**), indoles (**1.147**), quinolines (**1.149**), and pyrimidines (**1.150**).

Scheme 1.21. Enantioselective Pd-catalyzed halide-tolerant conjunctive cross-coupling with vinylmagnesium chloride and organobromide[a]

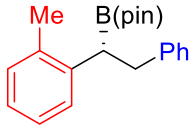




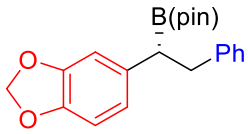
1.109, Ar = Ph: 84% yield, 97:3 er
1.110, Ar = *p*-MeOPh: 92% yield, 95:5 er
1.111, Ar = *p*-CF_3Ph: 76% yield, 93:7 er
1.113, Ar = *p*-ClPh: 53% yield, 94:6 er
1.114, Ar = *p*-CHOPh: 58% yield, 91:9 er
1.115, Ar = 3-pyridyl: 48% yield, 94:6 er



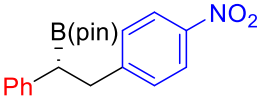
1.117
75% yield, 95:5 er



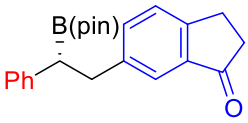
1.118
69% yield, 91:9 er



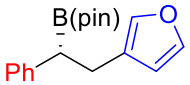
1.121
76% yield, 95:5 er



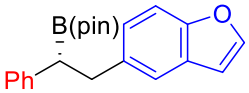
1.140
53% yield, 85:15 er



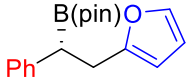
1.141
70% yield, 95:5 er



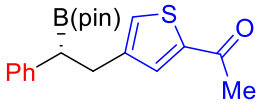
1.142
65% yield, 95:5 er



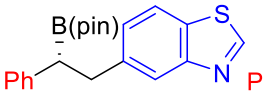
1.143
75% yield, 96:4 er



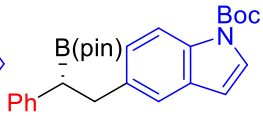
1.144
73% yield, 96:4 er



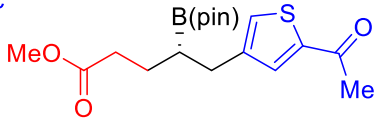
1.145
77% yield, 94:6 er



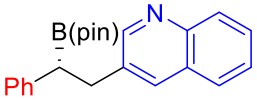
1.146
64% yield, 95:5 er



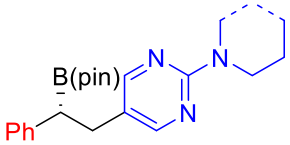
1.147
74% yield, 96:4 er



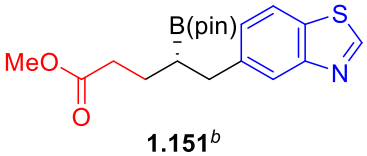
1.148
65% yield, 92:8 er



1.149
77% yield, 93:7 er



1.150
70% yield, 96:4 er



1.151[b]
73% yield, 98:2 er

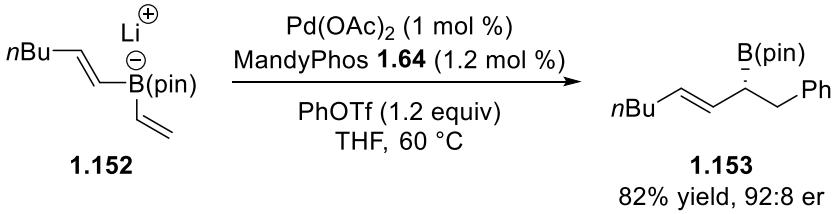
[a]Reactions conducted at 0.17 *M*. Yields and enantioselectivities represent isolated yields and are the average of two trials. [b]Reaction conducted at 55 °C.

1.4. Further Developments in the Conjunctive Cross-Coupling Reaction

Following this report,[31] the Morken group has fostered a fruitful research program centered on metal-induced 1,2-metallate shifts of organoboron compounds. Pd-catalyzed

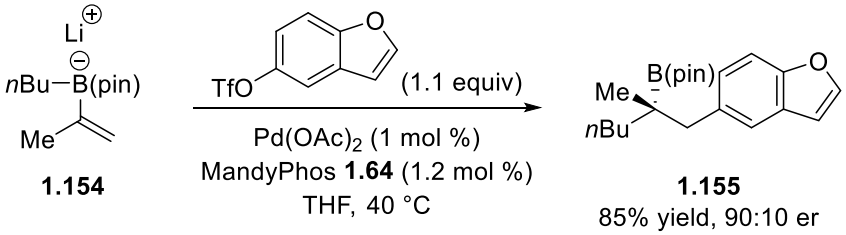
Scheme 1.22. Further developments in Pd-catalyzed conjunctive cross-coupling reactions

(a) Enantioselective conjunctive cross-coupling of alkenyl boronates[32]



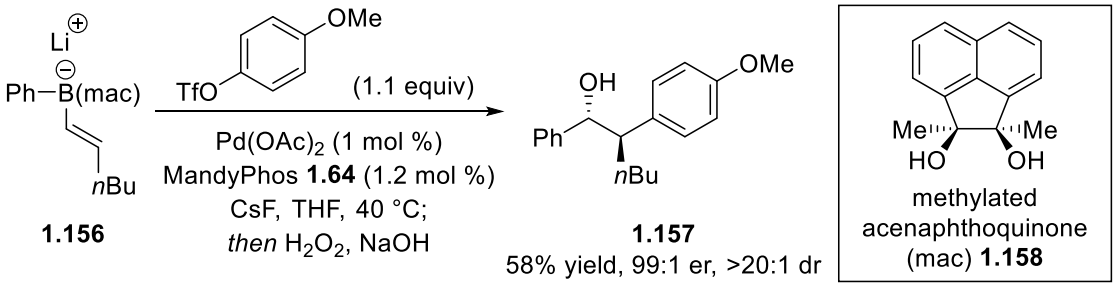
1.152 → **1.153**, 82% yield, 92:8 er

(b) Enantioselective conjunctive cross-coupling of α-substituted migration termini[33]



1.154 → **1.155**, 85% yield, 90:10 er

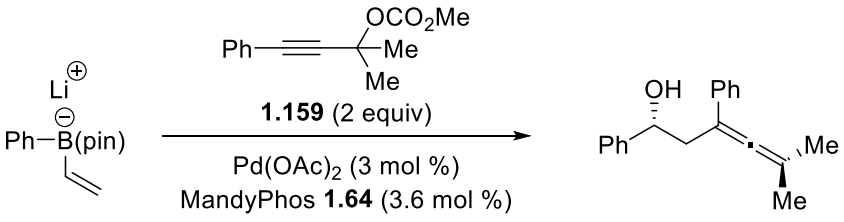
(c) Diastereoselective and enantioselective conjunctive cross-coupling of β-substituted migration termini[34]



1.156 → **1.157**, 58% yield, 99:1 er, >20:1 dr

methylated acenaphthoquinone (mac) **1.158**

(d) Enantioselective conjunctive cross-coupling of propargyl carbonates[35]



1.104 → **1.160**, 82% yield, 96:4 er

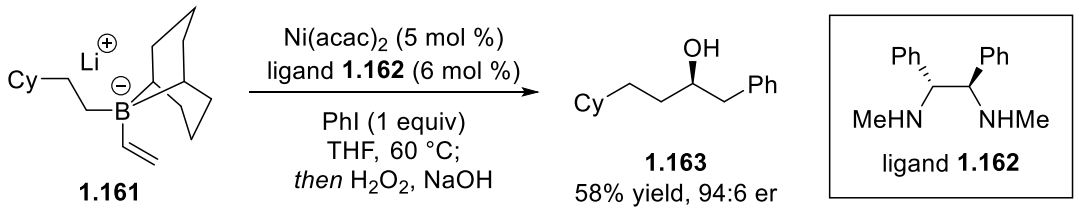
conjunctive cross-coupling reactions bisalkenyl boron "ate" complexes such as **1.152** to synthesize allylic boronates (**1.153**) have been reported (Scheme 1.22a),[32] as well as reactions with migration termini bearing substituents at the α position (**1.154**) to synthesize enantioenriched tertiary boronic esters (**1.155**) (Scheme 1.22b).[33] A novel methylated acenaphthoquinone (mac) boron ligand **1.158** was developed for Pd-catalyzed conjunctive cross-coupling reactions with β susbtituted migration termini (**1.156**) to access enantioenriched organoboronates bearing contiguous stereocenters with high levels diastereoselectivity (**1.157**) (Scheme 1.22c).[34] Propargylic carbonate electrophiles such as **1.159** have been shown to give enantioenriched β-boryl allenes (**1.160**); methanol additive has been shown to enhance both yields and enantioselectivities (Scheme 1.22d).[35]

Ni-catalyzed conjunctive cross-coupling reactions have also been developed, the earliest of which involves the coupling of 9-BBN boron "ate" derivatives (**1.161**) and aryl iodides in the presence of a chiral 1,2-diamine ligand **1.162** to give enantioenriched secondary alcohols (**1.163**) following oxidation (Scheme 1.23a).[36] Later, a radical–ionic mechanistic dichotomy was discovered depending on the type of sp^3-hybridized electrophile used: with primary aliphatic iodides such as **1.164** in the presence of a chiral PyBox ligand **1.165**, the reaction proceeds through a polar mechanism similar to that of the first-generation conjunctive cross coupling to give enantioenriched boronic esters (**1.166**), whereas with α-halocarbonyls such as **1.167** or perfluorinated alkyl iodides, the reaction proceeds through a radical-polar crossover mechanism similar to other reactions in

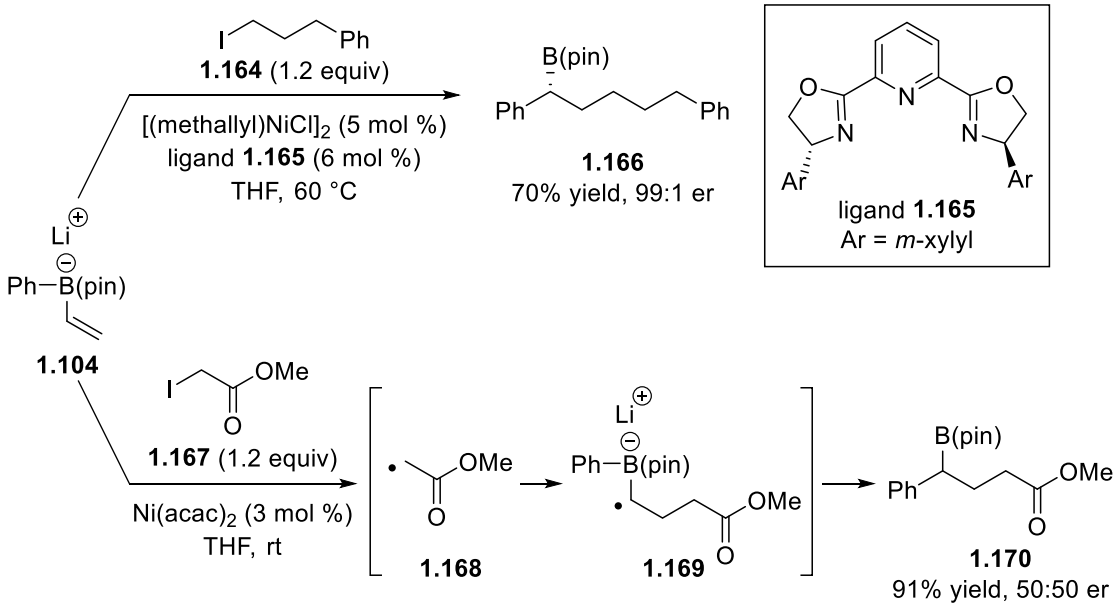
[32] Edelstein, E. K.; Namirembe, S.; Morken, J. P. *J. Am. Chem. Soc.* **2017**, *139*, 5027.
[33] Myhill, J. A.; Zhang, L.; Lovinger, G. J.; Morken, J. P. *Angew. Chem. Int. Ed.* **2018**, *57*, 12799.
[34] Myhill, J. A.; Wilhelmsen, C. A.; Zhang, L.; Morken, J. P. *J. Am. Chem. Soc.* **2018**, *140*, 15181.
[35] Aparece, M. D.; Hu, W.; Morken, J. P. *ACS Catal.* **2019**, *9*, 11381.
[36] Chierchia, M.; Law, C.; Morken, J. P. *Angew. Chem. Int. Ed.* **2017**, *56*, 11870.

Scheme 1.23. Developments in Ni-catalyzed conjunctive cross-coupling reactions

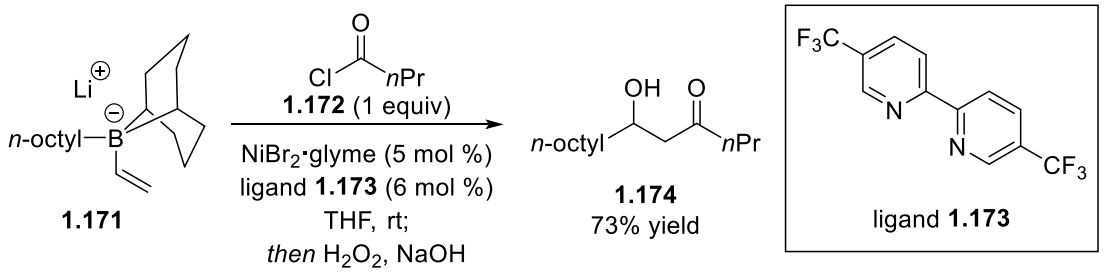
(a) Enantioselective conjunctive cross-coupling of 9-BBN derivatives and aryl iodides[36]



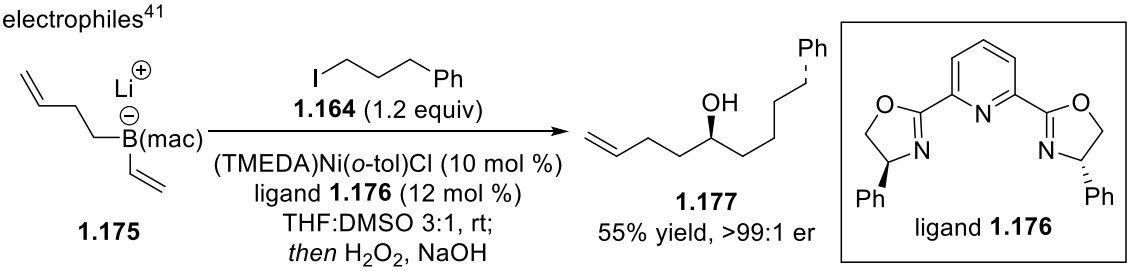
(b) Conjunctive cross-coupling of sp^3-hybridized electrophiles: a radical-ionic mechanistic dichotomy[39]



(c) Conjunctive cross-coupling of 9-BBN derivatives and acyl electrophiles[40]



(d) Enantioselective conjunctive cross-coupling of aliphatic B(mac) derivatives and aliphatic electrophiles[41]



contemporaneous reports by Studer[37] and Aggarwal[38] in which a stabilized *sp*^{3}-hybridized radical (**1.168**) is formed, which undergoes radical addition onto the boron "ate" complex to give an α-boryl radical (**1.169**); oxidation of this species to an α-boryl carbocation triggers the 1,2-metallate shift to give racemic boronic esters (**1.170**) (Scheme 1.23b).[39]

9-BBN boron "ate" derivatives were also shown to undergo Ni-catalyzed conjunctive cross-coupling with acyl electrophiles such as **1.172** in the presence of a bipyridine ligand **1.173** to give β-hydroxycarbonyls **1.174** (Scheme 1.23c).[40] Most recently, alkyl B(mac) "ate" complexes such as **1.175** were shown to react with primary alkyl iodides in the presence of chiral PyBox ligand **1.176** to give conjunctive cross-coupling products (**1.177**) with excellent levels of enantioselectivity (Scheme 1.23d).[41]

In conclusion, we have developed a halide-tolerant conjunctive cross-coupling reaction that employs commercially available vinyl Grignard reagents as opposed to halide-free vinyllithium that was synthesized in-house for the first-generation conjunctive cross-coupling reaction. Two equivalents of sodium triflate additive were required to not only enhance the nucleophilicity of Grignard reagents to form boron "ate" complexes but also to sequester halide ions that would bind to palladium and arrest catalysis. Aryl bromides could also be used as electrophiles, provided an additional equivalent of sodium triflate is used, thus expanding the diversity of products that can be formed. DMSO was added as a co-solvent to stabilize alkyl boron "ate" complexes derived from Grignard reagents, which would otherwise decompose in THF alone.

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[37] Kischkewitz, M.; Okamoto, K.; Mück-Lichtenfeld, C.; Studer, A. *Science* **2017**, *355*, 936.
[38] Silvi, M.; Sandford, C.; Aggarwal, V. K. *J. Am. Chem. Soc.* **2017**, *139*, 5736.
[39] Lovinger, G. J.; Morken, J. P. *J. Am. Chem. Soc.* **2017**, *139*, 17293.
[40] Law, C.; Meng, Y.; Koo, S. M.; Morken, J. P. *Angew. Chem.* **2019**, *131*, 6726.
[41] Koo, S. M.; Vendola, A. J.; Momm, S. N.; Morken, J. P. *Org. Lett.* **2020**, *22*, 666.

1.5. Experimental

1.5.1. General Information

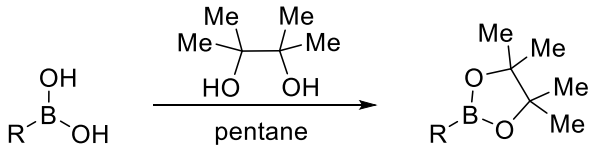
^{1}H NMR spectra were recorded on either a Varian Gemini-500 (500 MHz), Varian Gemini-600 (600 MHz), or Varian Inova-500 (500 MHz) spectrometer. Chemical shifts are reported in ppm with the solvent resonance as the internal standard ($CDCl_3$: 7.24 ppm). Data are reported as follows: chemical shift, integration, multiplicity (s = singlet, d = doublet, t = triplet, q = quartet, p = pentet, m = multiplet, app = apparent), and coupling constants (Hz). ^{13}C NMR spectra were recorded on either a Varian Gemini-500 (125 MHz), Varian Gemini-600 (150 MHz) or a Varian Inova-500 (125 MHz) spectrometer with complete proton decoupling. Chemical shifts are reported in ppm with the solvent resonance as the internal standard ($CDCl_3$: 77.24 ppm). Chemical shifts are reported in ppm using phosphoric acid as the external standard (H_3PO_4: 0.0 ppm). ^{11}B NMR spectra were recorded on a Varian Gemini-500 (128 MHz) spectrometer. Chemical shifts are reported in ppm using boron trifluoride diethyl etherate as the external standard ($BF{\cdot}OEt_2$: 0.0 ppm). ^{19}F NMR spectra were recorded on a Varian Gemini-500 (470 MHz) spectrometer. Infrared (IR) spectra were recorded on a Bruker alpha-P Spectrometer. Frequencies are reported in wavenumbers (cm^{-1}) as follows: strong (s), broad (br), medium (m), and weak (w). Optical rotations were measured on a Rudolph Analytical Research Autopol IV Polarimeter and the values reported are averages of seven measurements. High-resolution mass spectrometry (DART) was performed at the Mass Spectrometry Facility, Boston College, Chestnut Hill, MA. Liquid chromatography was performed using forced flow (flash chromatography) on silica gel (SiO_2, 230 x 450 Mesh, purchased from Silicycle) either manually or using an automated column (Biotage). Thin

layer chromatography (TLC) was performed on 25 μm silica gel aluminum backed plates from Silicycle. Visualization was performed using ultraviolet light (254 nm), ceric ammonium molybdate (CAM) in ethanol or phosphomolybdic acid, and cerium(IV) sulfate in ethanol with sulfuric acid (Seebach).

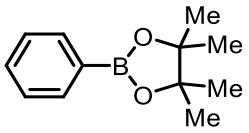
Analytical supercritical fluid chromatography (SFC) was performed on a TharSFC Method Station II equipped with Waters 2998 Photodiode Array Detector with isopropanol or methanol as the modifier.

Tetrahydrofuran (THF), diethyl ether (Et_2O), dichloromethane (DCM) and toluene were purified using Pure Solv MD-4 solvent purification system, from Innovative Technology, Inc., by passing the solvent through two activated alumina columns after purging with argon. Palladium (II) acetate, (S_p,S_p)-**3.3**, 1,1′-Bis(dicyclohexyl-phosphino)ferrocene, and 1,1′-Bis(diisopropylphosphino)ferrocene were purchased from Strem Chemicals, Inc. and used without further purification. Pinacol was purchased from Aldrich. All pinacol esters were purchased from Combi Blocks, Oakwood Chemicals, or Frontier Scientific and used without further purification. All arylbromides were purchased from Combi Blocks, Oakwood Chemicals, or Frontier Scientific and used without further purification. Phenyl trifluoromethanesulfonate, 4-methoxyphenyltrifluoro methane-sulfonate, and trifluoromethane-sulfonic anhydride were purchased from Oakwood Chemicals and used without further purification. All other reagents were purchased from either Aldrich, Alfa Aesar or Acros and used without further purification.

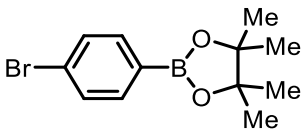
1.5.2. General Procedure for the Preparation of Boronate Esters



To an oven-dried round bottom flask with magnetic stir bar was added boronic acid (1.0 equiv) and pentane. The suspension was allowed to cool to 0 °C and 2,3-dimethylbutane-2,3-diol (pinacol) (1.05 equiv) was added neat and the solution was allowed to warm to room temperature and stir for 3 h. If a water layer was observed it was removed and the resulting pentane solution was dried with with Na_2SO_4, filtered with diethyl ether, and the solvent was removed *in vacuo*. The resulting residue was purified on silica gel (plug with CH_2Cl_2 as the eluent).



5,5-dimethyl-2-phenyl-1,3,2-dioxaborinane (1.94). Prepared according to the general procedure above with phenylboronic acid (0.268 g, 22.0 mmol, 1.0 equiv), pinacol (2.41 g, 23.1 mmol, 1.05 equiv), and pentane (60 mL). The resulting white solid (4.18 g, quantitative yield) was used without further purification. All spectroscopic data were in accord with the literature.[42]

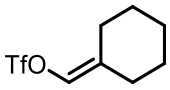


2-(4-bromophenyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (1.178). Prepared according to the general procedure above with 4-bromophenylboronic acid (1.00 g, 5.0 mmol, 1.0), pinacol (0.620 g, 5.25 mmol, 1.05),

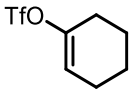
[42] Clary, J. W.; Rettenmaier, T. J.; Snelling, R.; Bryks, W.; Banwell, J.; Wipke, W. T.; Singaram, B. *J. Org. Chem.* **2011**, 76, 9602.

and pentane (15 mL). The resulting white solid (1.19 g, 84% yield) was used without further purification. All spectroscopic data were in accord with the literature.[43]

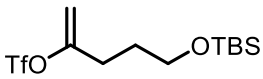
1.5.3. Procedures for Preparation of Alkenyl Trifluoromethanesulfonates



cyclohexylidenemethyl trifluoromethanesulfonate (1.179). The title compound was prepared according to the procedure reported in the literature.[44] All spectroscopic data were in accord with the literature.[45]



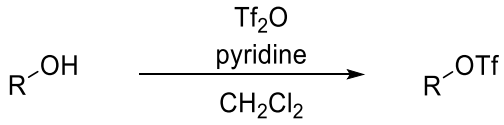
cyclohex-1-en-1-yl trifluoromethanesulfonate (1.180). The title compound was prepared according to the procedure reported in the literature.[89] All spectroscopic data were in accord with the literature.[45]



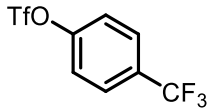
5-((*tert*-butyldimethylsilyl)oxy) pent-1-en-2-yl trifluoro-methanesulfonate (1.181). The title compound was prepared according to the procedure reported in the literature.[20] All spectroscopic data were in accord with the literature.

[43] Zhu, W.; Ma, D. *Org. Lett.* **2006**, 8, 261.
[44] Stang, P. J.; Treptow, W. *Synthesis* **1980**, 4, 283.
[45] Al-huniti, M. H.; Lepore, S. D. *Org. Lett*. **2014**, 16, 4154.

1.5.4. General Procedure for the Synthesis of Aryl Trifluoromethanesulfonates

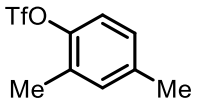


Aryl trifluoromethanesulfonates were made according to literature procedure with slight modification.[46] To a solution of the corresponding phenol and pyridine in CH_2Cl_2 at 0 °C, a solution of trifluoromethanesulfonic anhydride in CH_2Cl_2 was added dropwise. The mixture was then allowed to warm to room temperature and stir for 1 h. The mixture was diluted with Et_2O, quenched with a 3 M solution of aquious HCl and washed successively with a saturated solution of aqueous $NaHCO_3$ and brine. The solution was dried over Na_2SO_4, filtered with Et_2O, and the solvent was removed *in vacuo*. The residue was purified by silica gel chromatography to afford aryl trifluoromethanesulfones.

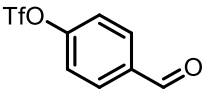


4-(trifluoromethyl)phenyl trifluoromethanesulfonate (1.182). Prepared according to the general procedure above with 4-trifluoromethylphenol (0.630 g, 3.8 mmol, 1.0 equiv), trifluoromethanesulfonic anyhydride (0.774 mL, 4.6 mmol, 1.21 equiv), pyridine (0.615 mL, 7.6 mmol, 2.0 equiv), and CH_2Cl_2 (6.0 mL). The unpurified residue was purified by silica gel chromatography (10% ethyl acetate/Hexanes) to afford the product as colorless oil (1.180 g, 98% yield). All spectroscopic data were in accord with the literature.[47]

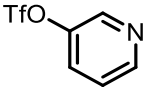
[46] Goosen, L. J.; Linder, C.; Rodríguez, N.; Lange, P. P. *Chem. Eur. J.* **2009**, 15, 9336.
[47] Gill, D.; Hester, A. J.; Lloyd-Jones, G. C. *Org. Biomol. Chem.* **2004**, 4, 2547.



2,4-dimethylphenyl trifluoromethanesulfonate (1.183). Prepared according to the general procedure above with 2,4-dimethylphenol (0.906 mL, 7.5 mmol, 1.0 equiv), trifluoromethanesulfonic anhydride (1.50 mL, 9.0 mmol, 1,2 equiv), pyridine (1.2 mL, 15.0 mmol, 2.0 equiv), and CH_2Cl_2 (13.0 mL). The unpurified residue was purified by silica gel chromatography (5% ethyl acetate/Hexanes) to afford the product as colorless oil (1.680 g, 88% yield). All spectroscopic data were in accord with the literature.[48]



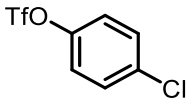
4-formylphenyl trifluoromethanesulfonate (1.184). Prepared according to the general procedure above with 4-hydroxybenzaldehyde (0.488 g, 4.0 mmol, 1.0 equiv), trifluoromethanesulfonic anhydride (0.81 mL, 4.8 mmol, 1.2 equiv), pyridine (0.65 mL, 8.0 mmol, 2.0 equiv), and CH_2Cl_2 (7.0 mL). Following quenching, extraction, drying, and concentrating *in vacuo*, the unprurified residue was passed through a Celite pad, which was washed with copious amounts of CH_2Cl_2, to afford the product as colorless oil (0.60 g, 60% yield); the product decomposes upon exposure to silica gel. All spectroscopic data were in accord with the literature.[49]



pyridin-3-yl trifluoromethanesulfonate (1.185). Prepared according to the general procedure above with 3-hydroxypyridine (0.380 g, 4.0 mmol, 1.0 equiv), trifluoromethanesulfonic anhydride (0.81 mL, 4.8 mmol, 1.2 equiv), pyridine (0.65 mL, 8.0 mmol, 1.2 equiv), and CH_2Cl_2 (20.0 mL). The reaction was quenched with water (20 mL) instead of HCl. Following quenching, extraction, drying, and concentrating *in*

[48] Radivoy, G.; Alonso, F.; Yus, M. *Tetrahedron* **1999**, 55, 14479.
[49] Echavarren, A. M.; Stille, J. K. *J. Am. Chem. Soc.* **1987**, 109, 5478.

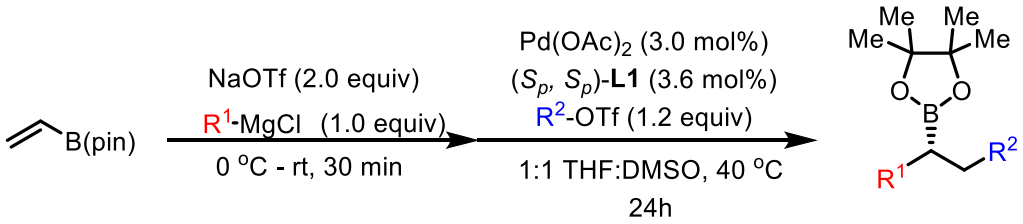
vacuo, the unpurified residue was purified by silica gel chromatography (30% ethylacetate/Hexanes) to afford the product as yellow oil (0.69 g, 76% yield). All spectroscopic data were in accord with the literature.[49]



4-chlorophenyl trifluoromethanesulfonate (1.186). Prepared according to the general procedure above with 4-chlorophenol (0.514 g, 4.0 mmol, 1.0 equiv), trifluoromethanesulfonic anhydride (0.81 mL, 4.8 mmol, 1.2 equiv), pyridine (0.65 mL, 8.0 mmol, 2.0 equiv), and CH_2Cl_2 (7.0 mL). The unpurified residue was purified by silica gel chromatography (30% ethyl acetate/Hexanes) to afford the product as colorless oil (0.877 g, 84% yield). All spectroscopic data were in accord with the literature.[50]

1.5.5. General Procedures for Conjunctive Cross-Coupling

1.5.5.1. Method A

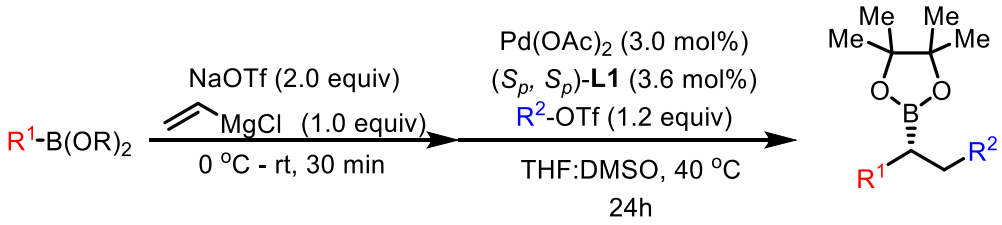


In a glovebox under argon an oven-dried 2-dram vial equipped with a magnetic stir bar was charged with 4,4,5,5-tetramethyl-2-vinyl-1,3,2-dioxaborolane (0.30 mmol, 1.00 equiv), sodium trifluoromethanesulfonate (0.60 mmol, 2.00 equiv), and tetrahydrofuran (0.5 mL), sealed with a septum cap, and removed from the glovebox. Under positive nitrogen pressure the vial was allowed to cool to 0 ºC, and organomagnesium chloride

[50] Murai, N.; Yonaga, M.; Tanaka, K. *Org. Lett.* **2012**, 14, 1278.

solution in tetrahydrofuran (0.30 mmol, 1.0 equiv) was added dropwise. The vial was allowed to warm to room temperature and stir for 30 min before being brought back into the glovebox. In the glovebox a second oven-dried 2-dram vial equipped with a magnetic stir bar was charged with $Pd(OAc)_2$ (0.90 mL, 0.01 M in dimethyl sulfoxide, 0.009 mmol, 0.03 equiv), and MandyPhos **1.64** (0.0108 mmol, 0.036 equiv). The $Pd(OAc)_2$/MandyPhos **1.64** solution was allowed to stir for 15 min at room temperature. The $Pd(OAc)_2$/MandyPhos **1.64** solution was then transferred into the vial, followed by tetrahydrofuran (0.2 mL) (used to rinse the $Pd(OAc)_2$/MandyPhos **1.64** vial), and aryl/vinyl trifluoromethanesulfonate (0.36 mmol, 1.20 equiv). The vial was sealed with a polypropylene cap, taped, and brought out of the glovebox where it was allowed to stir at 40 ºC for 24 h. To the resulting mixture was added water (10 mL) and the product was extracted from the aqueous layer with ethyl acetate (3 x 20 mL). The combined organic layers were dried over Na_2SO_4, concentrated under reduced pressure, filtered through a silica gel plug with diethyl ether, reconcentrated, and subsequently purified by silica gel chromatography to provide the desired products.

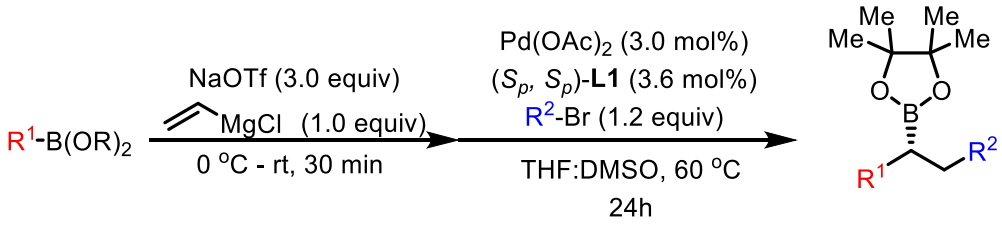
1.5.5.2. Method B



In a glovebox under argon an oven-dried 2-dram l equipped with a magnetic stir bar was charged with boronate (0.30 mmol, 1.00 equiv), sodium trifluoromethanesulfonate (0.60 mmol, 2.00 equiv), and tetrahydrofuran (0.5 mL), sealed with a septum cap, and removed from the glovebox. Under positive nitrogen pressure the vial was allowed to cool

to 0 ºC and vinylmagnesium chloride solution in tetrahydrofuran (0.30 mmol, 1.0 equiv) was added dropwise. The vial was allowed to warm to room temperature and stir for 30 min before being brought back into the glovebox. In the glovebox a second oven-dried 2-dram vial equipped with a magnetic stir bar was charged with $Pd(OAc)_2$ ((0.90 mL, 0.01 M in dimethyl sulfoxide, 0.009 mmol, 0.03 equiv), and MandyPhos **1.64** (0.0108 mmol, 0.036 equiv.). The $Pd(OAc)_2$/MandyPhos **1.64** solution was allowed to stir for 15 min at room temperature. The $Pd(OAc)_2$/MandyPhos **1.64** solution was then transferred into the vial, followed by tetrahydrofuran (0.2 mL) (used to rinse the $Pd(OAc)_2$/MandyPhos **1.64** vial), and aryl/vinyl trifluoromethanesulfonate (0.36 mmol, 1.20 equiv). The vial was sealed with a polypropylene cap, taped, and brought out of the glovebox where it was allowed to stir at 40 ºC for 24 h. To the resulting mixture was added water (10 mL) and the aqueous layer was extracted with ethyl acetate (3 x 20 mL). The combined organic layers were dried over Na_2SO_4, concentrated under reduced pressure, filtered through a silica gel plug with diethyl ether, reconcentrated, and subsequently purified by silica gel chromatography to provide the desired products.

1.5.5.3. Method C



In a glovebox under argon an oven-dried 2-dram vial equipped with a magnetic stir bar was charged with boronate (0.30 mmol, 1.00 equiv), sodium trifluoromethanesulfonate (0.60 mmol, 2.00 equiv), and tetrahydrofuran (0.5 mL), sealed with a septum cap, and removed from the glovebox. Under positive nitrogen pressure the vial was allowed to cool

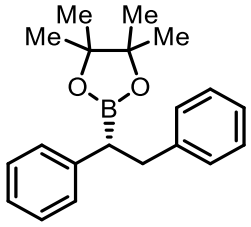
to 0 ºC, and vinylmagnesium chloride solution in tetrahydrofuran (0.30 mmol, 1.0 equiv) was added dropwise. The vial was allowed to warm to room temperature and stir for 30 min before being brought back into the glovebox. In the glovebox a second oven-dried 2-dram vial equipped with a magnetic stir bar was charged with $Pd(OAc)_2$ ((0.90 mL, 0.01 M in dimethyl sulfoxide, 0.009 mmol, 0.03 equiv), and MandyPhos **1.64** (0.0108 mmol, 0.036 equiv). The $Pd(OAc)_2$/MandyPhos **1.64** solution was allowed to stir for 15 min at room temperature. The $Pd(OAc)_2$/MandyPhos **1.64** solution was then transferred into the vial, followed by tetrahydrofuran (0.2 mL) (used to rinse the $Pd(OAc)_2$/MandyPhos **1.64** vial), and arylbromide (0.36 mmol, 1.20 equiv). The vial was sealed with a polypropylene cap, taped, and brought out of the glovebox where it was allowed to stir at 60 ºC for 24 h. To the resulting mixture was added water (10 mL) and the product was extracted from the aqueous layer with ethyl acetate (3 x 20 mL). The combined organic layers were dried over Na_2SO_4, concentrated under reduced pressure, filtered through a silica gel plug with diethyl ether, reconcentrated, and subsequently purified by silica gel chromatography to provide the desired products.

1.5.5.4. General Method for Oxidation of Boronic Ester Products

Note: Where appropriate, boronic ester products were oxidized. In these cases, the procedure used was the same as that described in the corresponding method A/B/C but with the modification that: After the reaction was completed the mixture was filtered through a silica gel plug with diethyl ether, concentrated under reduced pressure, and diluted with tetrahydrofuran (3 mL). The unpurified mixture was allowed to cool to 0 ºC and a 3 M solution of aqueous NaOH (2 mL) was added, followed by 30% H_2O_2 (1.0 mL), dropwise. The mixture was allowed to warm to room temperature, and stir for 3 h.

The mixture was allowed to cool to 0 ºC and a saturated solution of aqueous $Na_2S_2O_3$ (3 mL) was added dropwise. After warming to room temperature the product was extracted from the aqueous layer with ethyl acetate (3 x 20 mL). The combined organic layers were dried over Na_2SO_4, concentrated under reduced pressure, and subsequently purified by silica gel chromatography to provide the desired products.

1.5.6. Characterization of Conjunctive Cross-Coupling Products



(*R*)-2-(1,2-diphenylethyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (1.109). The reaction was performed according to the general procedure (***Method A***) with 4,4,5,5-tetramethyl-2-vinyl-1,3,2-dioxaborolane (46.2 mg, 0.30 mmol, 1.00 equiv), sodium trifluoromethanesulfonate (103.2 mg, 0.60 mmol, 2.00 equiv), phenylmagnesium chloride (0.17 mL, 1.77 M in tetrahydrofuan, 0.30 mmol, 1.00 equiv), phenyl trifluoromethanesulfonate (81.4 mg, 0.36 mmol, 1.20 equiv), palladium (II) acetate (0.9 mL, 0.01 M in dimethyl sulfoxide, 0.009 mmol, 0.030 equiv), MandyPhos (**1.64**, 11.37 mg, 0.0108 mmol). The unpurified product was purified by automated silica gel chromatography (Biotage 1% → 5% ethyl acetate in hexanes, stained in CAM) to afford white solid (74.9 mg, 81% yield).

(***Method B)*** with 4,4,5,5-tetramethyl-2-phenyl-1,3,2-dioxaborolane (**1.94**, 61.2 mg, 0.30 mmol, 1.00 equiv) sodium trifluoromethanesulfonate (103.2 mg, 0.60 mmol, 2.00 equiv), vinylmagnesium chloride (0.20 mL, 1.53 M in tetrahydrofuran, 0.30 mmol, 1.00 equiv), phenyl trifluoromethanesulfonate (81.4 mg, 0.36 mmol, 1.20 equiv), palladium (II) acetate (0.9 mL, 0.01 M in dimethyl sulfoxide, 0.009 mmol, 0.030 equiv), MandyPhos (**1.64**, 11.37

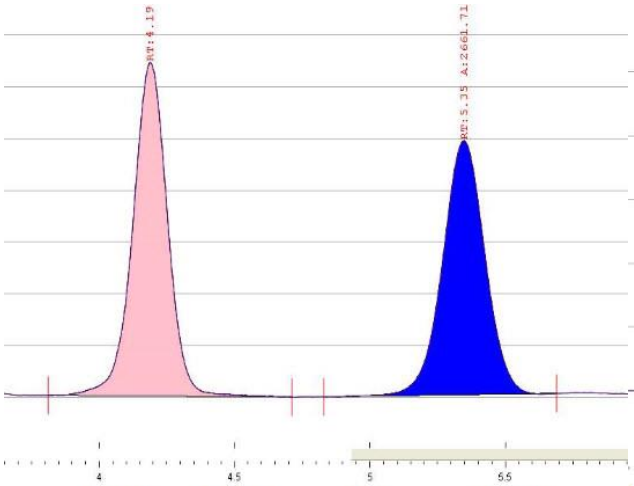
mg, 0.0108 mmol, 0.036 equiv). The unpurified product was purified by automated silica gel chromatography (Biotage 1% → 5% ethyl acetate in hexanes, stained in CAM) to afford white solid (74.9 mg, 81% yield).

(***Method C)*** with 4,4,5,5-tetramethyl-2-phenyl-1,3,2-dioxaborolane (**1.94**, 61.2 mg, 0.30 mmol, 1.00 equiv), sodium trifluoromethanesulfonate (154.9 mg, 0.90 mmol, 3.00 equiv), vinylmagnesium chloride (0.20 mL, 1.53 M in tetrahydrofuran, 0.30 mmol, 1.00 equiv bromobenzene (81.4 mg, 0.36 mmol, 1.20 equiv), palladium (II) acetate (0.9 mL, 0.01 M dimethyl sulfoxide, 0.009 mmol, 0.030 equiv), MandyPhos (**1.64**, 11.37 mg, 0.0108 mmol, 0.036 equiv). The unpurified product was purified by automated silica gel chromatography (Biotage 1% → 5% ethyl acetate in hexanes, stained in CAM) to afford white solid (77.7 mg, 84% yield).

^{1}H NMR (600 MHz, $CDCl_3$) δ 7.31 – 7.17 (m, 10H), 3.21 (dd, *J* = 13.5, 9.8 Hz, 1H), 3.02 (dd, *J* = 13.5, 6.9 Hz, 1H), 2.74 (dd, *J* = 9.8, 6.9 Hz, 1H), 1.17 (s, 6H), 1.16 (s, 6H). **^{11}B NMR** (160 MHz, $CDCl_3$) δ 33.00. ^{13}C NMR (151 MHz, $CDCl_3$) δ 142.78 , 141.95 , 129.09 , 128.61 , 128.53 , 128.23 , 125.95 , 125.59 , 83.60 , 39.07 , 34.64 , 24.80 , 24.72. **IR** (neat) ν_{max} 2977.30 (w), 2929.44 (w), 1493.68 (w), 1452.33 (w), 1361.52 (s), 1325.25 (s), 1140.53 (s), 967.43 (w), 853.72 (w), 761.56 (w), 698.98 (s), 528.85 (w) cm^{-1}. **HRMS** (DART) for $C_{20}H_{26}BO_2$ $[M+H]^+$ calculated: 309.2026, found: 309.2025. $[\alpha]^{20}_D$: -49.358 (*c* 3.69, $CHCl_3$, *l* =50 mm).

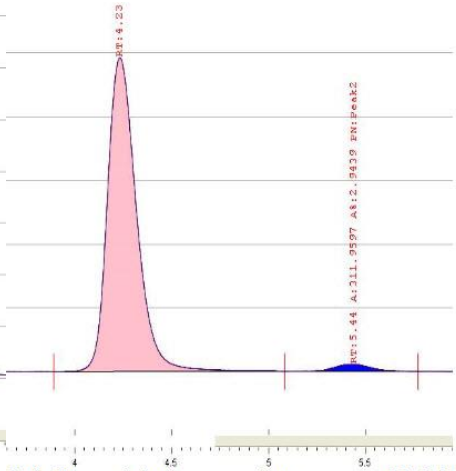
Analysis of Stereochemistry: Racemic compound was prepared according to the general procedure (***Method B, run at 60 ºC***) with $Pd(OAc)_2$ (5 mol%) and 1,1′-bis(dicyclohexylphosphino)ferrocene (6 mol%) as the catalyst. Chiral SFC (Chiracel OJ-H, 1% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of (*R*)-2-(1,2-diphenylethyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane **(1.109)**.

Racemic Material

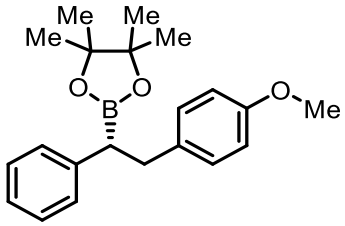


Peak No	% Area	Area	RT (min)
1	51.9205	2874.3543	4.19
2	48.0795	2661.7182	5.35
Total:	100	5536.0725	

Standard Conditions



Peak No	% Area	Area	RT (min)
1	97.0561	10284.9173	4.23
2	2.9439	311.9597	5.44
Total:	100	10596.877	



(*R*)-2-(2-(4-methoxyphenyl)-1-phenylethyl)-4,4,5,5-tetra methyl-1,3,2-dioxaborolane (1.110). The reaction was performed according to the general procedure ***(Method B)*** with 4,4,5,5-tetramethyl-2-phenyl-1,3,2-dioxaborolane (**1.94**, 61.2 mg, 0.30 mmol, 1.00 equiv), sodium trifluoromethanesulfonate (103.2 mg, 0.60 mmol, 2.00 equiv), vinylmagnesium chloride (0.20 mL, 1.53 M in tetrahydrofuran, 0.30 mmol, 1.00 equiv), 4-methoxyphenyl trifluoromethanesulfonate (92.2 mg, 0.36 mmol, 1.20 equiv), palladium (II) acetate (0.90 mL, 0.01 M in dimethyl sulfoxide, 0.009 mmol, 0.030

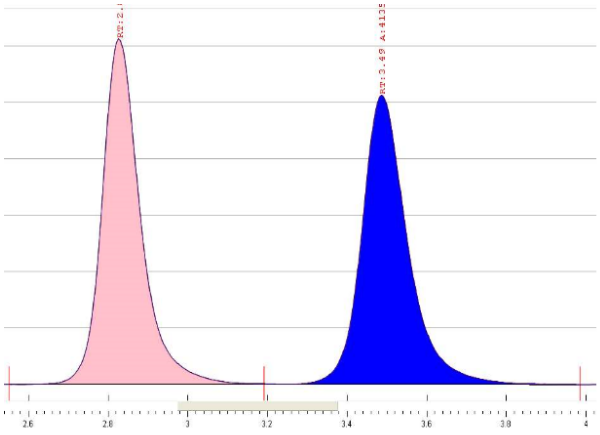
equiv), MandyPhos (**1.64**, 11.37 mg, 0.0108 mmol, 0.036 equiv). The unpurified product was purified by automated silica gel chromatography (Biotage 1% → 5% ethyl acetate in hexanes, stained in CAM) to afford white solid (91.3 mg, 90% yield).

(Method C) with 4,4,5,5-tetramethyl-2-phenyl-1,3,2-dioxaborolane (**1.94**, 61.2 mg, 0.30 mmol, 1.00 equiv), sodium trifluoromethanesulfonate (154.9 mg, 0.90 mmol, 3.00 equiv), vinylmagnesium chloride (0.20 mL, 1.53 M in tetrahydrofuran, 0.30 mmol, 1.00 equiv), 4-bromoanisole (67.3 mg, 0.36 mmol, 1.20 equiv), palladium (II) acetate (0.90 mL, 0.01 M in dimethyl sulfoxide, 0.009 mmol, 0.030 equiv), MandyPhos (**1.64**, 11.37 mg, 0.0108 mmol, 0.036 equiv). The unpurified product was purified by automated silica gel chromatography (Biotage 1% → 5% ethyl acetate in hexanes, stained in CAM) to afford white solid (93.4 mg, 92% yield).

^{1}H NMR (600 MHz, $CDCl_3$) δ 7.26 – 7.20 (m, 4H), 7.14 – 7.10 (m, 1H), 7.08 (d, *J* = 8.6 Hz, 2H), 6.75 (d, *J* = 8.6 Hz, 2H), 3.75 (s, 3H), 3.08 (dd, *J* = 13.6, 9.7 Hz, 1H), 2.89 (dd, *J* = 13.6, 6.9 Hz, 1H), 2.63 (dd, *J* = 9.6, 7.0 Hz, 1H), 1.11 (s, 6H), 1.10 (s, 6H). **^{11}B NMR** (128 MHz, $CDCl_3$) δ 32.97. **^{13}C NMR** (151 MHz, $CDCl_3$) δ 157.92, 142.83, 134.07, 129.95, 128.59, 128.48, 125.52, 113.62, 83.53, 55.38, 38.14, 34.91, 24.78, 24.73. **IR** (neat) ν_{max} 3060.40 (w), 3025.37 (w), 2976.85 (m), 2932.81 (w), 2834.43 (w), 1611.11 (m), 1510.56 (s), 1360.56 (s), 1324.02 (s), 1243.26 (s), 1139.26 (s), 1034.86 (m), 967.45 (m), 829.03 (m), 700.16 (s) cm^{-1}. **HRMS** (DART) for $C_{21}H_{28}BO_3$ $[M+H]^+$: calculated: 339.21315, found: 339.21403. $[\alpha]_D^{20}$ = – 46.292 (*c* 1.73, $CHCl_3$, *l* = 50 mm).

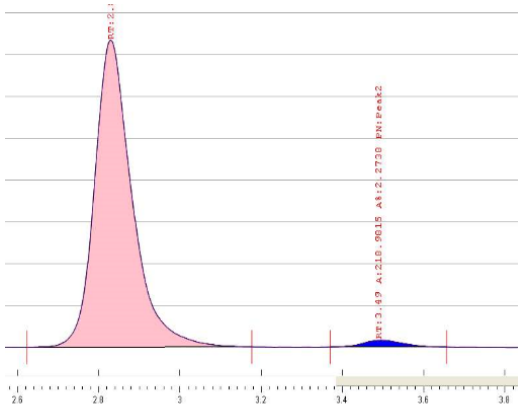
Analysis of Stereochemistry: Racemic compound was prepared according to the general procedure (***Method B, run at 60 ºC***) with $Pd(OAc)_2$ (5 mol%) and 1,1′-bis(dicyclohexylphosphino)ferrocene (6 mol%) as the catalyst. Chiral SFC (Chiracel OJ-H, 5% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of (*R*)-2-(2-(4-methoxyphenyl)-1-phenylethyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane **(1.110)**.

Racemic Material

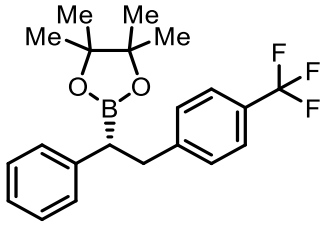


Peak No	% Area	Area	RT (min)
1	49.9893	4134.1383	2.83
2	50.0107	4135.9048	3.49
Total:	100	8270.0431	

Standard Conditions



Peak No	% Area	Area	RT (min)
1	97.7262	9411.7889	2.83
2	2.2738	218.9815	3.49
Total:	100	9630.7704	



(*R*)-4,4,5,5-tetramethyl-2-(1-phenyl-2-(4-(trifluoromethyl) phenyl) ethyl)-1,3,2-dioxaborolane (1.111). The reaction was performed according to the general procedure ***(Method B)*** with 4,4,5,5-tetramethyl-2-phenyl-1,3,2-dioxaborolane (**1.94**, 61.2 mg, 0.30 mmol, 1.00 equiv), sodium trifluoromethanesulfonate (103.2 mg, 0.60 mmol, 2.00 equiv), vinylmagnesium chloride (0.20 mL, 1.53 M in tetrahydrofuran, 0.30 mmol, 1.00 equiv), 4-(trifluoromethyl)phenyl trifluoromethanesulfonate (**1.182**, 105.9 mg, 0.36 mmol, 1.20 equiv), palladium (II) acetate (0.90 mL, 0.01 M in dimethyl sulfoxide, 0.009

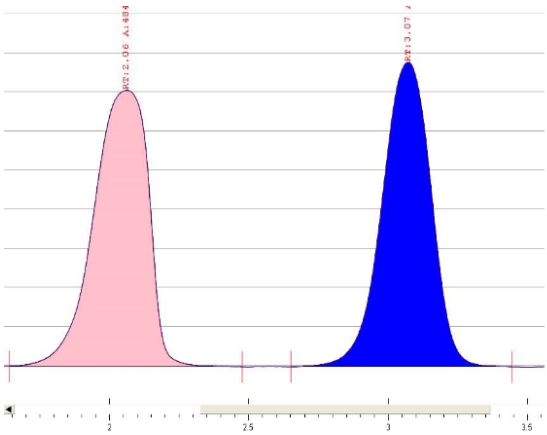
mmol, 0.030 equiv), MandyPhos (**1.64**, 11.37 mg, 0.0108 mmol, 0.036 equiv). The unpurified product was purified by automated silica gel chromatography (Biotage 1% → 5% ethyl acetate in hexanes, stained in CAM) to afford colorless oil (95.9 mg, 85% yield).

(Method C) with 4,4,5,5-tetramethyl-2-phenyl-1,3,2-dioxaborolane (**1.94**, 61.2 mg, 0.30 mmol, 1.00 equiv), sodium trifluoromethanesulfonate (154.9 mg, 0.90 mmol, 3.00 equiv), vinylmagnesium chloride (0.20 mL, 1.53 M in tetrahydrofuran, 0.30 mmol, 1.00 equiv), 4-bromobenzotrifluoride (81.0 mg, 0.36 mmol, 1.20 equiv), palladium (II) acetate (0.90 mL, 0.01 M in dimethyl sulfoxide, 0.009 mmol, 0.030 equiv), MandyPhos (**1.64**, 11.37 mg, 0.0108 mmol, 0.036 equiv). The unpurified product was purified by automated silica gel chromatography (Biotage 1% → 5% ethyl acetate in hexanes, stained in CAM) to afford colorless oil (85.8 mg, 76% yield).

^{1}H NMR (600 MHz, $CDCl_3$) δ 7.46 (d, *J* = 8.0 Hz, 2H), 7.29 – 7.23 (m, 4H), 7.21 (d, *J* = 6.9 Hz, 2H), 7.15 (t, *J* = 7.2 Hz, 1H), 3.20 (dd, *J* = 13.6, 9.3 Hz, 1H), 3.00 (dd, *J* = 13.6, 7.3 Hz, 1H), 2.66 (dd, *J* = 8.9, 7.6 Hz, 1H), 1.12 (s, 6H), 1.12 (s, 6H). **^{11}B NMR** (128 MHz, $CDCl_3$) δ 32.68. **^{13}C NMR** (151 MHz, $CDCl_3$) δ 146.14, 142.11, 129.37, 128.66, 128.59, 128.33 (partially buried, q, $^{2}J_{C–F}$ = 32.2 Hz), 125.85, 125.14 (q, $^{3}J_{C–F}$ = 3.7 Hz), 124.62 (q, $^{1}J_{C–F}$ = 271.7 Hz), 83.80, 38.81, 34.38, 24.76, 24.74. **IR** (neat) ν_{max} 3061.55 (w), 3025.45 (w), 2979.30 (m), 2932.67 (w), 1362.99 (m), 1321.35 (s), 1162.23 (m), 1139.06 (s), 1120.38 (s), 1066.83 (s), 842.37 (m), 700.83 (m) cm^{-1}. **HRMS** (DART) for $C_{21}H_{28}BF_3NO_2$ $[M+NH_4]^+$: calculated: 394.21652, found: 394.21675. $[\alpha]_D^{20}$ = – 41.075 (*c* 2.58, $CHCl_3$, *l* = 50 mm).

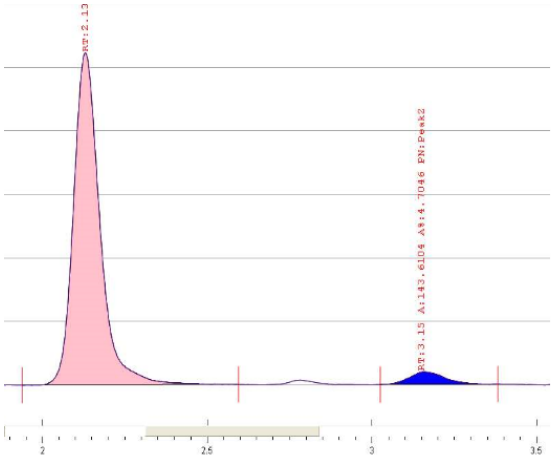
Analysis of Stereochemistry: Racemic compound was prepared according to the general procedure (***Method B, run at 60 ºC***) with $Pd(OAc)_2$ (5 mol%) and 1,1′-bis(dicyclohexylphosphino)ferrocene (6 mol%) as the catalyst. Chiral SFC (Chiracel OJ-H, 1% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of (*R*)-4,4,5,5-tetramethyl-2-(1-phenyl-2-(4-(trifluoromethyl)phenyl)ethyl)-1,3,2-dioxaborolane **(1.111)**.

Racemic Material

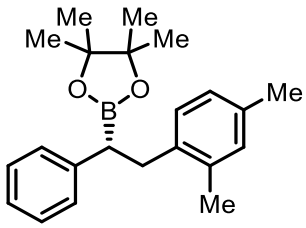


Peak No	% Area	Area	RT (min)
1	50.3616	4843.2255	2.06
2	49.6384	4773.6823	3.07
Total:	100	9616.9078	

Standard Conditions



Peak No	% Area	Area	RT (min)
1	95.2954	2908.9488	2.13
2	4.7046	143.6104	3.15
Total:	100	3052.5592	

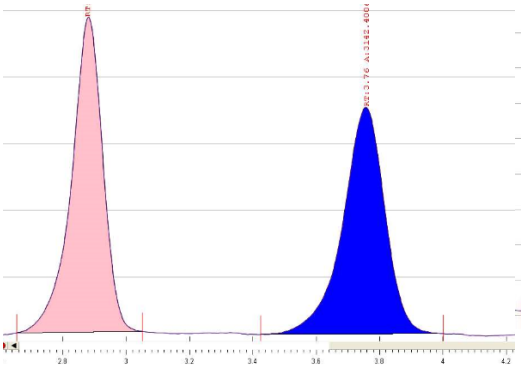


(*R*)-2-(2-(2,4-dimethylphenyl)-1-phenylethyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (1.112). The reaction was performed according to the general procedure ***(Method B, with the modification: the reaction was run at 60 ºC instead of 40 ºC)*** with 4,4,5,5-tetramethyl-2-phenyl-1,3,2-dioxaborolane (**1.94**, 61.2 mg, 0.30 mmol, 1.00 equiv), sodium trifluoromethanesulfonate (103.2 mg, 0.60 mmol, 2.00 equiv), vinylmagnesium chloride (0.20 mL, 1.53 M in tetrahydrofuran, 0.30 mmol, 1.00 equiv),

2,4-dimethylphenyl trifluoromethanesulfonate (**1.183**, 91.5 mg, 0.36 mmol, 1.20 equiv), palladium (II) acetate (0.90 mL, 0.01 M in dimethyl sulfoxide, 0.009 mmol, 0.030 equiv), MandyPhos (**1.64**, 11.37 mg, 0.0108 mmol, 0.036 equiv). The unpurified product was purified by silica gel chromatography (0% → 20% ethyl acetate in hexanes, stained in CAM) to afford colorless oil (71.1 mg, 70% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.24 (d, *J* = 3.9 Hz, 4H), 7.16 – 7.09 (m, 1H), 7.04 (d, *J* = 7.7 Hz, 1H), 6.90 (s, 1H), 6.85 (d, *J* = 7.6 Hz, 1H), 3.11 (dd, *J* = 13.7, 10.1 Hz, 1H), 2.85 (dd, *J* = 13.8, 6.2 Hz, 1H), 2.62 (dd, *J* = 9.8, 6.2 Hz, 1H), 2.24 (s, 3H), 2.22 (s, 3H), 1.11 (s, 6H), 1.10 (s, 6H). **^{11}B NMR** (128 MHz, $CDCl_3$) δ 32.79. **^{13}C NMR** (126 MHz, $CDCl_3$) δ 143.21, 137.00, 136.23, 135.36, 131.05, 129.28, 128.63, 128.53, 126.35, 125.57, 83.60, 35.95, 33.27, 24.86, 24.74, 21.12, 19.57. **IR** (neat) ν_{max} 3082.50 (w), 3057.14 (w), 3023.76 (w), 2976.78 (m), 2926.55 (m), 2863.88 (w), 1600.81 (w), 1493.07 (m), 1451.70 (m), 1359.49 (s), 1324.47 (s), 1141.37 (s), 967.98 (m), 853.68 (m), 700.02 (m) cm^{-1}. **HRMS** (DART) for $C_{22}H_{30}BO_2$ $[M+H]^+$: calculated: 337.2339, found: 337.2337. $[\alpha]_D^{20}$ = – 22.542 (*c* 1.02, $CHCl_3$, *l* = 50 mm).

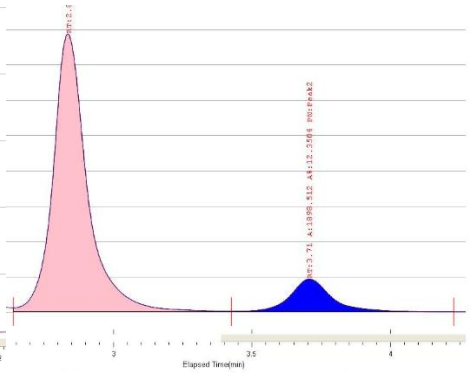
Analysis of Stereochemistry: Racemic compound was prepared according to the general procedure (***Method B, run at 60 ºC***) with $Pd(OAc)_2$ (5 mol%) and 1,1′-bis(diisopropylphosphino)ferrocene (6 mol%) as the catalyst. Chiral SFC (Chiracel OJ-H, 2% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of (*R*)-2-(2-(2,4-dimethylphenyl)-1-phenylethyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane **(1.112)**.

Racemic Material

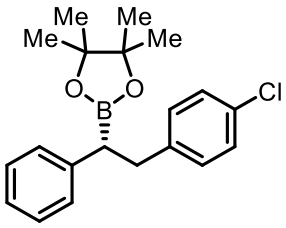


Peak No	% Area	Area	RT (min)
1	50.8958	3257.0512	2.88
2	49.1042	3142.4006	3.76
Total:	100	6399.4518	

Standard Conditions



Peak No	% Area	Area	RT (min)
1	87.6496	13473.5164	2.84
2	12.3504	1898.512	3.71
Total:	100	15372.0284	



(*R*)-2-(2-(4-chlorophenyl)-1-phenylethyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (1.113). The reaction was performed according to the general procedure ***(Method B)*** with 4,4,5,5-tetramethyl-2-phenyl-1,3,2-dioxaborolane (**1.94**, 61.2 mg, 0.30 mmol, 1.00 equiv), sodium trifluoromethanesulfonate (103.2 mg, 0.60 mmol, 2.00 equiv), vinylmagnesium chloride (0.20 mL, 1.53 M in tetrahydrofuran, 0.30 mmol, 1.00 equiv), 4-chlorophenyl trifluoromethanesulfonate (**1.186**, 93.8 mg, 0.36 mmol, 1.20 equiv), palladium (II) acetate (0.90 mL, 0.01 M in dimethyl sulfoxide, 0.009 mmol, 0.030 equiv), MandyPhos (**1.64**, 11.37 mg, 0.0108 mmol, 0.036 equiv). The unpurified product was purified by silica gel chromatography (0% → 20% CH_2Cl_2 in hexanes, stained in CAM) to afford white solid (77.1 mg, 75% yield).

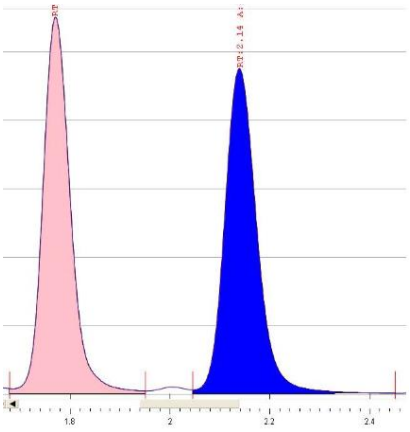
(Method C) with 4,4,5,5-tetramethyl-2-phenyl-1,3,2-dioxaborolane (**1.94**, 61.2 mg, 0.30 mmol, 1.00 equiv), sodium trifluoromethanesulfonate (154.9 mg, 0.90 mmol, 3.00 equiv), vinylmagnesium chloride (0.20 mL, 1.53 M in tetrahydrofuran, 0.30 mmol, 1.00 equiv), 1-

bromo-4-chlorobenzene (68.9 mg, 0.36 mmol, 1.20 equiv), palladium (II) acetate (0.90 mL, 0.01 M in dimethyl sulfoxide, 0.009 mmol, 0.030 equiv), MandyPhos (**1.64**, 11.37 mg, 0.0108 mmol, 0.036 equiv). The unpurified product was purified by silica gel chromatography (0% → 20% CH_2Cl_2 in hexanes, stained in CAM) to afford white solid (54.5 mg, 53% yield).

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.23 – 7.09 (m, 7H), 7.06 (d, *J* = 8.4 Hz, 2H), 3.09 (dd, *J* = 13.6, 9.3 Hz, 1H), 2.89 (dd, *J* = 13.6, 7.2 Hz, 1H), 2.60 (dd, *J* = 9.2, 7.4 Hz, 1H), 1.10 (s, 6H), 1.10 (s, 6H). **^{11}B NMR** (128 MHz, $CDCl_3$) δ 32.68. **^{13}C NMR** (126 MHz, $CDCl_3$) δ 142.31, 140.41, 131.64, 130.42, 128.59, 128.57, 128.28, 125.72, 83.69, 38.33, 34.57, 24.77, 24.76. **IR** (neat) ν_{max} 3062.99 (w), 3028.92 (w), 2992.58 (m), 2974.97 (m), 2926.86 (w), 2866.56 (w), 2854.54 (w), 1599.48 (w), 1491.98 (m), 1451.90 (m), 1361.24 (s), 1325.22 (m), 1137.88 (s), 840.95 (m), 698.86 (s), 526.61 (m) cm^{-1}. **HRMS** (DART) for $C_{20}H_{28}BClNO_2$ $[M+NH_4]^+$: calculated: 360.19016, found: 360.18982. $[\alpha]_D^{20}$ = – 51.441 (*c* 2.55, $CHCl_3$, *l* = 50 mm).

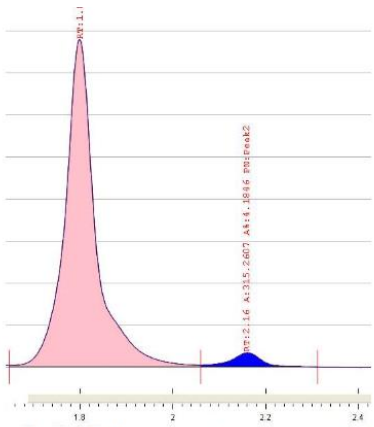
Analysis of Stereochemistry: Racemic compound was prepared according to the general procedure (***Method C, run at 60 ºC***) with $Pd(OAc)_2$ (5 mol%) and 1,1′-bis(diisopropylphosphino)ferrocene (6 mol%) as the catalyst. Chiral SFC (Chiracel OJ-H, 10% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of (*R*)-2-(2-(4-chlorophenyl)-1-phenylethyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane **(1.113)**.

Racemic Material

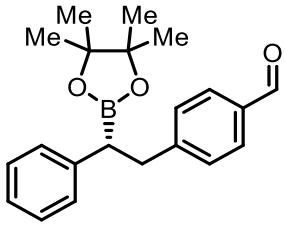


Peak No	% Area	Area	RT (min)
1	49.8972	4165.2611	1.77
2	50.1028	4182.4299	2.14
Total:	100	8347.691	

Standard Conditions



Peak No	% Area	Area	RT (min)
1	95.8154	7218.5232	1.8
2	4.1846	315.2607	2.16
Total:	100	7533.7839	



(*R*)-4-(2-phenyl-2-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)ethyl) benzaldehyde (1.114). The reaction was performed according to the general procedure ***(Method B)*** with 4,4,5,5-tetramethyl-2-phenyl-1,3,2-dioxaborolane (**1.94**, 61.2 mg, 0.30 mmol, 1.00 equiv), sodium trifluoromethanesulfonate (103.2 mg, 0.60 mmol, 2.00 equiv), vinylmagnesium chloride (0.20 mL, 1.53 M in tetrahydrofuran, 0.30 mmol, 1.00 equiv), 4-formylphenyl trifluoromethanesulfonate (**1.184**, 91.5 mg, 0.36 mmol, 1.20 equiv), palladium (II) acetate (0.90 mL, 0.01 M in dimethyl sulfoxide, 0.009 mmol, 0.030 equiv), MandyPhos (**1.64**, 11.37 mg, 0.0108 mmol, 0.036 equiv.). The unpurified product was purified by silica gel chromatography (0% → 50% → 100% CH_2Cl_2 in hexanes, stained in CAM) to afford white solid (74.6 mg, 74% yield).

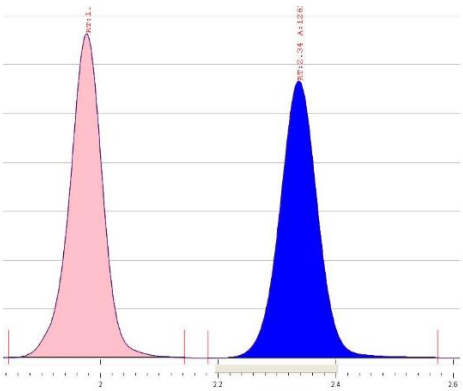
(Method C) with 4,4,5,5-tetramethyl-2-phenyl-1,3,2-dioxaborolane (**1.94**, 61.2 mg, 0.30 mmol, 1.00 equiv), sodium trifluoromethanesulfonate (154.9 mg, 0.90 mmol, 3.00 equiv),

vinylmagnesium chloride (0.20 mL, 1.53 M in tetrahydrofuran, 0.30 mmol, 1.00 equiv), 4-bromobenzaldehyde (66.6 mg, 0.36 mmol, 1.20 equiv), palladium (II) acetate (0.90 mL, 0.01 M in dimethyl sulfoxide, 0.009 mmol, 0.030 equiv), MandyPhos (**1.64**, 11.37 mg, 0.0108 mmol, 0.036 equiv). The unpurified product was purified by silica gel chromatography (0% → 50% → 100% CH_2Cl_2 in hexanes, stained in CAM) to afford white solid (58.5 mg, 58% yield).

^{1}H NMR (500 MHz, $CDCl_3$) δ 9.92 (s, 1H), 7.71 (d, *J* = 8.0 Hz, 2H), 7.30 (d, *J* = 8.0 Hz, 2H), 7.25 – 7.20 (m, 2H), 7.18 (d, *J* = 6.9 Hz, 2H), 7.13 (app t, *J* = 7.2 Hz, 1H), 3.21 (dd, *J* = 13.5, 9.3 Hz, 1H), 3.01 (dd, *J* = 13.5, 7.5 Hz, 1H), 2.66 (app t, *J* = 8.1 Hz, 1H), 1.11 (s, 6H), 1.10 (s, 6H). **^{11}B NMR** (128 MHz, $CDCl_3$) δ 33.00. **^{13}C NMR** (126 MHz, $CDCl_3$) δ 192.23, 149.53, 141.97, 134.63, 129.82, 129.73, 128.61, 128.55, 125.83, 83.78, 39.18, 34.24, 24.74, 24.72. **IR** (neat) ν_{max} 3059.19 (w), 3025.78 (w), 2977.21 (m), 2929.43 (w), 2861.26 (w), 2826.64 (w), 2733.18 (w), 1698.39 (s), 1604.87 (m), 1361.01 (s), 1326.41 (s), 1139.63 (s), 844.14 (m), 701.29 (m), 538.21 (m) cm^{-1}. **HRMS** (DART) for $C_{21}H_{26}BO_3$ $[M+H]^+$: calculated: 337.1975, found: 337.1981. $[\alpha]_D^{20}$ = – 57.821 (*c* 2.62, $CHCl_3$, *l* = 50 mm).

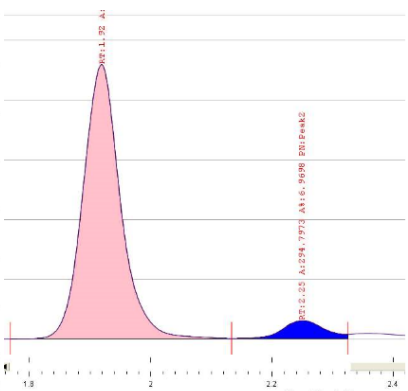
Analysis of Stereochemistry: Racemic compound was prepared according to the general procedure (***Method C, run at 60 ºC***) with $Pd(OAc)_2$ (5 mol%) and 1,1′-bis(diisopropylphosphino)ferrocene (6 mol%) as the catalyst. Chiral SFC (Chiracel OJ-H, 10% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of (*R*)-4-(2-phenyl-2-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)ethyl)benzaldehyde **(1.114)**.

Racemic Material

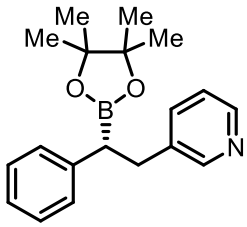


Peak No	% Area	Area	RT (min)
1	50.5587	1289.8685	1.98
2	49.4413	1261.3593	2.34
Total:	100	2551.2278	

Standard Conditions



Peak No	% Area	Area	RT (min)
1	93.0302	3934.8527	1.92
2	6.9698	294.7973	2.25
Total:	100	4229.65	



(*R*)-3-(2-Phenyl-2-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)ethyl) pyridine (1.115). The reaction was performed according to the general procedure ***(Method B)*** with 4,4,5,5-tetramethyl-2-phenyl-1,3,2-dioxaborolane (**1.94**, 61.2 mg, 0.30 mmol, 1.00 equiv), sodium trifluoromethanesulfonate (103.2 mg, 0.60 mmol, 2.00 equiv), vinylmagnesium chloride (0.20 mL, 1.53 M in tetrahydrofuran, 0.30 mmol, 1.00 equiv), 3-pyridyl trifluoromethanesulfonate (**1.185**, 81.8 mg, 0.36 mmol, 1.20 equiv), palladium (II) acetate (0.90 mL, 0.01 M in dimethyl sulfoxide, 0.009 mmol, 0.030 equiv), MandyPhos (**1.64**, 11.37 mg, 0.0108 mmol, 0.036 equiv). The unpurified product was purified by silica gel chromatography (0% → 50% → 100% CH_2Cl_2 in hexanes, stained in CAM) to afford pink oil (47.3 mg, 51% yield).

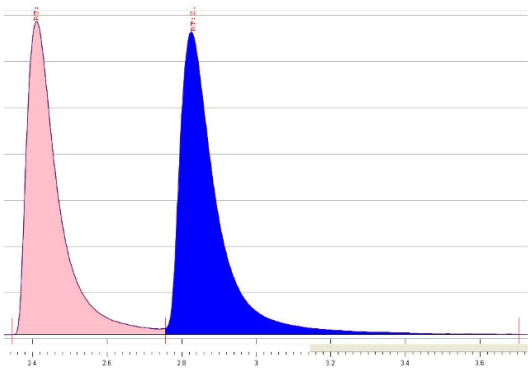
(Method C) with 4,4,5,5-tetramethyl-2-phenyl-1,3,2-dioxaborolane (**1.94**, 61.2 mg, 0.30 mmol, 1.00 equiv), sodium trifluoromethanesulfonate (154.9 mg, 0.90 mmol, 3.00 equiv), vinylmagnesium chloride (0.20 mL, 1.53 M in tetrahydrofuran, 0.30 mmol, 1.00 equiv), 3-

bromopyridine (56.9 mg, 0.36 mmol, 1.20 equiv), palladium (II) acetate (0.90 mL, 0.01 M in dimethyl sulfoxide, 0.009 mmol, 0.030 equiv), MandyPhos (**1.64**, 11.37 mg, 0.0108 mmol, 0.036 equiv). The unpurified product was purified by silica gel chromatography (0% → 50% → 100% CH_2CH_2 in hexanes, stained in CAM) to afford pink oil (45.5 mg, 49% yield).

^{1}H NMR (500 MHz, $CDCl_3$) δ 8.38 (s, 1H), 8.34 (d, *J* = 3.3 Hz, 1H), 7.41 (d, *J* = 7.8 Hz, 1H), 7.26 – 7.18 (m, 2H), 7.16 (d, *J* = 7.1 Hz, 2H), 7.13 – 7.05 (m, 2H), 3.11 (dd, *J* = 13.7, 9.2 Hz, 1H), 2.90 (dd, *J* = 13.7, 7.4 Hz, 1H), 2.59 (app t, *J* = 8.3 Hz, 1H), 1.10 (s, 6H), 1.09 (s, 6H). **^{11}B NMR** (128 MHz, $CDCl_3$) δ 32.81. **^{13}C NMR** (126 MHz, $CDCl_3$) δ 150.34, 147.24, 141.87, 137.25, 136.54, 128.64, 128.59, 125.87, 123.19, 83.81, 36.08, 34.37, 25.03, 24.73. **IR** (neat) ν_{max} 3083.23 (w), 3058.15 (w), 3025.24 (w), 2977.72 (m), 2929.39 (w), 2861.19 (w), 1600.02 (w), 1574.63 (w), 1493.42 (m), 1478.78 (m), 1451.31 (m), 1422.39 (m), 1364.27 (s), 1328.41 (s), 1141.17 (s), 968.05 (m), 853.25 (m), 701.71 (m) cm^{-1}. **HRMS** (DART) for $C_{19}H_{25}BNO_2$ $[M+H]^+$: calculated: 310.1978, found: 310.1990. $[\alpha]_D^{20}$ = – 39.247 (*c* 1.76, $CHCl_3$, *l* = 50 mm).

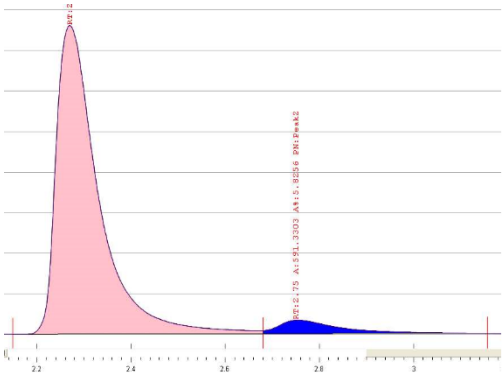
Analysis of Stereochemistry: Racemic compound was prepared according to the general procedure (***Method B, run at 60 ºC***) with $Pd(OAc)_2$ (3 mol%), (S_p, S_p)-MandyPhos **1.64** (1.8 mol%), and (R_p, R_p)-MandyPhos **1.64** (1.8 mol%) as the catalyst. Chiral SFC (Chiracel OJ-H, 4% MeOH, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of (*R*)-3-(2-phenyl-2-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)ethyl)pyridine **(1.115)**.

Racemic Material

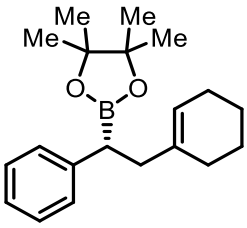


Peak No	% Area	Area	RT (min)
1	47.4152	4045.2841	2.41
2	52.5848	4486.3369	2.83
Total:	100	8531.621	

Standard Conditions

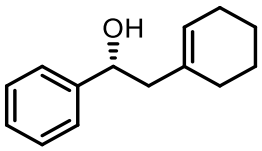


Peak No	% Area	Area	RT (min)
1	94.1744	9559.2412	2.27
2	5.8256	591.3303	2.75
Total:	100	10150.5715	



(*R*)-2-(2-(cyclohex-1-en-1-yl)-1-phenylethyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (1.116). The reaction was performed according to general procedure (***Method B)*** with 4,4,5,5-tetramethyl-2-phenyl-1,3,2-dioxaborolane (**1.94**, 61.2 mg, 0.30 mmol, 1.00 equiv) sodium trifluoromethanesulfonate (103.2 mg, 0.60 mmol, 2.00 equiv), vinylmagnesium chloride (0.20 mL, 1.53 M in tetrahydrofuran, 0.30 mmol, 1.00 equiv), cyclohex-1-en-1-yl trifluoromethanesulfonate (**1.180**, 82.9 mg, 0.36 mmol, 1.20 equiv), palladium (II) acetate (0.9 mL, 0.01 M in dimethyl sulfoxide, 0.009 mmol, 0.030 equiv), MandyPhos (**1.64**, 11.37 mg, 0.0108 mmol, 0.036 equiv). The unpurified product was purified by automated silica gel chromatography (Biotage 1% →5% ethyl acetate in hexanes, stained in CAM) to afford white solid (71.2 mg, 76% yield). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.25 – 7.19 (m, 4H), 7.13 – 7.08 (m, 1H), 5.42 (s, 1H), 2.56 (dd, *J* = 10.5, 5.9 Hz, 1H), 2.49 (app t, 1H), 2.22 (dd, *J* = 13.7, 5.6 Hz, 1H), 2.02 – 1.83 (m, 4H), 1.63 – 1.42 (m, 4H), 1.17 (s, 6H), 1.15 (s, 6H). **^{11}B NMR** (160 MHz, $CDCl_3$) δ 32.89. **^{13}C NMR** (151 MHz, $CDCl_3$) δ 143.42 , 137.42 , 128.48 , 128.41 , 125.32 , 121.77 , 83.43 , 41.14 , 30.86

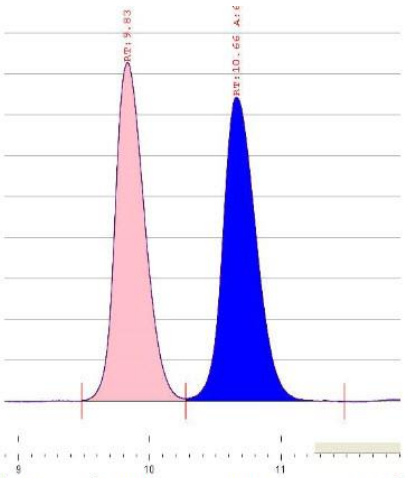
, 28.84 , 25.46 , 24.86 , 24.82 , 23.26 , 22.77. **IR** (neat) ν_{max} 2976.74 (w), 2925.87 (w), 1359.22 (m), 1323.98 (m), 1141.45 (m), 969.45 (w), 850.07 (w), 699.65 (m) cm^{-1}. **HRMS** (DART) for $C_{20}H_{30}BO_2$ $[M+H]^+$ calculated: 313.23388, found: 313.23507. $[\alpha]^{20}_D$: -6.100 (*c* 1.215, $CHCl_3$, *l* =50 mm).



(*R*)-2-(cyclohex-1-en-1-yl)-1-phenylethan-1-ol (1.116-OH) Product **1.116** was oxidized according to *General Method for Oxidation of Boronic Ester Products.* All spectroscopic data were in accord with the literature.[20]

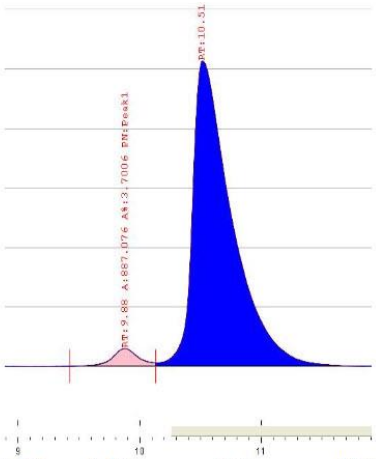
Analysis of Stereochemistry: Racemic compound was prepared according to the general procedure (***Method B, run at 60 ºC***) with $Pd(OAc)_2$ (5 mol%) and 1,1′-bis(dicyclohexylphosphino)ferrocene (6 mol%) as the catalyst. Chiral SFC (Chiracel OJ-H, 1% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of (*R*)-2-(cyclohex-1-en-1-yl)-1-phenylethan-1-ol **(1.116-OH)**.

Racemic Material

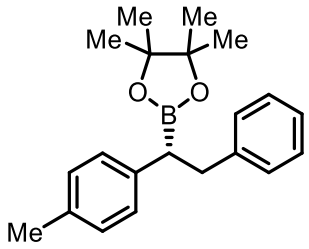


Peak No	% Area	Area	RT (min)
1	49.6784	6384.9152	9.83
2	50.3216	6467.5726	10.66
Total:	100	12852.4878	

Standard Conditions



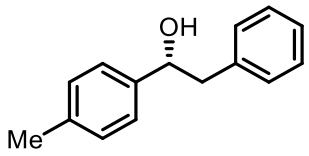
Peak No	% Area	Area	RT (min)
1	3.7006	887.076	9.88
2	96.2994	23083.9786	10.51
Total:	100	23971.0546	



(*R*)-4,4,5,5-tetramethyl-2-(2-phenyl-1-(p-tolyl)ethyl)-1,3,2-Dioxa-borolane (1.117). The reaction was performed according to the general procedure ***(Method B)*** with 4,4,5,5-tetramethyl-2-(p-tolyl)-1,3,2-dioxaborolane (65.4 mg, 0.30 mmol, 1.00 equiv), sodium trifluoromethanesulfonate (103.2 mg, 0.60 mmol, 2.00 equiv), vinylmagnesium chloride (0.20 mL, 1.53 M in tetrahydrofuran, 0.30 mmol, 1.00 equiv), phenyl trifluoromethanesulfonate (81.4 mg, 0.36 mmol, 1.20 equiv) palladium (II) acetate (0.90 mL, 0.01 M in dimethyl sulfoxide, 0.009 mmol, 0.030 equiv), MandyPhos (**1.64**, 11.37 mg, 0.0108 mmol, 0.036 equiv). The unpurified product was purified by silica gel chromatography (0% → 30% CH_2Cl_2 in hexanes, stained in CAM) to afford white solid (78.3 mg, 81% yield).

*(**Method C**)* with 4,4,5,5-tetramethyl-2-(p-tolyl)-1,3,2-dioxaborolane (65.4 mg, 0.30 mmol, 1.00 equiv), sodium trifluoromethanesulfonate (154.9 mg, 0.90 mmol, 3.00 equiv), vinylmagnesium chloride (0.20 mL, 1.53 M in tetrahydrofuran, 0.30 mmol, 1.00 equiv), bromobenzene (56.5 mg, 0.36 mmol, 1.20 equiv), palladium (II) acetate (0.90 mL, 0.01 M in dimethyl sulfoxide, 0.009 mmol, 0.030 equiv), MandyPhos (**1.64**, 11.37 mg, 0.0108 mmol, 0.036 equiv). The unpurified product was purified by silica gel chromatography (0% → 30% CH_2Cl_2 in hexanes, stained in CAM) to afford white solid (75.4 mg, 78% yield).

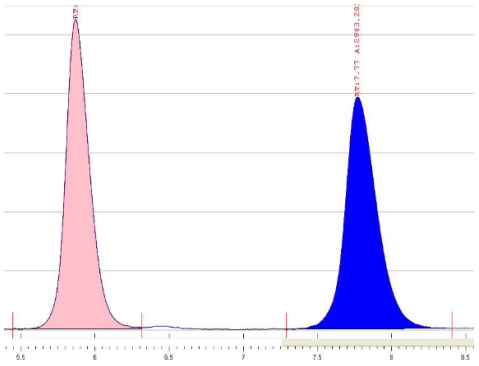
^{1}H NMR (500 MHz, $CDCl_3$) δ 7.30 – 7.21 (m, 4H), 7.21 – 7.14 (m, 3H), 7.10 (d, *J* = 7.8 Hz, 2H), 3.17 (dd, *J* = 13.4, 10.0 Hz, 1H), 2.98 (dd, *J* = 13.5, 6.8 Hz, 1H), 2.69 (dd, *J* = 9.8, 6.9 Hz, 1H), 2.33 (s, 3H), 1.14 (s, 6H), 1.13 (s, 6H). **^{11}B NMR** (128 MHz, $CDCl_3$) δ 32.91. **^{13}C NMR** (126 MHz, $CDCl_3$) δ 142.04, 139.64, 134.89, 129.24, 129.07, 128.43, 128.19, 125.89, 83.49, 39.26, 34.09, 24.79, 24.70, 21.20. **IR** (neat) ν_{max} 3085.45 (w), 3060.29 (w), 3025.44 (w), 2977.10 (m), 2924.49 (w), 2861.47 (w), 1603.87 (w), 1510.16 (m), 1359.23 (s), 1321.39 (s), 1140.06 (s), 967.33 (m), 855.65 (m), 815.57 (m), 698.19 (s), 537.31 (m) cm^{-1}. **HRMS** (DART) for $C_{21}H_{28}BO_2$ $[M+H]^+$: calculated: 323.21823, found: 323.21907. $[\alpha]_D^{20}$ = – 41.664 (*c* 3.50, $CHCl_3$, *l* = 50 mm).



(*R*)-2-phenyl-1-(p-tolyl)ethan-1-ol (1.117-OH). Product **1.117** was oxidized according to *General Method for Oxidation of Boronic Ester Products.* All spectroscopic data were in accord with the literature.[51]

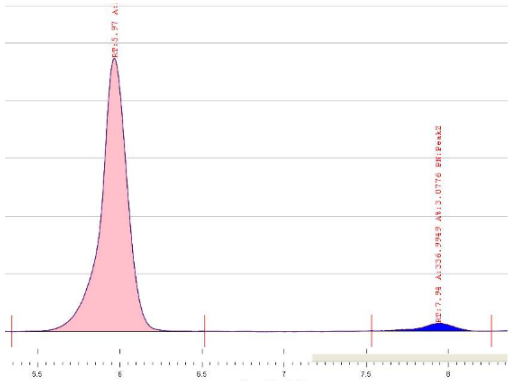
Analysis of Stereochemistry: Racemic compound was prepared according to the general procedure (***Method B, run at 60 ºC***) with $Pd(OAc)_2$ (5 mol%) and 1,1′-bis(diisopropylphosphino)ferrocene (6 mol%) as the catalyst. Chiral SFC (Chiracel OJ-H, 10% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of (*R*)-2-phenyl-1-(p-tolyl)ethan-1-ol **(1.117-OH)**.

Racemic Material



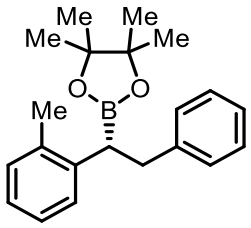
Peak No	% Area	Area	RT (min)
1	50.1383	2959.6156	5.87
2	49.8617	2943.2838	7.77
Total:	100	5902.8994	

Standard Conditions



Peak No	% Area	Area	RT (min)
1	96.9224	10612.8941	5.97
2	3.0776	336.9949	7.94
Total:	100	10949.889	

[51] Zhou, C.; Wang, Z. *Synthesis* **2005**, 10, 1649.

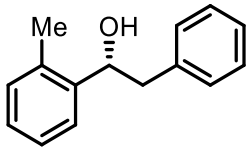


(*R*)-4,4,5,5-tetramethyl-2-(2-phenyl-1-(o-tolyl)ethyl)-1,3,2-dioxaborolane (1.118). The reaction was performed according to the general procedure ***(Method B)*** with 4,4,5,5-tetramethyl-2-(o-tolyl)-1,3,2-dioxaborolane (65.4 mg, 0.30 mmol, 1.00 equiv), sodium trifluoromethanesulfonate (103.2 mg, 0.60 mmol, 2.00 equiv), vinylmagnesium chloride (0.20 mL, 1.53 M in tetrahydrofuran, 0.30 mmol, 1.00 equiv), phenyl trifluoromethanesulfonate (81.4 mg, 0.36 mmol, 1.20 equiv), palladium (II) acetate (0.90 mL, 0.01 M in dimethyl sulfoxide, 0.009 mmol, 0.030 equiv), MandyPhos (**1.64**, 11.37 mg, 0.0108 mmol, 0.036 equiv). The unpurified product was purified by silica gel chromatography (0% → 20% CH_2Cl_2 in hexanes, stained in CAM) to afford white solid (86.3 mg, 89% yield).

(Method C) with 4,4,5,5-tetramethyl-2-(o-tolyl)-1,3,2-dioxaborolane (65.4 mg, 0.30 mmol, 1.00 equiv), sodium trifluoromethanesulfonate (154.9 mg, 0.90 mmol, 3.00 equiv), vinylmagnesium chloride (0.20 mL, 1.53 M in tetrahydrofuran, 0.30 mmol, 1.00 equiv), bromobenzene (56.5 mg, 0.36 mmol, 1.20 equiv), palladium (II) acetate (0.90 mL, 0.01 M in dimethyl sulfoxide, 0.009 mmol, 0.030 equiv), MandyPhos (**1.64**, 11.37 mg, 0.0108 mmol, 0.036 equiv). The unpurified product was purified by silica gel chromatography (0% → 20% CH_2Cl_2 in hexanes, stained in CAM) to afford white solid (68.6 mg, 71% yield).

^{1}H NMR (500 MHz, $CDCl_3$) δ 7.40 (d, *J* = 7.6 Hz, 1H), 7.29 – 7.22 (m, 4H), 7.22 – 7.16 (m, 2H), 7.15 (d, *J* = 7.0 Hz, 1H), 7.10 (app t, *J* = 7.3 Hz, 1H), 3.21 (dd, *J* = 12.7, 9.0 Hz,

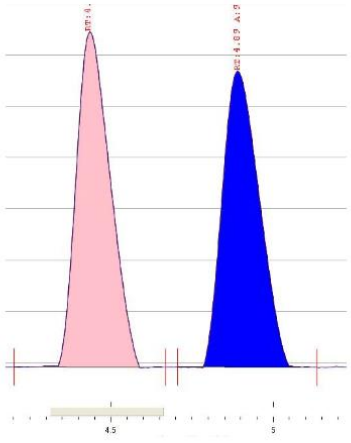
1H), 3.02 – 2.87 (m, 2H), 2.31 (s, 3H), 1.17 (s, 12H). **^{11}B NMR** (128 MHz, $CDCl_3$) δ 33.00. **^{13}C NMR** (126 MHz, $CDCl_3$) δ 142.16, 141.23, 136.29, 130.39, 129.05, 128.21, 128.14, 126.16, 125.93, 125.46, 83.49, 38.85, 30.42, 24.79, 24.77, 20.18. **IR** (neat) ν_{max} 3060.95 (w), 3026.24 (w), 2976.72 (m), 2928.80 (w), 2860.41 (w), 1601.71 (w) 1492.63 (m), 1453.84 (m), 1356.48 (s), 1322.40 (s), 1139.82 (s), 967.09 (m), 852.83 (m), 727.68 (s), 698.05 (s) cm^{-1}. **HRMS** (DART) for $C_{21}H_{28}BO_2$ $[M+H]^+$: calculated: 323.21823, found: 323.21834. $[\alpha]_D^{20}$ = – 28.296 (*c* 3.07, $CHCl_3$, *l* = 50 mm).



(*R*)-2-phenyl-1-(o-tolyl)ethan-1-ol (1.118-OH). Product **1.118** was oxidized according to *General Method for Oxidation of Boronic Ester Products.* All spectroscopic data were in accord with the literature.[20]

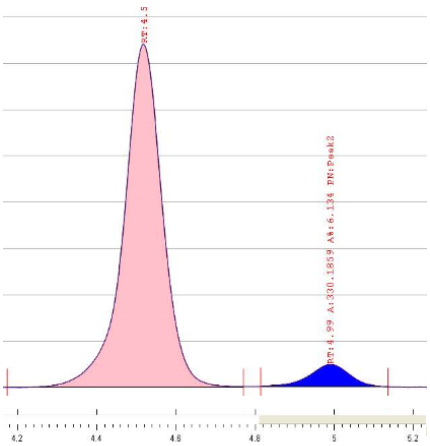
Analysis of Stereochemistry: Racemic compound was prepared according to the general procedure (***Method B, run at 60 ºC***) with $Pd(OAc)_2$ (5 mol%) and 1,1′-bis(diisopropylphosphino)ferrocene (6 mol%) as the catalyst. Chiral SFC (Chiracel OJ-H, 10% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of (*R*)-2-phenyl-1-(o-tolyl)ethan-1-ol **(1.118-OH)**.

Racemic Material

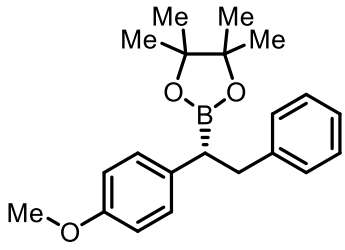


Peak No	% Area	Area	RT (min)
1	50.9739	943.0438	4.43
2	49.0261	907.009	4.89
Total:	100	1850.0528	

Standard Conditions

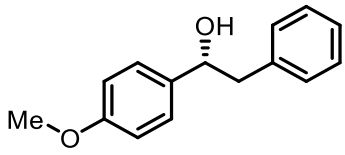


Peak No	% Area	Area	RT (min)
1	93.866	5052.7199	4.52
2	6.134	330.1859	4.99
Total:	100	5382.9058	



(*R*)-2-(1-(4-methoxyphenyl)-2-phenylethyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (1.119). The reaction was performed according to general procedure (***Method B)*** with 2-(4-methoxyphenyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (70.23 mg, 0.30 mmol, 1.00 equiv), sodium trifluoromethanesulfonate (103.2 mg, 0.60 mmol, 2.00 equiv), vinylmagnesium chloride (0.20 mL, 1.53 M in tetrahydrofuran, 0.30 mmol, 1.00 equiv), phenyl trifluoromethanesulfonate (81.4 mg, 0.36 mmol, 1.20 equiv), palladium (II) acetate (0.9 mL, 0.01 M in dimethyl sulfoxide, 0.009 mmol, 0.030 equiv), MandyPhos (**1.64**, 11.37 mg, 0.0108 mmol, 0.036). The unpurified product was purified by automated silica gel chromatography (Biotage 1% → 5% ethyl acetate in hexanes, stained in CAM) to afford white solid (91.3 mg, 90% yield). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.21 (t, *J* = 7.3 Hz, 1H), 7.19 – 7.11 (m, 3H), 6.80 (d, *J* = 8.7 Hz, 1H), 3.77 (s, 1H), 3.11 (dd, *J* = 13.5, 9.7 Hz, 1H), 2.92 (dd, *J* = 13.5, 7.0 Hz, 1H), 2.62 (dd, *J* = 9.6, 7.1 Hz, 1H),

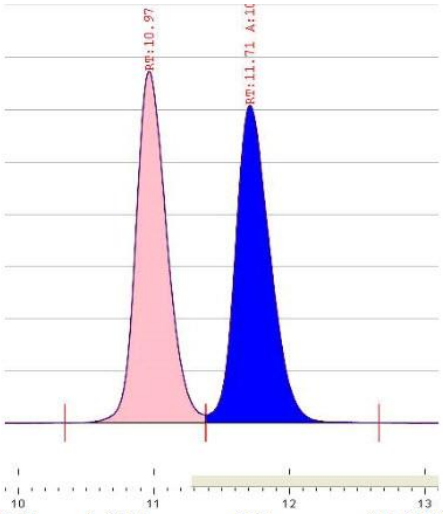
1.11 (s, 3H), 1.11 (s, 3H). **^{11}B NMR** (160 MHz, $CDCl_3$) δ 32.75. **^{13}C NMR** (126 MHz, $CDCl_3$) δ 157.67 , 142.01 , 134.76 , 129.48 , 129.08 , 128.19 , 125.88 , 113.97 , 83.51 , 55.36 , 39.36 , 33.56 , 24.80 , 24.72. **IR** (neat) ν_{max} 3337.49 (br), 3027.54 (w), 2976.97 (w), 1607.00 (w), 1508.51 (s), 1360.39 (m), 1322.59 (m), 1242.35 (s), 1139.13 (s), 1034.72 (m), 966.96 (m). 828.44 (m), 697.81 (m), 541.36 (m) cm^{-1}. **HRMS** (DART) for $C_{21}H_{27}BO_3$ $[M+NH_4]^+$ calculated: 356.23970, found: 356.23969. $[\alpha]^{20}_D$: -49.358 (*c* 3.69, $CHCl_3$, *l* =50 mm).



(*R*)-1-(4-methoxyphenyl)-2-phenylethan-1-ol (1.119-OH). Product **1.119** was oxidized according to *General Method for Oxidation of Boronic Ester Products. All spectroscopic data were* in accord with the literature.[20]

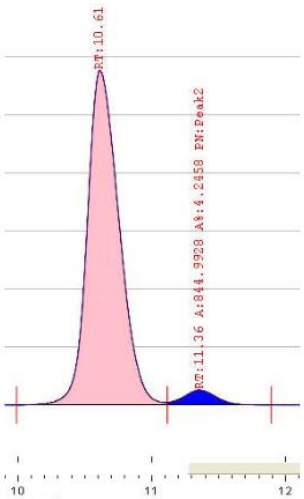
Analysis of Stereochemistry: Racemic compound was prepared according to the general procedure (***Method B, run at 60 ºC***) with $Pd(OAc)_2$ (5 mol%) and 1,1′-bis(dicyclohexylphosphino)ferrocene (6 mol%) as the catalyst. Chiral SFC (Chiracel OD-H, 8% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of (*R*)-1-(4-methoxyphenyl)-2-phenylethan-1-ol **(1.119-OH)**.

Racemic Material

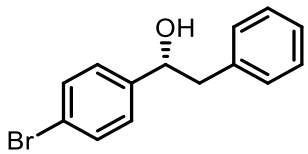


Peak No	% Area	Area	RT (min)
1	16.0614	2799.2453	7.02
2	83.9386	14629.1852	8.28
Total:	100	17428.4305	

Standard Conditions



Peak No	% Area	Area	RT (min)
1	95.7542	19056.8183	10.61
2	4.2458	844.9928	11.36
Total:	100	19901.8111	

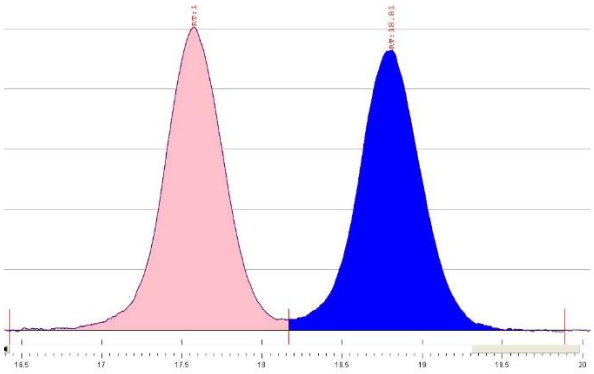


(*R*)-1-(4-bromophenyl)-2-phenylethan-1-ol (1.120-OH). The reaction was performed according to the general procedure ***(Method B)*** with 4,4,5,5-tetramethyl-2-(4-bromophenyl)-1,3,2-dioxaborolane (**1.178**, 84.9 mg, 0.30 mmol, 1.00 equiv), sodium trifluoromethanesulfonate (103.2 mg, 0.60 mmol, 2.00 equiv), vinylmagnesium chloride (0.20 mL, 1.53 M in tetrahydrofuran, 0.30 mmol, 1.00 equiv), phenyl trifluoromethanesulfonate (81.4 mg, 0.36 mmol, 1.20 equiv) palladium (II) acetate (0.90 mL, 0.01 M in dimethyl sulfoxide, 0.009 mmol, 0.030 equiv), MandyPhos (**1.64**, 11.37 mg, 0.0108 mmol, 0.036 equiv). Unpurified product **1.120** was oxidized according to *General Method for Oxidation of Boronic Ester Products.* The unpurified product was purified by silica gel chromatography (0% → 20% → 50% CH_2Cl_2 in hexanes, stained in CAM) to afford colorless oil (75.9 mg, 91% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.45 (d, *J* = 8.4 Hz, 2H), 7.29 (app t, *J* = 7.3 Hz, 2H), 7.24 (d, *J* = 7.3 Hz, 1H), 7.20 (d, *J* = 8.2 Hz, 2H), 7.15 (d, *J* = 6.8 Hz, 2H), 4.84 (dd, *J* = 8.2,

5.1 Hz, 1H), 2.99 (dd, J = 13.6, 5.0 Hz, 1H), 2.93 (dd, J = 13.6, 8.3 Hz, 1H), 2.01 (s, 1H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 142.94, 137.68, 131.66, 129.71, 128.80, 127.85, 126.99, 121.53, 74.87, 46.26. **IR** (neat) ν_{max} 3373.67 (m, br), 3084.72 (w), 3060.88 (w), 3027.32 (m), 2918.60 (m), 1591.86 (m), 1488.45 (s), 1453.70 (m), 1070.49 (s), 1044.49 (m), 1009.03 (s), 822.90 (s), 744.58 (s), 699.39 (s), 543.23 (s) cm^{-1}. **HRMS** (DART) for $C_{14}H_{12}Br$ $[M+H–H_2O]^+$: calculated: 259.01224, found: 259.01212. $[\alpha]_D^{20} = -3.182$ (*c* 2.28, $CHCl_3$, *l* = 50 mm).

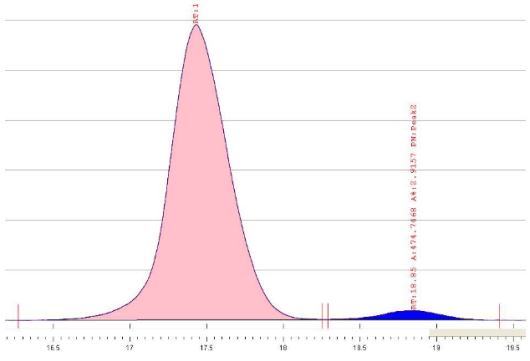
Analysis of Stereochemistry: Racemic compound was prepared according to the general procedure (***Method B, run at 60 ºC***) with $Pd(OAc)_2$ (5 mol%) and 1,1′-bis(diisopropylphosphino)ferrocene (6 mol%) as the catalyst. Chiral SFC (Chiracel OD-H, 6% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of (*R*)-1-(4-bromophenyl)-2-phenylethan-1-ol **(1.120-OH)**.

Racemic Material

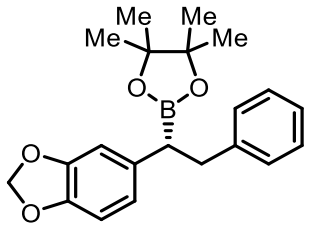


Peak No	% Area	Area	RT (min)
1	50.7049	2678.072	17.58
2	49.2951	2603.6058	18.81
Total:	100	5281.6778	

Standard Conditions



Peak No	% Area	Area	RT (min)
1	97.0843	15807.6836	17.43
2	2.9157	474.7468	18.85
Total:	100	16282.4304	



(*R*)-2-(1-(benzo[d][1,3]dioxol-5-yl)-2-phenylethyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (1.121). The reaction was performed according to the general procedure ***(Method B)*** with 2-(benzo[d][1,3]dioxol-5-yl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (74.4 mg, 0.30 mmol, 1.00 equiv), sodium trifluoromethanesulfonate (103.2 mg, 0.60 mmol, 2.00 equiv), vinylmagnesium chloride (0.20 mL, 1.53 M in tetrahydrofuran, 0.30 mmol, 1.00 equiv), phenyl trifluoromethanesulfonate (81.4 mg, 0.36 mmol, 1.20 equiv), palladium (II) acetate (0.90 mL, 0.01 M in dimethyl sulfoxide, 0.009 mmol, 0.030 equiv), MandyPhos (**1.64**, 11.37 mg, 0.0108 mmol, 0.036 equiv). The unpurified product was purified by automated silica gel chromatography (Biotage 1% → 10% ethyl acetate in hexanes, stained in CAM) to afford white solid (91.9 mg, 87% yield).

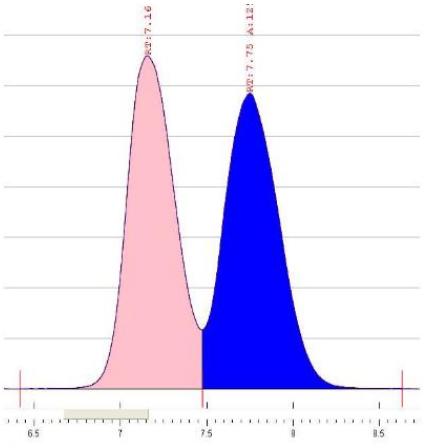
(Method C) with 2-(benzo[d][1,3]dioxol-5-yl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (74.4 mg, 0.30 mmol, 1.00 equiv), sodium trifluoromethanesulfonate (154.9 mg, 0.90 mmol, 3.00 equiv), vinylmagnesium chloride (0.20 mL, 1.53 M in tetrahydrofuran, 0.30 mmol, 1.00 equiv), bromobenzene (56.5 mg, 0.36 mmol, 1.20 equiv), palladium (II) acetate (0.90 mL, 0.01 M in dimethyl sulfoxide, 0.009 mmol, 0.030 equiv), MandyPhos (**1.64**, 11.37 mg, 0.0108 mmol, 0.036 equiv). Purification by automated silica gel chromatography (Biotage 1% → 10% ethyl acetate in hexanes, stained in CAM) to afford white solid (80.3 mg, 76% yield).

^{1}H NMR (600 MHz, $CDCl_3$) δ 7.20 (app t, J = 7.6 Hz, 2H), 7.15 (d, J = 7.4 Hz, 2H), 7.12 (app t, J = 7.2 Hz, 1H), 6.75 (d, J = 1.4 Hz, 1H), 6.68 (d, J = 8.0 Hz, 1H), 6.64 (dd, J = 8.0,

1.4 Hz, 1H), 5.89 (s, 2H), 3.07 (dd, J = 13.5, 9.5 Hz, 1H), 2.89 (dd, J = 13.5, 7.2 Hz, 1H), 2.58 (dd, J = 9.2, 7.4 Hz, 1H), 1.11 (s, 6H), 1.10 (s, 6H). **^{11}B NMR** (128 MHz, $CDCl_3$) δ 32.82. **^{13}C NMR** (151 MHz, $CDCl_3$) δ 147.71, 145.51, 141.80, 136.59, 129.08, 128.24, 125.97, 121.46, 109.12, 108.37, 100.87, 83.63, 39.43, 34.24, 24.82, 24.75. **IR** (neat) ν_{max} 3063.47 (w), 3027.13 (w), 2977.09 (m), 2925.36 (m), 2897.27 (m), 1486.69 (s), 1370.75 (s), 1327.09 (s), 1241.03 (s), 1142.13 (s), 1040.12 (s), 937.94 (m), 861.96 (m), 810.61 (m), 699.61 (m) cm^{-1}. **HRMS** (DART) for $C_{21}H_{26}BO_4$ $[M+H]^+$: calculated: 353.19241, found: 353.19152. $[\alpha]_D^{20}$ = – 53.108 (*c* 1.79, $CHCl_3$, *l* = 50 mm).

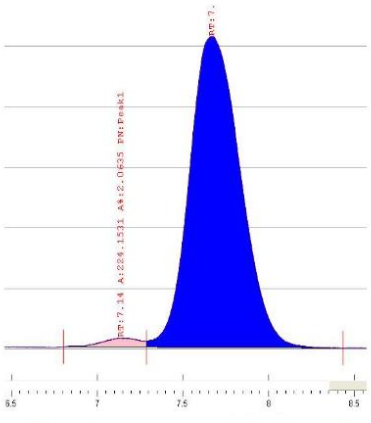
Analysis of Stereochemistry: Racemic compound was prepared according to the general procedure (***Method B, run at 60 ºC***) with $Pd(OAc)_2$ (5 mol%) and 1,1′-bis(dicyclohexylphosphino)ferrocene (6 mol%) as the catalyst. Chiral SFC (Chiracel OJ-H, 0% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of (*R*)-2-(1-(benzo[d][1,3]dioxol-5-yl)-2-phenylethyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane **(1.121)**.

Racemic Material

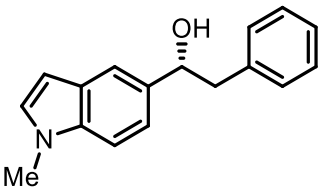


Peak No	% Area	Area	RT (min)
1	49.6278	12782.896	7.16
2	50.3722	12974.6567	7.75
Total:	100	25757.5527	

Standard Conditions



Peak No	% Area	Area	RT (min)
1	2.0635	224.1531	7.14
2	97.9365	10638.5433	7.67
Total:	100	10862.6964	

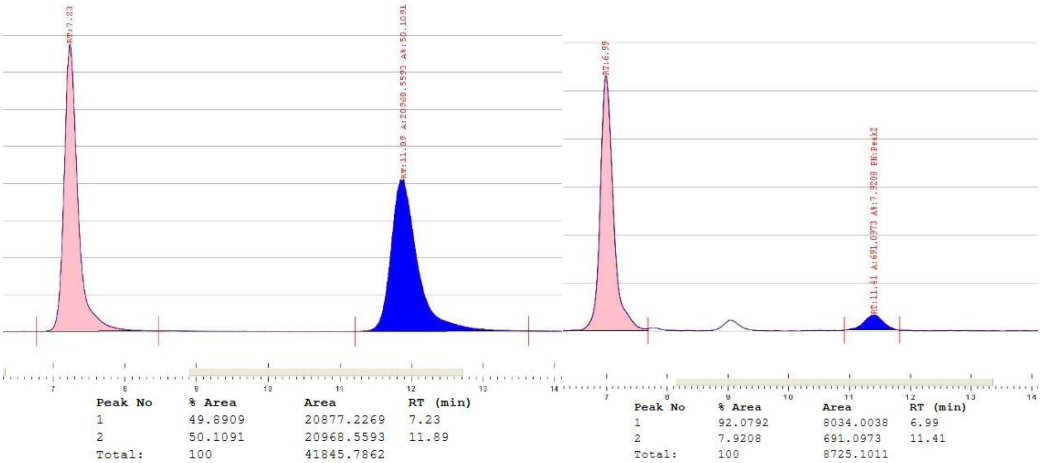


(*R*)-1-(1-methyl-1H-indol-5-yl)-2-phenylethan-1-ol (1.122-OH). The reaction was performed according to general procedure ***(Method B)*** with 1-methyl-5-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)-1H-indole (77.1 mg, 0.30 mmol, 1.00 equiv), sodium trifluoromethanesulfonate (103.2 mg, 0.60 mmol, 2.00 equiv), vinylmagnesium chloride (0.20 mL, 1.53 M in tetrahydrofuran, 0.30 mmol, 1.00 equiv), phenyl trifluoromethanesulfonate (81.4 mg, 0.36 mmol, 1.20 equiv), palladium (II) acetate (0.9 mL, 0.01 M in dimethyl sulfoxide, 0.009 mmol, 0.030 equiv), MandyPhos (**1.64**, 11.37 mg, 0.0108 mmol. 0.036). Unpurified product **1.122** was oxidized according to *General Method for Oxidation of Boronic Ester Products.* The unpurified product was purified by automated silica gel chromatography (Biotage 1% → 20% ethyl acetate in hexanes, stained in CAM) to afford white solid (37.7 mg, 50% yield). All spectroscopic data were in accord with the literature.[52]

Analysis of Stereochemistry: Racemic compound was prepared according to the general procedure (***Method B, run at 60 ºC***) with $Pd(OAc)_2$ (5 mol%) and 1,1′-bis(dicyclohexylphosphino)ferrocene (6 mol%) as the catalyst. Chiral SFC (Chiracel OJ-H, 30% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of (*R*)-1-(1-methyl-1H-indol-5-yl)-2-phenylethan-1-ol **(1.122-OH)**.

[52] Seyferth, D. *Organometallics* **2009**, 28, 1598.

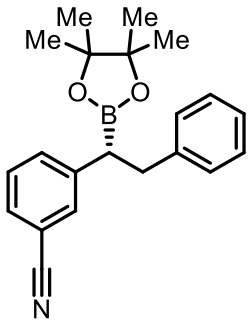
Racemic Material



Peak No	% Area	Area	RT (min)
1	49.8909	20877.2269	7.23
2	50.1091	20968.5593	11.89
Total:	100	41845.7862	

Standard Conditions

Peak No	% Area	Area	RT (min)
1	92.0792	8034.0038	6.99
2	7.9208	691.0973	11.41
Total:	100	8725.1011	

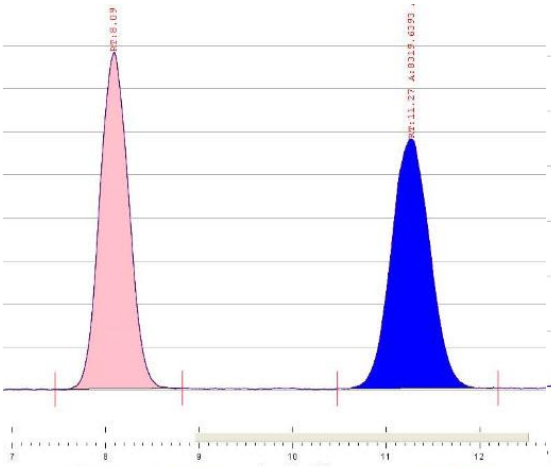


(*R*)-3-(2-phenyl-1-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)ethyl) benzonitrile (1.123). The reaction was performed according to general procedure ***(Method B)*** with 3-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)benzonitrile (68.7 mg, 0.30 mmol, 1.00 equiv), sodium trifluoromethanesulfonate (103.2 mg, 0.60 mmol, 2.00 equiv), vinylmagnesium chloride (0.20 mL, 1.53M in tetrahydrofuran, 0.30 mmol, 1.00 equiv), phenyl trifluoromethanesulfonate (81.4 mg, 0.36 mmol, 1.20 equiv), palladium (II) acetate (0.9 mL, 0.01 M in dimethyl sulfoxide, 0.009 mmol, 0.030 equiv), MandyPhos (**1.64**, 11.37 mg, 0.0108 mmol). The unpurified product was purified by automated silica gel chromatography (Biotage 1% → 5% ethyl acetate in hexanes, stained in CAM) to afford white solid (69.9 mg, 70% yield). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.49 (app t, *J* = 1.5 Hz, 1H), 7.40 (app dd, *J* = 7.8, 1.6 Hz, 2H), 7.30 (app t, 1H), 7.20 (app t, *J* = 7.4 Hz, 2H), 7.16 – 7.07 (m, 3H), 3.13 (dd, *J* = 13.6, 8.8 Hz, 1H), 2.91 (dd, *J* = 13.6, 7.8 Hz, 1H), 2.70 (app t, *J* = 8.3 Hz, 1H), 1.12 (s, 6H), 1.11 (s, 6H). **^{11}B NMR** (160 MHz, $CDCl_3$) δ 32.59. **^{13}C NMR** (151 MHz, $CDCl_3$) δ 144.25, 140.80, 133.35, 132.16,

129.43, 129.16, 128.94, 128.36, 126.27, 119.37, 112.40, 84.00, 38.64, 34.37, 24.77, 24.70. **IR** (neat) ν_{max} 3027.61 (w), 2931.10 (w), 2228.22 (w), 1599.68 (w), 1579.48 (w), 1480.71 (w), 1359.55 (m), 1332.50 (m), 1139.37 (w), 969.24 (w), 859.19 (w). 798.94 (w), 699.91 (s) cm^{-1}. **HRMS** (DART) for $C_{21}H_{28}BO_3N_2$ $[M+NH_4]^+$ calculated: 351.22438, found: 351.22411. $[\alpha]^{20}_D$: -57.715 (*c* 2.83, $CHCl_3$, *l* =50 mm).

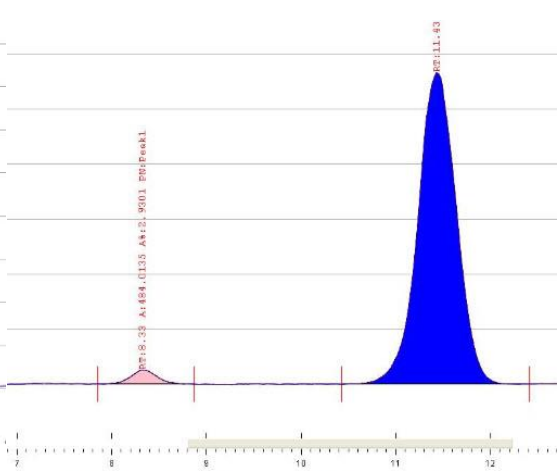
Analysis of Stereochemistry: Racemic compound was prepared according to the general procedure (***Method B, run at 60***) with $Pd(OAc)_2$ (5 mol%) and 1,1′-bis(dicyclohexylphosphino)ferrocene (6 mol%) as the catalyst. Chiral SFC (Chiracel OJ-H, 1% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of (*R*)-3-(2-phenyl-1-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)ethyl)benzonitrile **(1.123)**.

Racemic Material

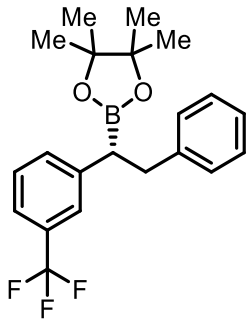


Peak No	% Area	Area	RT (min)
1	50.1611	8373.4164	8.09
2	49.8389	8319.6393	11.27
Total:	100	16693.0557	

Standard Conditions



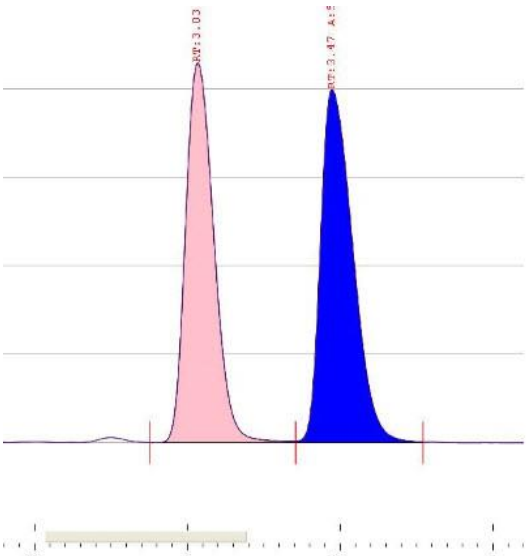
Peak No	% Area	Area	RT (min)
1	2.9301	484.0135	8.33
2	97.0699	16034.4013	11.43
Total:	100	16518.4148	



(*R*)-4,4,5,5-tetramethyl-2-(2-phenyl-1-(3-(trifluoromethyl) phenyl)ethyl)-1,3,2-dioxaborolane (1.124). The reaction was performed according to general procedure ***(Method B, with the modification that the reaction was run at 60 ºC instead of 40 ºC)*** with 4,4,5,5-tetramethyl-2-(3-(trifluoromethyl)phenyl)-1,3,2-dioxaborolane (81.6 mg, 0.30 mmol, 1.00 equiv), sodium trifluoromethanesulfonate (103.2 mg, 0.60 mmol, 2.00 equiv), vinylmagnesium chloride (0.20 mL, 1.53 M in tetrahydrofuran, 0.30 mmol, 1.00 equiv), phenyl trifluoromethanesulfonate (81.4 mg, 0.36 mmol, 1.20 equiv), palladium (II) acetate (0.9 mL, 0.01 M in dimethyl sulfoxide, 0.009 mmol, 0.030 equiv), MandyPhos (**1.64**, 11.37 mg, 0.0108 mmol, 0.036). The unpurified product was purified by automated silica gel chromatography (Biotage 1% → 5% ethyl acetate in hexanes, stained in CAM) to afford white solid (65.5 mg, 58% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.49 (s, 1H), 7.41 – 7.36 (m, 2H), 7.36 – 7.30 (m, 1H), 7.26 – 7.18 (m, 2H), 7.17 – 7.11 (m, 3H), 3.15 (dd, *J* = 13.5, 9.5 Hz, 1H), 2.95 (dd, *J* = 13.5, 7.2 Hz, 1H), 2.80 – 2.68 (m, 1H), 1.12 (s, 6H), 1.10 (s, 6H). **^{11}B NMR** (160 MHz, $CDCl_3$) δ 32.79. **^{13}C NMR** (126 MHz, $CDCl_3$) δ 143.77 , 141.27 , 132.15 , 130.75 (q, *J* = 31.8 Hz), 129.05 , 128.87 , 128.36 , 126.20 , 125.41 (q, *J* = 3.8 Hz), 124.56 (q, *J* = 272.3 Hz), 122.51 (q, *J* = 3.9 Hz), 83.91 , 38.97 , 34.69 , 24.81 , 24.67. **IR** (neat) ν_{max} 2979.24 (w), 2929.51 (w), 1370.49 (m), 1328.10 (s), 1162.98 (m), 1140.73 (s), 1075.10 (w), 6.98.96 (w) cm^{-1}. **HRMS** (DART) for $C_{21}H_{25}BF_3O_2$ $[M+H]^+$ calculated: 377.19, found: 377.1915. $[\alpha]^{20}_D$: -34.893 (*c* 1.720, $CHCl_3$, *l* =50 mm).

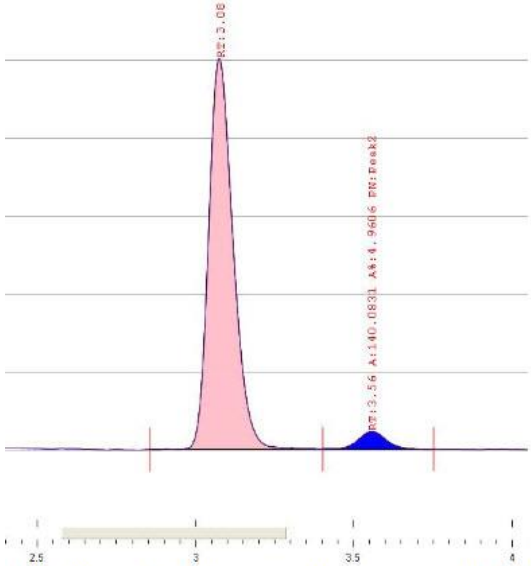
Analysis of Stereochemistry: Racemic compound was prepared according to the general procedure (***Method B, run a t60 ºC***) with $Pd(OAc)_2$ (5 mol%) and 1,1′-bis(dicyclohexylphosphino)ferrocene (6 mol%) as the catalyst. Chiral SFC (Chiracel ODR-H, 1% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of (*R*)-4,4,5,5-tetramethyl-2-(2-phenyl-1-(3-(trifluoromethyl)phenyl)ethyl)-1,3,2-dioxaborolane **(1.124)**.

Racemic Material

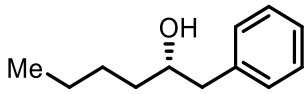


Peak No	% Area	Area	RT (min)
1	48.6367	5493.607	3.03
2	51.3633	5801.5807	3.47
Total:	100	11295.1877	

Standard Conditions



Peak No	% Area	Area	RT (min)
1	95.0394	2683.8159	3.08
2	4.9606	140.0831	3.56
Total:	100	2823.899	

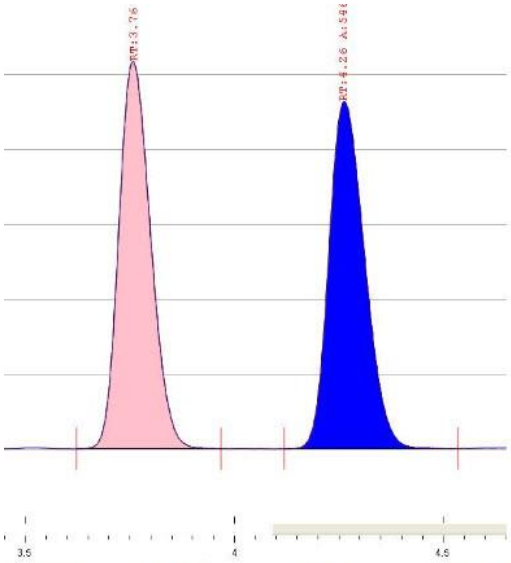


(S)*-1-phenylhexan-2-ol (1.125-OH).** The reaction was performed according to general procedure ***(Method B) with 2-butyl-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (55.2 mg, 0.30 mmol, 1.00 equiv), sodium trifluoromethanesulfonate (103.2 mg, 0.60 mmol, 2.00 equiv), vinylmagnesium chloride (0.20 mL, 1.53 M in tetrahydrofuran, 0.30 mmol, 1.00 equiv), phenyl trifluoromethanesulfonate (81.4 mg, 0.36 mmol, 1.20 equiv), palladium (II) acetate (0.9 mL, 0.01 M in dimethyl sulfoxide, 0.009 mmol, 0.030 equiv), MandyPhos (**1.64**, 11.37 mg,

0.0108 mmol, 0.036). Unpurified product **1.125** was oxidized according to *General Method for Oxidation of Boronic Ester Products.* The unpurified product was purified by automated silica gel chromatography (Biotage 1% → 5% ethyl acetate in hexanes, stained in CAM) to afford colorless oil (31.0 mg, 58% yield). All spectroscopic data were in accord with the literature.[20]

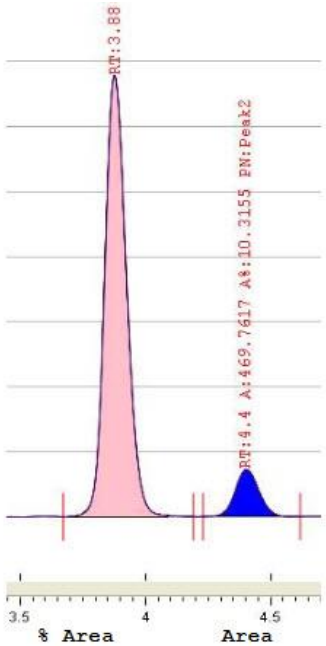
Analysis of Stereochemistry: Racemic compound was prepared according to the general procedure **(*Method B, run at 60 ºC*)** with $Pd(OAc)_2$ (5 mol%) and 1,1′-bis(dicyclohexylphosphino)ferrocene (6 mol%) as the catalyst. Chiral SFC (Chiracel OD-H, 5% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of (*S*)-1-phenylhexan-2-ol **(1.125-OH)**.

Racemic Material

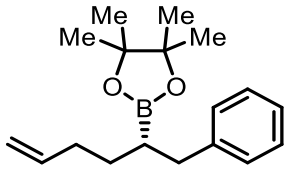


Peak No	% Area	Area	RT (min)
1	49.8946	5442.8203	3.76
2	50.1054	5465.8191	4.26
Total:	100	10908.6394	

Standard Conditions



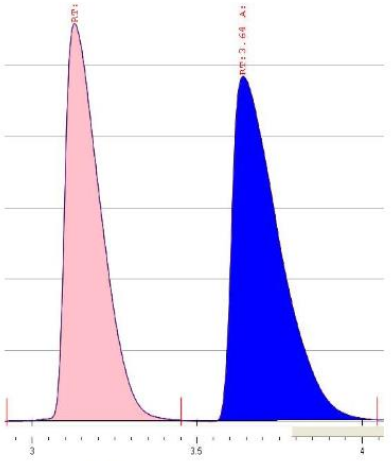
Peak No	% Area	Area	RT (min)
1	89.6845	4084.1825	3.88
2	10.3155	469.7617	4.4
Total:	100	4553.9442	



(*S*)-4,4,5,5-tetramethyl-2-(1-phenylhex-5-en-2-yl)-1,3,2-dioxaborolane (1.126). The reaction was performed according to the general procedure ***(Method B)*** with 2-(3-buten-1-yl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (54.6 mg, 0.30 mmol, 1.00 equiv), sodium trifluoromethanesulfonate (103.2 mg, 0.60 mmol, 2.00 equiv), vinylmagnesium chloride (0.20 mL, 1.53 M in tetrahydrofuran, 0.30 mmol, 1.00 equiv), phenyl trifluoromethanesulfonate (81.4 mg, 0.36 mmol, 1.20 equiv), palladium (II) acetate (0.90 mL, 0.01 M in dimethyl sulfoxide, 0.009 mmol, 0.030 equiv), MandyPhos (**1.64**, 11.37 mg, 0.0108 mmol, 0.036 equiv). The unpurified product was purified by automated silica gel chromatography (Biotage 1% → 4% ethyl acetate in hexanes, stained in CAM) to afford colorless oil (62.7 mg, 73% yield). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.24 – 7.17 (m, 4H), 7.13 (app t, *J* = 7.1 Hz, 1H), 5.78 (dddd, *J* = 16.9, 10.2, 6.7, 6.7 Hz, 1H), 4.98 (dd, *J* = 17.1, 1.8 Hz, 1H), 4.91 (dd, *J* = 10.2, 1.1 Hz, 1H), 2.71 (dd, *J* = 13.6, 8.7 Hz, 1H), 2.66 (dd, *J* = 13.6, 7.5 Hz, 1H), 2.14 – 2.00 (m, 2H), 1.58 – 1.43 (m, 2H), 1.43 – 1.35 (m, 1H), 1.15 (s, 6H), 1.12 (s, 6H). **^{11}B NMR** (128 MHz, $CDCl_3$) δ 33.82. **^{13}C NMR** (151 MHz, $CDCl_3$) δ 142.36, 139.16, 129.07, 128.24, 125.81, 114.61, 83.21, 37.44, 33.58, 30.63, 25.56, 25.01, 24.93. **IR** (neat) ν_{max} 3063.58 (w), 3026.57 (w), 2977.20 (m), 2925.82 (m), 2855.22 (w), 1729.94 (w), 1380.67 (s), 1318.76 (s), 1143.00 (s), 908.95 (m), 860.66 (m), 743.50 (m), 698.71 (m) cm^{-1}. **HRMS** (DART) for $C_{18}H_{31}BNO_2$ $[M+NH_4]^+$: calculated: 304.24478, found: 304.24478. $[\alpha]_D^{20}$ = – 3.876 (*c* 1.84, $CHCl_3$, *l* = 50 mm).

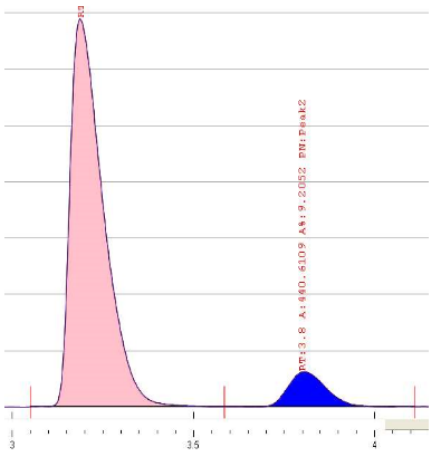
Analysis of Stereochemistry: Racemic compound was prepared according to the general procedure (***Method B, run at 60 ºC***) with $Pd(OAc)_2$ (5 mol%) and 1,1′-bis(dicyclohexylphosphino)ferrocene (6 mol%) as the catalyst. Chiral SFC (Chiracel ODR-H, 1% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of (*S*)-4,4,5,5-tetramethyl-2-(1-phenylhex-5-en-2-yl)-1,3,2-dioxaborolane **(1.126)**.

Racemic Material

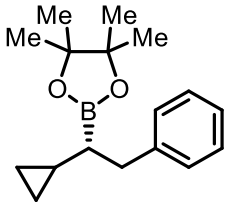


Peak No	% Area	Area	RT (min)
1	46.717	8238.0355	3.13
2	53.283	9395.8698	3.64
Total:	100	17633.9053	

Standard Conditions



Peak No	% Area	Area	RT (min)
1	90.7948	4345.9488	3.19
2	9.2052	440.6109	3.8
Total:	100	4786.5597	

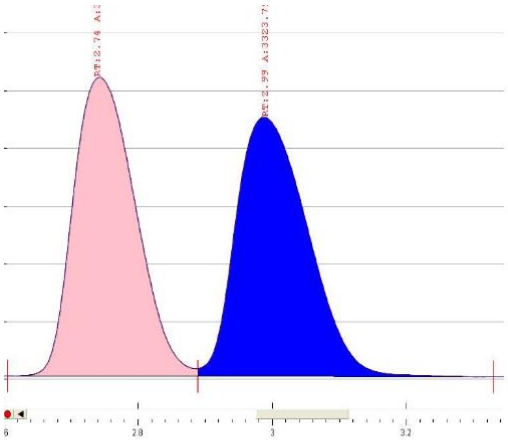


(*R*)-2-(1-cyclopropyl-2-phenylethyl)-4,4,5,5-tetramethyl-1,3,2-dioxaboro lane (1.127). The reaction was performed according to the general procedure ***(Method B)*** with 2-cyclopropyl-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (50.4 mg, 0.30 mmol, 1.00 equiv), sodium trifluoromethanesulfonate (103.2 mg, 0.60 mmol, 2.00 equiv), vinylmagnesium chloride (0.20 mL, 1.53 M in tetrahydrofuran, 0.30 mmol, 1.00 equiv), phenyl trifluoromethanesulfonate (81.4 mg, 0.36 mmol, 1.20 equiv), palladium (II) acetate (0.90

mL, 0.01 M in dimethyl sulfoxide, 0.009 mmol, 0.030 equiv), MandyPhos (**1.64**, 11.37 mg, 0.0108 mmol, 0.036 equiv). The unpurified product was purified by automated silica gel chromatography (Biotage 1% → 5% ethyl acetate in hexanes, stained in CAM) to afford colorless oil (62.1 mg, 76% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.23 – 7.17 (m, 4H), 7.14 – 7.09 (m, 1H), 2.85 – 2.74 (m, 2H), 1.14 (s, 6H), 1.12 (s, 6H), 0.79 – 0.67 (m, 2H), 0.44 – 0.34 (m, 2H), 0.16 – 0.11 (m, 1H), 0.03 – -0.02 (m, 1H). **^{11}B NMR** (128 MHz, $CDCl_3$) δ 33.49. **^{13}C NMR** (151 MHz, $CDCl_3$) δ 142.60, 129.09, 128.17, 125.72, 83.21, 37.89, 31.51, 24.92, 24.86, 12.87, 5.52, 3.82. **IR** (neat) ν_{max} 3074.67 (w), 3027.59 (w), 2977.93 (m), 2928.94 (w), 2855.57 (w), 1603.16 (w), 1377.91 (s), 1320.03 (s), 1216.53 (m), 1142.57 (s), 977.86 (m), 865.02 (m), 744.32 (m), 698.31 (s) cm^{-1}. **HRMS** (DART) for $C_{17}H_{26}BO_2$ $[M+H]^+$: calculated: 273.20258, found: 273.20328. $[\alpha]_D^{20}$ = – 10.575 (*c* 2.89, $CHCl_3$, *l* = 50 mm).

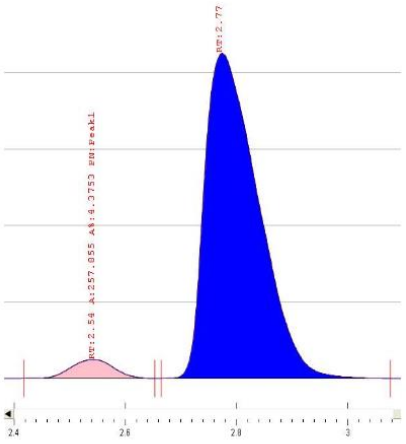
Analysis of Stereochemistry: Racemic compound was prepared according to the general procedure (***Method B, run at 60 ºC***) with $Pd(OAc)_2$ (5 mol%) and 1,1′-bis(dicyclohexylphosphino)ferrocene (6 mol%) as the catalyst. Chiral SFC (Chiracel ODR-H, 1% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of (*R*)-2-(1-cyclopropyl-2-phenylethyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane **(1.127)**.

Racemic Material

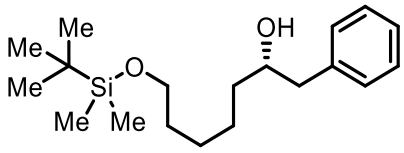


Peak No	% Area	Area	RT (min)
1	49.8436	3303.0686	2.74
2	50.1564	3323.7975	2.99
Total:	100	6626.8661	

Standard Conditions



Peak No	% Area	Area	RT (min)
1	4.3753	257.855	2.54
2	95.6247	5635.5716	2.77
Total:	100	5893.4266	

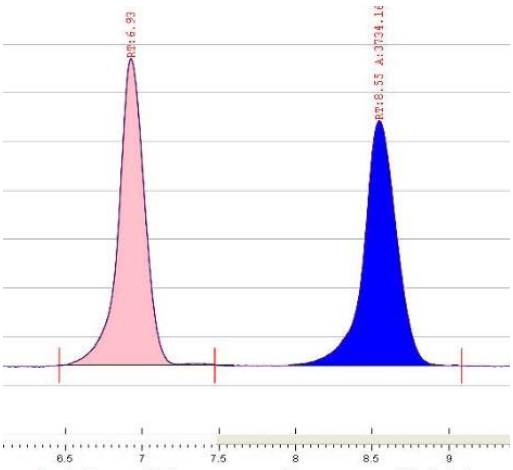


(*S*)-7-((*tert*-butyldimethylsilyl)oxy)-1-phenylheptan-2-ol (1.128-OH). The reaction was performed according to general procedure ***(Method B)*** with *tert*-butyldimethyl((5-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)pentyl)oxy)silane (98.6 mg, 0.30 mmol, 1.00 equiv), sodium trifluoromethanesulfonate (103.2 mg, 0.60 mmol, 2.00 equiv), vinylmagnesium chloride (0.20 mL, 1.53 M in tetrahydrofuran, 0.30 mmol, 1.00 equiv), phenyl trifluoromethanesulfonate (81.4 mg, 0.36 mmol, 1.20 equiv), palladium (II) acetate (0.9 mL, 0.01 M in dimethyl sulfoxide, 0.009 mmol, 0.030 equiv), MandyPhos (**1.64**, 11.37 mg, 0.0108 mmol, 0.036). Unpurified product **1.128** was oxidized according to *General Method for Oxidation of Boronic Ester Products.* The unpurified product was purified by automated silica gel chromatography (Biotage 1% → 20% ethyl acetate in hexanes, stained in CAM) to afford colorless oil (80.3 mg, 83% yield). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.33 – 7.27 (m, 2H), 7.23 – 7.17 (m, 3H), 3.87 – 3.73 (m, 1H), 3.59 (t, *J* = 6.6 Hz, 2H), 2.81 (dd, *J* = 13.6, 4.2 Hz, 1H), 2.63 (dd, *J* = 13.6, 8.4 Hz, 1H), 1.56 –

1.45 (m, 6H), 1.40 – 1.28 (m, 3H), 0.88 (s, 9H), 0.03 (s, 6H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 138.83, 129.63, 128.78, 126.66, 72.85, 63.42, 44.31, 37.07, 33.06, 26.22, 26.10, 25.80, 18.60, -5.02. **IR** (neat) ν_{max} 3410.16 (br), 2928.75 (s), 2856.29 (s), 1253.25 (m), 1094.72 (m), 832.61 (m), 773.80 (m), 698.82 (m) cm^{-1}. **HRMS** (DART) for $C_{19}H_{34}O_2Si$ $[M+H]^+$ calculated: 323.2406, found: 323.2418. $[\alpha]^{20}_D$: +5.549 (*c* 1.135, $CHCl_3$, *l* =50 mm).

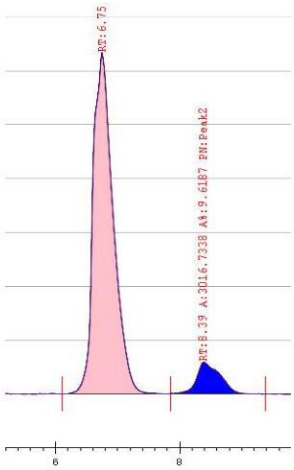
Analysis of Stereochemistry: Racemic compound was prepared according to the general procedure **(*Method B, run at 60 ºC*)** with $Pd(OAc)_2$ (5 mol%) and 1,1′-bis(dicyclohexylphosphino)ferrocene (6 mol%) as the catalyst. Chiral SFC (Chiracel OD-H, 5% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of (*S*)-7-((*tert*-butyldimethylsilyl)oxy)-1-phenylheptan-2-ol **(1.128-OH)**.

Racemic Material

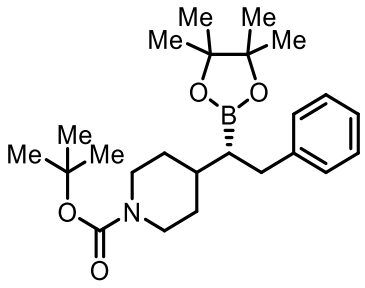


Peak No	% Area	Area	RT (min)
1	50.0389	3739.9901	6.93
2	49.9611	3734.1684	8.55
Total:	100	7474.1585	

Standard Conditions



Peak No	% Area	Area	RT (min)
1	90.3813	28346.3254	6.75
2	9.6187	3016.7338	8.39
Total:	100	31363.0592	

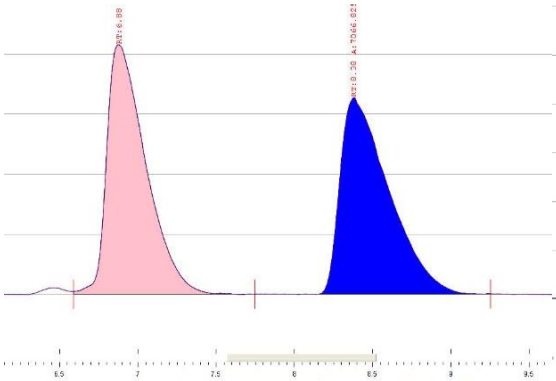


tert*-butyl (*R*)-4-(2-phenyl-1-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)ethyl)piperidine-1-carboxylate (1.129).** The reaction was performed according to the general procedure ***(Method B) with *tert*-butyl 4-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)piperidine-1-carboxylate (70.2 mg, 0.30 mmol, 1,00 equiv), sodium trifluoromethanesulfonate (103.2 mg, 0.60 mmol, 2.00 equiv), vinylmagnesium chloride (0.20 mL, 1.53 M in tetrahydrofuran, 0.30 mmol, 1.00 equiv), phenyl trifluoromethanesulfonate (81.4 mg, 0.36 mmol, 1.20 equiv), palladium (II) acetate (0.9 mL, 0.01 M in dimethyl sulfoxide, 0.009 mmol, 0.030 equiv), MandyPhos (**1.64**, 11.37 mg, 0.0108 mmol, 0.036). The unpurified product was purified by automated silica gel chromatography (Biotage 1% →10% ethyl acetate in hexanes, stained in CAM) to afford white solid (42.9 mg, 46% yield). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.23 – 7.14 (m, 4H), 7.11 (app t, *J* = 7.1 Hz, 1H), 4.25 – 3.90 (m, 2H), 2.75 (dd, *J* = 13.5, 6.4 Hz, 1H), 2.63 (m, 3H), 1.79 – 1.63 (m, 2H), 1.58 – 1.49 (m, 1H), 1.42 (s, 9H), 1.32 (ddd, *J* = 10.6, 6.4, 6.4 Hz, 1H), 1.29 – 1.21 (m, 2H), 1.08 (s, 6H), 1.03 (s, 6H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 155.10, 142.24, 129.04, 128.26, 125.87, 83.28, 79.30, 44.65, 38.29, 34.99, 32.24, 31.19, 28.67, 25.04, 24. **IR** (neat) ν_{max} 2975.99 (w), 2930.24 (w), 2853.01 (w), 1690.68 (s), 1417.52 (m), 1364.98 (m), 1243.51 (m), 1164.62 (s), 1142.25 (s), 864.31 (w), 698.70 (w) cm^{-1}. **HRMS** (DART) for $C_{24}H_{38}BNO_4$ $[M+H]^+$ calculated: 416.29721, found: 416.29674. $[\alpha]^{20}_D$: -3.644 (*c* 3.065, $CHCl_3$, *l* =50 mm).

Analysis of Stereochemistry: Racemic compound was prepared according to the general procedure ***(Method B, run at 60 ºC)*** with $Pd(OAc)_2$ (5 mol%) and 1,1′-

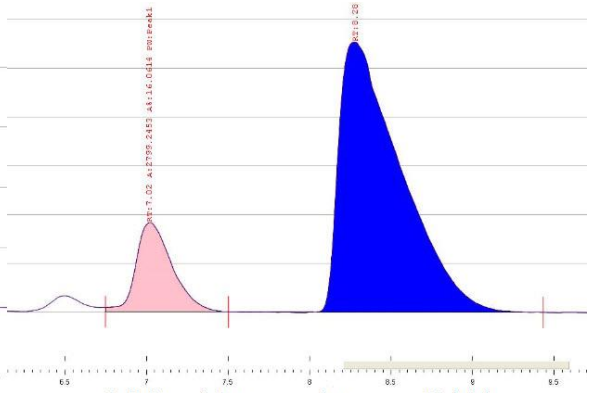
bis(dicyclohexylphosphino)ferrocene (6 mol%) as the catalyst. Chiral SFC (Chiracel ODR-H, 3% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of *tert*-buryl (*R*)-4-(2-phenyl-1-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)ethyl)piperidine-1-carboxylate **(1.129)**.

Racemic Material

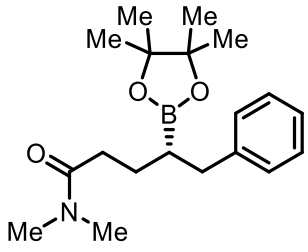


Peak No	% Area	Area	RT (min)
1	50.5596	7226.7896	6.88
2	49.4404	7066.8253	8.38
Total:	100	14293.6149	

Standard Conditions



Peak No	% Area	Area	RT (min)
1	16.0614	2799.2453	7.02
2	83.9386	14629.1852	8.28
Total:	100	17428.4305	

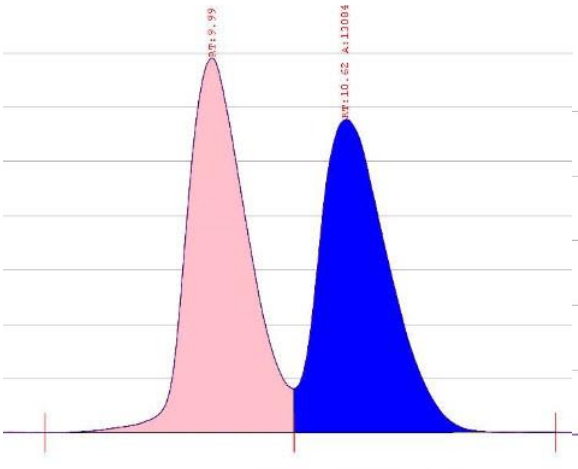


(*S*)-*N*,*N*-dimethyl-5-phenyl-4-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)pentanamide (1.130). The reaction was performed according to general procedure ***(Method B)*** with *N*,*N*-dimethyl-3-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl) propanamide (68.1 mg, 0.30 mmol, 1.00 equiv), sodium trifluoromethanesulfonate (103.2 mg, 0.60 mmol, 2.00 equiv), vinylmagnesium chloride (0.20 mL, 1.53M in tetrahydrofuran, 0.30 mmol, 1.00 equiv), phenyl trifluoromethanesulfonate (81.4 mg, 0.36 mmol, 1.20 equiv), palladium (II) acetate (0.9 mL, 0.01 M in dimethyl sulfoxide, 0.009 mmol, 0.030 equiv), MandyPhos (**1.64**, 11.37 mg, 0.0108 mmol, 0.036). The unpurified product was purified by automated silica gel chromatography (Biotage 1% → 5 → 10% ethyl acetate in hexanes, stained in CAM) to afford colorless oil (63.6 mg, 64% yield). **^{1}H**

NMR (600 MHz, $CDCl_3$) δ 7.23 – 7.15 (m, 4H), 7.13 – 7.08 (m, 1H), 2.93 (s, 3H), 2.89 (s, 3H), 2.74 (dd, *J* = 13.7, 8.4 Hz, 1H), 2.65 (dd, *J* = 13.7, 7.7 Hz, 1H), 2.39 – 2.28 (m, 1H), 2.30 – 2.22 (m, 1H), 1.78 – 1.66 (m, 2H), 1.36 (p, *J* = 8.1 Hz, 1H), 1.14 (s, 6H), 1.12 (s, 6H). **^{11}B NMR** (160 MHz, $CDCl_3$) δ 33.41. **^{13}C NMR** (126 MHz, $CDCl_3$) δ 173.27, 142.08, 129.04, 128.25, 125.85, 83.28, 37.41, 35.51, 33.33, 26.73, 25.76, 25.01, 24.95. **IR** (neat) ν_{max} 2976.10 (w), 2927.55 (w), 1643.88 (s), 1380.86 (m), 1320.38 (m), 11141.62 (s), 700.02 (w) cm^{-1}. **HRMS** (DART) for $C_{19}H_{31}BNO_3$ $[M+H]^+$ calculated: 332.23970, found: 332.24058. $[\alpha]^{20}_D$: -8.9656 (*c* 1.010, $CHCl_3$, *l* =50 mm).

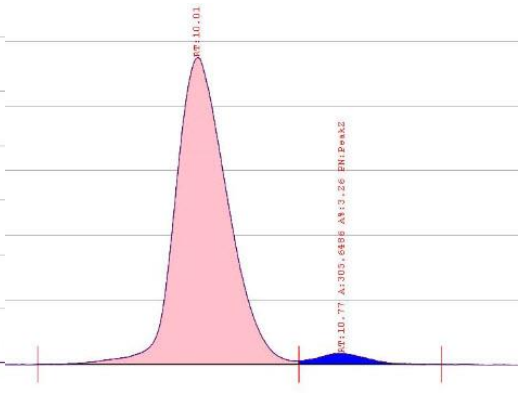
Analysis of Stereochemistry: Racemic compound was prepared according to the general procedure (***Method B, run at 60 ºC***) with $Pd(OAc)_2$ (5 mol%) and 1,1′-bis(dicyclohexylphosphino)ferrocene (6 mol%) as the catalyst. Chiral SFC (Chiracel OD-H, 3% MeOH, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of (*S*)-*N,N*-dimethyl-5-phenyl-4-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)pentanamide **(1.130)**.

Racemic Material

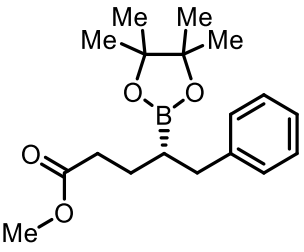


Peak No	% Area	Area	RT (min)
1	51.126	13687.032	9.99
2	48.874	13084.1678	10.62
Total:	100	26771.1998	

Standard Conditions



Peak No	% Area	Area	RT (min)
1	96.74	9070.0641	10.01
2	3.26	305.6486	10.77
Total:	100	9375.7127	

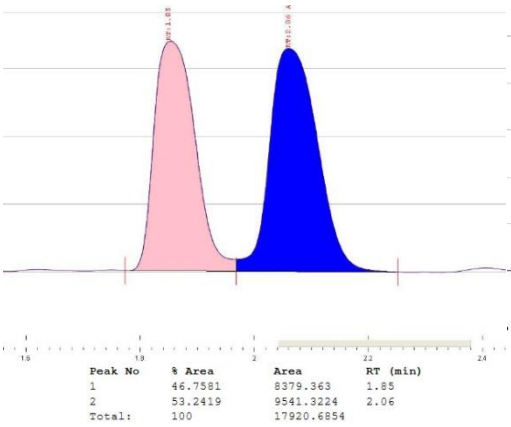


Methyl (*S*)-5-phenyl-4-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)pentanoate (1.131). The reaction was performed according to general procedure (***Method B)*** with methyl 3-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)propanoate (64.2 mg, 0.30 mmol, 1.00 equiv), sodium trifluoromethanesulfonate (103.2 mg, 0.60 mmol, 2.00 equiv), vinylmagnesium chloride (0.20 mL, 1.53 M in tetrahydrofuran, 0.30 mmol, 1.00 equiv), phenyl trifluoromethanesulfonate (81.4 mg, 0.36 mmol, 1.20 equiv), palladium (II) acetate (0.9 mL, 0.01 M in dimethyl sulfoxide, 0.009 mmol, 0.030 equiv), MandyPhos (**1.64**, 11.37 mg, 0.0108 mmol, 0.036 equiv). The unpurified product was purified by automated silica gel chromatography (Biotage 1% → 5 → 10% ethyl acetate in hexanes, stain in CAM) to afford colorless solid (77.3 mg, 81% yield). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.23 – 7.19 (m, 2H), 7.19 – 7.15 (m, 2H), 7.15 – 7.10 (m, 1H), 3.62 (s, 3H), 2.73 (dd, *J* = 13.7, 8.4 Hz, 1H), 2.64 (dd, *J* = 13.7, 7.6 Hz, 1H), 2.42 – 2.22 (m, 2H), 1.72 (q, *J* = 7.9 Hz, 2H), 1.35 (p, *J* = 7.8 Hz, 1H), 1.15 (s, 6H), 1.12 (s, 6H). **^{11}B NMR** (160 MHz, $CDCl_3$) δ 33.67. **^{13}C NMR** (151 MHz, $CDCl_3$) δ 174.25, 141.88, 129.05, 128.29, 125.94, 83.38, 51.63, 37.21, 33.75, 26.25, 25.43, 24.99, 24.92. **IR** (neat) ν_{max} 2977.22 (w), 2929.20 (w), 1737.15 (s), 1381.23 (m), 1320.47 (m), 1213.06 (m), 1132.14 (s), 699.57 (w) cm^{-1}. **HRMS** (DART) for $C_{18}H_{28}BO_4$ $[M+H]^+$ calculated: 319.2081, found: 319.2095. $[\alpha]^{20}_D$: -8.385 (*c* 2.555, $CHCl_3$, *l* =50 mm).

Analysis of Stereochemistry: Racemic compound was prepared according to the general procedure (***Method B, run at 60 ºC***) with $Pd(OAc)_2$ (5 mol%) and 1,1′-bis(dicyclohexylphosphino)ferrocene (6 mol%) as the catalyst. Chiral SFC (Chiracel ODR-

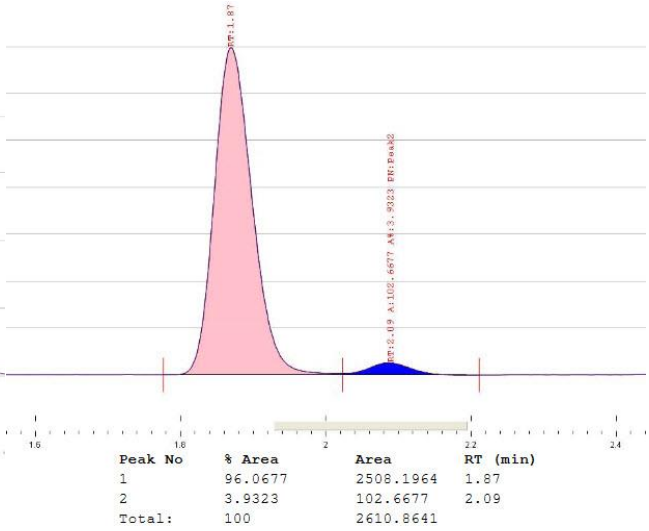
H, 5% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of methyl (*S*)-5-phenyl-4-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)pentanoate **(1.131)**.

Racemic Material

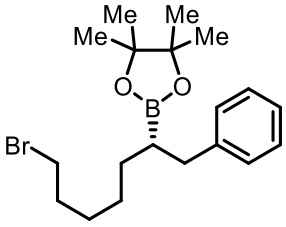


Peak No	% Area	Area	RT (min)
1	46.7581	8379.363	1.85
2	53.2419	9541.3224	2.06
Total:	100	17920.6854	

Standard Conditions



Peak No	% Area	Area	RT (min)
1	96.0677	2508.1964	1.87
2	3.9323	102.6677	2.09
Total:	100	2610.8641	

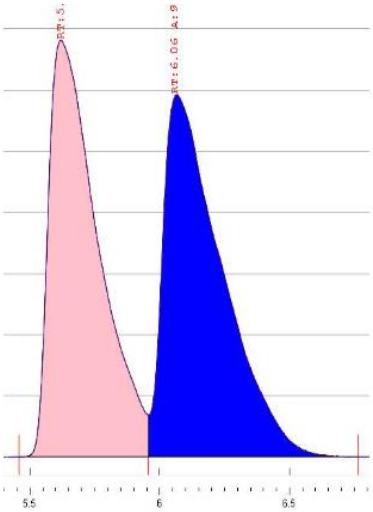


(*S*)-2-(7-bromo-1-phenylheptan-2-yl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (1.132). The reaction was performed according to the general procedure ***(Method B)*** with 2-(5-bromopentyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (83.1 mg, 0.30 mmol, 1.00 equiv), sodium trifluoromethanesulfonate (103.2 mg, 0.60 mmol, 2.00 equiv), vinylmagnesium chloride (0.20 mL, 1.53 M in tetrahydrofuran, 0.30 mmol, 1.00 equiv), phenyl trifluoromethanesulfonate (81.4 mg, 0.36 mmol, 1.20 equiv), palladium (II) acetate (0.90 mL, 0.01 M in dimethyl sulfoxide, 0.009 mmol, 0.030 equiv), MandyPhos (**1.64**, 11.37 mg, 0.0108 mmol, 0.036 equiv). The unpurified product was purified by automated silica gel chromatography (Biotage 1% → 5% ethyl acetate in hexanes, stain in CAM) to afford colorless oil (76.6 mg, 67% yield). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.22 (app t, *J* = 7.5 Hz, 2H), 7.18 (d, *J* = 7.0 Hz, 2H), 7.12 (app t, *J* = 7.2 Hz, 1H), 3.36 (t, *J* =

6.9 Hz, 2H), 2.70 (dd, *J* = 13.6, 8.5 Hz, 1H), 2.63 (dd, *J* = 13.6, 7.3 Hz, 1H), 1.81 (app p, *J* = 7.2 Hz, 2H), 1.48 – 1.26 (m, 7H), 1.15 (s, 6H), 1.12 (s, 6H). **^{11}B NMR** (128 MHz, $CDCl_3$) δ 33.86. **^{13}C NMR** (151 MHz, $CDCl_3$) δ 144.84, 131.48, 130.68, 128.25, 85.65, 39.96, 36.53, 35.34, 33.49, 30.98, 30.87, 28.44, 27.45, 27.37. **IR** (neat) ν_{max} 3025.93 (w), 2977.04 (m), 2927.75 (m), 2854.50 (m), 1454.40 (m), 1380.74 (m), 1319.26 (m), 1142.84 (s), 966.64 (m), 861.78 (m), 746.57 (m), 699.08 (m) cm^{-1}. **HRMS** (DART) for $C_{19}H_{34}BBrNO_2$ $[M+NH_4]^+$: calculated: 398.1866, found: 398.1847. $[\alpha]_D^{20}$ = – 6.243 (*c* 2.92, $CHCl_3$, *l* = 50 mm).

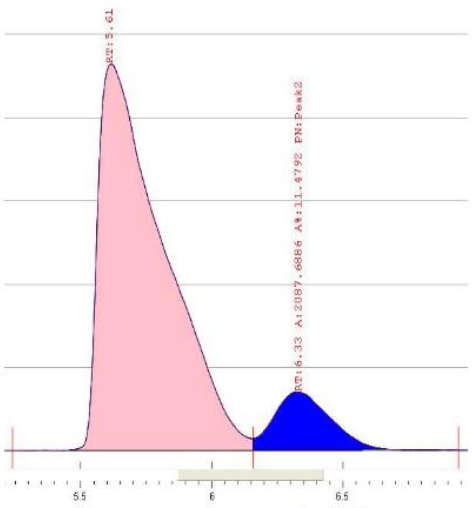
Analysis of Stereochemistry: Racemic compound was prepared according to the general procedure (***Method B, run at 60 ºC***) with $Pd(OAc)_2$ (5 mol%) and 1,1′-bis(dicyclohexylphosphino)ferrocene (6 mol%) as the catalyst. Chiral SFC (Chiracel ODR-H, 2% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of (*S*)-2-(7-bromo-1-phenylheptan-2-yl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane **(1.132)**.

Racemic Material

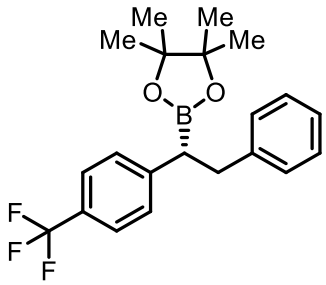


Peak No	% Area	Area	RT (min)
1	49.0818	8953.338	5.62
2	50.9182	9288.3425	6.06
Total:	100	18241.6805	

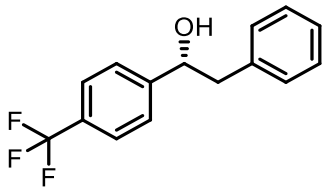
Standard Conditions



Peak No	% Area	Area	RT (min)
1	88.5208	16098.9933	5.61
2	11.4792	2087.6886	6.33
Total:	100	18186.6819	



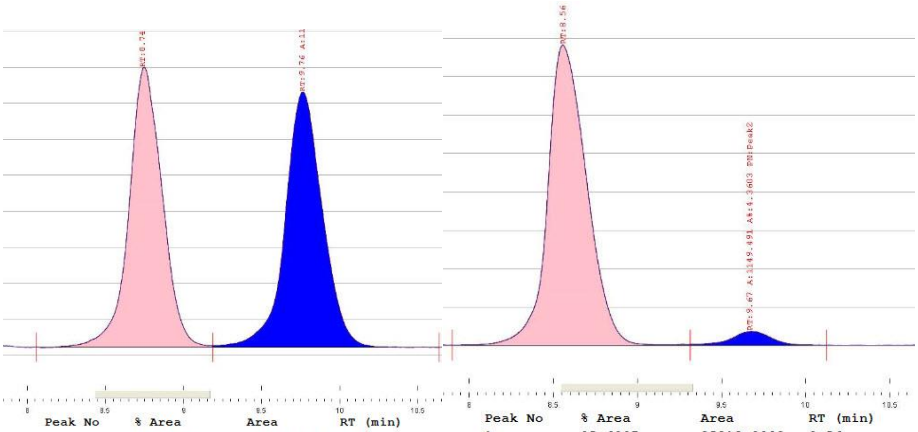
(*R*)-4,4,5,5-tetramethyl-2-(2-phenyl-1-(4-(trifluoromethyl) phenyl) ethyl)-1,3,2-dioxaborolane (1.133). The reaction was performed according to general procedure (***Method B, with the modification that the reaction was run at 60 ºC instead of 40 ºC)*** with 4,4,5,5-tetramethyl-2-(4-(trifluoromethyl)phenyl)-1,3,2-dioxaborolane (81.6 mg, 0.30 mmol, 1.00 equiv), sodium trifluoromethanesulfonate (103.2 mg, 0.60 mmol, 2.00 equiv), vinylmagnesium chloride (0.20 mL, 1.53 M in tetrahydrofuran, 0.30 mmol, 1.00 equiv), phenyl trifluoromethanesulfonate (81.4 mg, 0.36 mmol, 1.20 equiv), palladium (II) acetate (0.9 mL, 0.01 M in dimethyl sulfoxide, 0.009 mmol, 0.030 equiv), MandyPhos (**1.64**, 11.37 mg, 0.0108 mmol, 0.036). The unpurified product was purified by automated silica gel chromatography (Biotage 1% → 5% ethyl acetate in hexanes, stained in CAM) to afford white solid (77.9 mg, 69% yield). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.49 (d, *J* = 8.1 Hz, 2H), 7.33 (d, *J* = 8.1 Hz, 2H), 7.23 – 7.19 (m, 2H), 7.17 – 7.12 (m, 3H), 3.17 (dd, *J* = 13.6, 9.2 Hz, 1H), 2.96 (dd, *J* = 13.6, 7.4 Hz, 1H), 2.76 (app t, 1H), 1.12 (s, 6H), 1.11 (s, 6H). **^{11}B NMR** (160 MHz, $CDCl_3$) δ 32.59. **^{13}C NMR** (151 MHz, $CDCl_3$) δ 147.07, 141.26, 129.01, 128.88, 128.36, 127.90 (q, *J* = 32.2 Hz), 126.20, 125.41 (q, *J* = 3.8 Hz), 124.68 (q, *J* = 271.7 Hz), 83.90, 38.70, 34.77, 24.80, 24.72. **IR** (neat) ν_{max} 2979.33 (w), 2931.73 (w), 1616.08 (w), 1370.55 (w), 1321.35 (m), 1161.97 (w), 1135.95 (m), 1109.00 (m), 1067.27 (m), 843.69 (w), 698.28 (m) cm^{-1}. **HRMS** (DART) for $C_{21}H_{25}BF_3O_2$ $[M+H]^+$ calculated: 377.19, found: 377.1898. $[\alpha]^{20}_D$: -42.814 (*c* 3.20, $CHCl_3$, *l* =50 mm).



(*R*)-2-phenyl-1-(4-(trifluoromethyl)phenyl)ethan-1-ol (1.133-OH). Product **1.133** was oxidized according to *General Method for Oxidation of Boronic Ester Products.* **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.59 (d, *J* = 8.2 Hz, 2H), 7.45 (d, *J* = 8.1 Hz, 2H), 7.31 (app t, *J* = 7.5 Hz, 2H), 7.25 (app t, 1H), 7.17 (app d, *J* = 7.1 Hz, 2H), 4.96 – 4.91 (m, 1H), 3.03 (dd, *J* = 13.7, 4.7 Hz, 1H), 2.95 (dd, *J* = 13.7, 8.7 Hz, 1H), 2.09 – 2.01 (m, 1H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 147.86, 137.48, 129.97 (q, *J* = 32.1 Hz), 129.72, 128.89, 127.13, 126.39, 125.54 (q, *J* = 3.7 Hz), 124.38 (q, *J* = 271.9 Hz), 74.87, 46.36. **IR** (neat) ν_{max} 3327.52 (br), 2920.13 (w), 1325.74 (s), 1153.77 (m), 1120.51 (s), 1066.42 (s), 832.69 (w), 737.84 (w), 701.37 (w) cm^{-1}. **HRMS** (DART) for $C_{15}H_{12}F$ $[M+H-H_2O]^+$ calculated: 249.0891, found: 249.0881. $[\alpha]^{20}_D$: +7.565 (*c* 1.465, $CHCl_3$, *l* =50 mm).

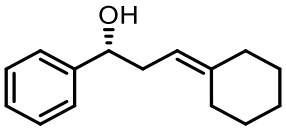
Analysis of Stereochemistry: Racemic compound was prepared according to the general procedure (***Method B, run at 60 ºC***) with $Pd(OAc)_2$ (5 mol%) and 1,1′-bis(dicyclohexylphosphino)ferrocene (6 mol%) as the catalyst. Chiral SFC (Chiracel OD-H, 5% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of (*R*)-2-phenyl-1-(4-(trifluoromethyl)phenyl)ethan-1-ol **(1.133-OH)**.

Racemic Material Standard Conditions



Peak No	% Area	Area	RT (min)
1	49.4338	11552.877	8.74
2	50.5662	11817.539	9.76
Total:	100	23370.416	

Peak No	% Area	Area	RT (min)
1	95.6397	25212.8832	8.56
2	4.3603	1149.491	9.67
Total:	100	26362.3742	

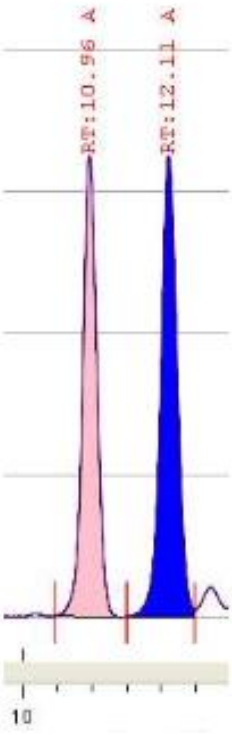


(R)*-3-Cyclohexylidene-1-phenylpropan-1-ol (1.134-OH).** The reaction was performed according to the general procedure ***(Method B) with 4,4,5,5-tetramethyl-2-phenyl-1,3,2-dioxaborolane (**1.94**, 61.2 mg, 0.30 mmol, 1.00 equiv), sodium trifluoromethanesulfonate (103.2 mg, 0.60 mmol, 2.00 equiv), vinylmagnesium chloride (0.20 mL, 1.53 M in tetrahydrofuran, 0.30 mmol, 1.00 equiv), cyclohexylidenemethyl trifluoromethanesulfonate (**1.179**, 87.9 mg, 0.36 mmol, 1.20 equiv), palladium (II) acetate (0.90 mL, 0.01 M in dimethyl sulfoxide, 0.009 mmol, 0.030 equiv), MandyPhos (**1.64**, 11.37 mg, 0.0108 mmol, 0.036 equiv). Unpurified product **1.134** was oxidized according to *General Method for Oxidation of Boronic Ester Products.* The unpurified product was purified by silica gel chromatography (0% → 20% ethyl acetate in hexanes, stained in CAM) to afford a colorless oil (26.6 mg, 41% yield). All spectroscopic data were in accord with the literature.[20]

Analysis of Stereochemistry: Racemic compound was prepared and reported previously[49] with 4,4,5,5-tetramethyl-2-vinyl-1,3,2-dioxaborolane, and $Pd(OAc)_2$ (5 mol%) and 1,1′-

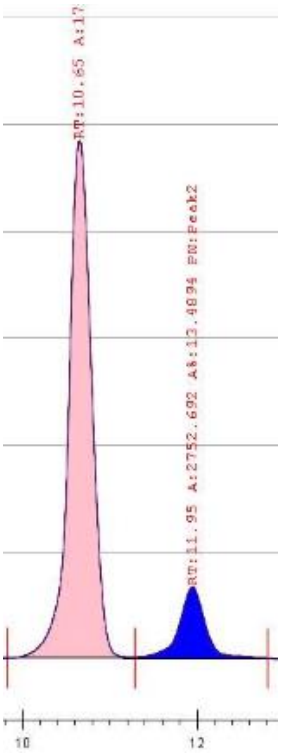
bis(dicyclohexylphosphino) ferrocene (6 mol%) as the catalyst. Chiral SFC (Chiracel OD-H, 5% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of (*R*)-3-cyclohexylidene-1-phenylpropan-1-ol **(1.134-OH)**.

Racemic Material

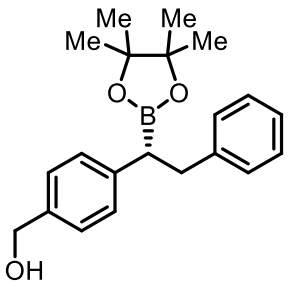


Peak No	% Area	Area	RT (min)
1	46.2512	4641.7789	10.96
2	53.7488	5394.2368	12.11
Total:	100	10036.0157	

Standard Conditions



Peak No	% Area	Area	RT (min)
1	86.5106	17653.659	10.65
2	13.4894	2752.692	11.95
Total:	100	20406.351	

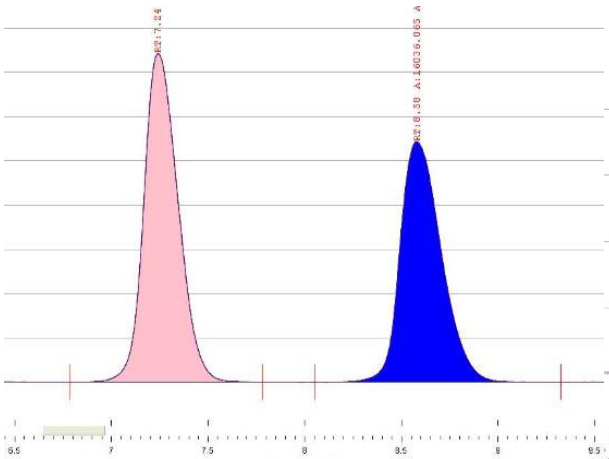


(*R*)-(4-(2-phenyl-1-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)ethyl)phenyl)methanol (1.135). The reaction was performed according to the general procedure (***Method B)*** with (4-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)phenyl)methanol (70.2 mg, 0.30 mmol, 1,00 equiv), sodium trifluoromethanesulfonate (103.2 mg, 0.60 mmol, 2.00

equiv), vinylmagnesium chloride (0.20 mL, 1.53 M in tetrahydrofuran, 0.30 mmol, 1.00 equiv), phenyl trifluoromethanesulfonate (81.4 mg, 0.36 mmol, 1.20 equiv), palladium (II) acetate (0.9 mL, 0.01 M in dimethyl sulfoxide, 0.009 mmol, 0.030 equiv), MandyPhos (**1.64**, 11.37 mg, 0.0108 mmol, 0.036 equiv). The unpurified product was purified by automated silica gel chromatography (Biotage 1% → 10% ethyl acetate in hexanes, stained in CAM) to afford white solid (75.1 mg, 74% yield). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.25 – 7.14 (m, 8H), 7.12 (app t, *J* = 7.1 Hz, 1H), 4.62 (d, *J* = 5.3 Hz, 2H), 3.13 (dd, *J* = 13.5, 9.6 Hz, 1H), 2.93 (dd, *J* = 13.5, 7.1 Hz, 1H), 2.67 (dd, *J* = 9.3, 7.3 Hz, 1H), 1.59 (app t, *J* = 5.6 Hz, 1H), 1.09 (s, 6H), 1.09 (s, 6H). **^{11}B NMR** (160 MHz, $CDCl_3$) δ 32.87. **^{13}C NMR** (151 MHz, $CDCl_3$) δ 142.37, 141.83, 138.09, 129.07, 128.82, 128.26, 127.43, 125.99, 83.66, 65.57, 39.07, 34.39, 24.82, 24.74. **IR** (neat) ν_{max} 3412.74 (br), 2976.75 (w), 2928.81 (w), 2863.18 (w), 1360.14 (m), 1325.38 (s), 1139.99 (s), 967.34 (w), 854.84 (w), 742.70 (w), 698.84 (w) cm^{-1}. **HRMS** (DART) for $C_{21}H_{26}BO_2$ $[M+ H-H_2O]^+$ calculated: 321.2026, found: 321.2017. $[\alpha]^{20}_D$: -43.381 (*c* 3.18, $CHCl_3$, *l* =50 mm).

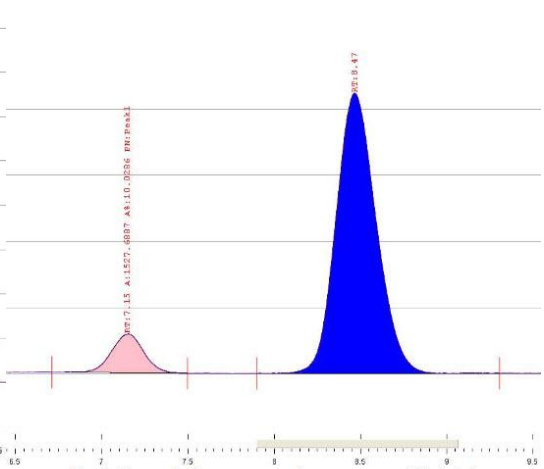
Analysis of Stereochemistry: Racemic compound was prepared according to the general procedure (***Method B****, run at 60 ºC*) with $Pd(OAc)_2$ (5 mol%) and (S_p,S_p)-MandyPhos **1.64** (1.8 mol%), and (R_p,R_p)-MandyPhos **1.64** (1.8 mol%) as the catalyst. Chiral SFC (Chiracel AD-H, 10% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of (*R*)-(4-(2-phenyl-1-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)ethyl)phenyl)methanol **(1.135)**.

Racemic Material

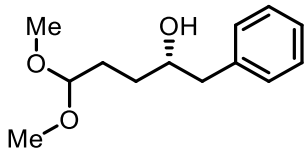


Peak No	% Area	Area	RT (min)
1	53.2621	18274.5947	7.24
2	46.7379	16036.065	8.58
Total:	100	34310.6597	

Standard Conditions



Peak No	% Area	Area	RT (min)
1	10.0286	1527.6887	7.15
2	89.9714	13705.5946	8.47
Total:	100	15233.2833	

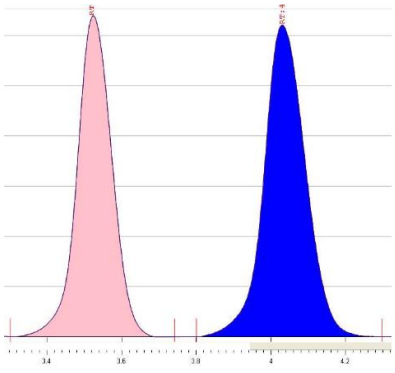


(*S*)-5,5-dimethoxy-1-phenylpentan-2-ol (1.136-OH). The reaction was performed according to the general procedure *(**Method B**)* with 4,4,5,5-tetramethyl-2-(3,3-dimethoxypropyl)-1,3,2-dioxaborolane (69.0 mg, 0.30 mmol, 1.00 equiv), sodium trifluoromethanesulfonate (103.2 mg, 0.60 mmol, 2.00 equiv), vinylmagnesium chloride (0.20 mL, 1.53 M in tetrahydrofuran, 0.30 mmol, 1.00 equiv), phenyl trifluoromethanesulfonate (81.4 mg, 0.36 mmol, 1.20 equiv) palladium (II) acetate (0.90 mL, 0.01 M in dimethyl sulfoxide, 0.009 mmol, 0.030 equiv), MandyPhos (**1.64**, 11.37 mg, 0.0108 mmol, 0.036 equiv). Unpurified product **1.136** was oxidized according to *General Method for Oxidation of Boronic Ester Products.* The unpurified product was purified by automated silica gel chromatography (Biotage 1% → 20% ethyl acetate in hexanes, stained in CAM) to afford colorless oil (49.0 mg, 73% yield). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.30 (app t, *J* = 7.4 Hz, 2H), 7.24 – 7.19 (m, 3H), 4.38 (app t, *J* = 5.5 Hz, 1H), 3.82 (dddd, *J* = 8.4, 8.4, 4.3, 4.3 Hz, 1H), 3.32 (s, 3H), 3.32 (s, 3H), 2.79 (dd, *J* = 13.6, 4.7 Hz, 1H), 2.69 (dd, *J* = 13.6, 8.1 Hz, 1H), 2.17 (s,

1H), 1.81 (dddd, J = 14.4, 9.0, 6.0, 6.0 Hz, 1H), 1.72 (dddd, J = 15.0, 9.0, 6.0, 6.0 Hz, 1H), 1.63 (dddd, J = 15.0, 13.2, 9.0, 3.6 Hz, 1H), 1.52 (dddd, J = 18.0, 9.0, 9.0, 6.0 Hz, 1H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 138.76, 129.57, 128.68, 126.58, 104.82, 72.57, 53.22, 52.96, 44.31, 31.76, 29.17. **IR** (neat) ν_{max} 3453.77 (m, br), 3026.59 (w), 2935.82 (s), 2830.25 (m), 1495.30 (m), 1453.48 (m), 1385.15 (m), 1362.68 (m), 1127.88 (s), 1055.47 (s), 961.97 (m), 744.01 (s), 700.87 (s) cm^{-1}. **HRMS** (DART) for $C_{13}H_{19}O_2$ $[M+H-H_2O]^+$: calculated: 207.1385, found: 207.1379. $[\alpha]_D^{20}$ = + 7.783 (*c* 2.14, $CHCl_3$, *l* = 50 mm).

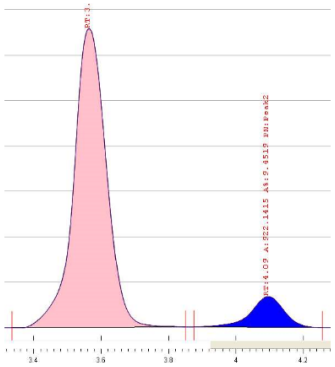
Analysis of Stereochemistry: Racemic compound was prepared according to the general procedure (***Method B, run at 60 ºC***) with $Pd(OAc)_2$ (3 mol%), (S_p,S_p)-MandyPhos **1.64** (1.8 mol%), and (R_p,R_p)-MandyPhos **1.64** (1.8 mol%) as the catalyst. Chiral SFC (Chiracel OD-H, 10% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of (*S*)-5,5-dimethoxy-1-phenylpentan-2-ol **(1.136-OH)**.

Racemic Material

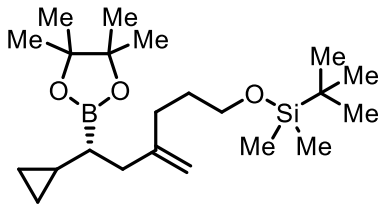


Peak No	% Area	Area	RT (min)
1	46.3381	4158.5954	3.52
2	53.6619	4815.868	4.03
Total:	100	8974.4634	

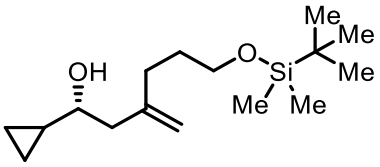
Standard Conditions



Peak No	% Area	Area	RT (min)
1	90.5481	8834.0367	3.56
2	9.4519	922.1415	4.09
Total:	100	9756.1782	



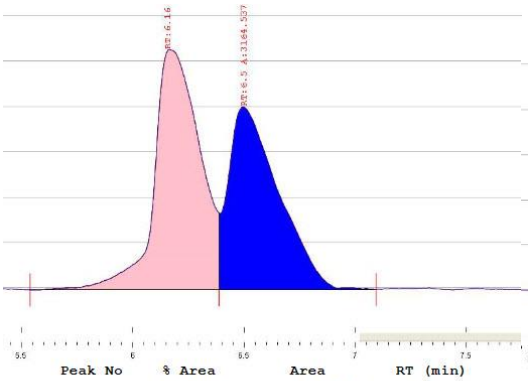
(*R*)-*tert*-butyl((6-cyclopropyl-4-methylene-6-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)hexyl)oxy) dimethylsilane (1.137). The reaction was performed according to general procedure (***Method B, with the modification that tetrahydrofuran was used instead of 1:1 dimethyl sulfoxide:tetrahydrofuran)*** with 2-cyclopropyl-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (50.4 mg, 0.30 mmol, 1.00 equiv), sodium trifluoromethanesulfonate (103.2 mg, 0.60 mmol, 2.00 equiv), vinylmagnesium chloride (0.20 mL, 1.53M in tetrahydrofuran, 0.30 mmol, 1.00 equiv), 5-((*tert*-butyldimethylsilyl)oxy)pent-1-en-2-yl trifluoromethanesulfonate (**1.181**, 125.3 mg, 0.36 mmol, 1.20 equiv), palladium (II) acetate (0.9 mL, 0.01 M in dimethyl sulfoxide, 0.009 mmol, 0.030 equiv), MandyPhos (**1.64**, 11.37 mg, 0.0108 mmol, 0.036 equiv). The unpurified product was purified by automated silica gel chromatography (Biotage 1% → 5% ethyl acetate in hexanes, stained in CAM) to afford colorless oil (66.2 mg, 56% yield). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 4.70 (s, 1H), 4.66 (s, 1H), 3.57 (dddd, *J* = 6.6, 1.6 Hz, 2H), 2.27 – 2.14 (m, 2H), 2.01 (app t, *J* = 7.7 Hz, 2H), 1.69 – 1.53 (m, 2H), 1.20 (s, 12H), 0.87 (s, 9H), 0.71 – 0.61 (m, 1H), 0.61 – 0.54 (m, 1H), 0.44 – 0.31 (m, 2H), 0.12 (dddd, *J* = 9.3, 5.0 Hz, 1H), 0.05 – -0.03 (m, 7H). **^{11}B NMR** (160 MHz, THF-d_8) δ 33.55. **^{13}C NMR** (151 MHz, $CDCl_3$) δ 155.10, 142.24, 129.04, 128.26, 125.87, 83.28, 79.30, 45.08, 44.21, 38.29, 34.99, 32.21, 31.17, 28.67, 25.04, 24.95. **IR** (neat) ν_{max} 2928.91 (w), 1378.20 (w), 1319.33 (w), 1144.04 (m), 1099.98 (m), 834.98 (m), 774.57 (w) cm^{-1}. **HRMS** (DART) for $C_{22}H_{44}BO_3Si$ $[M+H]^+$ calculated: 395.3179, found: 395.319397 $[\alpha]^{20}_D$: -12.203 (c = 1.360, $CHCl_3$, *l* =50 mm).



(*R*)-6-((*tert*-butyldimethylsilyl)oxy)-1-cyclopropyl-3-methylenehexan-1-ol (1.137-OH). Product **1.137** was oxidized according to *General Method for Oxidation of Boronic Ester Products.* **^{1}H NMR** (600 MHz, $CDCl_3$) δ 4.88 – 4.85 (m, 1H), 4.85 – 4.82 (m, 1H), 3.59 (dddd, *J* = 10.1, 6.3, 3.7, 1.6 Hz, 2H), 2.99 (ddd, *J* = 9.3, 3.3 Hz, 1H), 2.38 (dd, *J* = 14.0, 3.3 Hz, 1H), 2.23 (app dd, 1H), 2.12 – 2.01 (m, 2H), 1.76 (s, 1H), 1.70 – 1.58 (m, 2H), 0.91 – 0.83 (m, 10H), 0.54 – 0.44 (m, 2H), 0.36 – 0.29 (m, 1H), 0.21 – 0.14 (m, 1H), 0.04 – -0.00 (m, 6H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 146.54, 112.39, 74.11, 62.89, 44.55, 32.26, 31.14, 26.17, 18.55, 17.72, 3.13, 2.51, -5.06. **IR** (neat) ν_{max} 3390.94 (br), 3077.98 (w), 2928.92 (s), 2856.84 (s), 1471.51 (w), 1254.11 (m), 1100.10 (s), 834.26 (s), 774.57 (m) cm^{-1}. **HRMS** (DART) for $C_{16}H_{31}BOSi$ $[M+H-H_2O]^+$ calculated: 267.2144, found: 267.2153 $[\alpha]^{20}_D$: -4.404 (*c* 2.050, $CHCl_3$, *l* =50 mm).

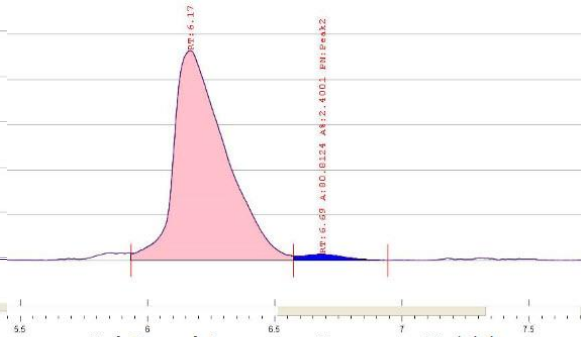
Analysis of Stereochemistry: Racemic compound was prepared according to the general procedure (***Method B, run at 60 ºC***) with $Pd(OAc)_2$ (5 mol%) and 1,1′-bis(dicyclohexylphosphino)ferrocene (6 mol%) as the catalyst. Chiral SFC (Chiracel OD-H, 1% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of (*R*)-6-((tert-butyldimethylsilyl)oxy)-1-cyclopropyl-3-methylenehexan-1-ol **(1.137-OH)**.

Racemic Material

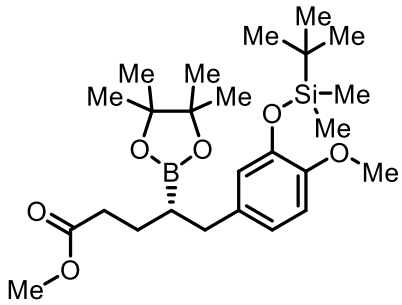


Peak No	% Area	Area	RT (min)
1	54.4908	3789.088	6.16
2	45.5092	3164.5373	6.5
Total:	100	6953.6253	

Standard Conditions



Peak No	% Area	Area	RT (min)
1	97.5999	3286.2517	6.17
2	2.4001	80.8124	6.69
Total:	100	3367.0641	

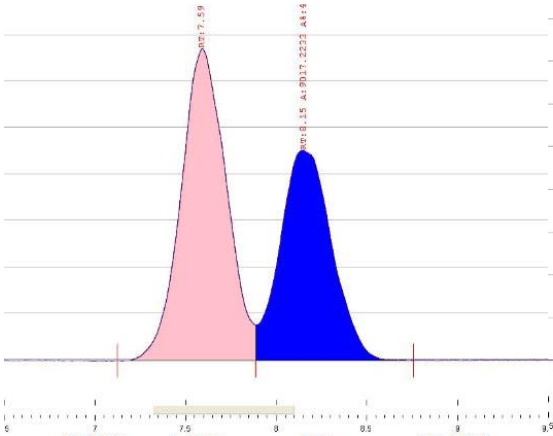


methyl (*S*)-5-(3-((*tert*-butyldimethylsilyl)oxy)-4-methoxyphenyl)-4-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)pentanoate (1.138). The reaction was performed according to general procedure (***Method B)*** with methyl 3-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)propanoate (64.2 mg, 0.30 mmol, 1.00 equiv), sodium trifluoromethanesulfonate (103.2 mg, 0.60 mmol, 2.00 equiv), vinylmagnesium chloride (0.20 mL, 1.53 M in tetrahydrofuran, 0.30 mmol, 1.00 equiv), 3-((*tert*-butyldimethylsilyl)oxy)-4-methoxyphenyl trifluoromethanesulfonate (139.1 mg, 0.36 mmol, 1.20 equiv), palladium (II) acetate (0.9 mL, 0.01 M in dimethyl sulfoxide, 0.009 mmol, 0.030 equiv), MandyPhos (**1.64**, 11.37 mg, 0.0108 mmol, 0.036 equiv). The unpurified product was purified by automated silica gel chromatography (Biotage 1% → 5 →10% ethyl acetate in hexanes, stain in CAM) to afford white solid (99.0 mg, 69% yield). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 6.72 – 6.67 (m, 3H), 3.73 (s, 3H), 3.61 (s, 3H), 2.63 (dd, *J* = 13.8, 8.2 Hz, 1H), 2.51 (dd, *J* = 13.8, 7.8 Hz, 1H), 2.39 – 2.22 (m, 2H), 1.71 – 1.63

(m, 2H), 1.27 (app p, J = 8.0 Hz, 1H), 1.16 (s, 6H), 1.14 (s, 6H), 0.96 (s, 9H), 0.11 (s, 6H). **^{11}B NMR** (160 MHz, $CDCl_3$) δ 33.73. **^{13}C NMR** (151 MHz, $CDCl_3$) δ 174.30, 149.26, 144.82, 134.60, 122.05, 121.87, 112.19, 83.36, 55.82, 51.62, 36.37, 33.81, 26.12, 25.97, 25.52, 25.05, 24.97, 18.66, -4.41, -4.42. **IR** (neat) ν_{max} 2929.47 (w), 2857.37 (w), 1738.36 (s), 1509.32 (s), 1317.69 (m), 1140.73 (s), 987.08 (m), 838.67 (s), 782.09 (m) cm^{-1}. **HRMS** (DART) for $C_{25}H_{44}BO_{6Si}$ $[M+H]^+$ calculated: 479.3, found: 479.2983. $[\alpha]^{20}_D$: -7.689 (*c* 1.865, $CHCl_3$, *l* =50 mm).

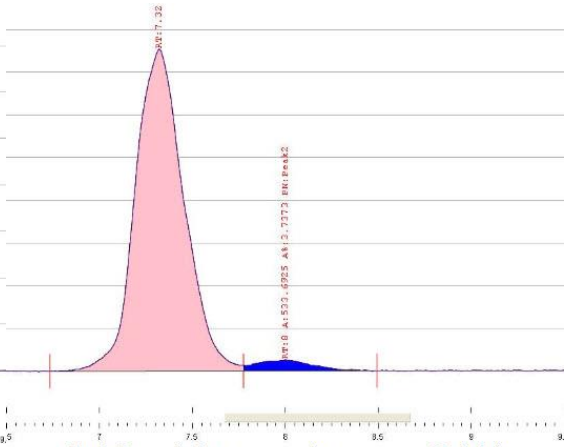
Analysis of Stereochemistry: Racemic compound was prepared according to the general procedure (***Method B****, run at 60 ºC*) with $Pd(OAc)_2$ (5 mol%) and 1,1′-bis(dicyclohexylphosphino)ferrocene (6 mol%) as the catalyst. Chiral SFC (Chiracel OJ-H, 1% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of methyl (*S*)-5-(3-((*tert*-butyldimethylsilyl)oxy)-4-methoxyphenyl)-4-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)pentanoate **(1.138)**.

Racemic Material

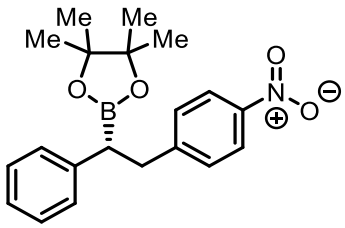


Peak No	% Area	Area	RT (min)
1	56.4852	11704.9976	7.59
2	43.5148	9017.2233	8.15
Total:	100	20722.2209	

Standard Conditions



Peak No	% Area	Area	RT (min)
1	96.2627	13746.3978	7.32
2	3.7373	533.6925	8
Total:	100	14280.0903	

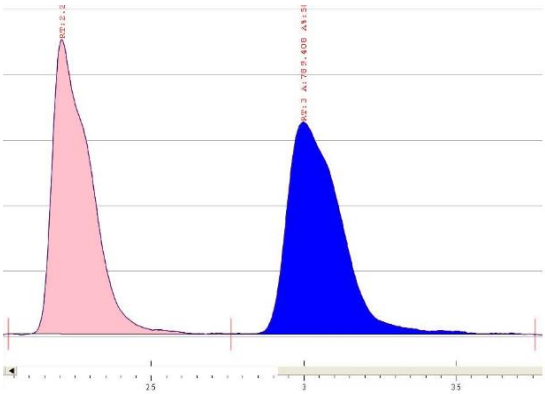


(*R*)-4,4,5,5-tetramethyl-2-(2-(4-nitrophenyl)-1-phenylethyl)-1,3,2-dioxaborolane (1.140). The reaction was performed according to the general procedure ***(Method C)*** with 4,4,5,5-tetramethyl-2-phenyl-1,3,2-dioxaborolane (**1.94**, 61.2 mg, 0.30 mmol, 1.00 equiv), sodium trifluoromethanesulfonate (154.9 mg, 0.90 mmol, 3.00 equiv), vinylmagnesium chloride (0.20 mL, 1.53 M in tetrahydrofuran, 0.30 mmol, 1.00 equiv), 4-bromonitrobenzene (72.7 mg, 0.36 mmol, 1.20 equiv), palladium (II) acetate (0.90 mL, 0.01 M in dimethyl sulfoxide, 0.009 mmol, 0.030 equiv), MandyPhos (**1.64**, 11.37 mg, 0.0108 mmol, 0.036 equiv). The unpurified product was purified by silica gel chromatography (30% → 60% → 100% CH_2Cl_2 in hexanes, stained in CAM) to afford yellow solid (59.6 mg, 56% yield). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 8.12 (d, *J* = 8.6 Hz, 2H), 7.34 (d, *J* = 8.5 Hz, 2H), 7.31 (app t, *J* = 7.6 Hz, 2H), 7.27 – 7.18 (m, 3H), 3.31 (dd, *J* = 13.6, 8.7 Hz, 1H), 3.10 (dd, *J* = 13.6, 7.8 Hz, 1H), 2.71 (app t, *J* = 8.2 Hz, 1H), 1.21 (s, 6H), 1.19 (s, 6H). **^{11}B NMR** (128 MHz, $CDCl_3$) δ 31.17. **^{13}C NMR** (151 MHz, $CDCl_3$) δ 149.97, 146.48, 141.58, 129.84, 128.70, 128.57, 125.99, 123.47, 83.90, 38.82, 34.20, 24.77, 24.75. **IR** (neat) ν_{max} 2973.89 (m), 2928.27 (w), 1600.99 (m), 1514.68 (s), 1344.29 (s), 1137.89 (s), 963.97 (m), 847.21 (s), 703.28 (s) cm^{-1}. **HRMS** (DART) for $C_{20}H_{25}BNO_4$ $[M+H]^+$: calculated: 354.1877, found: 354.1892. $[\alpha]_D^{20}$ = – 56.087 (*c* 2.10, $CHCl_3$, *l* = 50 mm).

Analysis of Stereochemistry: Racemic compound was prepared according to the general procedure (***Method C, run at 60 ºC***) with $Pd(OAc)_2$ (5 mol%) and 1,1′-bis(diisopropylphosphino)ferrocene (6 mol%) as the catalyst. Chiral SFC (Chiracel OJ-H,

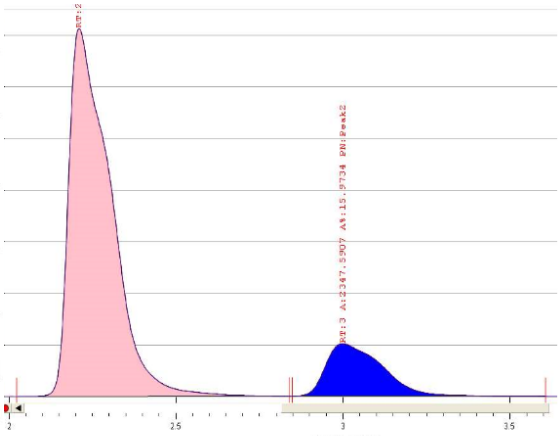
8% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of (*R*)-4,4,5,5-tetramethyl-2-(2-(4-nitrophenyl)-1-phenylethyl)-1,3,2-dioxaborolane **(1.140)**.

Racemic Material

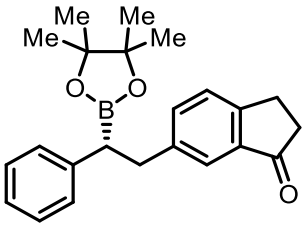


Peak No	% Area	Area	RT (min)
1	49.4108	771.0201	2.21
2	50.5892	789.408	3
Total:	100	1560.4281	

Standard Conditions



Peak No	% Area	Area	RT (min)
1	84.0266	12349.2825	2.21
2	15.9734	2347.5907	3
Total:	100	14696.8732	

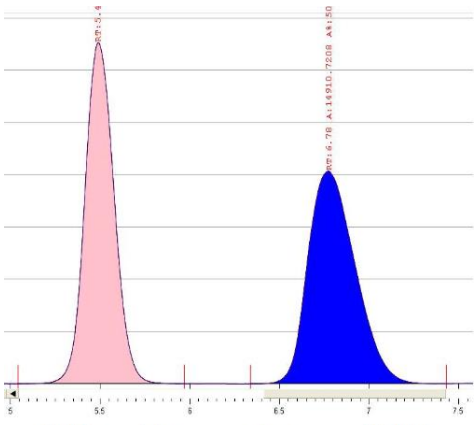


(*R*)-6-(2-phenyl-2-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl) ethyl)-2,3-dihydro-1H-inden-1-one (1.141). The reaction was performed according to the general procedure ***(Method C)*** with 4,4,5,5-tetramethyl-2-phenyl-1,3,2-dioxaborolane (**1.94**, 61.2 mg, 0.30 mmol, 1.00 equiv), sodium trifluoromethanesulfonate (154.9 mg, 0.90 mmol, 3.00 equiv), vinylmagnesium chloride (0.20 mL, 1.53 M in tetrahydrofuran, 0.30 mmol, 1.00 equiv), 6-bromoindanone (76.0 mg, 0.36 mmol, 1.20 equiv), palladium (II) acetate (0.90 mL, 0.01 M in dimethyl sulfoxide, 0.009 mmol, 0.030 equiv), MandyPhos (**1.64**, 11.37 mg, 0.0108 mmol, 0.036 equiv). The unpurified product was purified by automated silica gel chromatography (Biotage 1% →40% ethyl acetate in hexanes, stained in CAM) to afford white solid (90.2 mg, 83% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.59

(s, 1H), 7.35 (dd, J = 7.8, 1.6 Hz, 1H), 7.28 (d, J = 7.8 Hz, 1H), 7.24 – 7.16 (m, 4H), 7.10 (app t, J = 7.0 Hz, 1H), 3.20 (dd, J = 13.5, 9.3 Hz, 1H), 3.04 (app t, J = 5.8 Hz, 2H), 2.96 (dd, J = 13.5, 7.1 Hz, 1H), 2.66 – 2.59 (m, 3H), 1.11 (s, 12H). **^{11}B NMR** (128 MHz, $CDCl_3$) δ 32.58. **^{13}C NMR** (126 MHz, $CDCl_3$) δ 207.13, 153.04, 142.25, 141.46, 137.23, 135.90, 128.56, 128.54, 126.32, 125.70, 123.85, 83.70, 38.56, 36.73, 34.81, 25.61, 24.76, 24.73. **IR** (neat) ν_{max} 3024.40 (w), 2976.54 (m), 2926.69 (m), 2862.22 (w), 1707.07 (s), 1361.02 (s), 1325.34 (s), 1279.18 (m), 1139.02 (s), 967.44 (m), 840.00 (m), 757.28 (m), 700.39 (s) cm^{-1}. **HRMS** (DART) for $C_{23}H_{28}BO_3$ $[M+H]^+$: calculated: 363.21315, found: 363.21350. $[\alpha]_D^{20}$ = – 61.409 (*c* 3.37, $CHCl_3$, *l* = 50 mm).

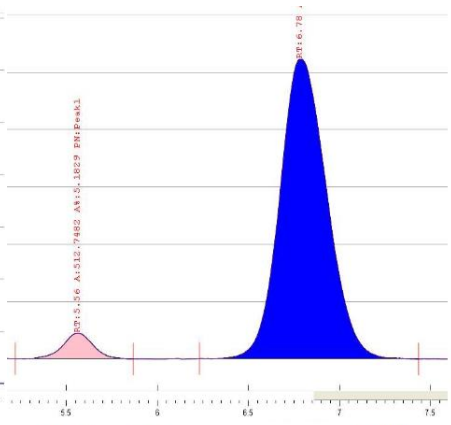
Analysis of Stereochemistry: Racemic compound was prepared according to the general procedure (***Method C, run at 60 ºC***) with $Pd(OAc)_2$ (5 mol%) and 1,1′-bis(diisopropylphosphino)ferrocene (6 mol%) as the catalyst. Chiral SFC (Chiracel OJ-H, 5% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of (*R*)-6-(2-phenyl-2-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)ethyl)-2,3-dihydro-1H-inden-1-one **(1.141)**.

Racemic Material

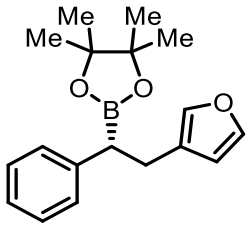


Peak No	% Area	Area	RT (min)
1	49.8	14791.8907	5.49
2	50.2	14910.7208	6.78
Total:	100	29702.6115	

Standard Conditions



Peak No	% Area	Area	RT (min)
1	5.1829	512.7482	5.56
2	94.8171	9380.2646	6.78
Total:	100	9893.0128	

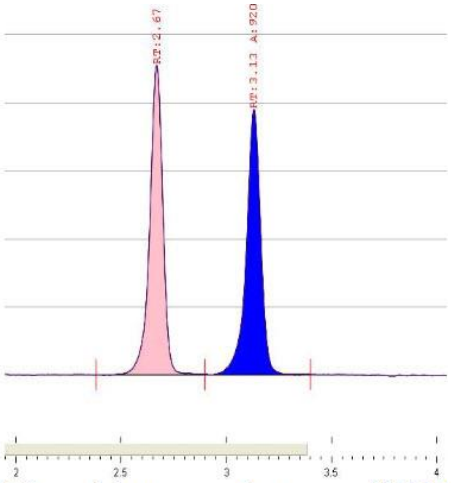


(*R*)-2-(2-(furan-3-yl)-1-phenylethyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (1.142). The reaction was performed according to general procedure (***Method C)*** with 4,4,5,5-tetramethyl-2-phenyl-1,3,2-dioxaborolane (**1.94**, 61.2 mg, 0.30 mmol, 1.00 equiv), sodium trifluoromethanesulfonate (154.9 mg, 0.90 mmol, 3.00 equiv), vinylmagnesium chloride (0.20 mL, 1.53 M in tetrahydrofuran, 0.30 mmol, 1.00 equiv), 3-bromofuran (52.9 mg, 0.36 mmol, 1.20 equiv), palladium (II) acetate (0.9 mL, 0.01 M in dimethyl sulfoxide, 0.009 mmol, 0.030 equiv), MandyPhos (**1.64**, 11.37 mg, 0.0108 mmol, 0.036 equiv). The unpurified product was purified by automated silica gel chromatography (Biotage 1% →5% ethyl acetate in hexanes, stained in CAM) to afford white solid (71.4 mg, 65% yield). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.29 – 7.22 (m, 5H), 7.18 – 7.12 (m, 2H), 6.22 (s, 1H), 2.98 (dd, J = 14.4, 9.5 Hz, 1H), 2.75 (dd, J = 14.4, 7.0 Hz, 1H), 2.59 (dd, J = 9.3, 7.1 Hz, 1H), 1.15 (s, 6H), 1.14 (s, 6H). **^{11}B NMR** (160 MHz, THF-d_8) δ 32.78. **^{13}C NMR** (151 MHz, $CDCl_3$) δ 142.73, 142.52, 139.55, 128.56, 128.51, 125.66, 124.75, 111.55, 83.65, 33.46,

28.03, 24.80, 24.75. **IR** (neat) ν_{max} 2977.58 (w), 2930.86 (w), 1493.42. (w), 1451.59.88 (w), 1351.13 (w), 1325.48 (s), 1140.24 (s), 1023.50 (m), 966.20 (m), 872.27 (m), 850.44 (m). 775.04 (m), 700.20 (m) cm^{-1}. **HRMS** (DART) for $C_{18}H_{24}BO_3$ $[M+H]^+$ calculated: 299.18185, found: 299.18238. $[\alpha]^{20}_D$: -35.466 (*c* 1.550, $CHCl_3$, *l* =50 mm).

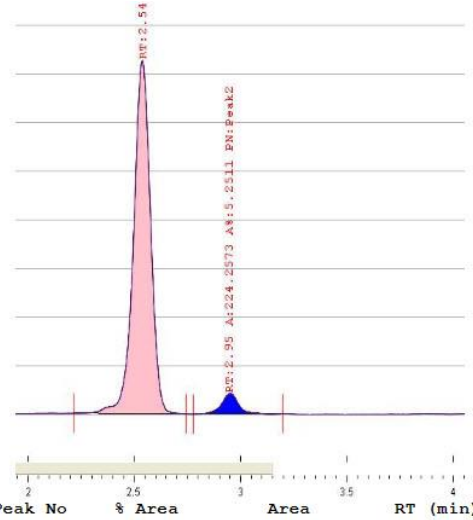
Analysis of Stereochemistry: Racemic compound was prepared according to the general procedure (***Method C, run at 60 ºC***) with $Pd(OAc)_2$ (5 mol%) and 1,1′-bis(dicyclohexylphosphino)ferrocene (6 mol%) as the catalyst. Chiral SFC (Chiracel OJ-H, 1% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of (*R*)-2-(2-(furan-3-yl)-1-phenylethyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane **(1.142)**.

Racemic Material

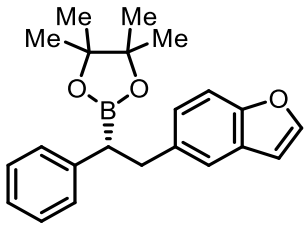


Peak No	% Area	Area	RT (min)
1	51.6531	983.5679	2.67
2	48.3469	920.6134	3.13
Total:	100	1904.1813	

Standard Conditions



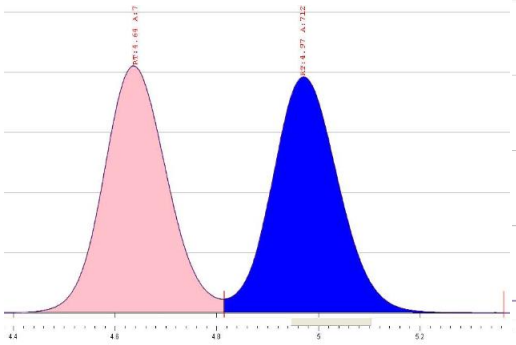
Peak No	% Area	Area	RT (min)
1	94.7489	4046.431	2.54
2	5.2511	224.2573	2.95
Total:	100	4270.6883	



(*R*)-2-(2-(benzofuran-5-yl)-1-phenylethyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (1.143). The reaction was performed according to the general procedure *(**Method C**)* with 4,4,5,5-tetramethyl-2-phenyl-1,3,2-dioxaborolane (**1.94**, 61.2 mg, 0.30 mmol, 1.00 equiv), sodium trifluoromethanesulfonate (154.9 mg, 0.90 mmol, 3.00 equiv), vinylmagnesium chloride (0.20 mL, 1.53 M in tetrahydrofuran, 0.30 mmol, 1.00 equiv), 5-bromobenzofuran (70.9 mg, 0.36 mmol, 1.20 equiv), palladium (II) acetate (0.90 mL, 0.01 M in dimethyl sulfoxide, 0.009 mmol, 0.030 equiv), MandyPhos (**1.64**, 11.37 mg, 0.0108 mmol, 0.036 equiv). The unpurified product was purified by automated silica gel chromatography (Biotage 0% →10% ethyl acetate in hexanes, stained in CAM) to afford colorless oil (79.4 mg, 76% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.52 (s, 1H), 7.39 (s, 1H), 7.33 (d, *J* = 8.5 Hz, 1H), 7.28 – 7.18 (m, 4H), 7.11 (d, *J* = 8.2 Hz, 2H), 6.63 (s, 1H), 3.24 (dd, *J* = 13.2, 10.1 Hz, 1H), 3.04 (dd, *J* = 13.4, 6.8 Hz, 1H), 2.70 (dd, *J* = 9.0, 7.0 Hz, 1H), 1.08 (s, 6H), 1.06 (s, 6H). **^{11}B NMR** (128 MHz, $CDCl_3$) δ 33.20. **^{13}C NMR** (126 MHz, $CDCl_3$) δ 153.78, 145.05, 142.81, 136.41, 128.59, 128.52, 127.42, 125.61, 125.57, 121.20, 110.87, 106.57, 83.55, 38.96, 35.34, 24.74, 24.73. **IR** (neat) ν_{max} 3058.01 (w), 3024.78 (w), 2976.61 (m), 2929.75 (m), 2859.41 (w), 1467.87 (m), 1360.28 (s), 1323.53 (s), 1139.59 (s), 1031.41 (m), 968.33 (m), 850.72 (m), 765.57 (m), 734.35 (m), 700.04 (s) cm^{-1}. **HRMS** (DART) for $C_{22}H_{26}BO_3$ $[M+H]^+$: calculated: 349.1975, found: 349.1980. $[\alpha]_D^{20}$ = – 43.515 (*c* 3.495, $CHCl_3$, *l* = 50 mm).

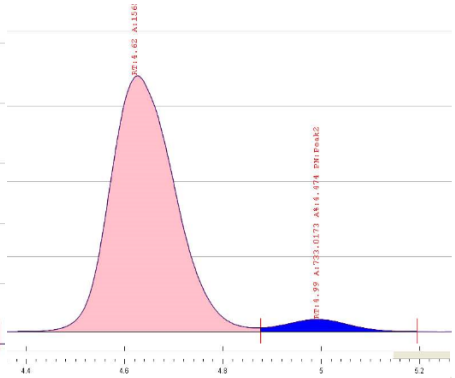
Analysis of Stereochemistry: Racemic compound was prepared according to the general procedure (***Method C, run at 60 ºC***) with $Pd(OAc)_2$ (5 mol%) and 1,1′-bis(diisopropylphosphino)ferrocene (6 mol%) as the catalyst. Chiral SFC (Chiracel OJ-H, 5% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of (*R*)-2-(2-(benzofuran-5-yl)-1-phenylethyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane **(1.143)**.

Racemic Material

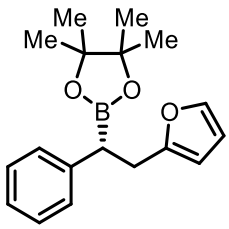


Peak No	% Area	Area	RT (min)
1	50.0183	7132.5765	4.64
2	49.9817	7127.3546	4.97
Total:	100	14259.9311	

Standard Conditions



Peak No	% Area	Area	RT (min)
1	95.526	15650.8875	4.62
2	4.474	733.0173	4.99
Total:	100	16383.9048	

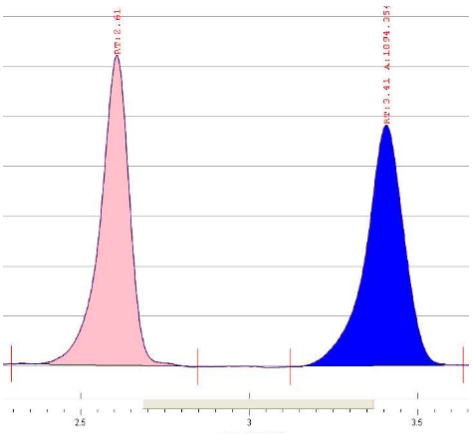


(*R*)-2-(2-(furan-2-yl)-1-phenylethyl)-4,4,5,5-tetramethyl-1,3,2-dioxaboro lane (1.144). The reaction was performed according to the general procedure *(**Method C**)* with 4,4,5,5-tetramethyl-2-phenyl-1,3,2-dioxaborolane (**1.94**, 61.2 mg, 0.30 mmol, 1.00 equiv), sodium trifluoromethanesulfonate (154.9 mg, 0.90 mmol, 3.00 equiv), vinylmagnesium chloride (0.20 mL, 1.53 M in tetrahydrofuran, 0.30 mmol, 1.00 equiv), 2-bromofuran (52.9 mg, 0.36 mmol, 1.20 equiv), palladium (II) acetate (0.90 mL, 0.01 M in dimethyl sulfoxide, 0.009 mmol, 0.030 equiv), MandyPhos (**1.64**, 11.37 mg, 0.0108 mmol, 0.036 equiv). The unpurified product was purified by automated silica gel chromatography (Biotage 1%

→5% Ethyl acetate in hexanes, stained in CAM) to afford white solid (65.3 mg, 73% yield). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.29 – 7.20 (m, 5H), 7.17 – 7.11 (m, 1H), 6.22 (dd, *J* = 3.1, 1.8 Hz, 1H), 5.94 (dd, *J* = 3.2, 0.9 Hz, 1H), 3.19 (dd, *J* = 15.1, 9.9 Hz, 1H), 2.95 (dd, *J* = 15.1, 6.6 Hz, 1H), 2.75 (dd, *J* = 9.9, 6.6 Hz, 1H), 1.17 (s, 6H), 1.14 (s, 6H). **^{11}B NMR** (128 MHz, $CDCl_3$) δ 32.64. **^{13}C NMR** (151 MHz, $CDCl_3$) δ 155.81, 142.31, 140.85, 128.58, 128.42, 125.73, 110.19, 105.53, 83.70, 31.22, 24.77, 24.74 (methine C adjacent to B not observed). **IR** (neat) ν_{max} 3026.86 (w), 2977.47 (m), 2928.74 (w), 2854.97 (w), 1599.24 (m), 1360.95 (s), 1326.42 (s), 1140.45 (s), 1008.03 (m), 967.54 (m), 850.12 (m), 729.28 (m), 699.69 (s) cm^{-1}. **HRMS** (DART) for $C_{18}H_{24}BO_3$ $[M+H]^+$: calculated: 299.18185, found: 299.18327. $[\alpha]_D^{20}$ = – 30.982 (*c* 1.19, $CHCl_3$, *l* = 50 mm).

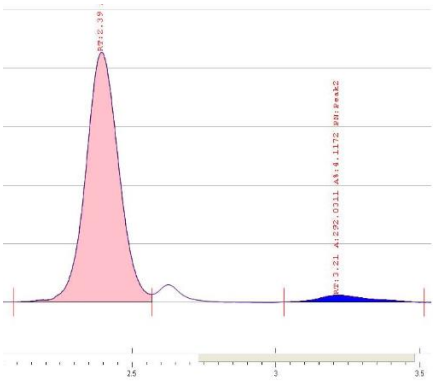
Analysis of Stereochemistry: Racemic compound was prepared according to the general procedure (***Method C, run at 60 ºC***) with $Pd(OAc)_2$ (5 mol%) and 1,1′-bis(diisopropylphosphino)ferrocene (6 mol%) as the catalyst. Chiral SFC (Chiracel OJ-H, 1% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of (*R*)-2-(2-(furan-2-yl)-1-phenylethyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane **(1.144)**.

Racemic Material

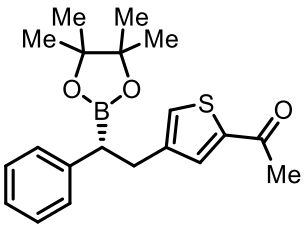


Peak No	% Area	Area	RT (min)
1	49.6198	1865.7639	2.61
2	50.3802	1894.3546	3.41
Total:	100	3760.1185	

Standard Conditions



Peak No	% Area	Area	RT (min)
1	95.8828	6800.8486	2.39
2	4.1172	292.0311	3.21
Total:	100	7092.8797	

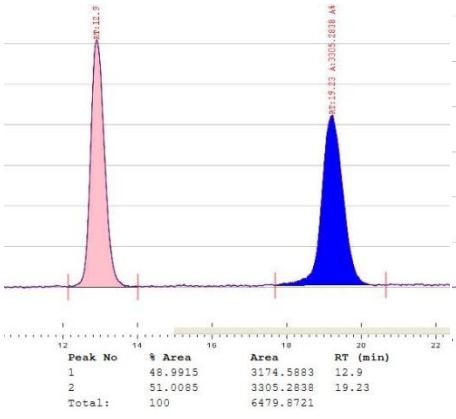


(*R*)-1-(4-(2-phenyl-2-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)ethyl)thiophen-2-yl)ethan-1-one (1.145). The reaction was performed according to general procedure (***Method C)*** with 4,4,5,5-tetramethyl-2-phenyl-1,3,2-dioxaborolane (**1.94**, 61.2 mg, 0.30 mmol, 1.00 equiv.), sodium trifluoromethanesulfonate (154.9 mg, 0.90 mmol, 3.00 equiv), vinylmagnesium chloride (0.20 mL, 1.53 M in tetrahydrofuran, 0.30 mmol, 1.00 equiv), 1-(4-bromothiophen-2-yl)ethan-1-one (73.8 mg, 0.36 mmol, 1.20 equiv), palladium (II) acetate (0.9 mL, 0.01 M dimethyl sulfoxide, 0.009 mmol, 0.030 equiv), MandyPhos (**1.64**, 11.37 mg, 0.0108 mmol, 0.036 equiv). The unpurified product was purified by automated silica gel chromatography (Biotage 1% →5% ethyl acetate in hexanes, stained in CAM) to afford off-white solid (82.3 mg, 77% yield). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.44 (app d, *J* = 1.3 Hz, 1H), 7.26 (app t, *J* = 7.6 Hz, 2H), 7.20 (app d, *J* = 6.9 Hz, 3H), 7.15 (app t, *J* = 6.9 Hz, 1H), 3.15 (dd, *J* = 14.2, 9.3 Hz, 1H), 2.93 (dd, *J* = 14.2, 7.2 Hz, 1H), 2.63 (dd, *J* = 9.2, 7.2 Hz, 1H), 2.48 (s, 3H), 1.14 (s, 6H), 1.13 (s, 6H).

^{11}B NMR (160 MHz, $CDCl_3$) δ 32.59. **^{13}C NMR** (151 MHz, $CDCl_3$) δ 190.91, 143.93, 143.62, 142.06, 134.28, 130.11, 128.64, 128.54, 125.87, 83.76, 33.93, 33.43, 26.89, 24.76, 24.74. **IR** (neat) ν_{max} 2975.69 (w), 2933.00 (w), 1661.22. (s), 11356.74 (s), 1324.69 (s), 1138.00 (s), 848.18 (m), 764.63 (w), 700.66 (m) cm^{-1}. **HRMS** (DART) for $C_{20}H_{25}BO_3S$ $[M+H]^+$ calculated: 357.16957, found: 357.16935. $[\alpha]^{20}_D$: -40.579 (*c* 3.890, $CHCl_3$, *l* =50 mm).

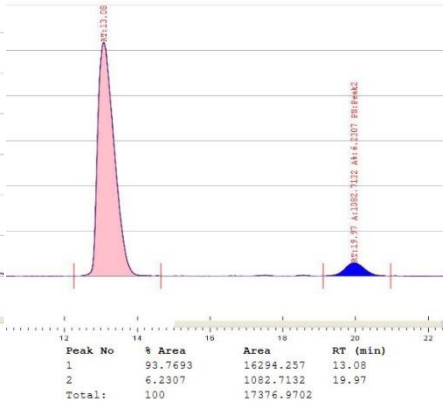
Analysis of Stereochemistry: Racemic compound was prepared according to the general procedure (***Method C****, run at 60 ºC*) with $Pd(OAc)_2$ (5 mol%) and 1,1′-bis(dicyclohexylphosphino)ferrocene (6 mol%) as the catalyst. Chiral SFC (Chiracel OJ-H, 1% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of (*R*)-1-(4-(2-phenyl-2-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)ethyl)thiophen-2-yl)ethan-1-one **(1.145)**.

Racemic Material

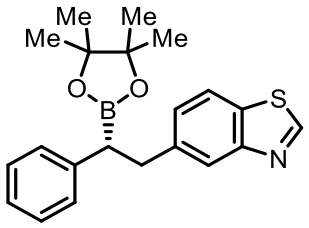


Peak No	% Area	Area	RT (min)
1	48.9915	3174.5883	12.9
2	51.0085	3305.2838	19.23
Total:	100	6479.8721	

Standard Conditions



Peak No	% Area	Area	RT (min)
1	93.7693	16294.257	13.08
2	6.2307	1082.7132	19.97
Total:	100	17376.9702	

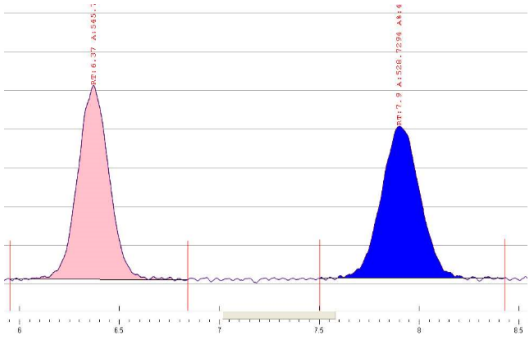


(*R*)-5-(2-phenyl-2-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)ethyl)benzo[d]thiazole (1.146). The reaction was performed according to the general procedure ***(Method C)*** with 4,4,5,5-tetramethyl-2-phenyl-1,3,2-dioxaborolane (**1.94**, 61.2 mg, 0.30 mmol, 1.00 equiv), sodium trifluoromethanesulfonate (154.9 mg, 0.90 mmol, 3.00 equiv), vinylmagnesium chloride (0.20 mL, 1.53 M in tetrahydrofuran, 0.30 mmol, 1.00 equiv), 5-bromobenzothiazole (77.1 mg, 0.36 mmol, 1.20 equiv), palladium (II) acetate (0.90 mL, 0.01 M in dimethyl sulfoxide, 0.009 mmol, 0.030 equiv), MandyPhos (**1.64**, 11.37 mg, 0.0108 mmol, 0.036 equiv). The unpurified product was purified by automated silica gel chromatography (Biotage 0% →50% CH_2Cl_2 in hexanes, stained in CAM) to afford colorless oil (71.2 mg, 65% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 8.94 (s, 1H), 7.96 (s, 1H), 7.79 (d, *J* = 8.2 Hz, 1H), 7.29 – 7.21 (m, 5H), 7.14 (app hept, *J* = 3.7 Hz, 1H), 3.34 (dd, *J* = 13.5, 9.3 Hz, 1H), 3.12 (dd, *J* = 13.6, 7.2 Hz, 1H), 2.74 (dd, *J* = 9.0, 7.5 Hz, 1H), 1.12 (s, 6H), 1.11 (s, 6H). **^{11}B NMR** (128 MHz, $CDCl_3$) δ 33.00. **^{13}C NMR** (126 MHz, $CDCl_3$) δ 153.97, 153.58, 142.34, 140.49, 131.14, 128.55, 128.52, 127.18, 125.65, 123.67, 121.31, 83.65, 38.78, 34.90, 24.72, 24.68**. IR** (neat) ν_{max} 3060.66 (w), 3025.02 (w), 2976.11 (m), 2928.50 (m), 2860.23 (w), 1440.95 (s), 1359.88 (s), 1324.95 (s), 1139.88 (s), 969.17 (m), 845.81 (s), 700.65 (s) cm^{-1}. **HRMS** (DART) for $C_{21}H_{25}BNO_2S$ $[M+H]^+$: calculated: 366.16990, found: 366.17111. $[\alpha]_D^{20}$ = – 41.788 (*c* 3.77, $CHCl_3$, *l* = 50 mm).

Analysis of Stereochemistry: Racemic compound was prepared according to the general procedure (***Method C, run at 60 ºC***) with $Pd(OAc)_2$ (5 mol%) and 1,1′-bis(diisopropylphosphino)ferrocene (6 mol%) as the catalyst. Chiral SFC (Chiracel OD-H,

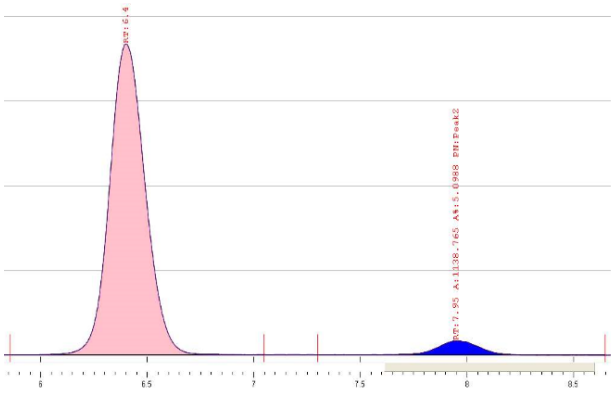
10% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of (*R*)-5-(2-phenyl-2-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)ethyl)benzo[d]thiazole **(1.146)**.

Racemic Material

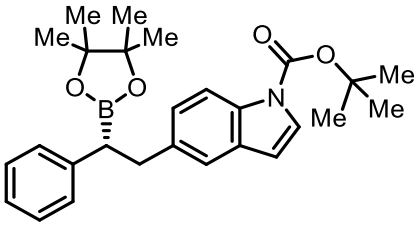


Peak No	% Area	Area	RT (min)
1	50.7936	545.7844	6.37
2	49.2064	528.7294	7.9
Total:	100	1074.5138	

Standard Conditions



Peak No	% Area	Area	RT (min)
1	94.9012	21195.3246	6.4
2	5.0988	1138.765	7.95
Total:	100	22334.0896	

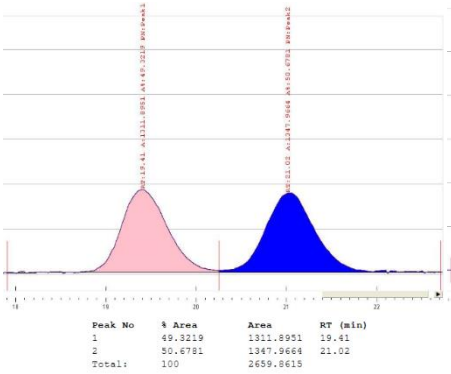


***tert*-butyl (*R*)-5-(2-phenyl-2-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)ethyl)-1H-indole-1-carboxylate (1.147).** The reaction was performed according to the general procedure *(**Method C**)* with 4,4,5,5-tetramethyl-2-phenyl-1,3,2-dioxaborolane (**1.94**, 61.2 mg, 0.30 mmol, 1.00 equiv), sodium trifluoromethanesulfonate (154.9 mg, 0.90 mmol, 3.00 equiv), vinylmagnesium chloride (0.20 mL, 1.53 M in tetrahydrofuran, 0.30 mmol, 1.00 equiv), *t*-butyl 5-bromoindole-1-carboxylate (106.6 mg, 0.36 mmol, 1.20 equiv), palladium (II) acetate (0.90 mL, 0.01 M in dimethyl sulfoxide, 0.009 mmol, 0.030 equiv), MandyPhos (**1.64**, 11.37 mg, 0.0108 mmol, 0.036 equiv). The unpurified product was purified by automated silica gel chromatography (Biotage 0% →50% CH_2Cl_2 in hexanes, stained in CAM) to afford white solid (105.1 mg, 78% yield). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 8.01 (s, 1H), 7.55

(s, 1H), 7.39 (s, 1H), 7.31 – 7.25 (m, 4H), 7.21 – 7.11 (m, 2H), 6.48 (d, *J* = 3.7 Hz, 1H), 3.29 (dd, *J* = 13.5, 9.8 Hz, 1H), 3.07 (dd, *J* = 13.5, 6.8 Hz, 1H), 2.75 (dd, *J* = 9.7, 6.8 Hz, 1H), 1.67 (s, 9H), 1.13 (s, 6H), 1.12 (s, 6H). **^{11}B NMR** (128 MHz, $CDCl_3$) δ 32.64. **^{13}C NMR** (151 MHz, $CDCl_3$) δ 149.96, 142.88, 136.31, 133.81, 130.68, 128.57, 128.47, 125.90, 125.60, 125.50, 121.00, 114.79, 107.34, 83.51, 38.92, 35.17, 28.38, 24.75, 24.73 (quaternary C of *tert*-butyl group not observed). **IR** (neat) ν_{max} 2976.84 (w), 2931.15 (m), 1730.38 (s), 1469.06 (m), 1369.70 (s), 1348.51 (s), 1325.08 (s), 1255.59 (m), 1217.42 (m), 1162.60 (s), 1128.89 (s), 1082.05 (m), 1023.09 (m), 764.85 (m), 700.63 (m) cm^{-1}. **HRMS** (DART) for $C_{27}H_{35}BNO_4$ $[M+H]^+$: calculated: 448.26591, found: 448.26791. $[\alpha]_D^{20}$ = – 39.460 (*c* 4.03, $CHCl_3$, *l* = 50 mm).

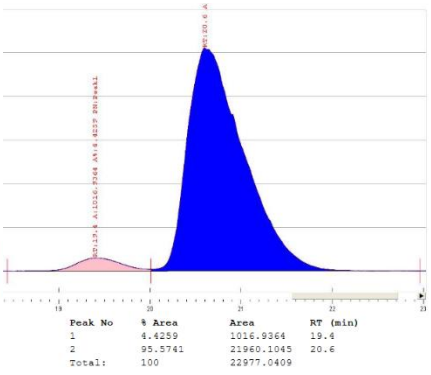
Analysis of Stereochemistry: Racemic compound was prepared according to the general procedure (***Method C, run at 60 ºC***) with $Pd(OAc)_2$ (5 mol%) and 1,1′-bis(diisopropylphosphino)ferrocene (6 mol%) as the catalyst. Chiral SFC (Chiracel OD-H, 2% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of *tert*-butyl (*R*)-5-(2-phenyl-2-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)ethyl)-1H-indole-1-carboxylate **(1.147)**.

Racemic Material

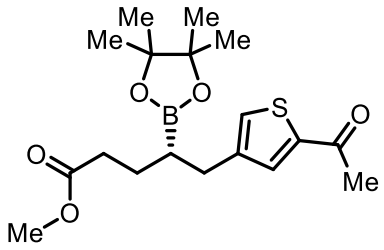


Peak No	% Area	Area	RT (min)
1	49.3219	1311.8951	19.41
2	50.6781	1347.9664	21.02
Total:	100	2659.8615	

Standard Conditions



Peak No	% Area	Area	RT (min)
1	4.4259	1016.9364	19.4
2	95.5741	21960.1045	20.6
Total:	100	22977.0409	

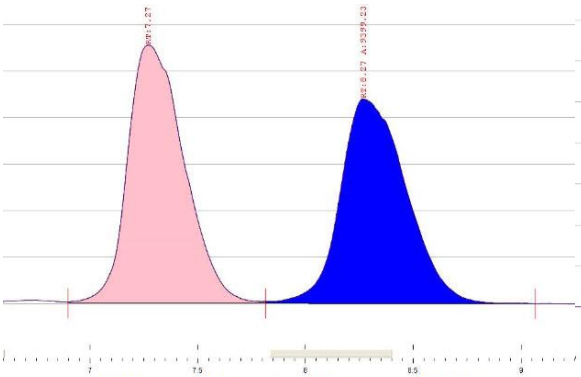


methyl (*S*)-5-(5-acetylthiophen-3-yl)-4-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)pentanoate (1.148). The reaction was performed according to general procedure (***Method C)*** with methyl 3-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)propanoate (64.2 mg, 0.30 mmol, 1.00 equiv), sodium trifluoromethanesulfonate (154.9 mg, 0.90 mmol, 3.00 equiv), vinylmagnesium chloride (0.20 mL, 1.53 M in tetrahydrofuran, 0.30 mmol, 1.00 equiv), 1-(4-bromothiophen-2-yl)ethan-1-one (73.8 mg, 0.36 mmol, 1.20 equiv), palladium (II) acetate (0.9 mL, 0.01 M in dimethyl sulfoxide, 0.009 mmol, 0.030 equiv), MandyPhos (**1.64**, 11.37 mg, 0.0108 mmol, 0.036 equiv). The unpurified product was purified by automated silica gel chromatography (Biotage 1% →5% ethyl acetate in hexanes, stained in CAM) to afford white solid (71.4 mg, 65% yield). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.52 (s, 1H), 7.26 (s, 1H), 3.63 (s, 3H), 2.73 (dd, *J* = 14.4, 8.8 Hz, 1H), 2.65 (dd, *J* = 14.4, 6.9 Hz, 1H), 2.49 (s, 3H), 2.42 – 2.23 (m, 2H), 1.73 (q, *J* = 7.7 Hz, 2H), 1.32 (p, *J* = 7.5 Hz, 1H), 1.14 (s, 6H), 1.13 (s, 6H). **^{11}B NMR** (128 MHz, $CDCl_3$) δ 33.49. **^{13}C NMR** (151 MHz, $CDCl_3$) δ 190.95, 174.11, 144.18, 143.67, 134.19, 130.04, 83.58, 51.73, 33.54, 31.67, 26.98, 26.28, 24.98, 24.97, 24.72. **IR** (neat) ν_{max} 2976.61 (w), 2927.68 (w), 1734.68 (s), 1662.98 (s), 1417.13 (m), 1371.65 (m), 1270.26 (m), 1140.38 (s) cm^{-1}. **HRMS** (DART) for $C_{18}H_{28}BO_5S$ $[M+H]^+$ calculated: 367.1751, found: 367.176. $[\alpha]^{20}_D$: +2.173 (*c* 1.900, $CHCl_3$, *l* =50 mm).

Analysis of Stereochemistry: Racemic compound was prepared according to the general procedure (***Method C, run at 60 ºC***) with $Pd(OAc)_2$ (5 mol%) and (S_p, S_p)-MandyPhos **1.64** (1.8 mol%), and (R_p, R_p)-MandyPhos **1.64** (1.8 mol%) as the catalyst. Chiral SFC (Chiracel

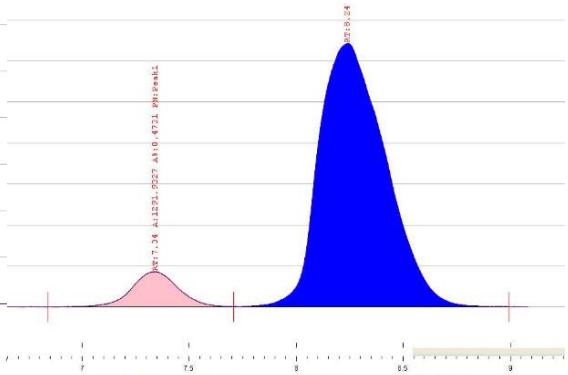
OJ-H, 1% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of methyl (*S*)-5-(5-acetylthiophen-3-yl)-4-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)pentanoate **(1.148)**.

Racemic Material

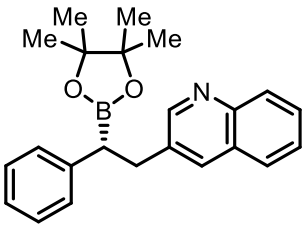


Peak No	% Area	Area	RT (min)
1	51.9467	10160.8085	7.27
2	48.0533	9399.2393	8.27
Total:	100	19560.0478	

Standard Conditions



Peak No	% Area	Area	RT (min)
1	8.4731	1291.9327	7.34
2	91.5269	13955.5406	8.24
Total:	100	15247.4733	

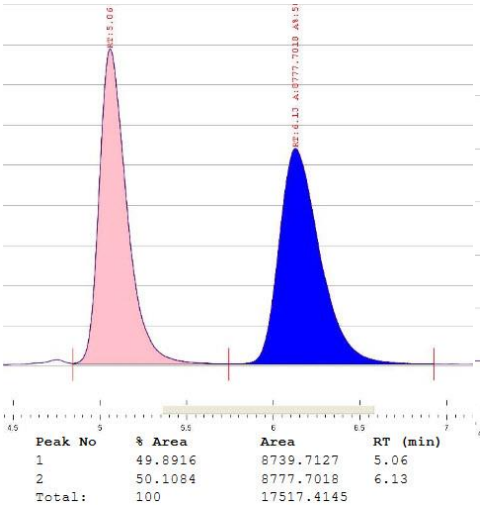


(*R*)-3-(2-phenyl-2-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl) ethyl)quinolone (1.149). The reaction was performed according to general procedure (***Method C)*** with 4,4,5,5-tetramethyl-2-phenyl-1,3,2-dioxaborolane (**1.94**, 61.2 mg, 0.30 mmol, 1.00 equiv), sodium trifluoromethanesulfonate (154.9 mg, 0.90 mmol, 3.00 equiv), vinylmagnesium chloride (0.20 mL, 1.53 M in tetrahydrofuran, 0.30 mmol, 1.00 equiv), 3-bromoquinoline (74.5 mg, 0.36 mmol, 1.20 equiv), palladium (II) acetate (0.9 mL, 0.01 M in dimethyl sulfoxide, 0.009 mmol, 0.030 equiv), MandyPhos (**1.64**, 11.37 mg, 0.0108 mmol, 0.036). The unpurified product was purified by automated silica gel chromatography (Biotage 2% →20% ethyl acetate in hexanes, stained in CAM) to afford white solid (82.9 mg, 77% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 8.75 (d, *J* = 1.8 Hz, 1H), 8.05 (app d, *J* = 8.4 Hz, 1H), 7.87 (app s, 1H), 7.69 (app d, *J* = 8.2 Hz, 1H), 7.62 (app t, *J*

= 7.7 Hz, 1H), 7.47 (app t, *J* = 7.5 Hz, 1H), 7.25 (app t, 4H), 7.15 (app t, *J* = 6.5 Hz, 1H), 3.34 (dd, *J* = 13.8, 9.1 Hz, 1H), 3.12 (dd, *J* = 13.9, 7.3 Hz, 1H), 2.75 (app t, 1H), 1.11 (s, 12H). **^{11}B NMR** (160 MHz, $CDCl_3$) δ 32.86. **^{13}C NMR** (126 MHz, $CDCl_3$) δ 152.59, 146.96, 141.91, 134.94, 134.63, 129.30, 128.70, 128.68, 128.64, 128.17, 127.50, 126.57, 125.93, 83.84, 36.27, 34.42, 24.80, 24.74. **IR** (neat) ν_{max} 2976.63 (m), 2929.93 (w), 1726.48 (w), 1493.83 (m), 1327.42 (m), 1141.06 (s), 967.37 (w), 849.21 (w), 751.75 (w), 701.56 (w) cm^{-1}. **HRMS** (DART) for $C_{23}H_{27}BNO_2$ $[M+H]^+$ calculated: 360.21348, found: 360.21532. $[\alpha]^{20}_D$: -46.5119 (*c* 3.18, $CHCl_3$, *l* =50 mm).

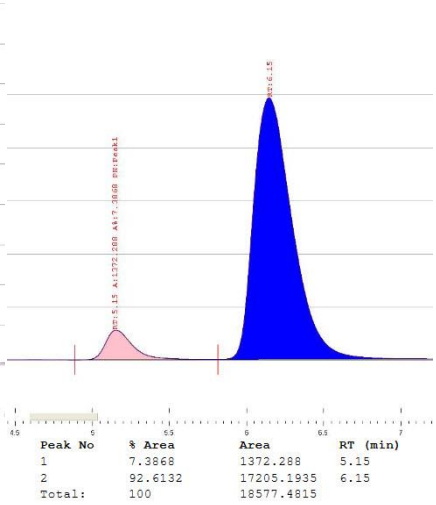
Analysis of Stereochemistry: Racemic compound was prepared according to the general procedure (***Method C, run at 60 ºC***) with $Pd(OAc)_2$ (5 mol%) and 1,1′-bis(dicyclohexylphosphino)ferrocene (6 mol%) as the catalyst. Chiral SFC (Chiracel OJ-H, 7% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of (*R*)-3-(2-phenyl-2-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)ethyl)quinolone **(1.149)**.

Racemic Material

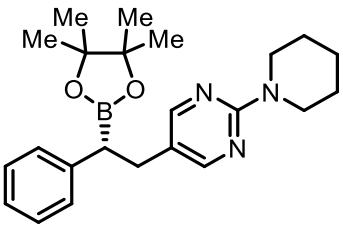


Peak No	% Area	Area	RT (min)
1	49.8916	8739.7127	5.06
2	50.1084	8777.7018	6.13
Total:	100	17517.4145	

Standard Conditions



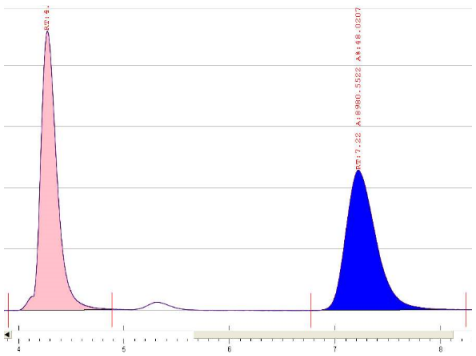
Peak No	% Area	Area	RT (min)
1	7.3868	1372.288	5.15
2	92.6132	17205.1935	6.15
Total:	100	18577.4815	



(*R*)-5-(2-phenyl-2-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan -2-yl)ethyl)-2-(piperidin-1-yl)pyrimidine (1.150). The reaction was performed according to the general procedure ***(Method C)*** with 4,4,5,5-tetramethyl-2-phenyl-1,3,2-dioxaborolane (**1.94**, 61.2 mg, 0.30 mmol, 1.00 equiv), sodium trifluoromethanesulfonate (154.9 mg, 0.90 mmol, 3.00 equiv), vinylmagnesium chloride (0.20 mL, 1.53 M in tetrahydrofuran, 0.30 mmol, 1.00 equiv), 5-bromo-2-(piperidin-1-yl)pyrimidine (87.2 mg, 0.36 mmol, 1.20 equiv), palladium (II) acetate (0.90 mL, 0.01 M in dimethyl sulfoxide, 0.009 mmol, 0.030 equiv), MandyPhos (**1.64**, 11.37 mg, 0.0108 mmol, 0.036 equiv). The unpurified product was purified by automated silica gel chromatography (Biotage 0% →15% ethyl acetate in hexanes, stained in CAM) to afford white solid (83.8 mg, 71% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 8.04 (s, 2H), 7.21 (app t, *J* = 7.6 Hz, 2H), 7.18 – 7.14 (m, 2H), 7.11 (app t, *J* = 7.3 Hz, 1H), 3.71 – 3.65 (m, 4H), 2.91 (dd, *J* = 14.1, 8.5 Hz, 1H), 2.72 (dd, *J* = 14.1, 7.9 Hz, 1H), 2.50 (app t, *J* = 8.2 Hz, 1H), 1.61 (p, *J* = 5.7 Hz, 2H), 1.54 (app p, *J* = 5.6 Hz, 4H), 1.14 (s, 6H), 1.13 (s, 6H). **^{11}B NMR** (128 MHz, $CDCl_3$) δ 32.75. **^{13}C NMR** (126 MHz, $CDCl_3$) δ 161.03, 158.01, 141.92, 128.66, 128.64, 125.82, 121.64, 83.76, 45.19, 34.53, 32.58, 25.85, 25.09, 24.82, 24.79. **IR** (neat) ν_{max} 3348.31 (w, br), 2977.12 (m), 2931.39 (m), 2853.55 (m), 1604.14 (s), 1498.41 (s), 1444.64 (s), 1361.24 (s), 1328.15 (s), 1140.94 (s), 946.09 (m), 851.03 (m), 755.50 (m), 699.52 (s), 673.07 (m) cm^{-1}. **HRMS** (DART) for $C_{23}H_{33}BN_3O_2$ $[M+H]^+$: calculated: 394.26658, found: 394.26775. $[\alpha]_D^{20}$ = – 20.812 (*c* 3.78, $CHCl_3$, *l* = 50 mm).

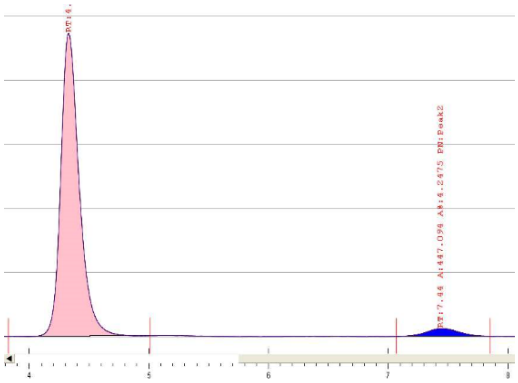
Analysis of Stereochemistry: Racemic compound was prepared according to the general procedure (***Method C, run at 60 ºC***) with $Pd(OAc)_2$ (5 mol%) and (S_p,S_p)-MandyPhos **1.64** (1.8 mol%), and (R_p,R_p)-MandyPhos **1.64** (1.8 mol%) as the catalyst. Chiral SFC (Chiracel OJ-H, 5% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis (*R*)-5-(2-phenyl-2-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)ethyl)-2-(piperidin-1-yl)pyrimidine **(1.150)**.

Racemic Material

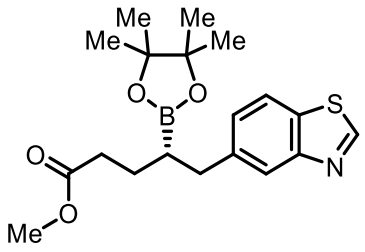


Peak No	% Area	Area	RT (min)
1	51.9793	9720.859	4.27
2	48.0207	8980.5522	7.22
Total:	100	18701.4112	

Standard Conditions



Peak No	% Area	Area	RT (min)
1	95.7525	10078.9185	4.33
2	4.2475	447.094	7.44
Total:	100	10526.0125	

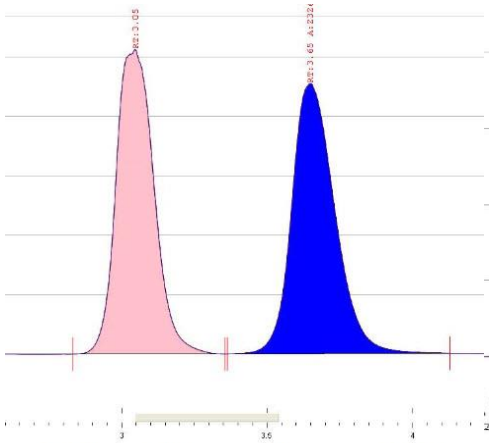


methyl (*S*)-5-(benzo[d]thiazol-5-yl)-4-(4,4,5,5-tetra-methyl-1,3,2-dioxaborolan-2-yl)pentanoate (1.151). The reaction was performed according to general procedure ***(Method C, with modification: reaction conducted at 55 ºC)*** with methyl 3-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)propanoate (64.2 mg, 0.30 mmol, 1.00 equiv), sodium trifluoromethanesulfonate (154.9 mg, 0.90 mmol, 3.00 equiv), vinylmagnesium chloride (0.20 mL, 1.53 M in tetrahydrofuran, 0.30 mmol, 1.00 equiv), 5-bromobenzo[d]thiazole (77.1 mg, 0.36 mmol, 1.20 equiv), palladium (II) acetate (0.9 mL, 0.01 M in dimethyl sulfoxide, 0.009 mmol, 0.030 equiv), MandyPhos (**1.64**, 11.37 mg,

0.0108 mmol. 0.036 equiv). The unpurified product was purified by automated silica gel chromatography (Biotage 1% →5% ethyl acetate in hexanes, stained in CAM) to afford white solid (82.2 mg, 73% yield). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 8.91 (s, 1H), 7.93 (s, 1H), 7.79 (d, *J* = 8.2 Hz, 1H), 7.28 (d, *J* = 9.7 Hz, 1H), 3.60 (s, 3H), 2.91 (dd, *J* = 13.7, 8.2 Hz, 1H), 2.78 (dd, *J* = 13.7, 7.7 Hz, 1H), 2.38 (ddd, *J* = 15.7, 8.0, 8.0 Hz, 1H), 2.29 (ddd, *J* = 15.9, 7.9, 7.9 Hz, 1H), 1.73 (app q, *J* = 7.8 Hz, 2H), 1.40 (app q, *J* = 7.7 Hz, 1H), 1.14 (s, 6H), 1.11 (s, 6H). **^{11}B NMR** (160 MHz, $CDCl_3$) δ 33.51. **^{13}C NMR** (151 MHz, $CDCl_3$) δ 174.14, 154.01, 153.73, 140.47, 131.23, 127.13, 123.73, 121.50, 83.48, 51.63, 37.09, 33.67, 26.12, 25.72, 24.97, 24.95. **IR** (neat) ν_{max} 2977.05 (w), 2929.89 (w), 1734.75 (s), 1440.78 (m), 1380.71 (m), 1319.51 (m), 1141.49 (s), 846.47 (m) cm^{-1}. **HRMS** (DART) for $C_{19}H_{26}BNO_4S$ $[M+H]^+$ calculated: 376.1754, found: 376.1753. $[\alpha]^{20}_D$: -7.957 (*c* 2.075, $CHCl_3$, *l* =50 mm).

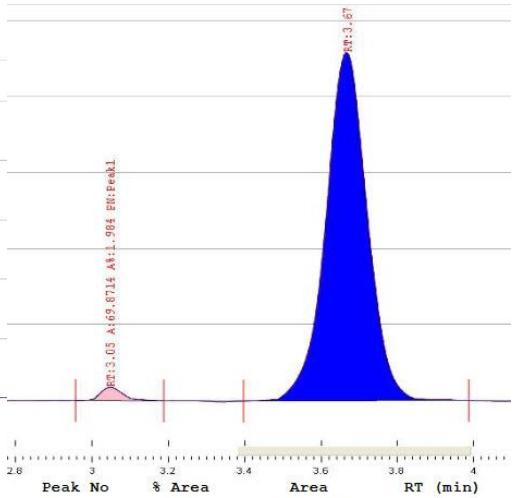
Analysis of Stereochemistry: Racemic compound was prepared according to the general procedure (***Method C, run at 60 ºC***) with $Pd(OAc)_2$ (5 mol%) and (S_p,S_p)-MandyPhos **1.64** (1.8 mol%), and (R_p, R_p)-MandyPhos **1.64** (1.8 mol%) as the catalyst. Chiral SFC (Chiracel OJ-H, 6% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of methyl (*S*)-5-(benzo[d]thiazol-5-yl)-4-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)pentanoate **(1.151)**.

Racemic Material



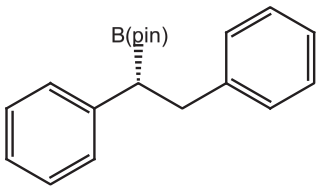
Peak No	% Area	Area	RT (min)
1	49.9263	23200.9761	3.05
2	50.0737	23269.4624	3.65
Total:	100	46470.4385	

Standard Conditions

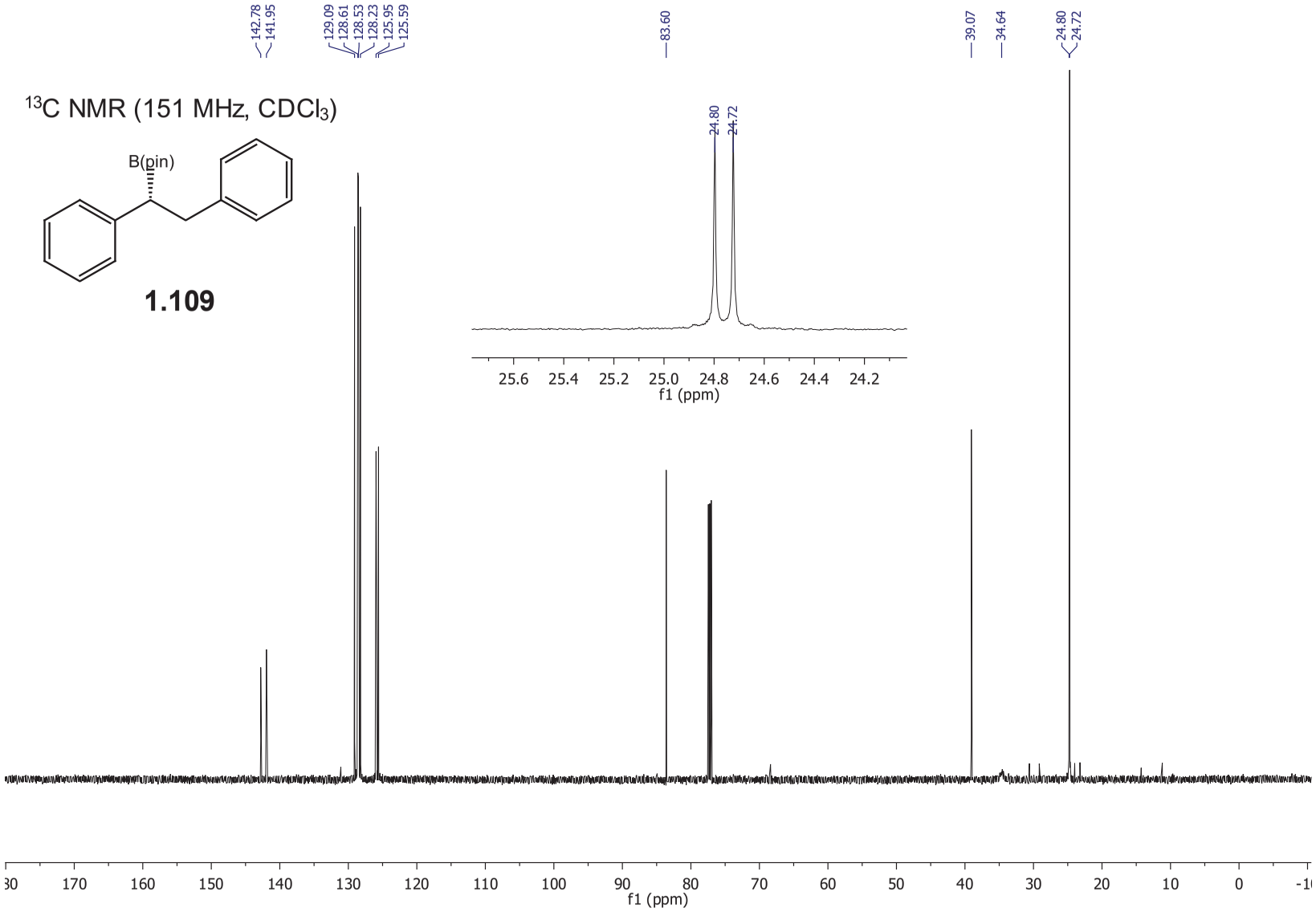


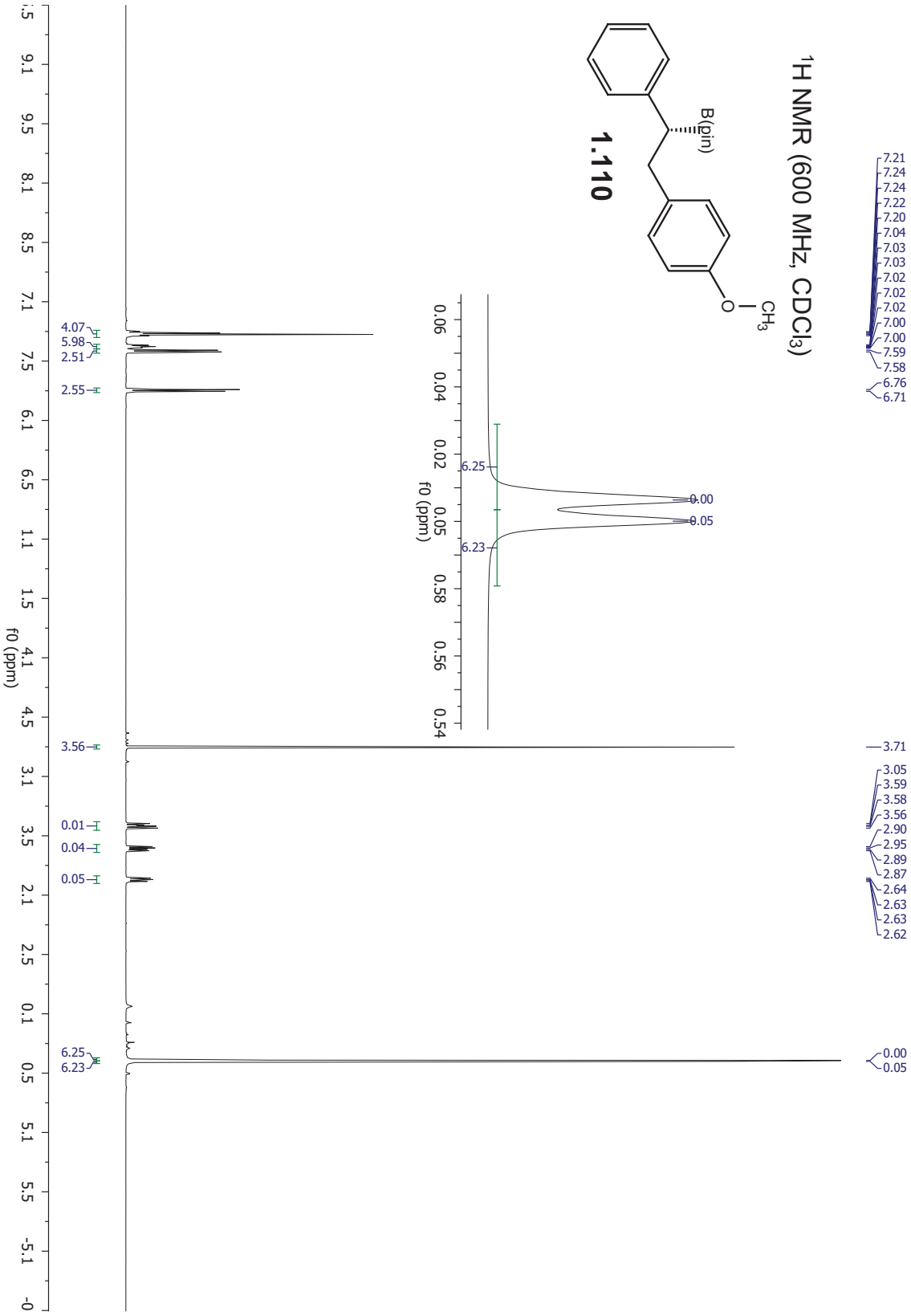
Peak No	% Area	Area	RT (min)
1	1.984	69.8714	3.05
2	98.016	3451.9318	3.67
Total:	100	3521.8032	

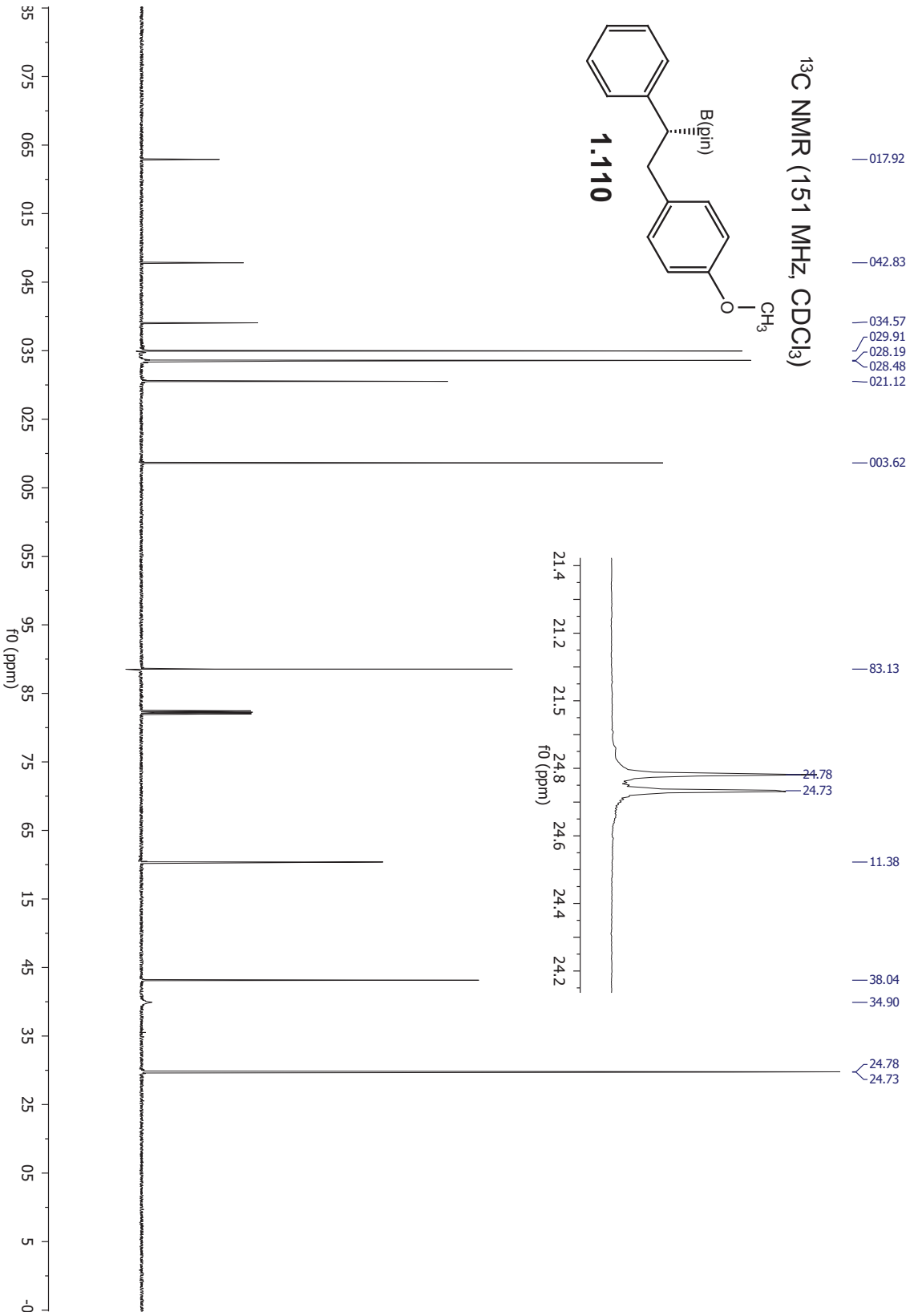
^{1}H NMR (600 MHz, $CDCl_3$)

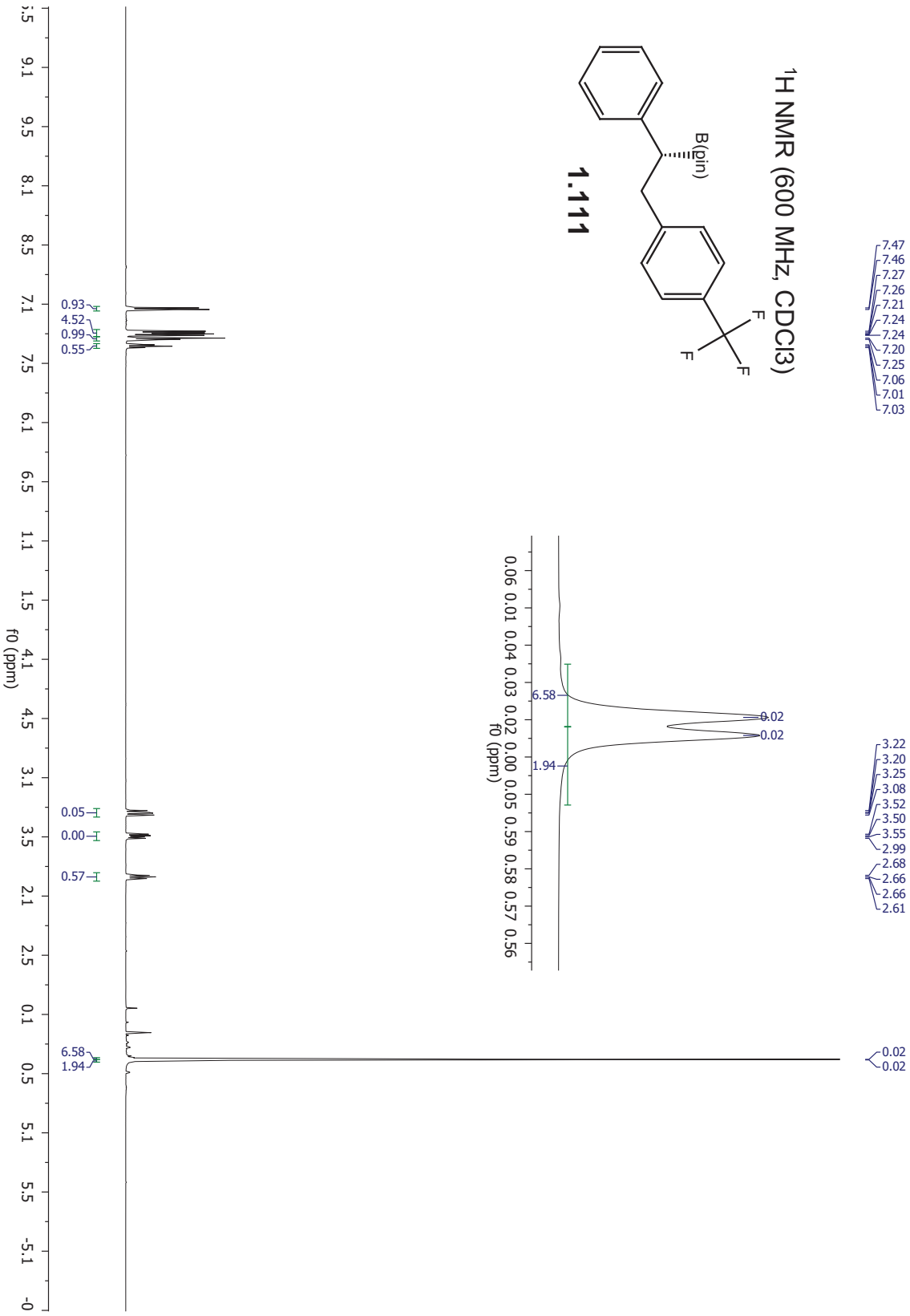


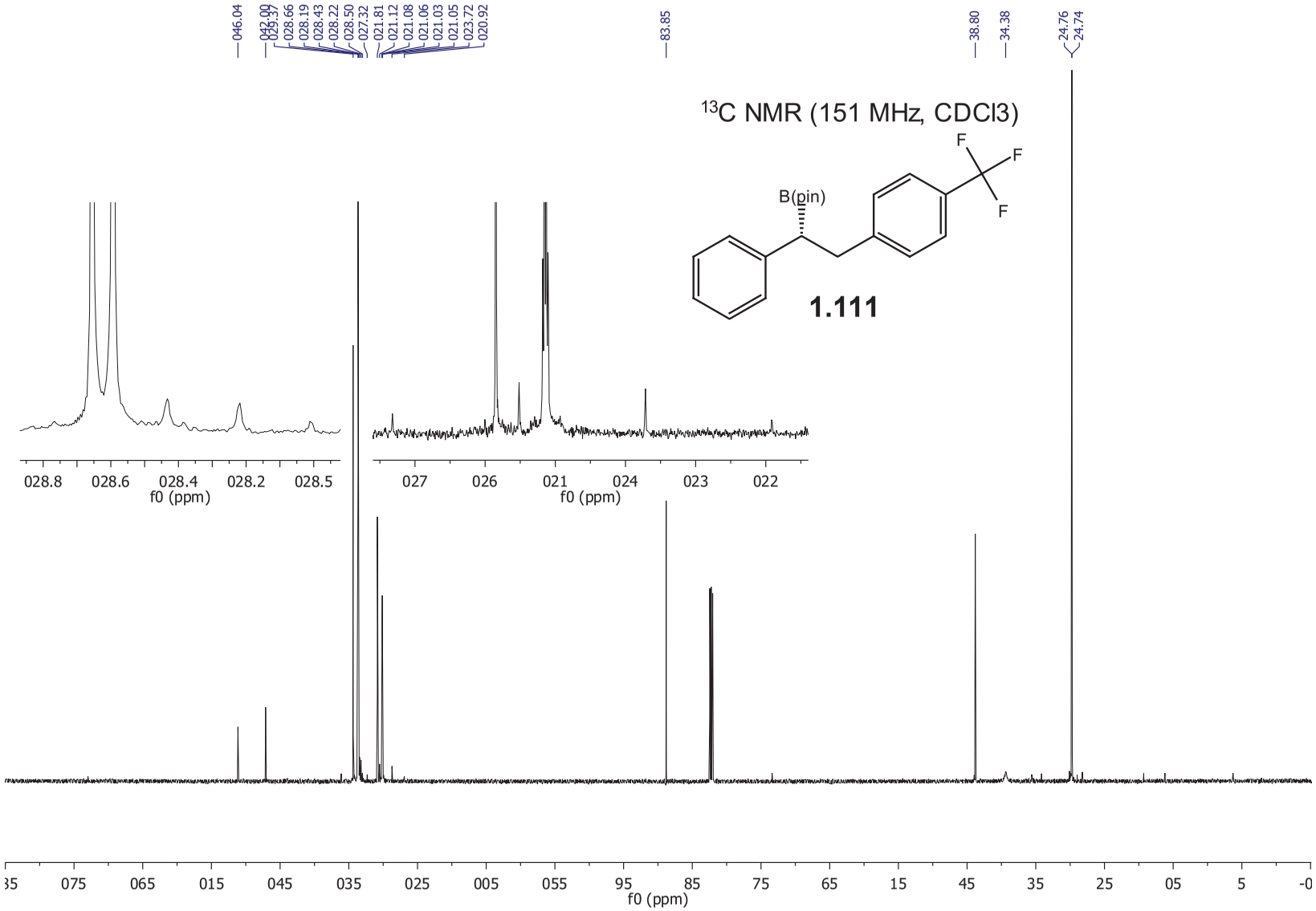
1.109

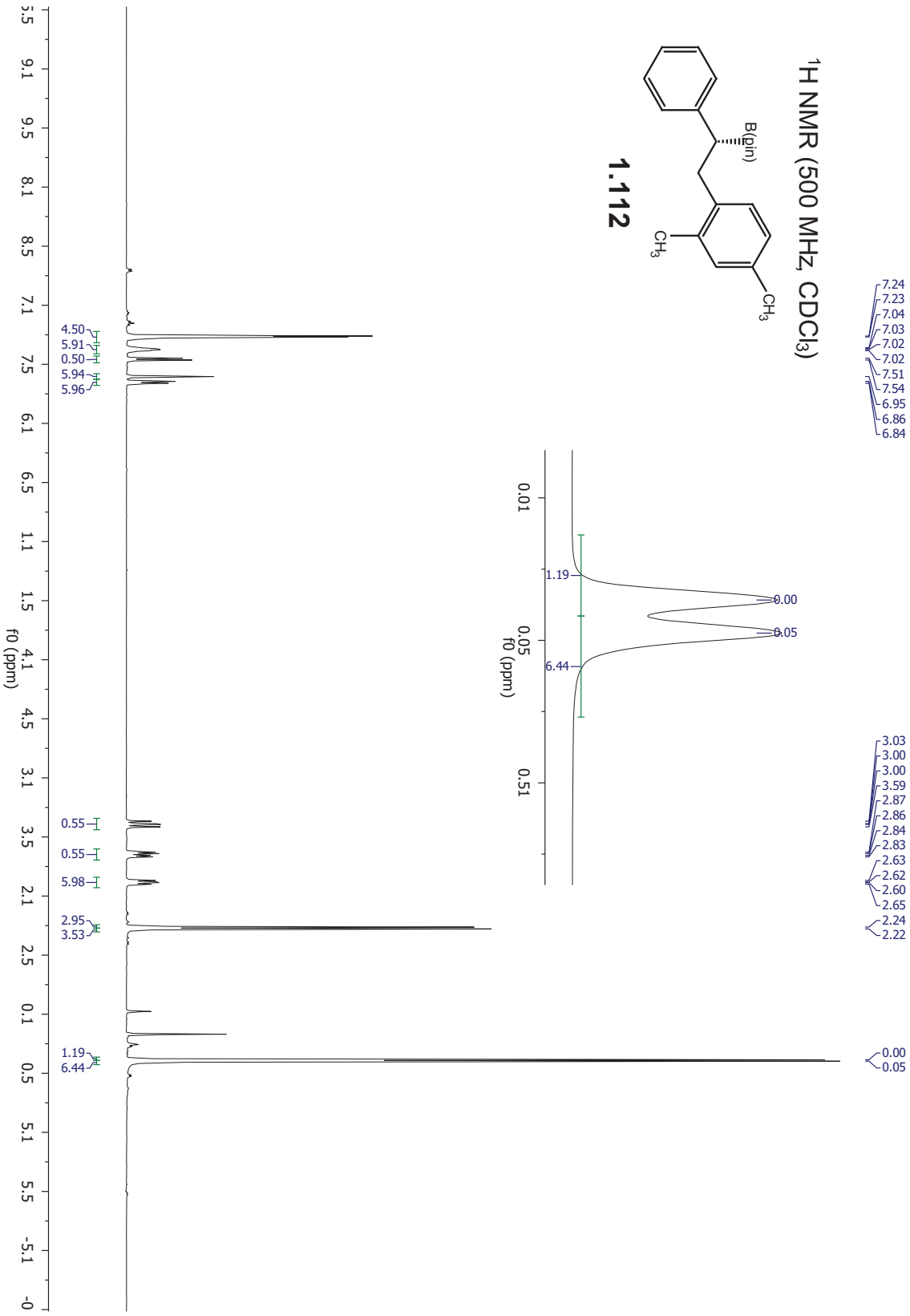

142.78
141.95
129.09
128.61
128.53
128.23
125.95
125.59
83.60
39.07
34.64
24.80
24.72
13C NMR (151 MHz, CDCl3)
B(pin)
1.109
24.80
24.72
25.6 25.4 25.2 25.0 24.8 24.6 24.4 24.2
f1 (ppm)
170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)

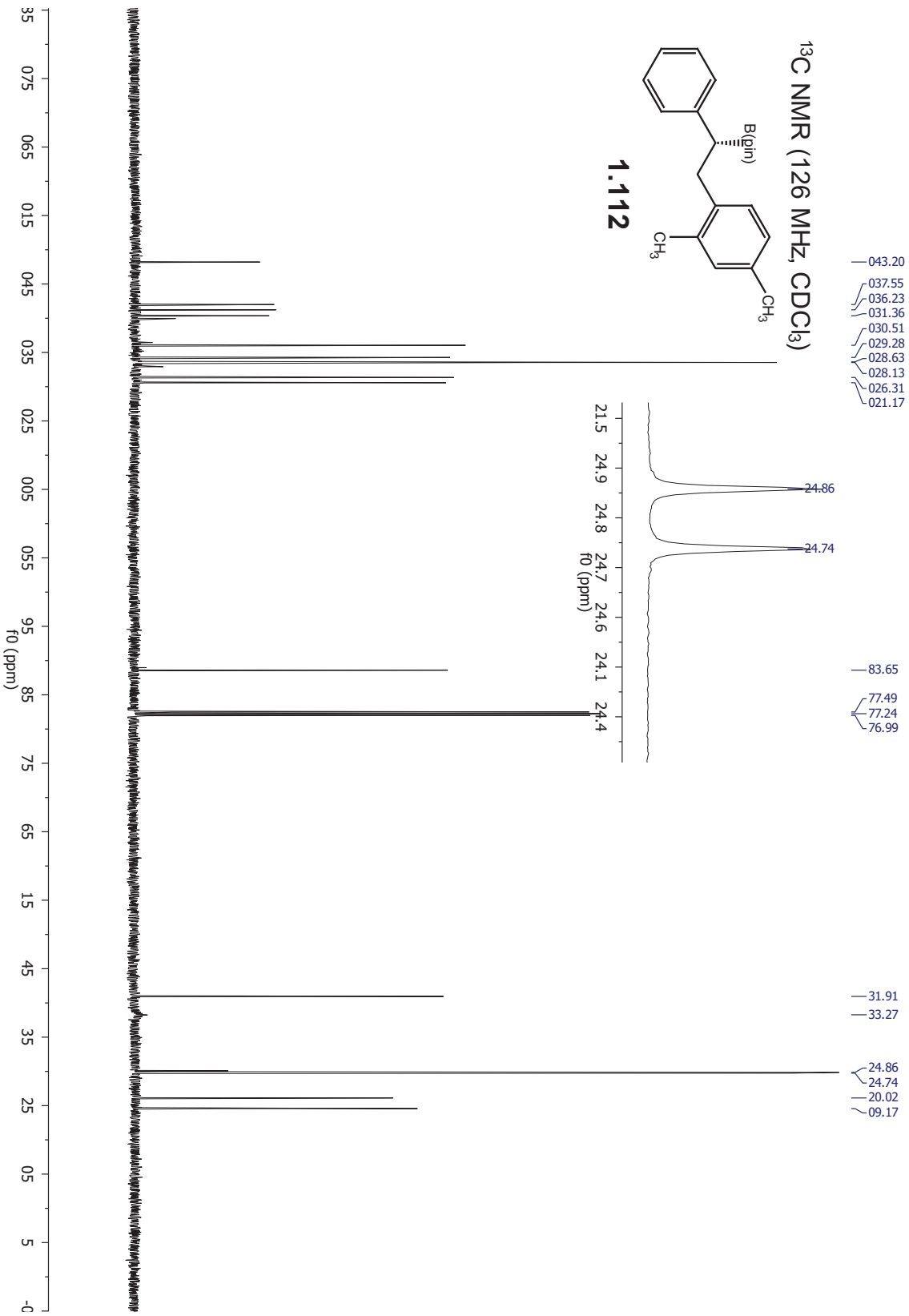

^{1}H NMR (600 MHz, CDCl$_3$)
1.110
B(pin)
CH$_3$
O
f0 (ppm)
7.21
7.24
7.24
7.22
7.20
7.04
7.03
7.03
7.02
7.02
7.02
7.00
7.00
7.59
7.58
6.76
6.71
4.07
5.98
2.51
2.55
3.56
0.01
0.04
0.05
6.25
6.23
3.71
3.05
3.59
3.58
3.56
2.90
2.95
2.89
2.87
2.64
2.63
2.63
2.62
0.00
0.05


^{13}C NMR (151 MHz, CDCl$_3$)
1.110
B(pin)
CH$_3$
O
017.92
042.83
034.57
029.91
028.19
028.48
021.12
003.62
83.13
24.78
24.73
11.38
38.04
34.90
24.78
24.73
f0 (ppm)
f0 (ppm)


1H NMR (600 MHz, CDCl3)
1.111
B(pin)
F
F
F
7.47
7.46
7.27
7.26
7.21
7.24
7.24
7.20
7.25
7.06
7.01
7.03
3.22
3.20
3.25
3.08
3.52
3.50
3.55
2.99
2.68
2.66
2.66
2.61
0.02
0.02
6.58
0.02
0.02
1.94
0.93
4.52
0.99
0.55
0.05
0.00
0.57
6.58
1.94
f0 (ppm)


046.04
042.00
029.37
028.66
028.19
028.43
028.22
028.50
027.32
021.81
021.12
021.08
021.06
021.03
021.05
023.72
020.92
083.85
038.80
034.38
24.76
24.74
13C NMR (151 MHz, CDCl3)
F
F
F
B(pin)
1.111
028.8
028.6
028.4
028.2
028.5
f0 (ppm)
027
026
021
024
023
022
f0 (ppm)
f0 (ppm)


1.112
B(pin)
CH3
CH3
1H NMR (500 MHz, CDCl3)
7.24
7.23
7.04
7.03
7.02
7.02
7.51
7.54
6.95
6.86
6.84
3.03
3.00
3.00
3.59
2.87
2.86
2.84
2.83
2.63
2.62
2.60
2.65
2.24
2.22
0.00
0.05
4.50
5.91
0.50
5.94
5.96
0.55
0.55
5.98
2.95
3.53
1.19
6.44
1.19
0.00
0.05
6.44
f0 (ppm)
f0 (ppm)


^{13}C NMR (126 MHz, CDCl$_3$)
1.112
B(pin)
CH$_3$
CH$_3$
043.20
037.55
036.23
031.36
030.51
029.28
028.63
028.13
026.31
021.17
24.86
24.74
83.65
77.49
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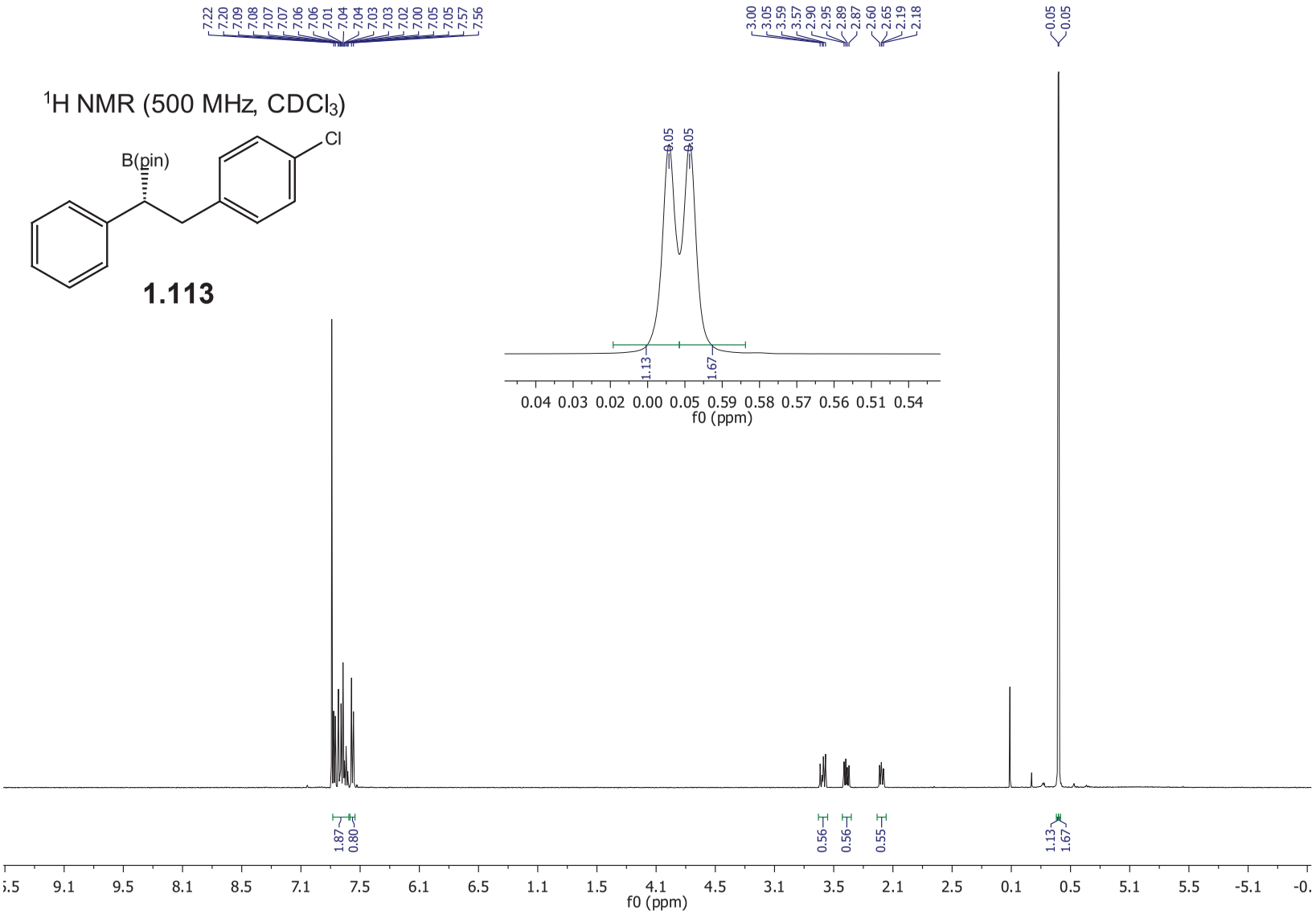
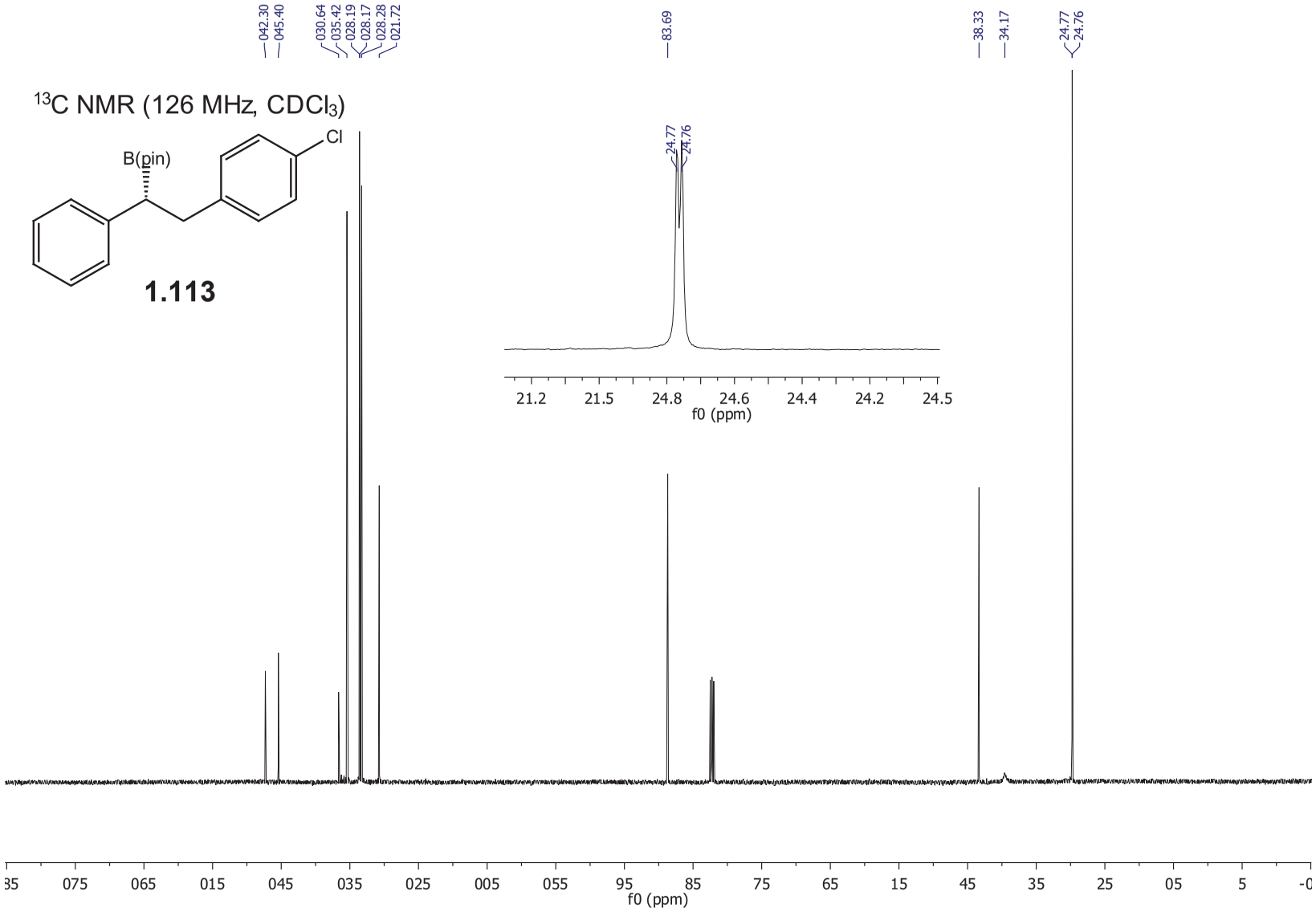
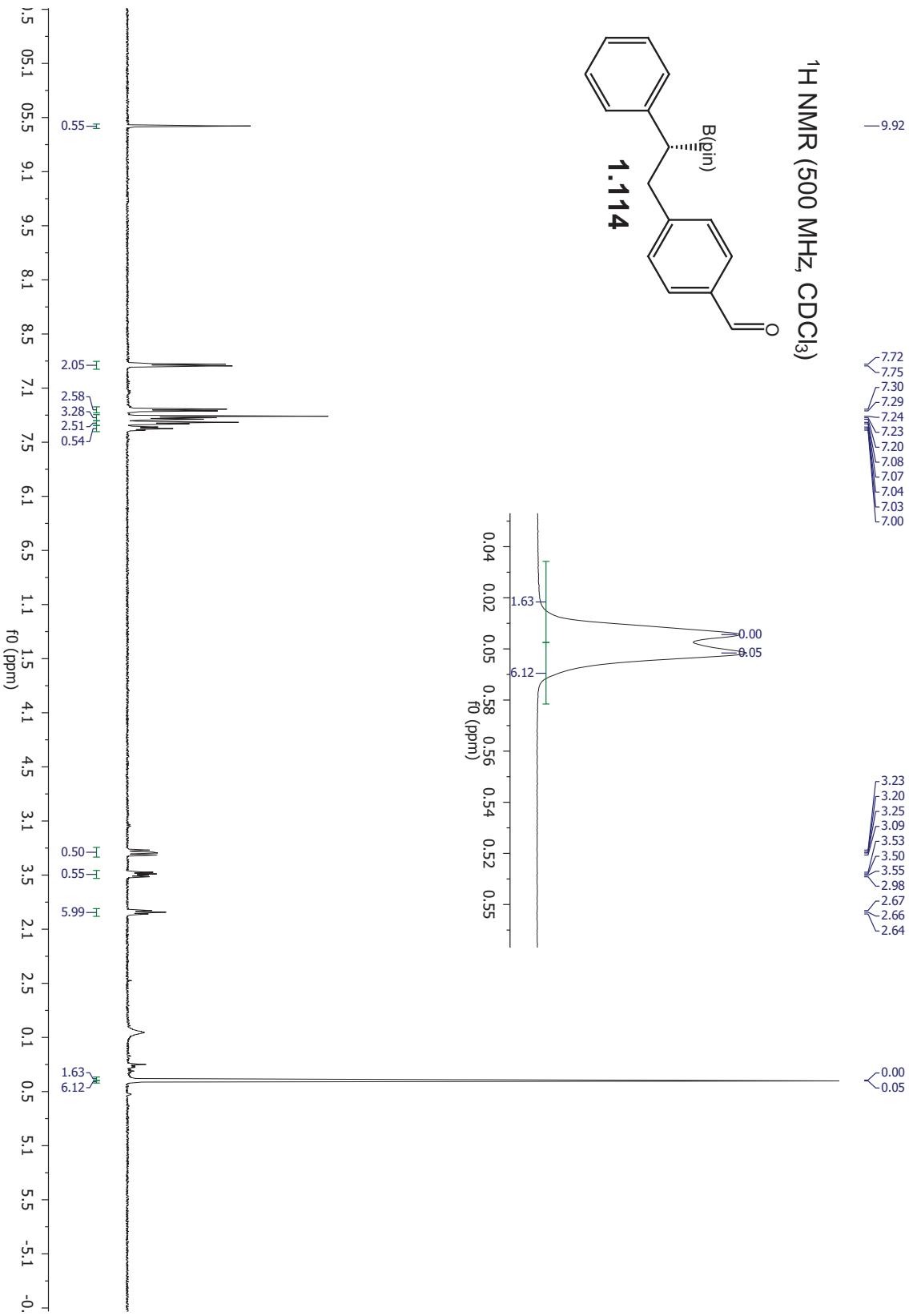
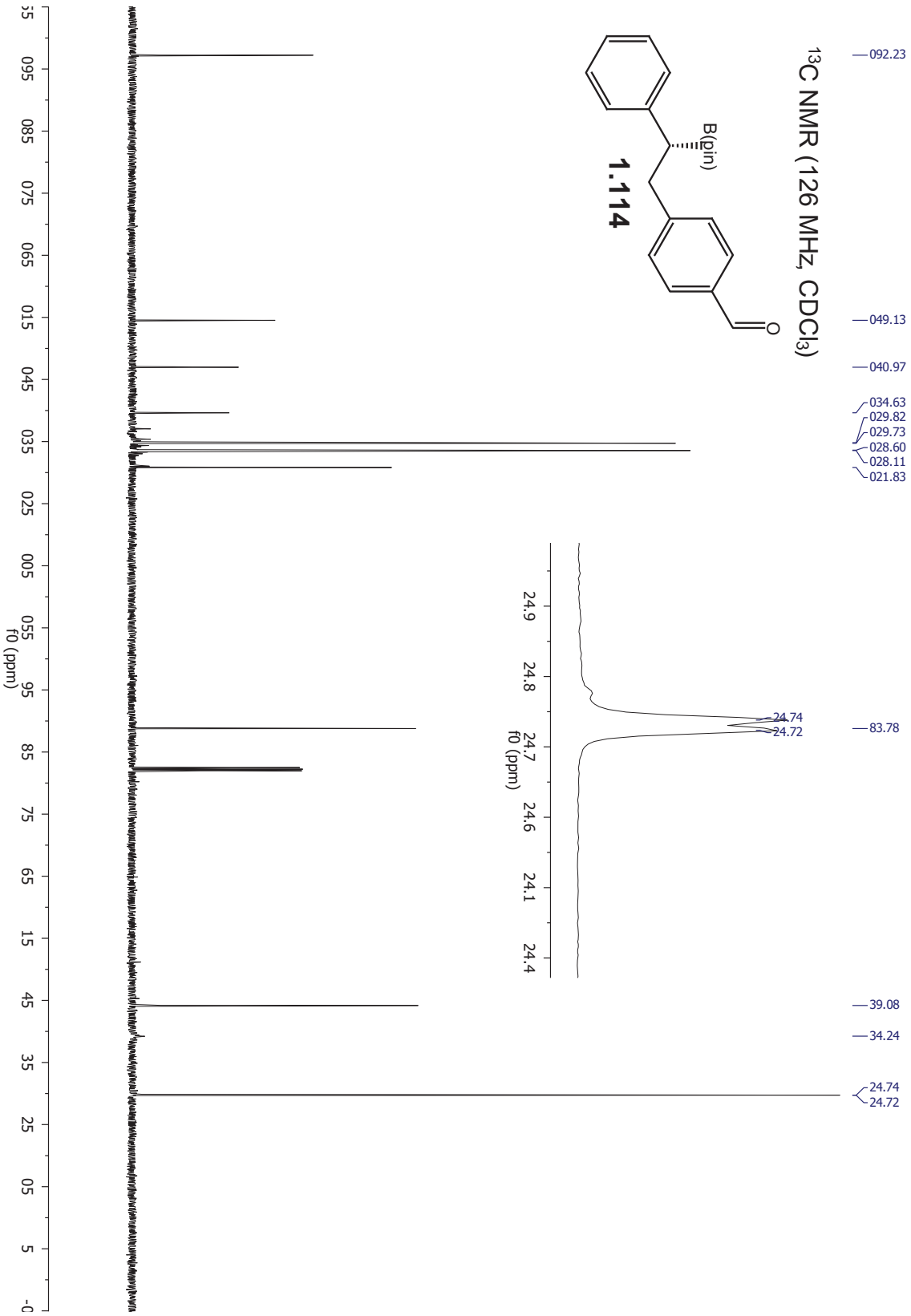
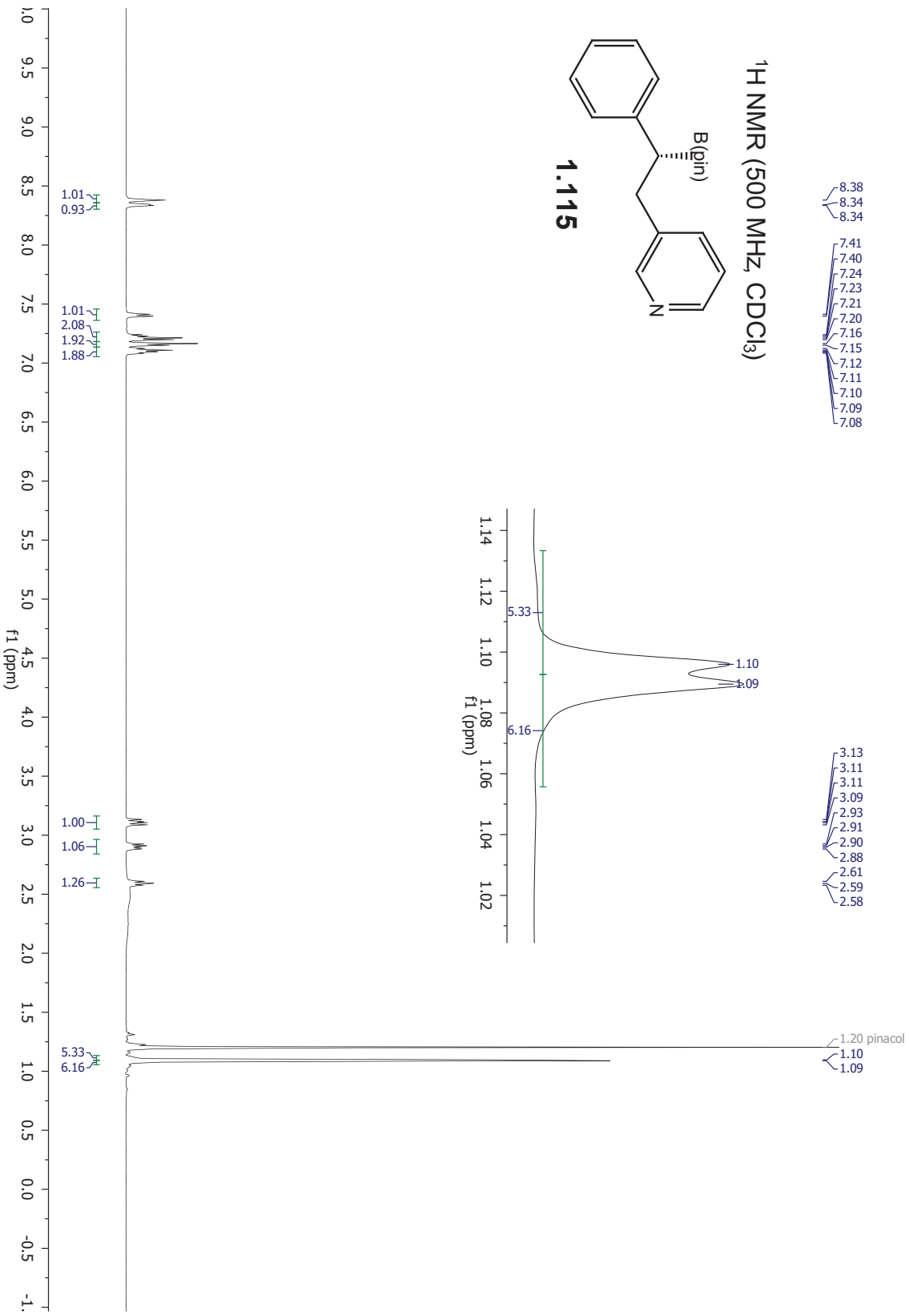
31.91
33.27
24.86
24.74
20.02
09.17
f0 (ppm)
f0 (ppm)

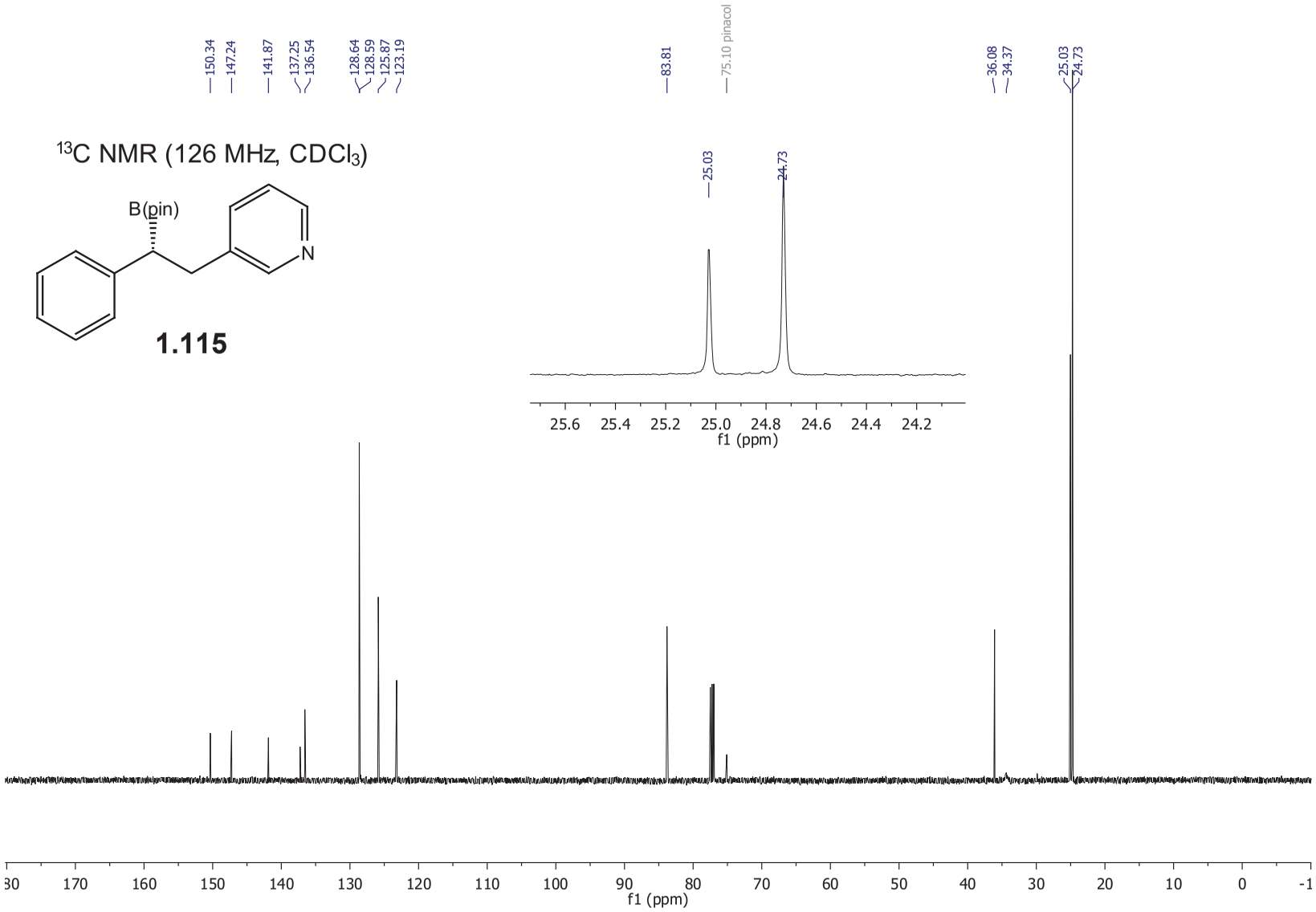

^{1}H NMR (500 MHz, $CDCl_3$)
B(pin)
Cl
1.113
f0 (ppm)

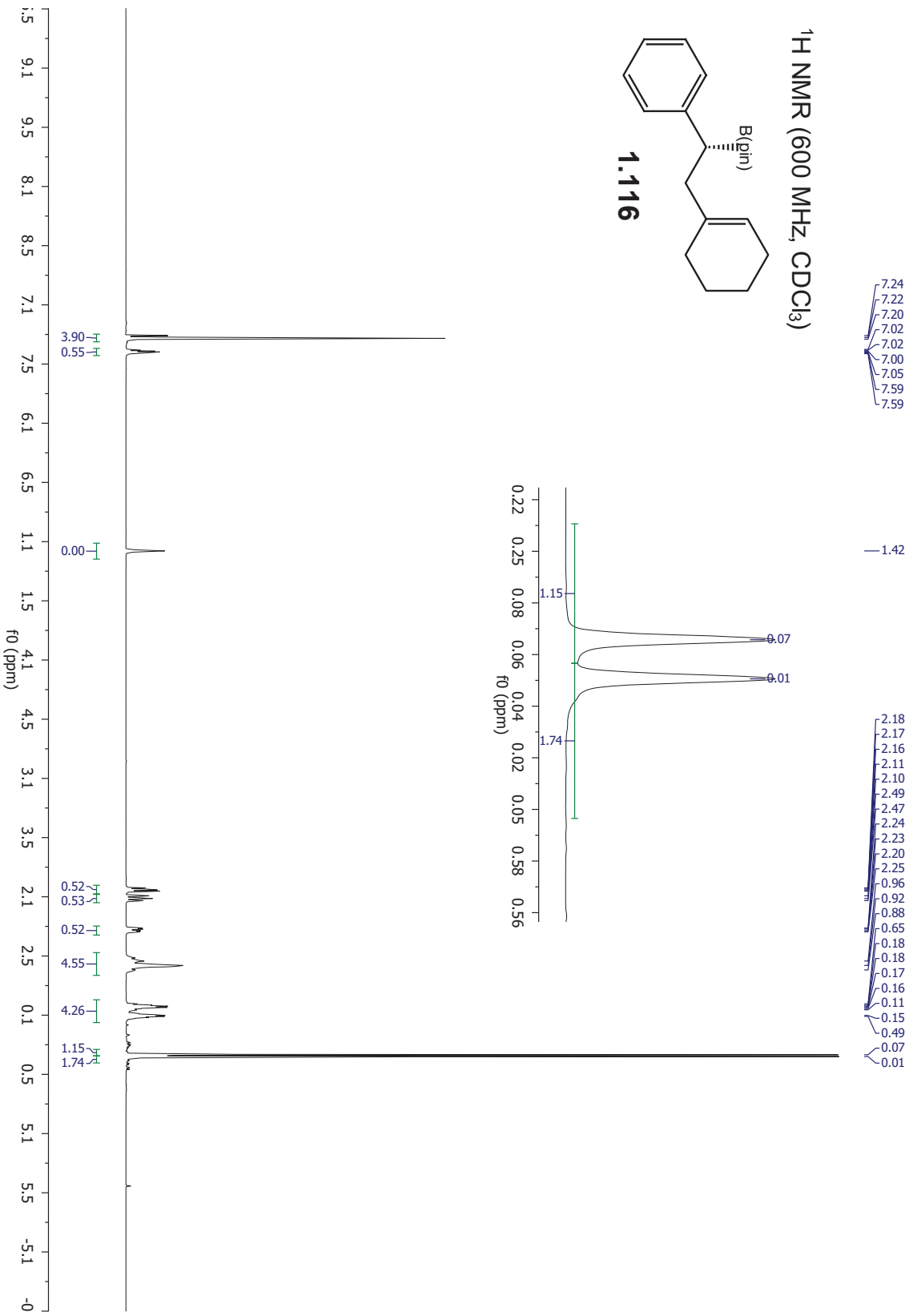

042.30
045.40
030.64
035.42
028.19
028.17
028.28
021.72
83.69
38.33
34.17
24.77
24.76
13C NMR (126 MHz, CDCl3)
B(pin)
Cl
1.113
24.77
24.76
21.2
21.5
24.8
24.6
24.4
24.2
24.5
f0 (ppm)
f0 (ppm)


^{1}H NMR (500 MHz, CDCl$_3$)
B(pin)
1.114
O
9.92
7.72
7.75
7.30
7.29
7.24
7.23
7.20
7.08
7.07
7.04
7.03
7.00
3.23
3.20
3.25
3.09
3.53
3.50
3.55
2.98
2.67
2.66
2.64
0.00
0.05
0.55
2.05
2.58
3.28
2.51
0.54
0.50
0.55
5.99
1.63
6.12
f0 (ppm)

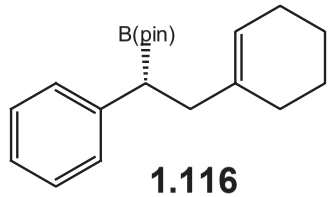

^{13}C NMR (126 MHz, CDCl$_3$)
B(pin)
1.114
O
092.23
049.13
040.97
034.63
029.82
029.73
028.60
028.11
021.83
24.74
24.72
83.78
39.08
34.24
24.74
24.72
f0 (ppm)


1H NMR (500 MHz, CDCl3)
1.115
B(pin)
N
8.38
8.34
8.34
7.41
7.40
7.24
7.23
7.21
7.20
7.16
7.15
7.12
7.11
7.10
7.09
7.08
3.13
3.11
3.11
3.09
2.93
2.91
2.90
2.88
2.61
2.59
2.58
1.20 pinacol
1.10
1.09
1.01
0.93
1.01
2.08
1.92
1.88
1.00
1.06
1.26
5.33
6.16
f1 (ppm)

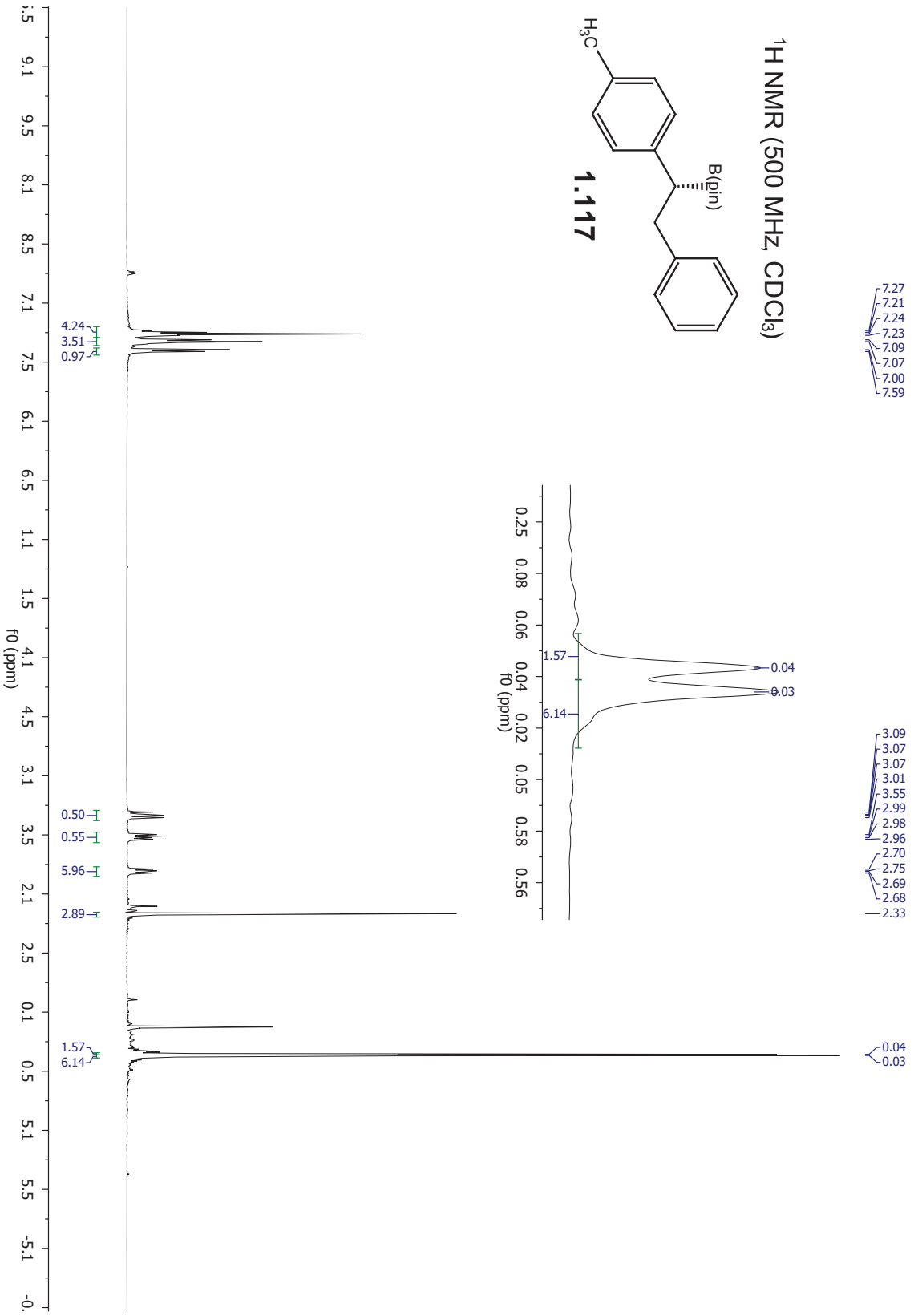

150.34
147.24
141.87
137.25
136.54
128.64
128.59
125.87
123.19
83.81
75.10 pinacol
36.08
34.37
25.03
24.73
13C NMR (126 MHz, CDCl3)
B(pin)
N
1.115
25.03
24.73
25.6 25.4 25.2 25.0 24.8 24.6 24.4 24.2
f1 (ppm)
30 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -1
f1 (ppm)

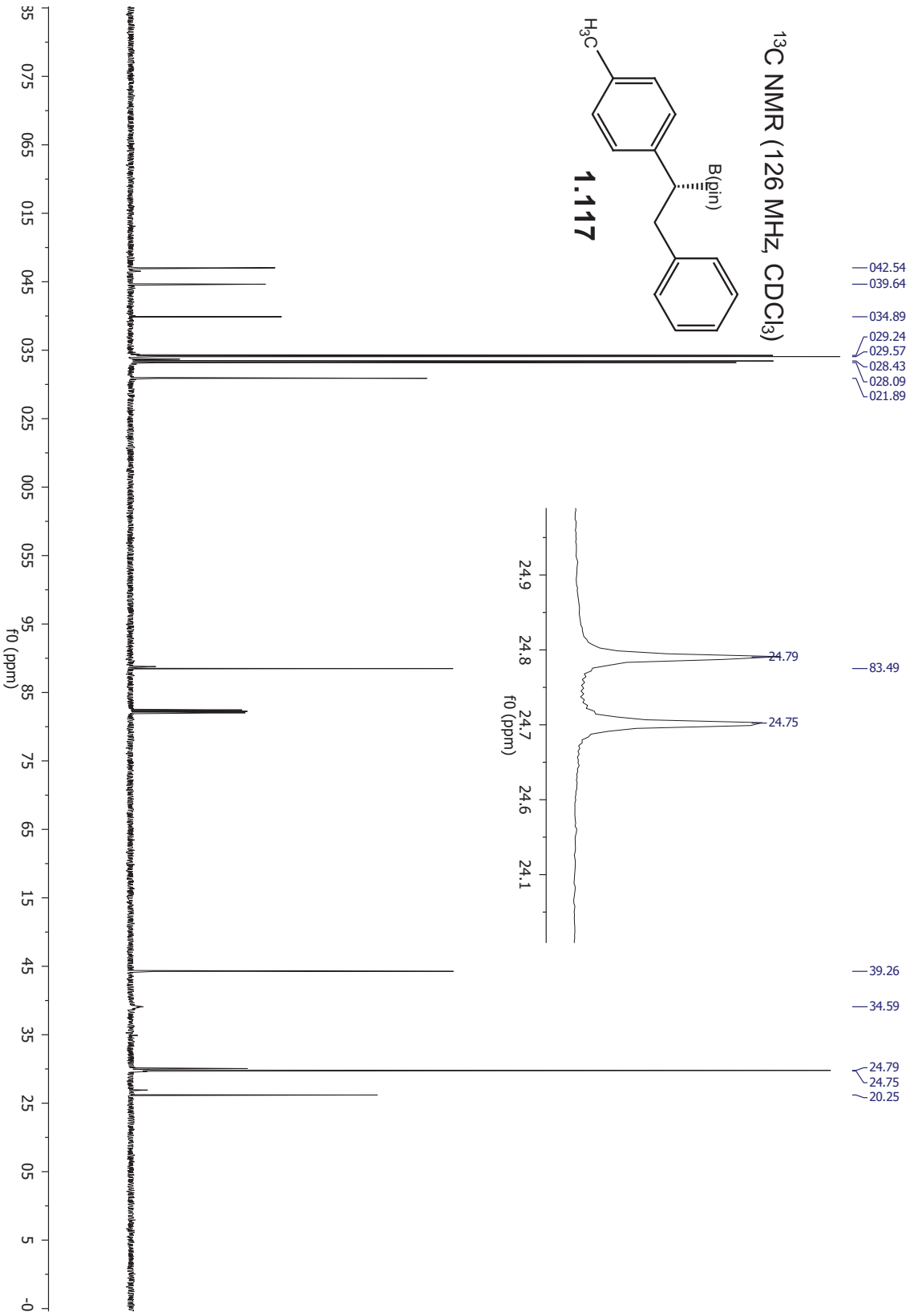

^{1}H NMR (600 MHz, CDCl$_3$)
B(pin)
1.116
7.24
7.22
7.20
7.02
7.02
7.00
7.05
7.59
7.59
1.42
2.18
2.17
2.16
2.11
2.10
2.49
2.47
2.24
2.23
2.20
2.25
0.96
0.92
0.88
0.65
0.18
0.18
0.17
0.16
0.11
0.15
0.49
0.07
0.01
3.90
0.55
0.00
0.52
0.53
0.52
4.55
4.26
1.15
1.74
1.15
1.74
0.07
0.01
f0 (ppm)
f0 (ppm)

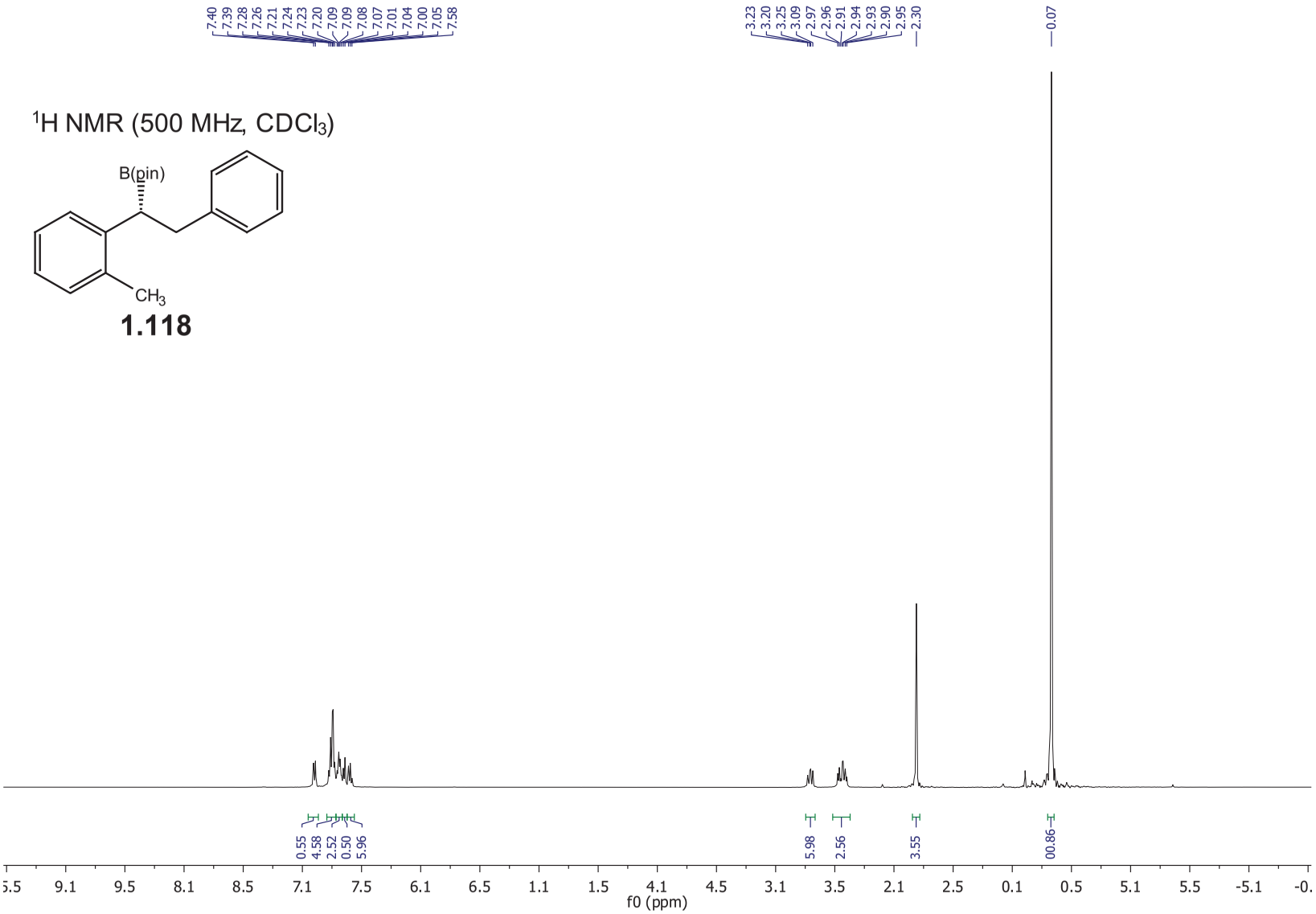
^{13}C NMR (151 MHz, $CDCl_3$)

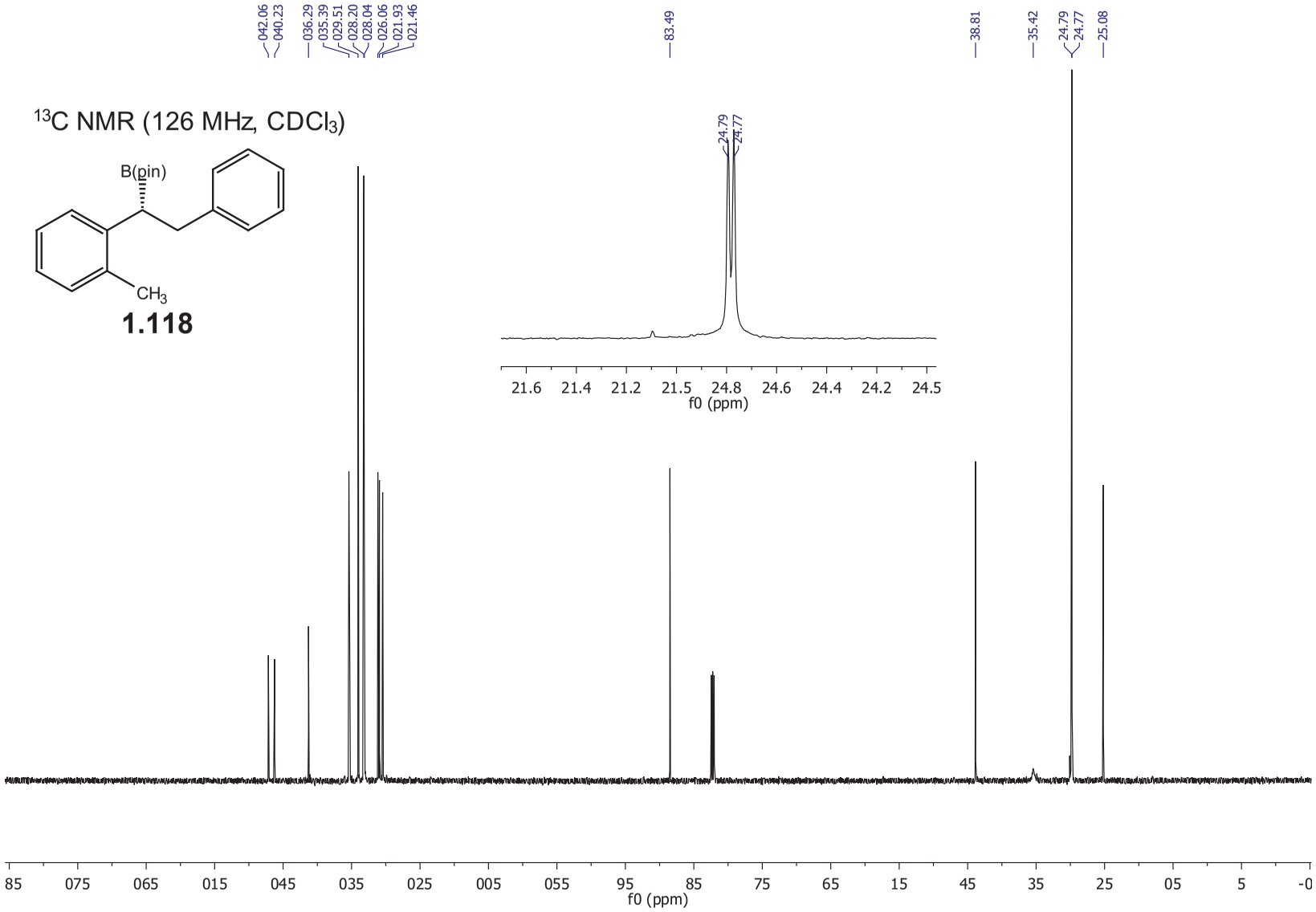


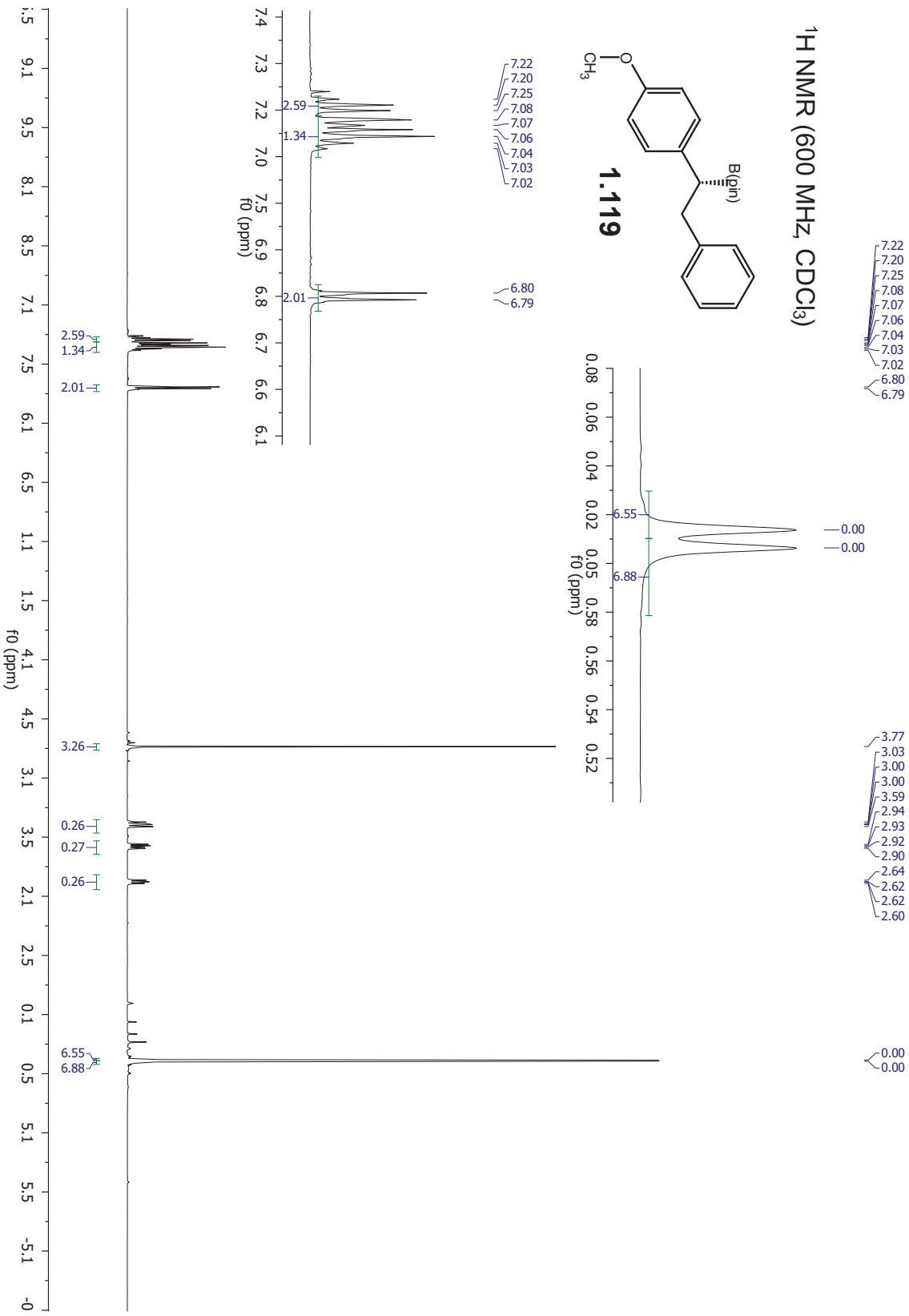
1.116

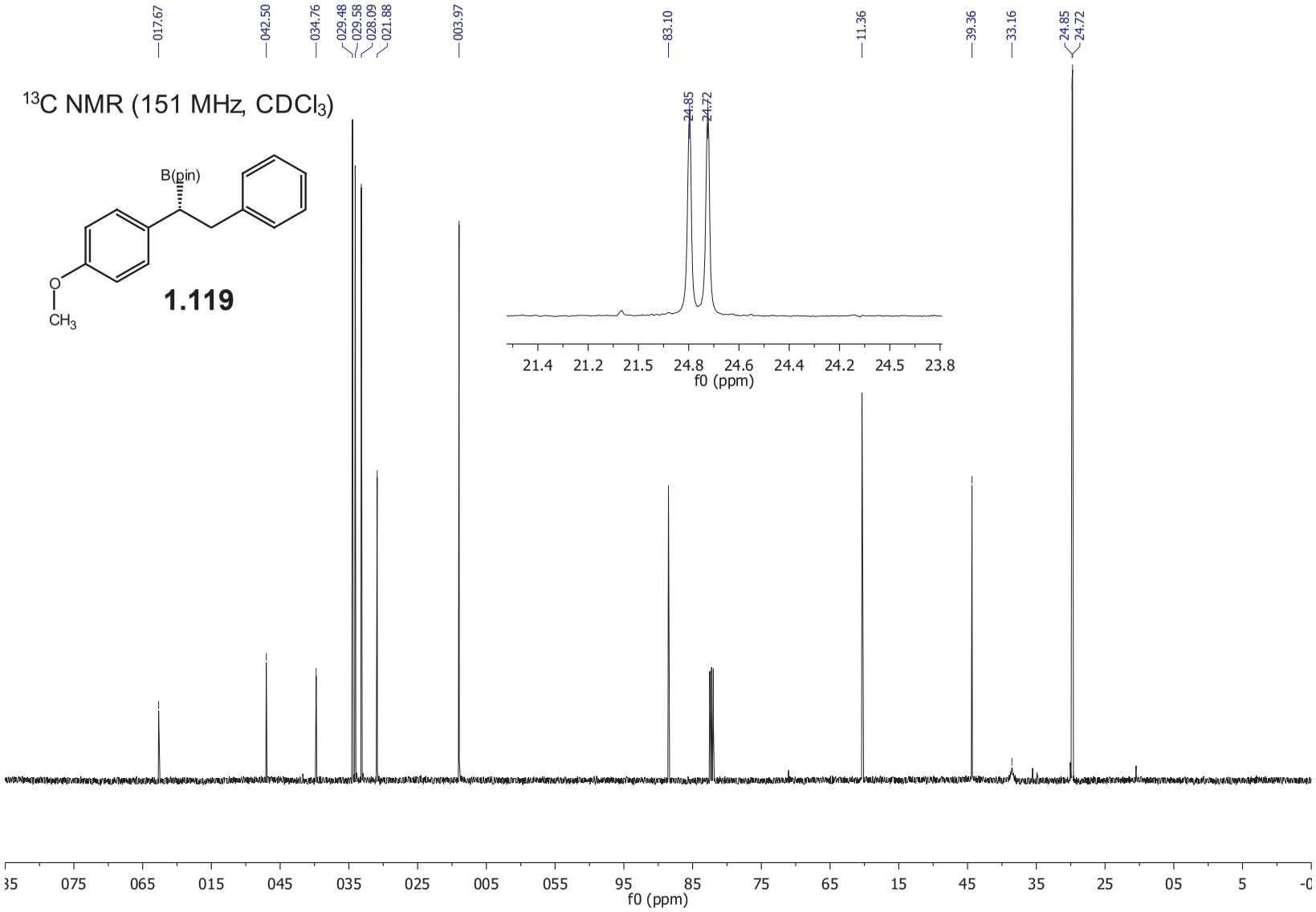

^{1}H NMR (500 MHz, CDCl$_3$)
1.117
H$_3$C
B(pin)
f0 (ppm)
4.24
3.51
0.97
0.50
0.55
5.96
2.89
1.57
6.14
7.27
7.21
7.24
7.23
7.09
7.07
7.00
7.59
3.09
3.07
3.07
3.01
3.55
2.99
2.98
2.96
2.70
2.75
2.69
2.68
2.33
0.04
0.03

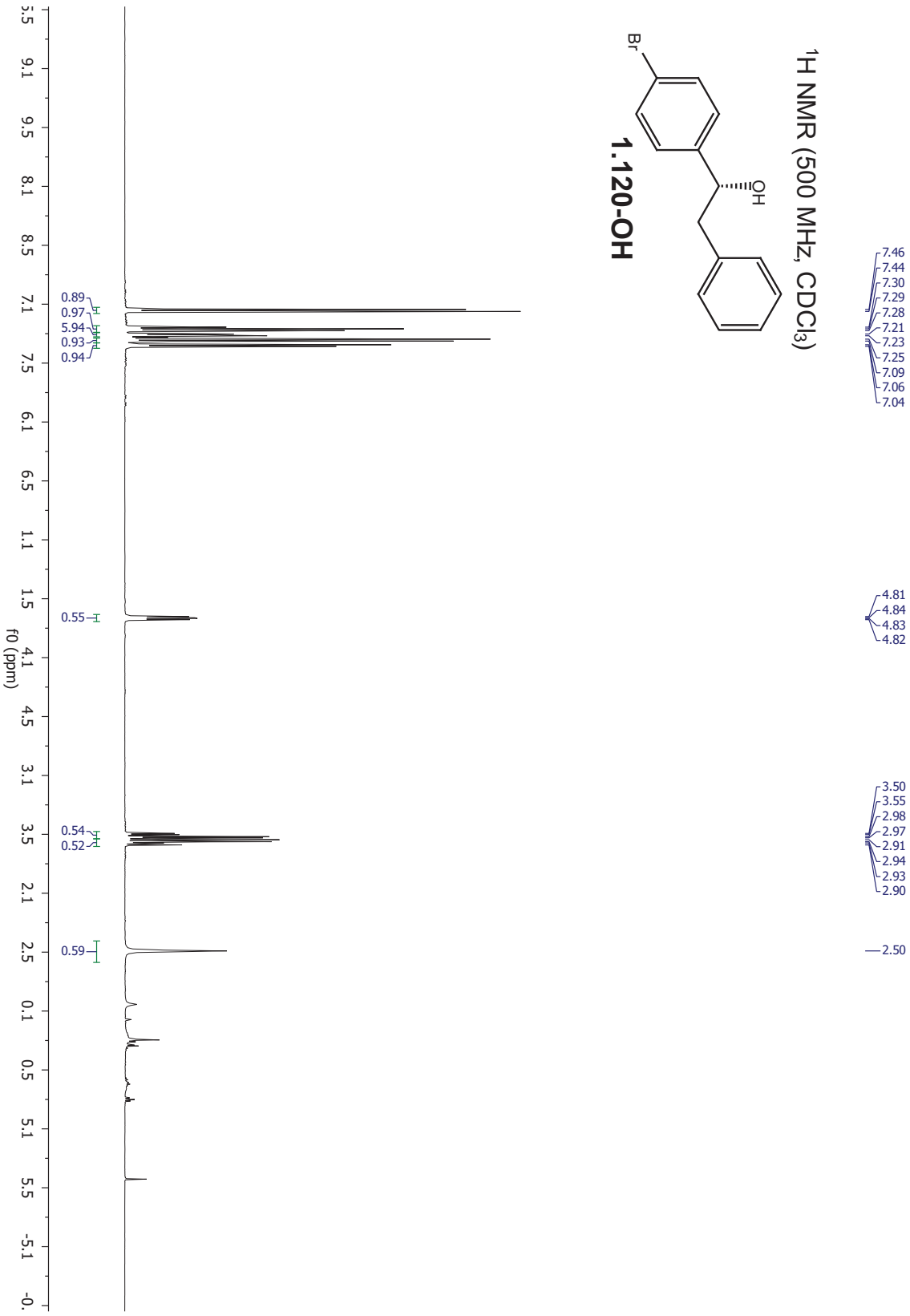

13C NMR (126 MHz, CDCl3)
H3C
B(pin)
1.117
042.54
039.64
034.89
029.24
029.57
028.43
028.09
021.89
24.79
83.49
24.75
39.26
34.59
24.79
24.75
20.25
f0 (ppm)

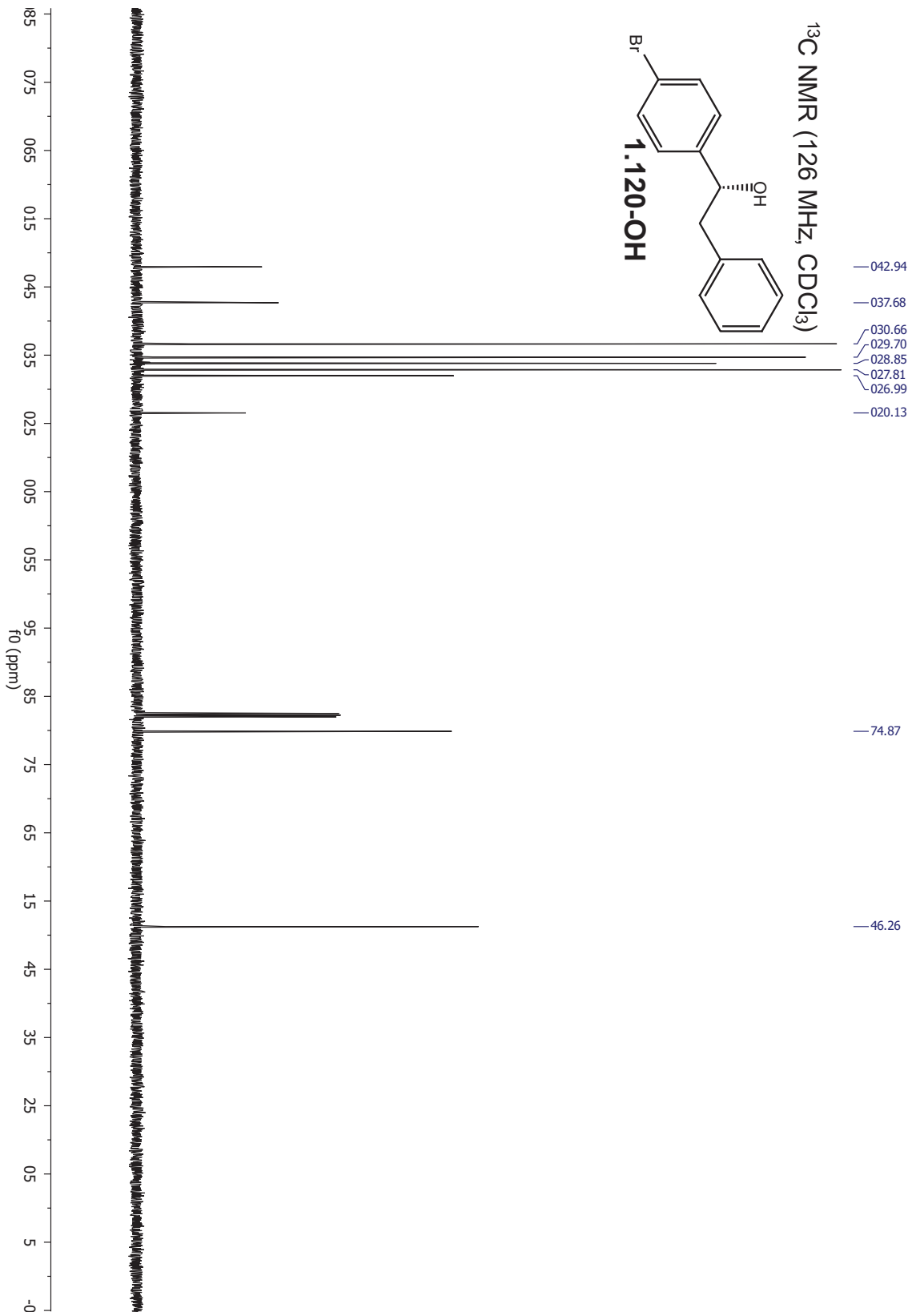

7.40
7.39
7.28
7.26
7.21
7.24
7.23
7.20
7.09
7.09
7.08
7.07
7.01
7.04
7.00
7.05
7.58
3.23
3.20
3.25
3.09
2.97
2.96
2.91
2.94
2.93
2.90
2.95
2.30
0.07
^{1}H NMR (500 MHz, $CDCl_3$)
B(pin)
CH_3
1.118
0.55
4.58
2.52
0.50
5.96
5.98
2.56
3.55
00.86
f0 (ppm)

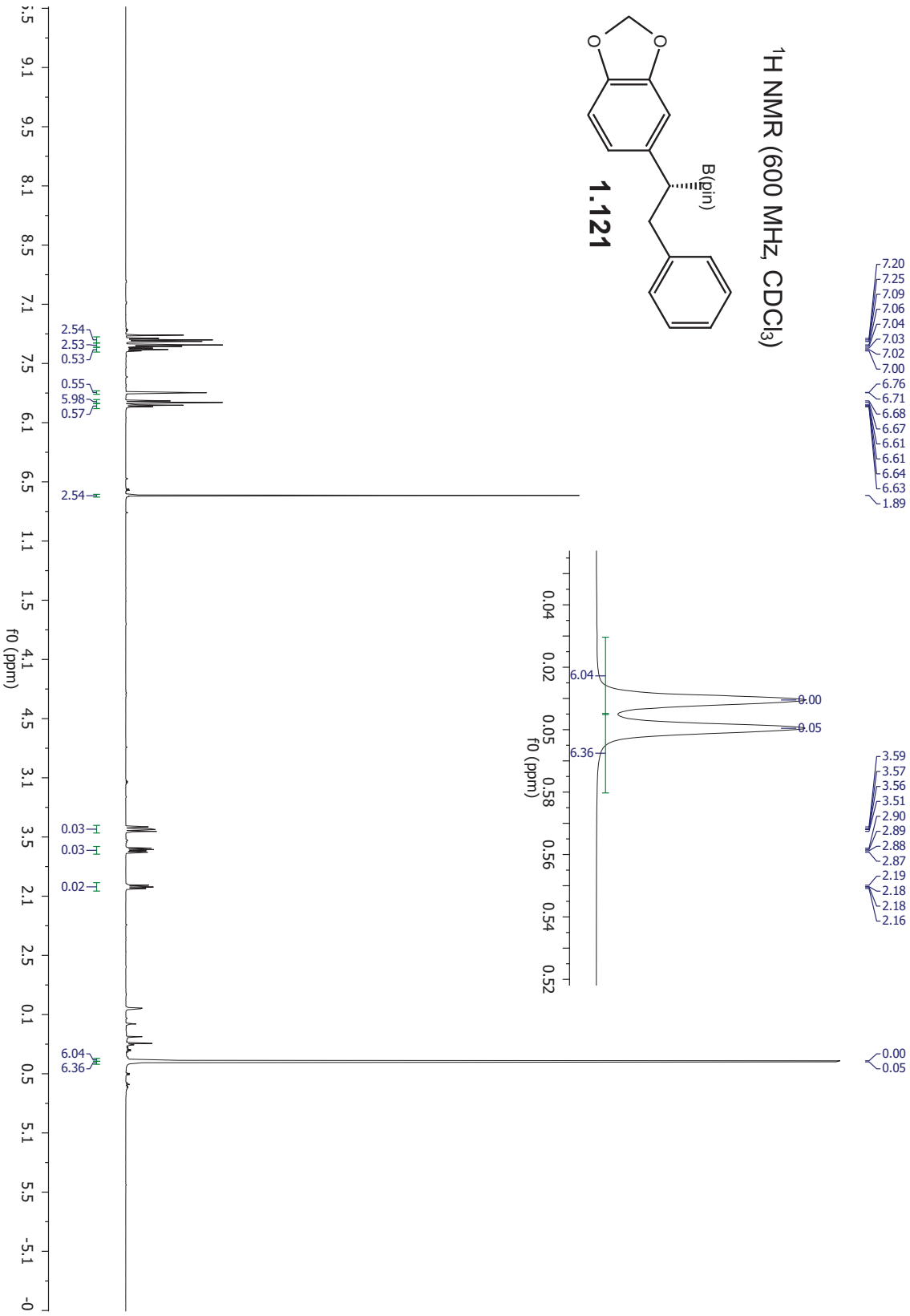

042.06
040.23
036.29
035.39
029.51
028.20
028.04
026.06
021.93
021.46
83.49
38.81
35.42
24.79
24.77
25.08
^{13}C NMR (126 MHz, CDCl$_3$)
B(pin)
CH$_3$
1.118
24.79
24.77
21.6 21.4 21.2 21.5 24.8 24.6 24.4 24.2 24.5
f0 (ppm)
85 075 065 015 045 035 025 005 055 95 85 75 65 15 45 35 25 05 5 -0
f0 (ppm)

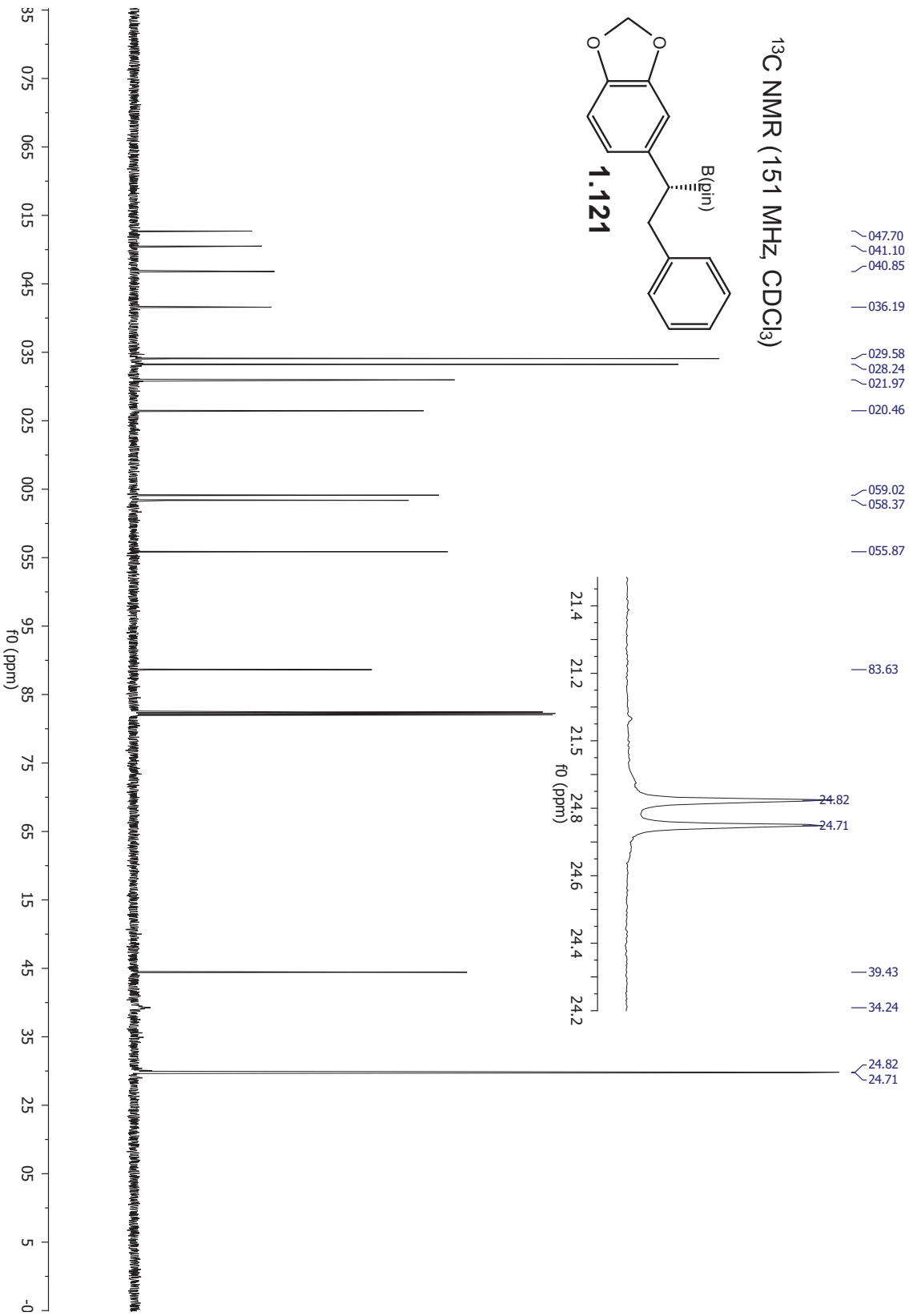

^{1}H NMR (600 MHz, $CDCl_3$)
1.119
B(pin)
CH_3
f0 (ppm)
7.22
7.20
7.25
7.08
7.07
7.06
7.04
7.03
7.02
6.80
6.79
3.77
3.03
3.00
3.00
3.59
2.94
2.93
2.92
2.90
2.64
2.62
2.62
2.60
0.00
0.00
2.59
1.34
2.01
3.26
0.26
0.27
0.26
6.55
6.88

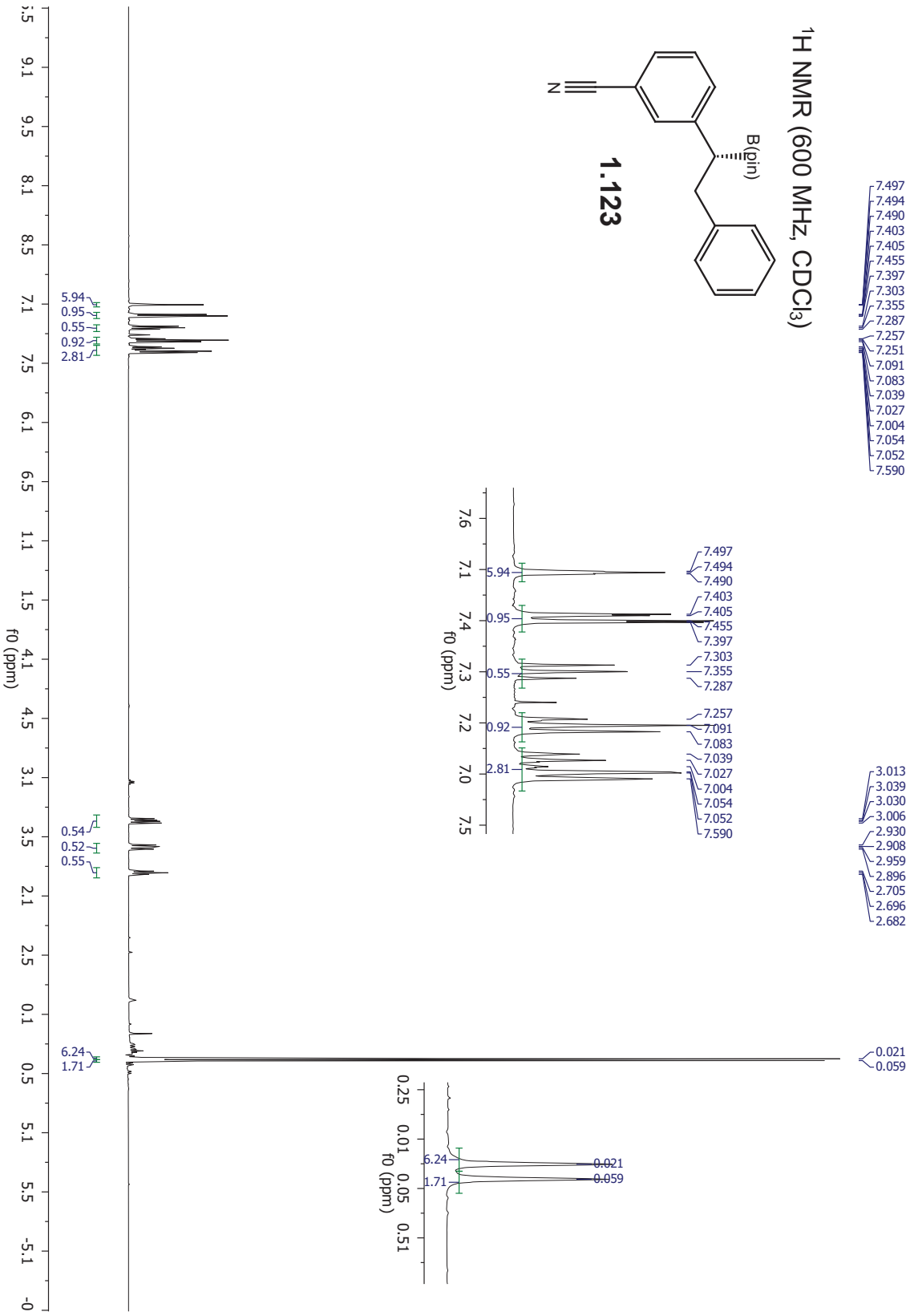

017.67
042.50
034.76
029.48
029.58
028.09
021.88
003.97
083.10
011.36
039.36
033.16
024.85
024.72
13C NMR (151 MHz, CDCl3)
B(pin)
O
CH3
1.119
24.85
24.72
21.4
21.2
21.5
24.8
24.6
24.4
24.2
24.5
23.8
f0 (ppm)
f0 (ppm)

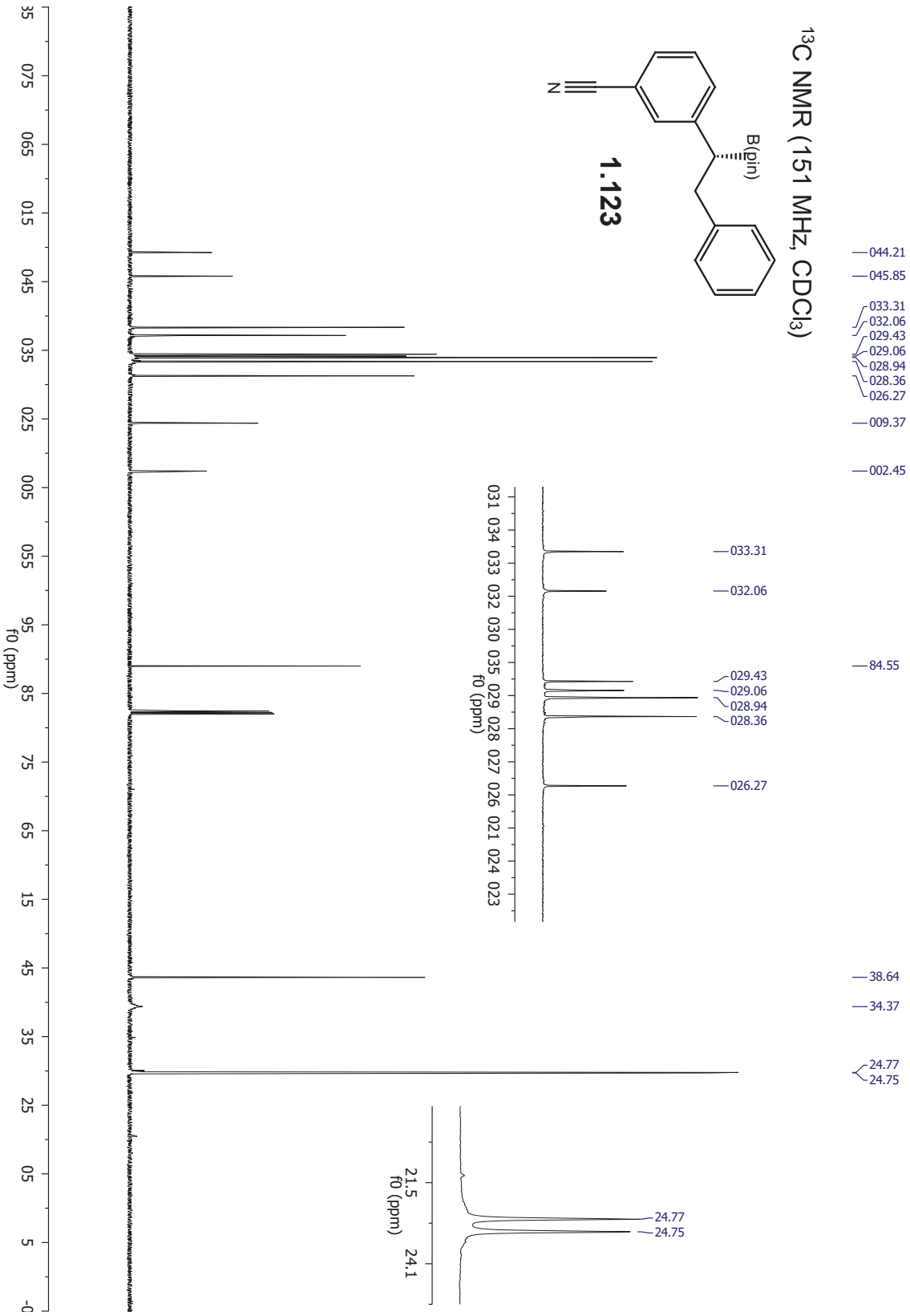

1H NMR (500 MHz, CDCl3)
1.120-OH
Br
OH
7.46
7.44
7.30
7.29
7.28
7.21
7.23
7.25
7.09
7.06
7.04
4.81
4.84
4.83
4.82
3.50
3.55
2.98
2.97
2.91
2.94
2.93
2.90
2.50
0.89
0.97
5.94
0.93
0.94
0.55
0.54
0.52
0.59
f0 (ppm)

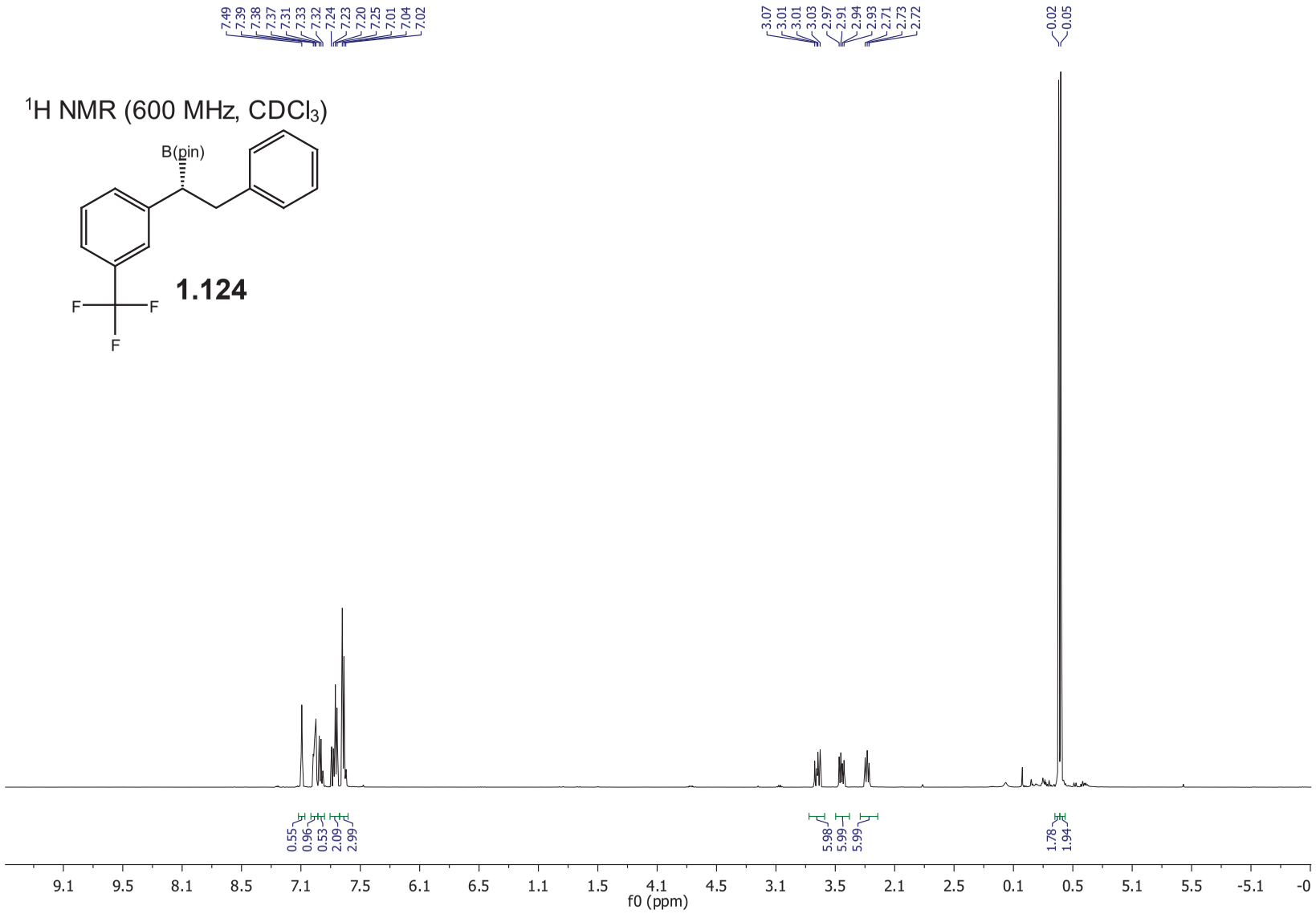

^{13}C NMR (126 MHz, CDCl$_3$)
1.120-OH
Br
OH
042.94
037.68
030.66
029.70
028.85
027.81
026.99
020.13
74.87
46.26
f0 (ppm)

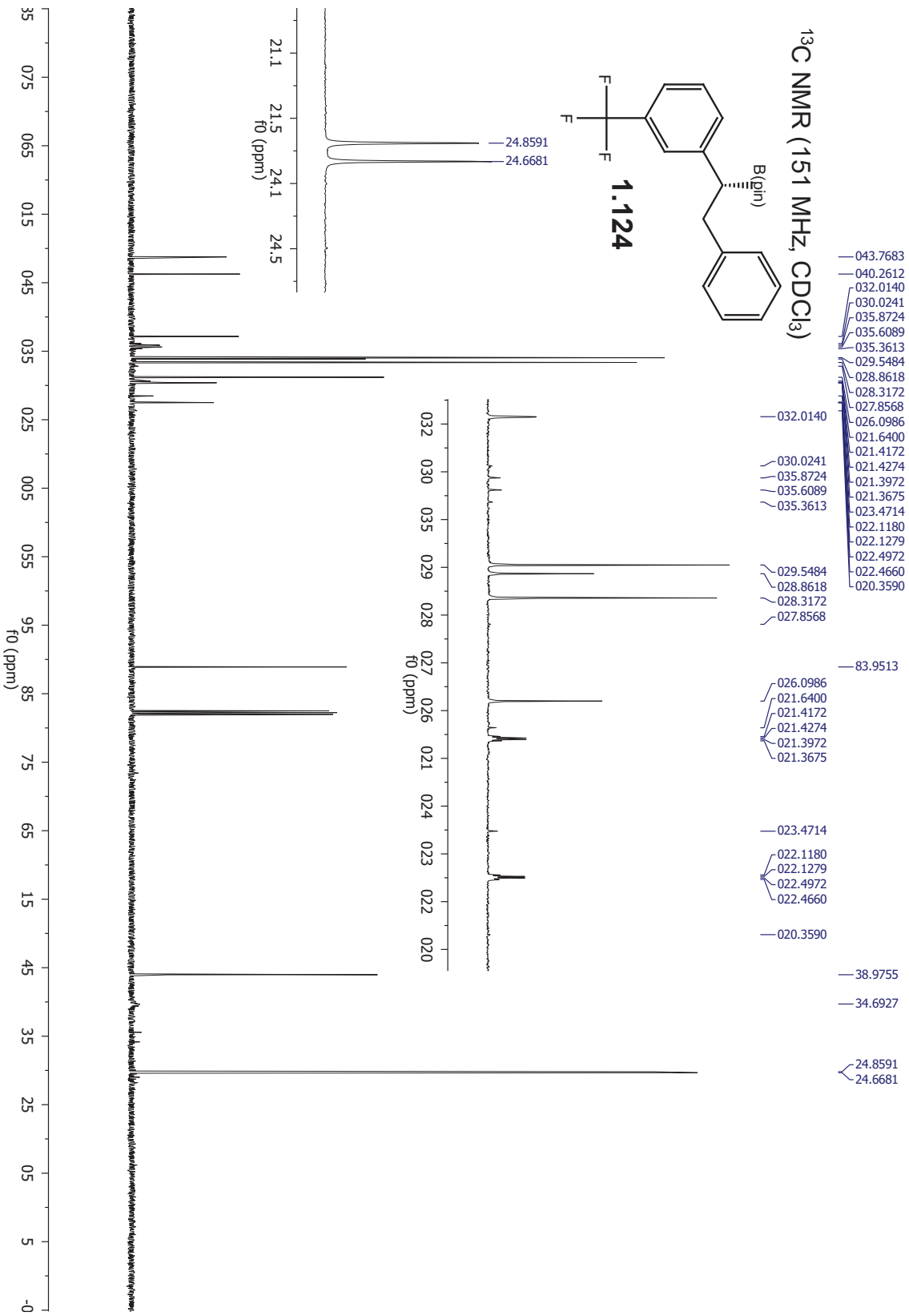

^{1}H NMR (600 MHz, CDCl$_3$)
B(pin)
1.121
f0 (ppm)
7.20
7.25
7.09
7.06
7.04
7.03
7.02
7.00
6.76
6.71
6.68
6.67
6.61
6.61
6.64
6.63
1.89
3.59
3.57
3.56
3.51
2.90
2.89
2.88
2.87
2.19
2.18
2.18
2.16
0.00
0.05
2.54
2.53
0.53
0.55
5.98
0.57
2.54
0.03
0.03
0.02
6.04
6.36
6.04
6.36
0.00
0.05

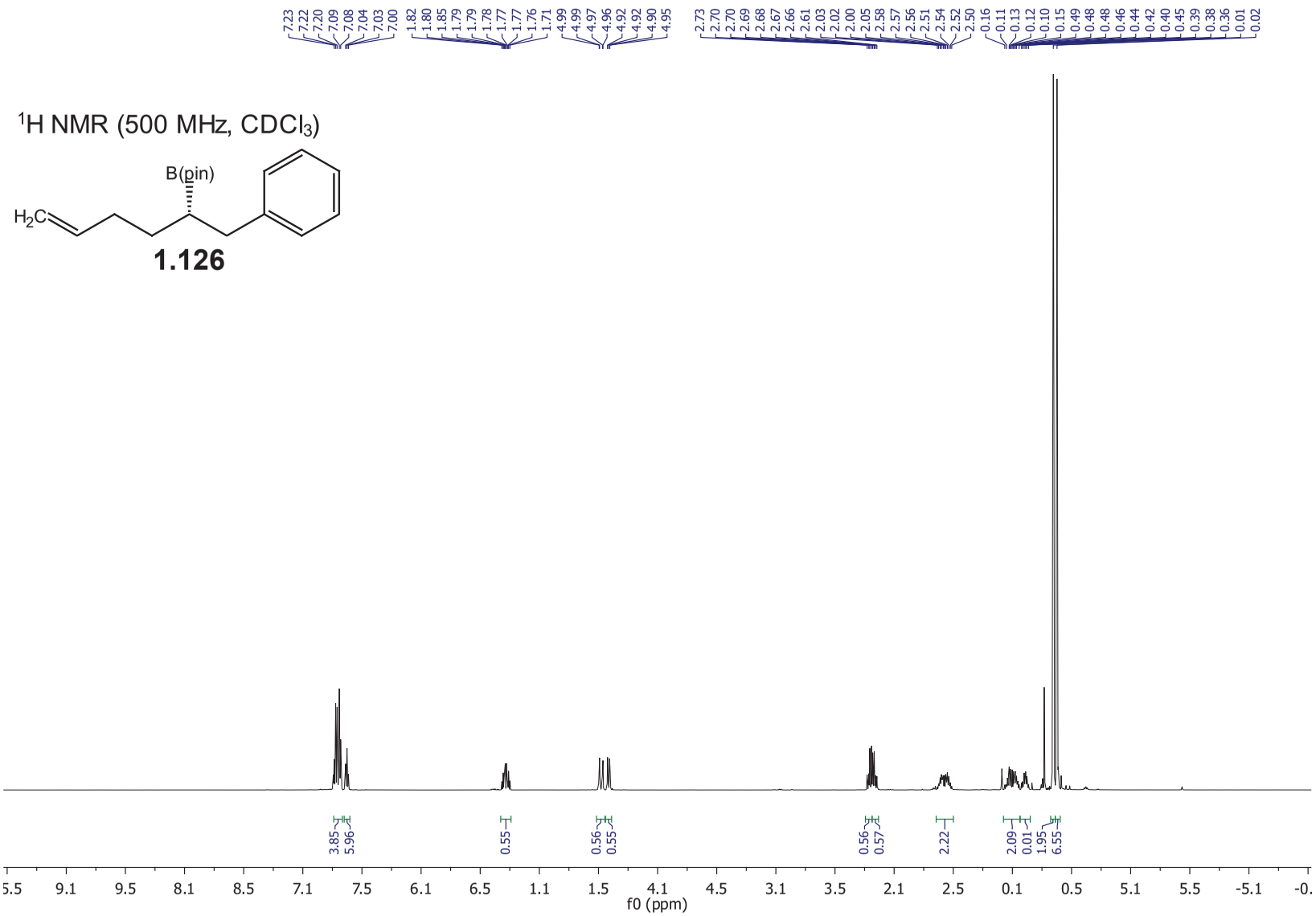

13C NMR (151 MHz, CDCl3)
B(pin)
1.121
047.70
041.10
040.85
036.19
029.58
028.24
021.97
020.46
059.02
058.37
055.87
83.63
24.82
24.71
39.43
34.24
24.82
24.71
f0 (ppm)
f0 (ppm)

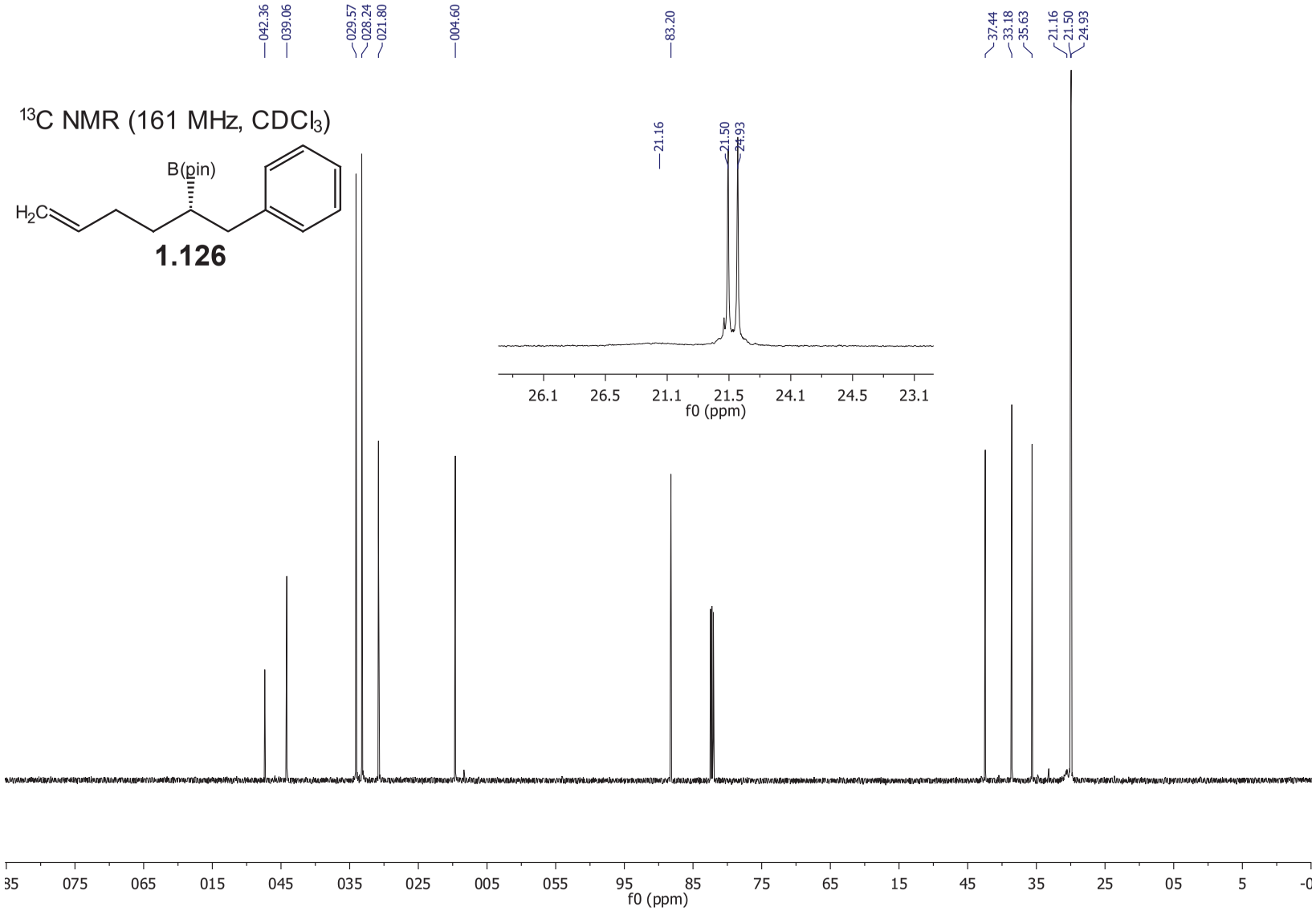

1H NMR (600 MHz, CDCl3)
1.123
B(pin)
N
f0 (ppm)
5.94
0.95
0.55
0.92
2.81
0.54
0.52
0.55
6.24
1.71
7.497
7.494
7.490
7.403
7.405
7.455
7.397
7.303
7.355
7.287
7.257
7.251
7.091
7.083
7.039
7.027
7.004
7.054
7.052
7.590
3.013
3.039
3.030
3.006
2.930
2.908
2.959
2.896
2.705
2.696
2.682
0.021
0.059

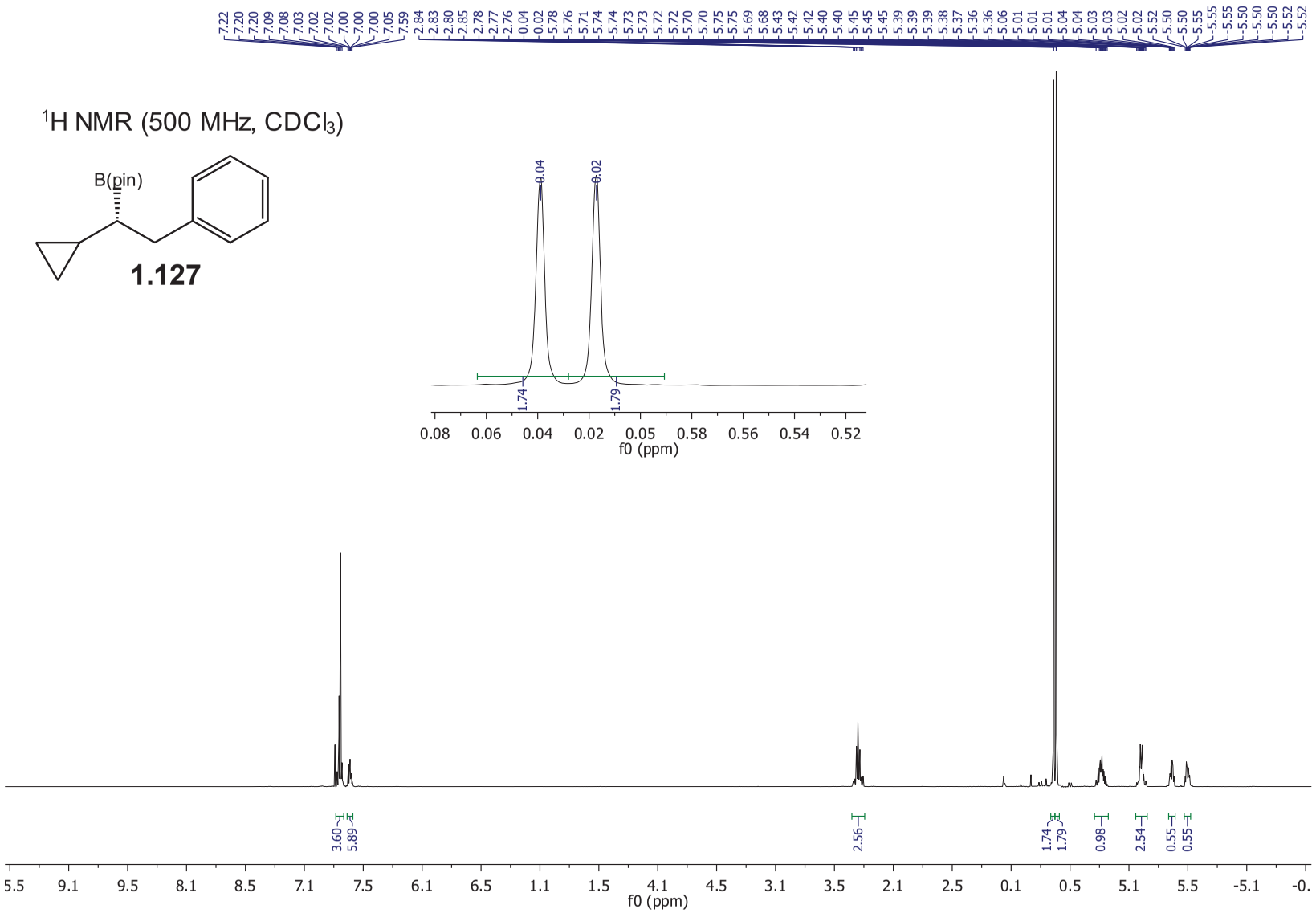

^{13}C NMR (151 MHz, CDCl$_3$)
1.123
B(pin)
N
044.21
045.85
033.31
032.06
029.43
029.06
028.94
028.36
026.27
009.37
002.45
84.55
38.64
34.37
24.77
24.75
f0 (ppm)

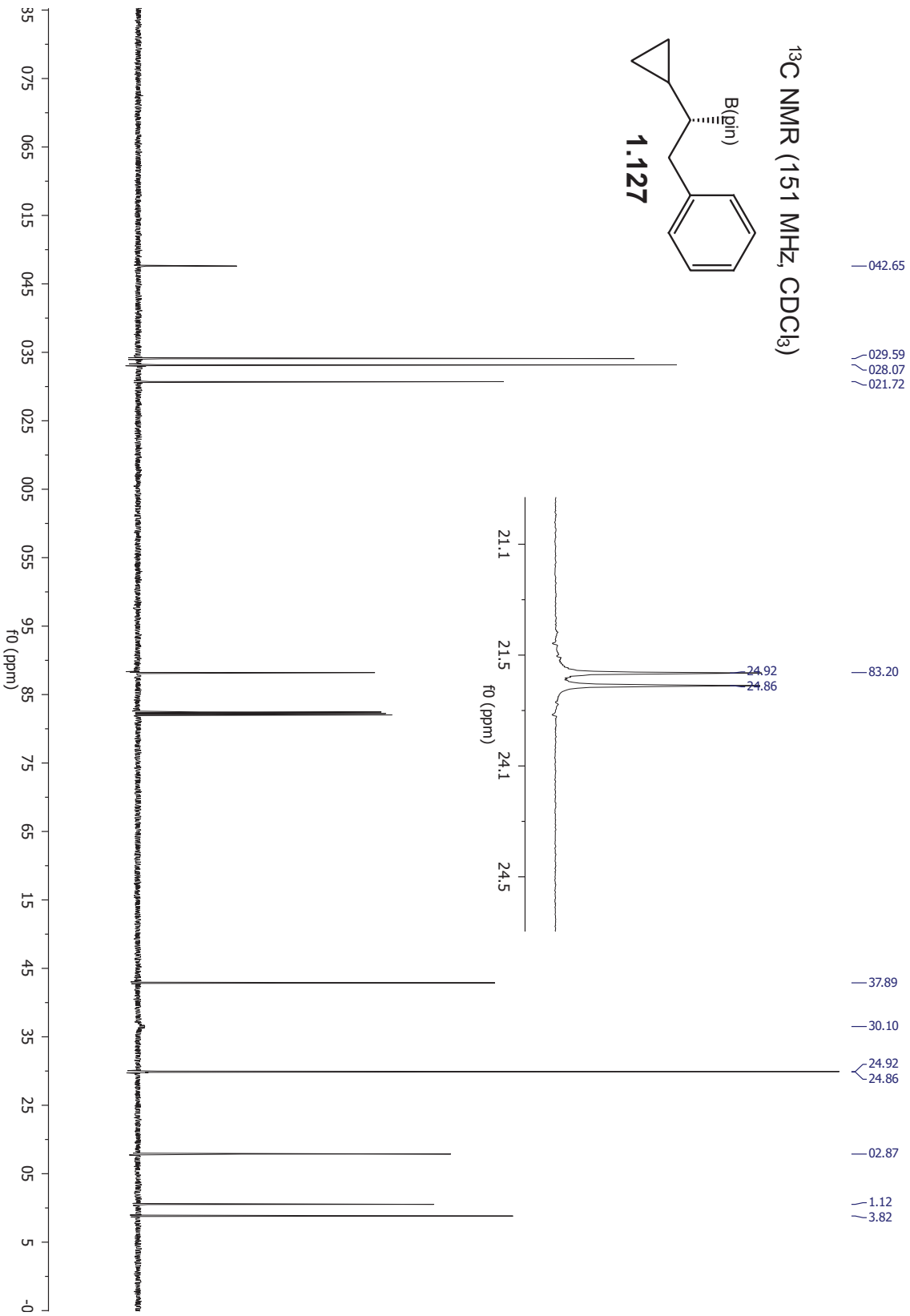

7.49
7.39
7.38
7.37
7.31
7.33
7.32
7.24
7.23
7.20
7.25
7.01
7.04
7.02
3.07
3.01
3.01
3.03
2.97
2.91
2.94
2.93
2.71
2.73
2.72
0.02
0.05
1H NMR (600 MHz, CDCl3)
B(pin)
F
F
F
1.124
0.55
0.96
0.53
2.09
2.99
5.98
5.99
5.99
1.78
1.94
9.1
9.5
8.1
8.5
7.1
7.5
6.1
6.5
1.1
1.5
4.1
4.5
3.1
3.5
2.1
2.5
0.1
0.5
5.1
5.5
-5.1
-0
f0 (ppm)

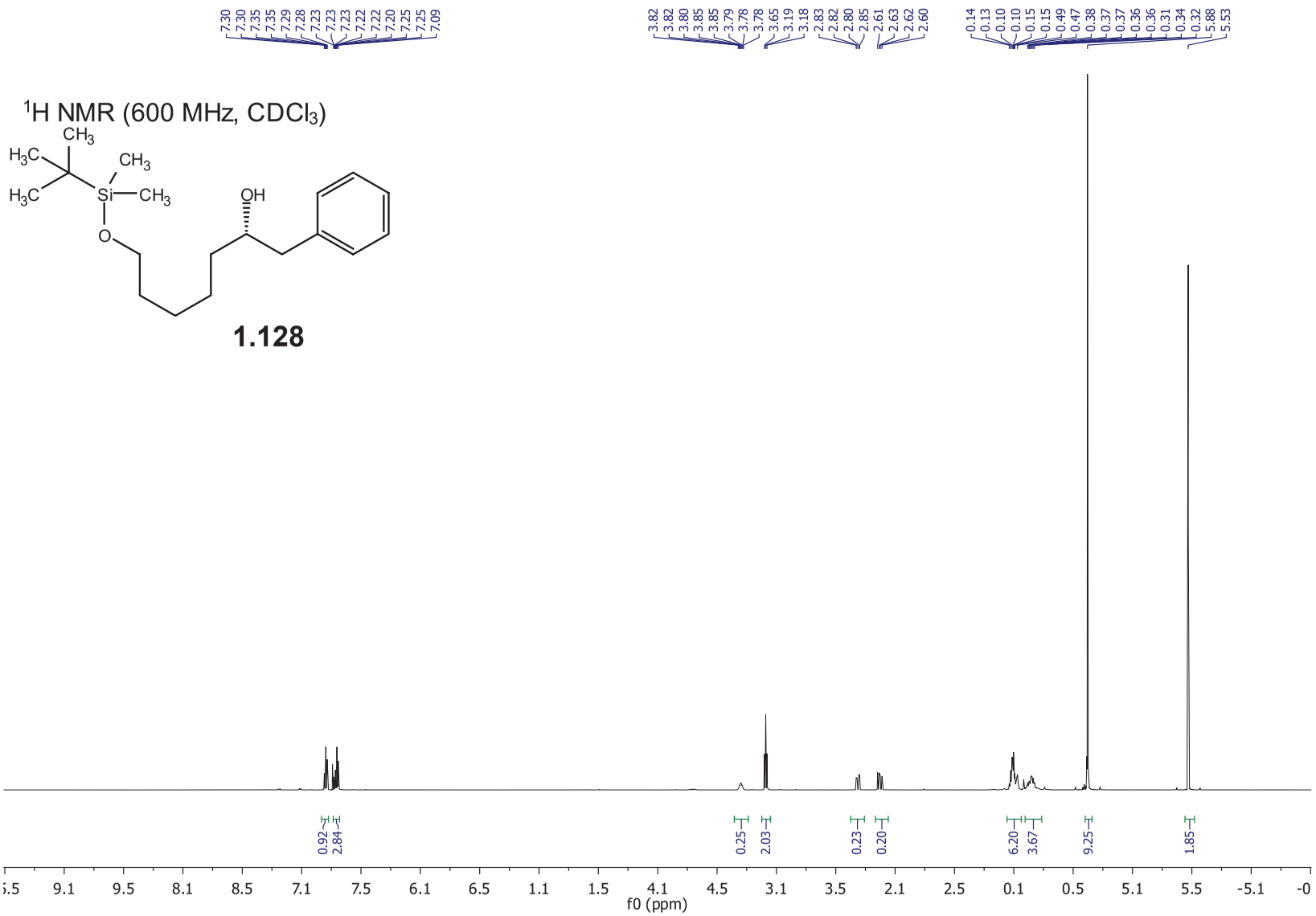

^{13}C NMR (151 MHz, CDCl$_3$)
1.124
B(pin)
F
F
F
043.7683
040.2612
032.0140
030.0241
035.8724
035.6089
035.3613
029.5484
028.8618
028.3172
027.8568
026.0986
021.6400
021.4172
021.4274
021.3972
021.3675
023.4714
022.1180
022.1279
022.4972
022.4660
020.3590
83.9513
38.9755
34.6927
24.8591
24.6681
f0 (ppm)

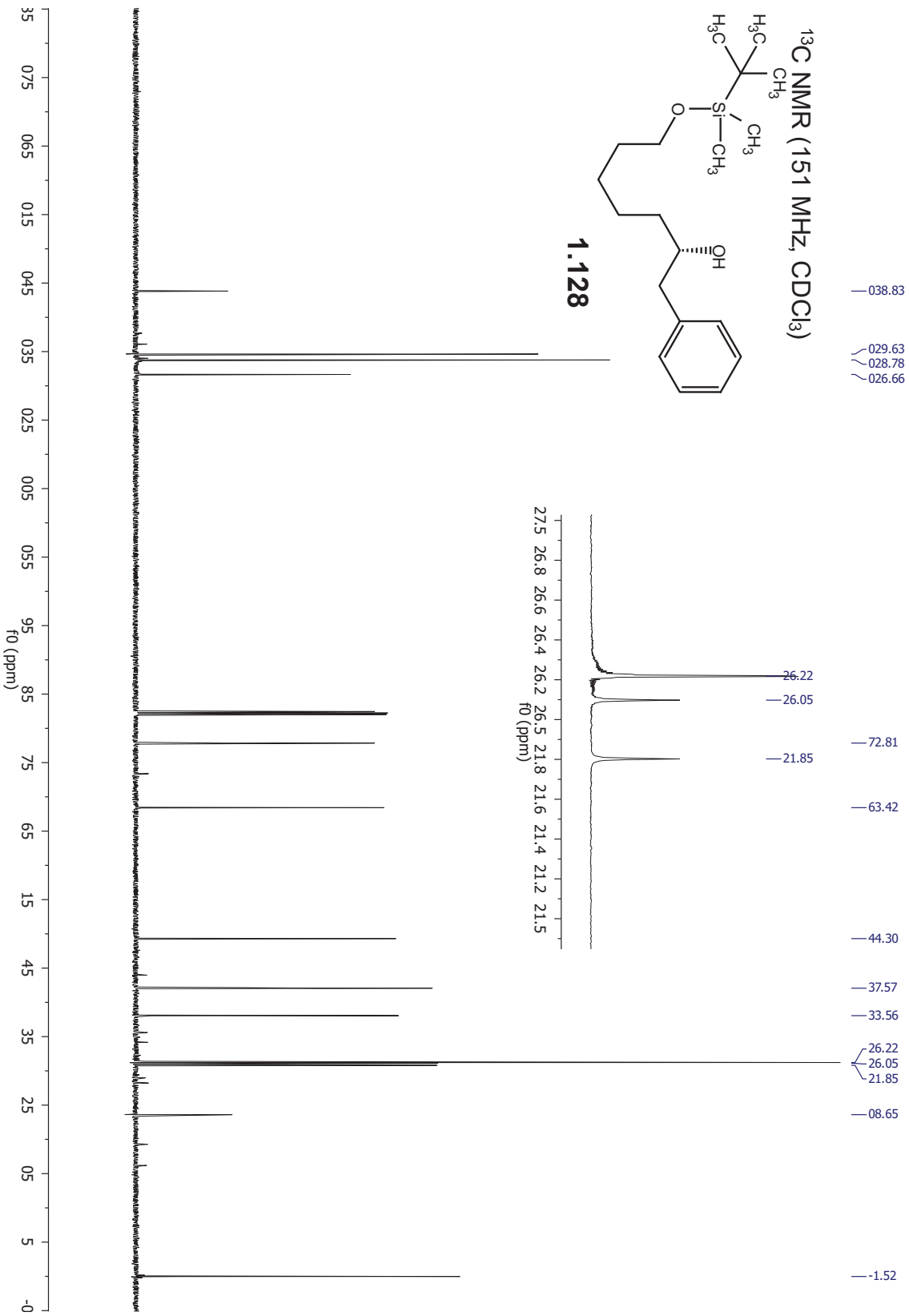

7.23 7.22 7.20 7.09 7.08 7.04 7.03 7.00 1.82 1.80 1.85 1.79 1.79 1.78 1.77 1.77 1.76 1.71 4.99 4.99 4.97 4.96 4.92 4.92 4.90 4.95 2.73 2.70 2.70 2.69 2.68 2.67 2.66 2.61 2.03 2.02 2.00 2.05 2.58 2.57 2.56 2.51 2.54 2.52 2.50 0.16 0.11 0.13 0.12 0.10 0.15 0.49 0.48 0.48 0.46 0.44 0.42 0.40 0.45 0.39 0.38 0.36 0.01 0.02
1H NMR (500 MHz, CDCl3)
B(pin)
H2C
1.126
3.85 5.96 0.55 0.56 0.55 0.56 0.57 2.22 2.09 0.01 1.95 6.55
5.5 9.1 9.5 8.1 8.5 7.1 7.5 6.1 6.5 1.1 1.5 4.1 4.5 3.1 3.5 2.1 2.5 0.1 0.5 5.1 5.5 -5.1 -0.
f0 (ppm)

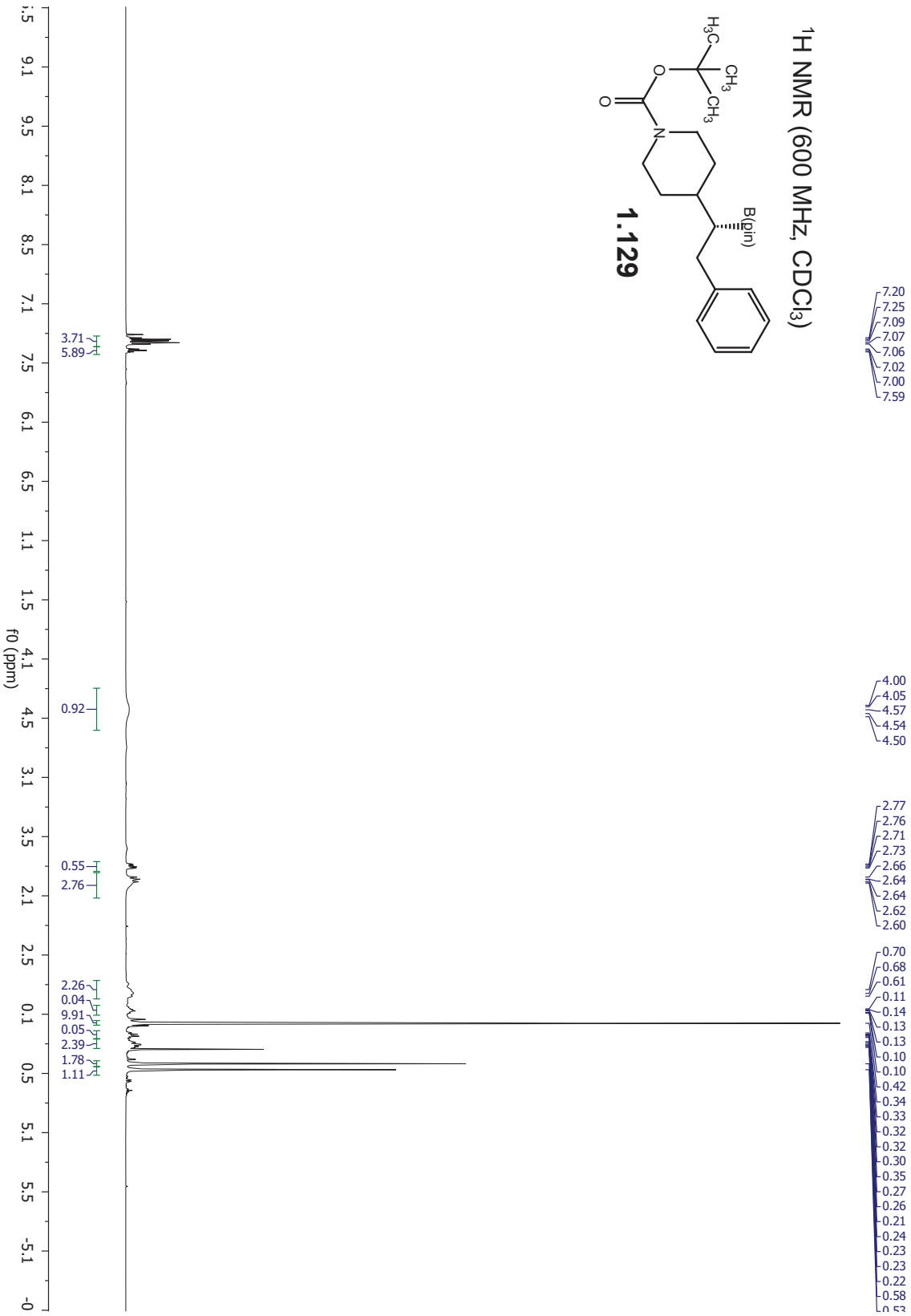

042.36
039.06
029.57
028.24
021.80
004.60
083.20
037.44
033.18
035.63
021.16
021.50
024.93
13C NMR (161 MHz, CDCl3)
B(pin)
H2C
1.126
21.16
21.50
24.93
26.1
26.5
21.1
21.5
24.1
24.5
23.1
f0 (ppm)
f0 (ppm)

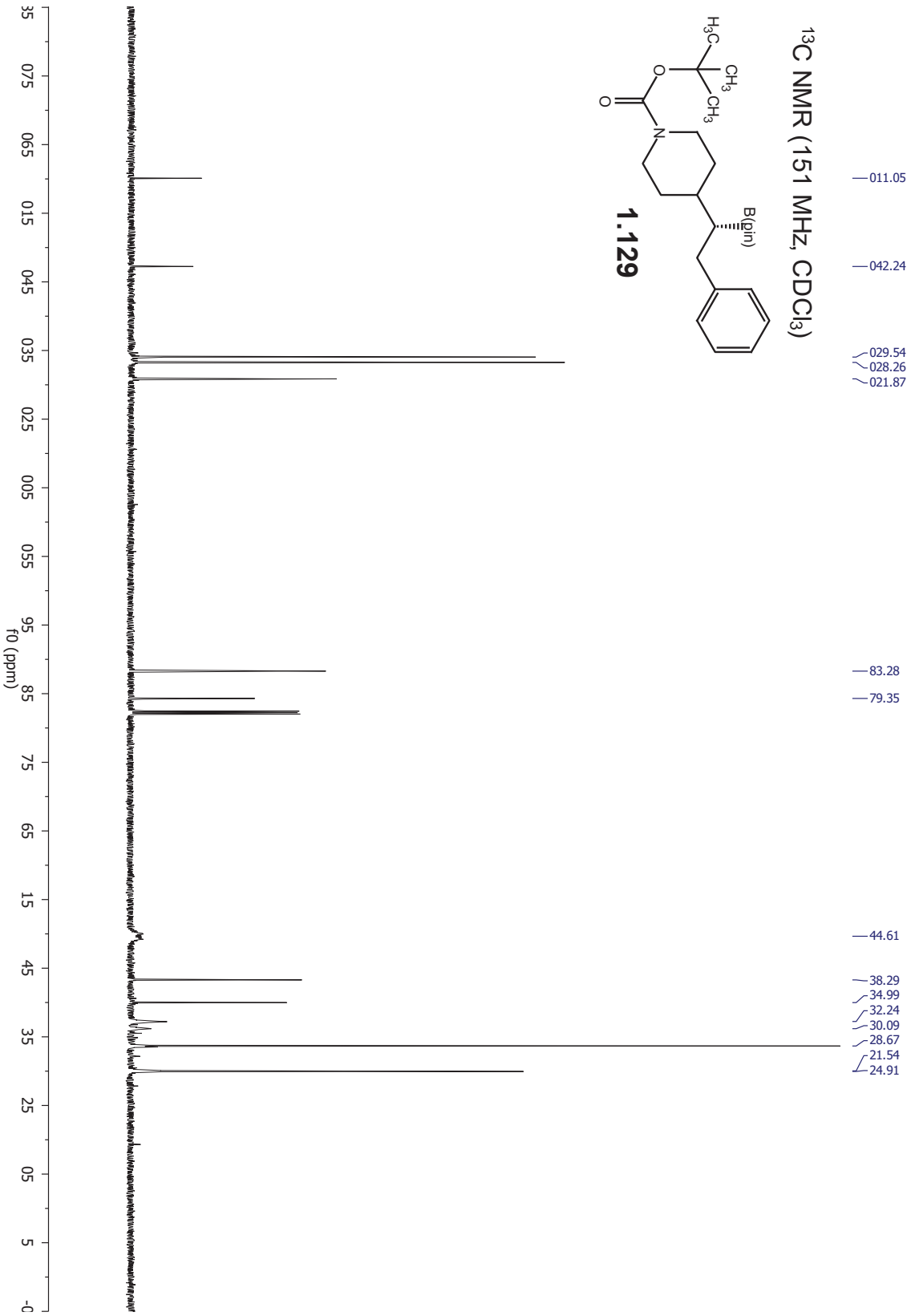

^{1}H NMR (500 MHz, $CDCl_3$)
B(pin)
1.127
f0 (ppm)

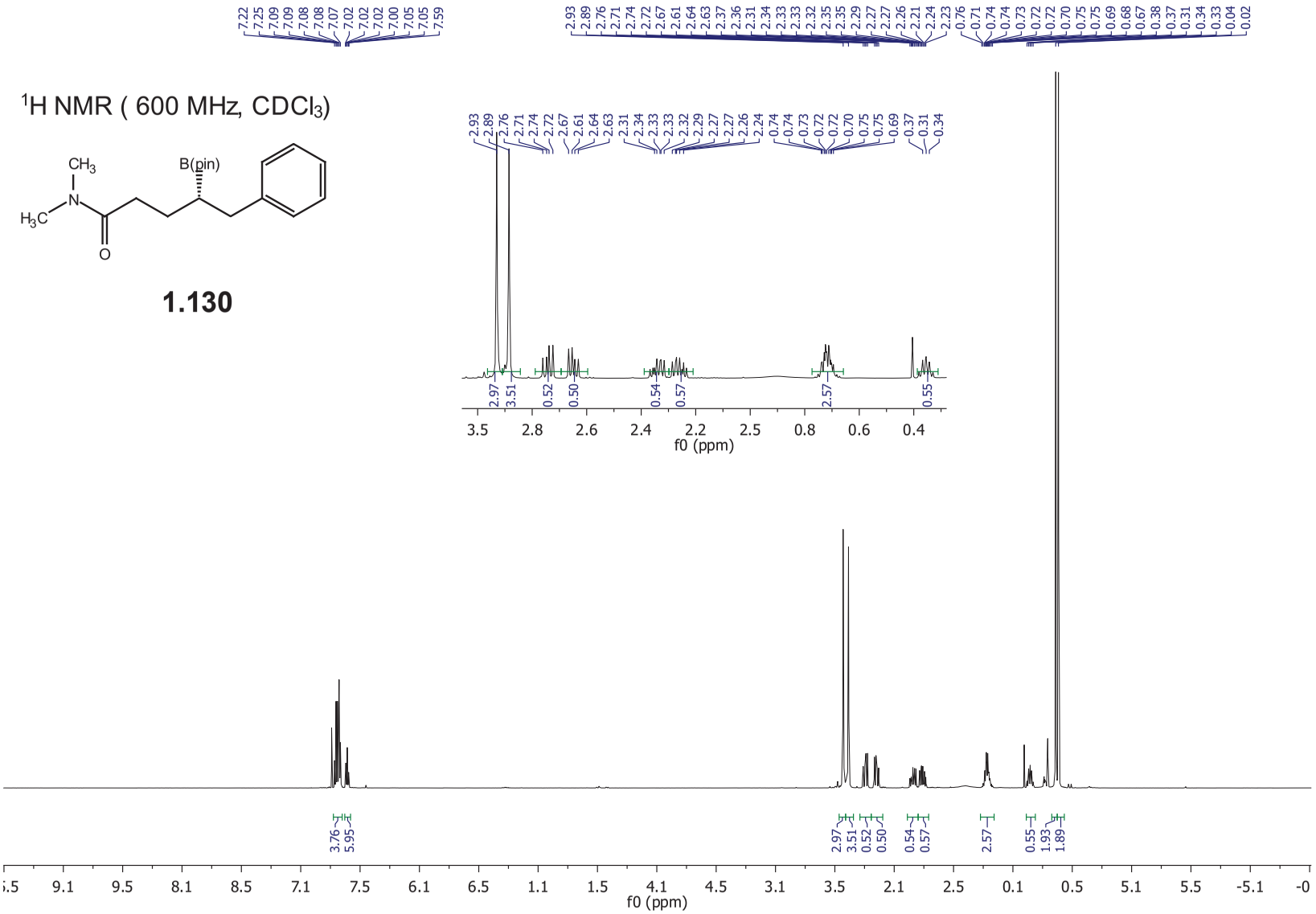

13C NMR (151 MHz, CDCl3)
B(pin)
1.127
042.65
029.59
028.07
021.72
83.20
24.92
24.86
37.89
30.10
24.92
24.86
02.87
1.12
3.82
f0 (ppm)

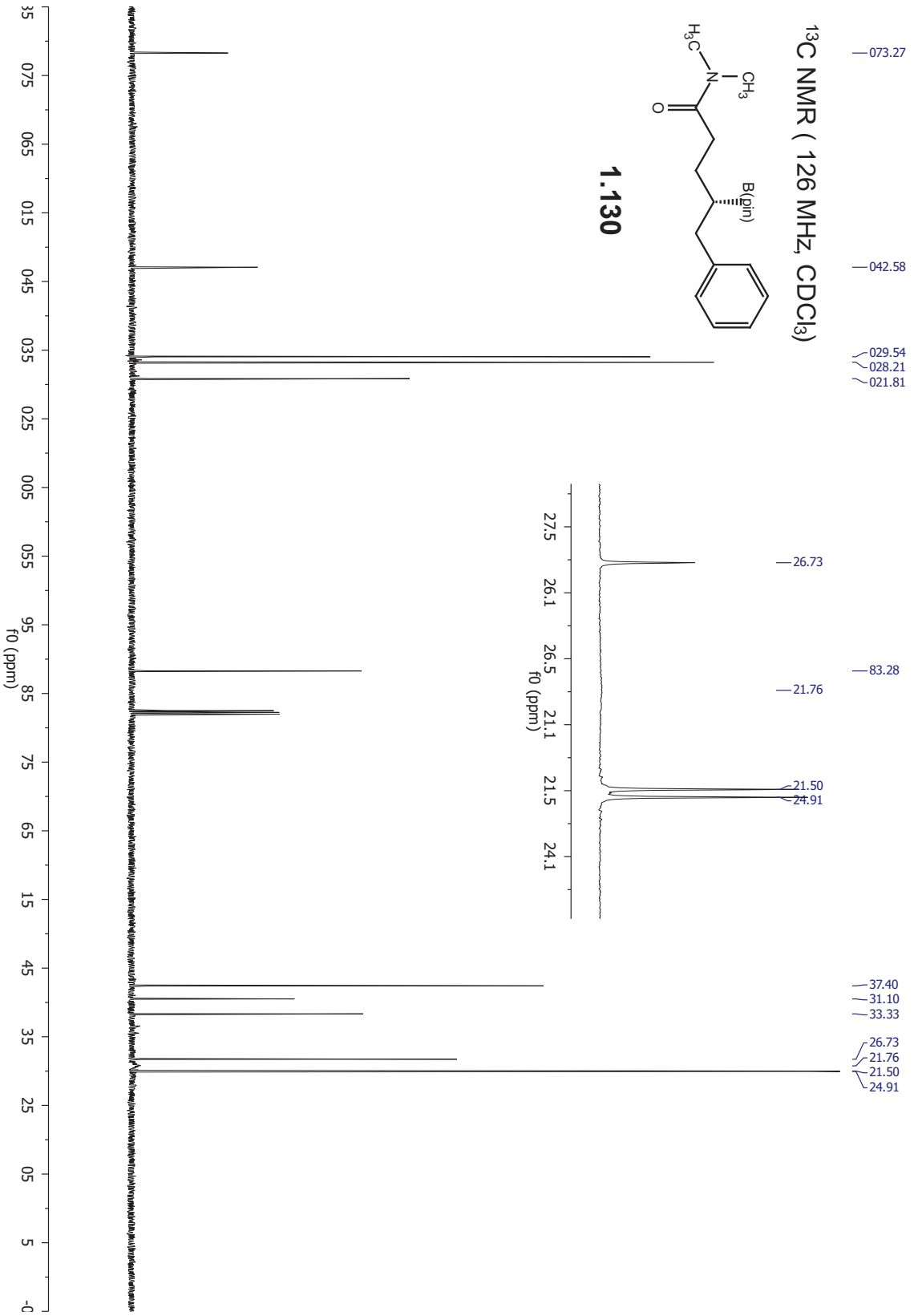

7.30
7.30
7.35
7.35
7.29
7.28
7.23
7.23
7.22
7.22
7.20
7.25
7.25
7.09
3.82
3.82
3.80
3.85
3.85
3.79
3.78
3.78
3.65
3.19
3.18
2.83
2.82
2.80
2.85
2.61
2.63
2.62
2.60
0.14
0.13
0.10
0.10
0.15
0.15
0.49
0.47
0.38
0.37
0.37
0.36
0.36
0.31
0.34
0.32
5.88
5.53
^{1}H NMR (600 MHz, CDCl$_3$)
CH$_3$
H$_3$C
CH$_3$
H$_3$C
Si
CH$_3$
OH
O
1.128
0.92
2.84
0.25
2.03
0.23
0.20
6.20
3.67
9.25
1.85
9.1
9.5
8.1
8.5
7.1
7.5
6.1
6.5
1.1
1.5
4.1
4.5
3.1
3.5
2.1
2.5
0.1
0.5
5.1
5.5
-5.1
f0 (ppm)

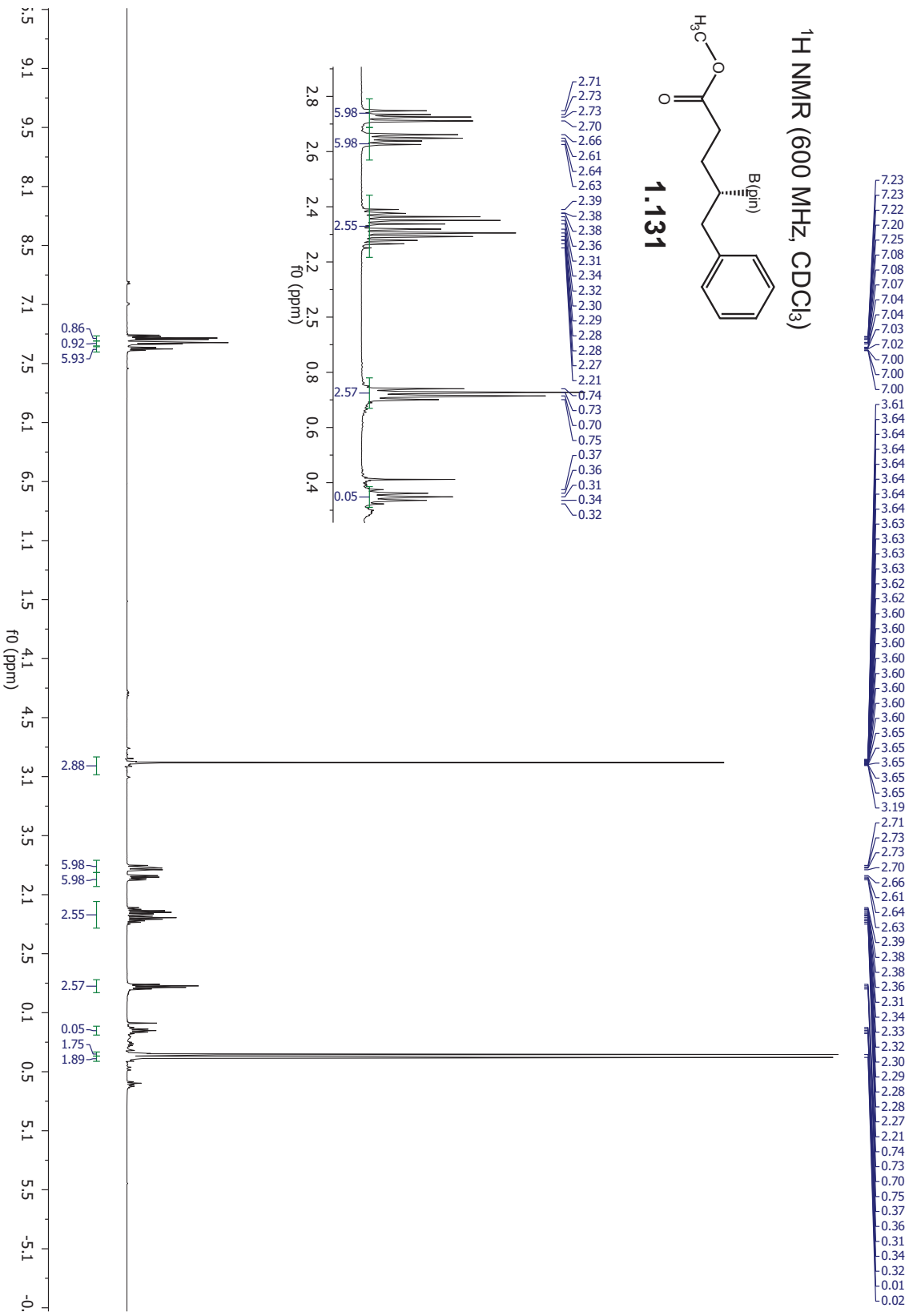

^{13}C NMR (151 MHz, CDCl$_3$)
1.128
038.83
029.63
028.78
026.66
26.22
26.05
72.81
21.85
63.42
44.30
37.57
33.56
26.22
26.05
21.85
08.65
-1.52
f0 (ppm)
f0 (ppm)

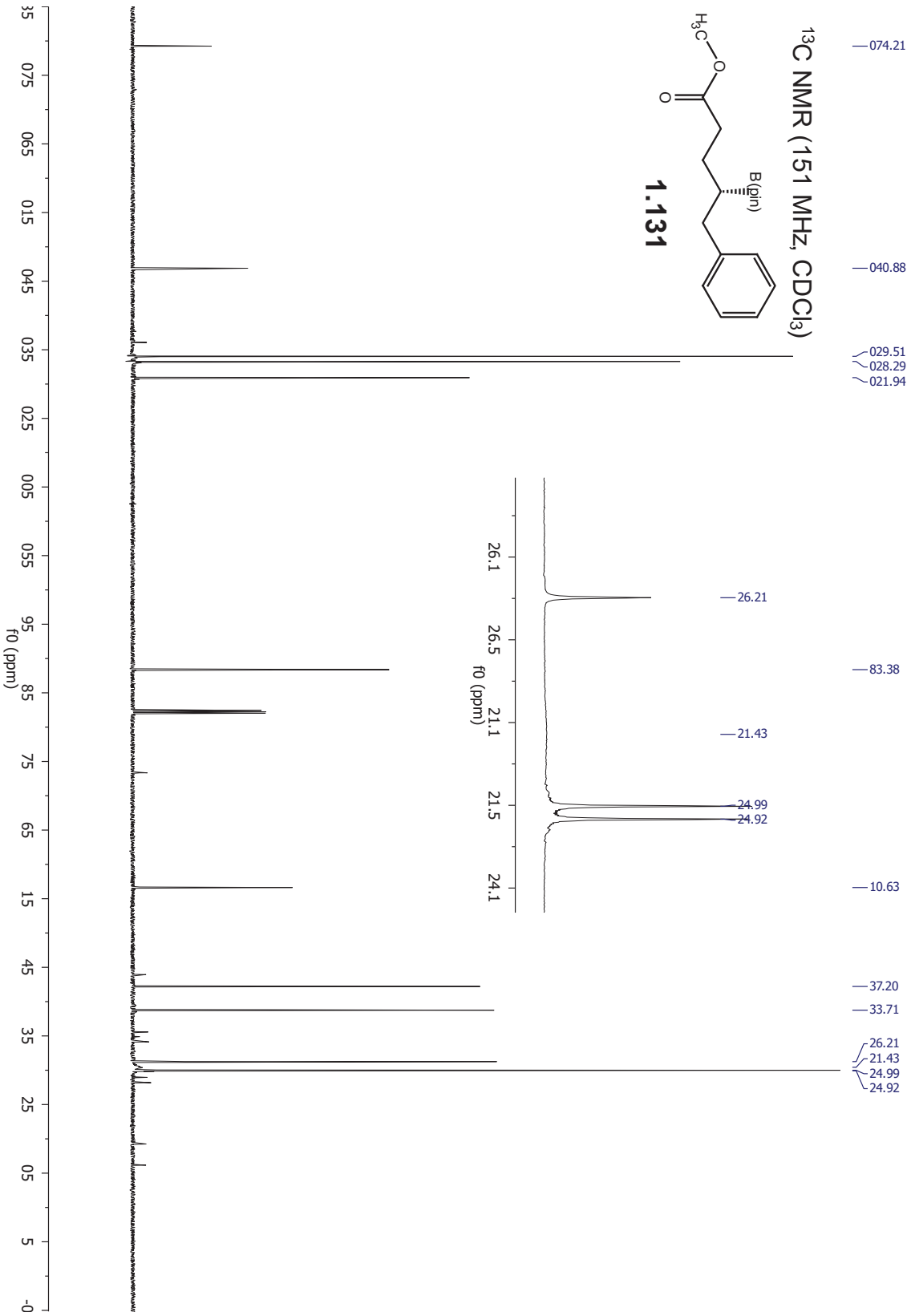

1H NMR (600 MHz, CDCl3)
1.129
B(pin)
f0 (ppm)
3.71
5.89
0.92
0.55
2.76
2.26
0.04
9.91
0.05
2.39
1.78
1.11
7.20
7.25
7.09
7.07
7.06
7.02
7.00
7.59
4.00
4.05
4.57
4.54
4.50
2.77
2.76
2.71
2.73
2.66
2.64
2.64
2.62
2.60
0.70
0.68
0.61
0.11
0.14
0.13
0.13
0.10
0.10
0.42
0.34
0.33
0.32
0.32
0.30
0.35
0.27
0.26
0.21
0.24
0.23
0.23
0.22
0.58


^{13}C NMR (151 MHz, CDCl$_3$)
1.129
B(pin)
011.05
042.24
029.54
028.26
021.87
83.28
79.35
44.61
38.29
34.99
32.24
30.09
28.67
21.54
24.91
f0 (ppm)

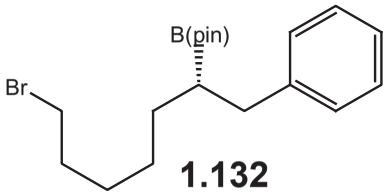

^{1}H NMR (600 MHz, $CDCl_3$)
CH3
B(pin)
N
H3C
O
1.130
f0 (ppm)


^{13}C NMR (126 MHz, CDCl$_3$)
1.130
B(pin)
CH$_3$
H$_3$C
N
O
073.27
042.58
029.54
028.21
021.81
26.73
21.76
83.28
21.50
24.91
37.40
31.10
33.33
f0 (ppm)

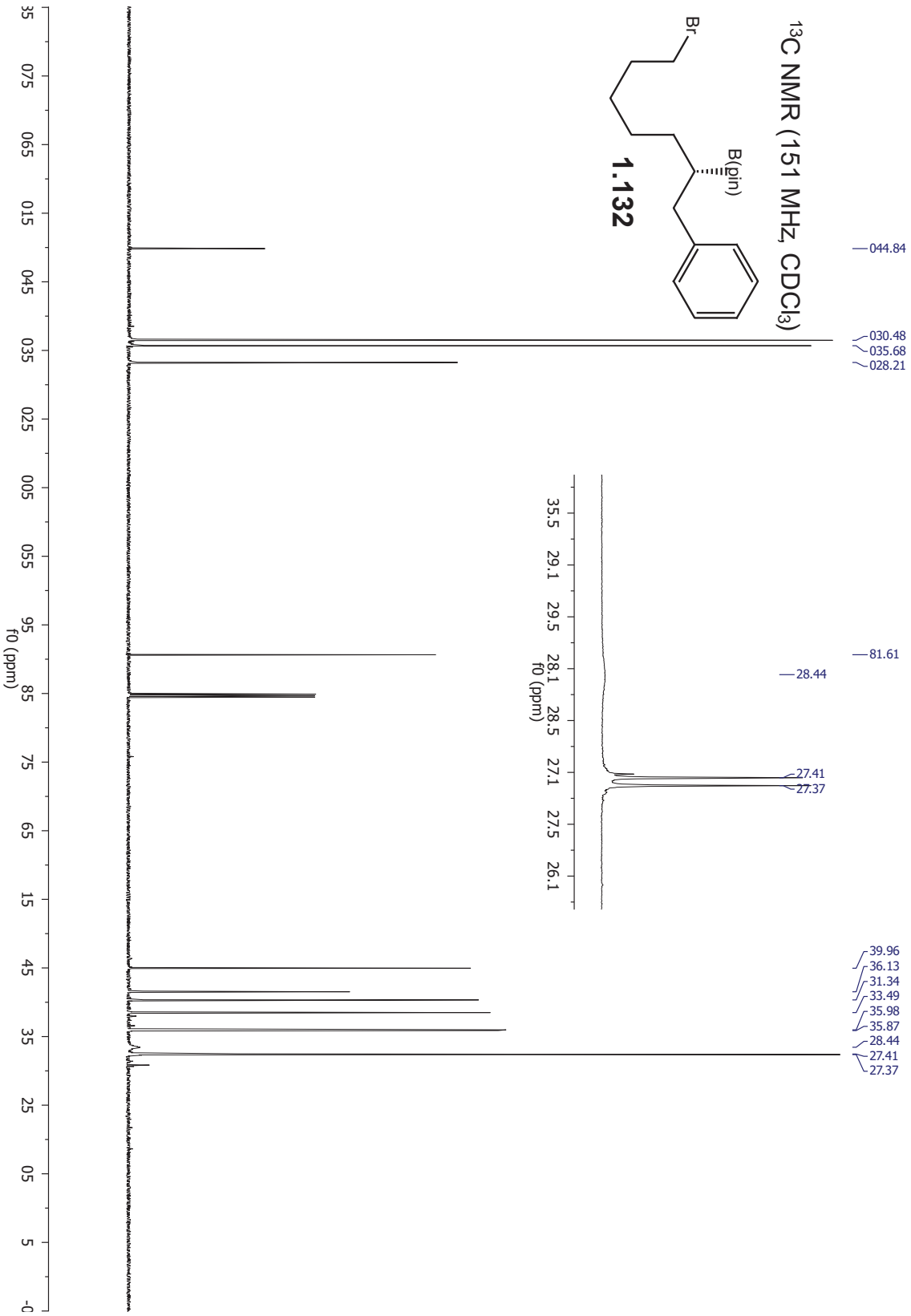

^{1}H NMR (600 MHz, CDCl$_3$)
1.131
B(pin)
H$_3$C
O
O
f0 (ppm)

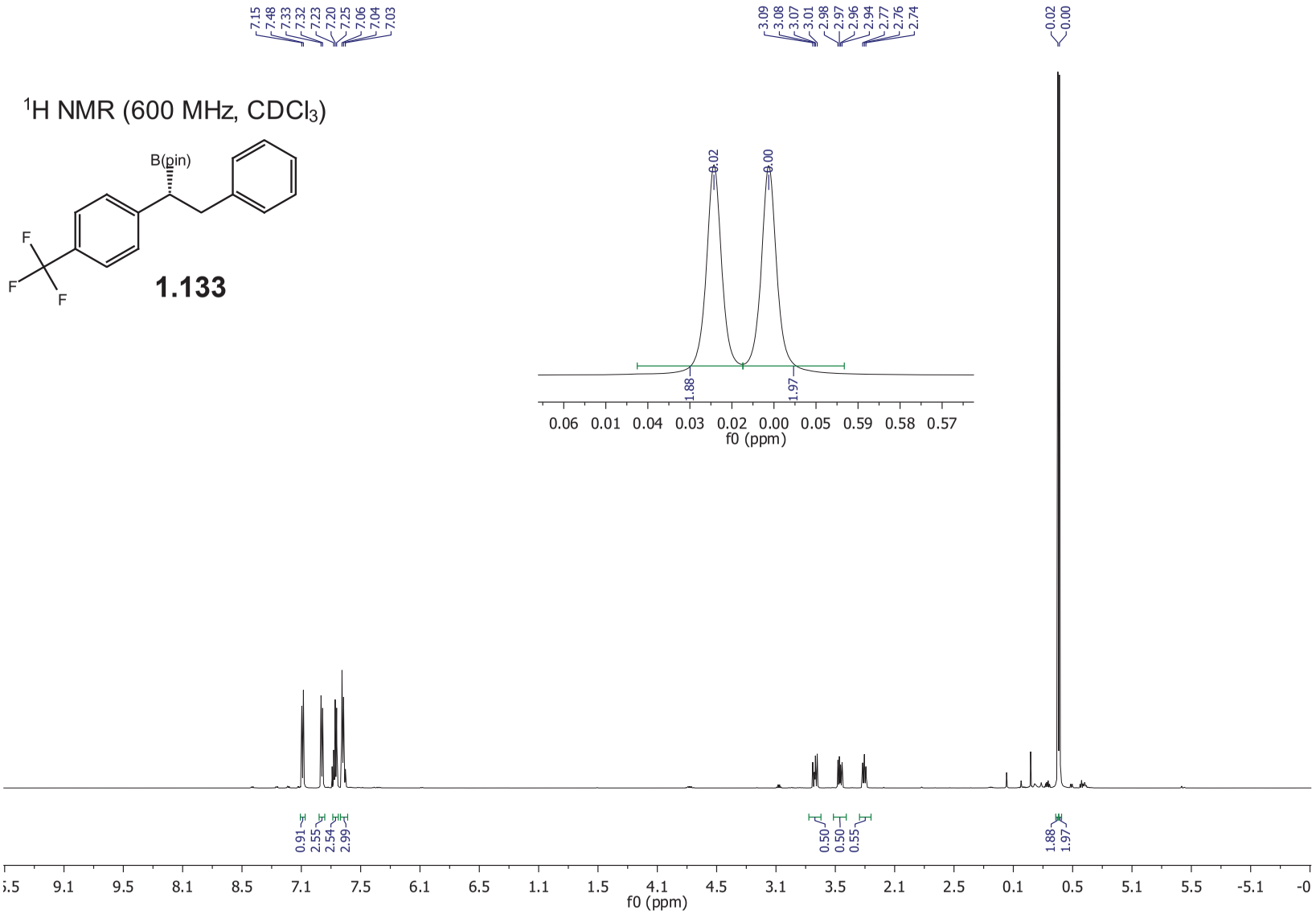

13C NMR (151 MHz, CDCl3)
1.131
B(pin)
H3C
O
O
074.21
040.88
029.51
028.29
021.94
26.21
83.38
21.43
24.99
24.92
10.63
37.20
33.71
26.21
21.43
24.99
24.92
f0 (ppm)
f0 (ppm)

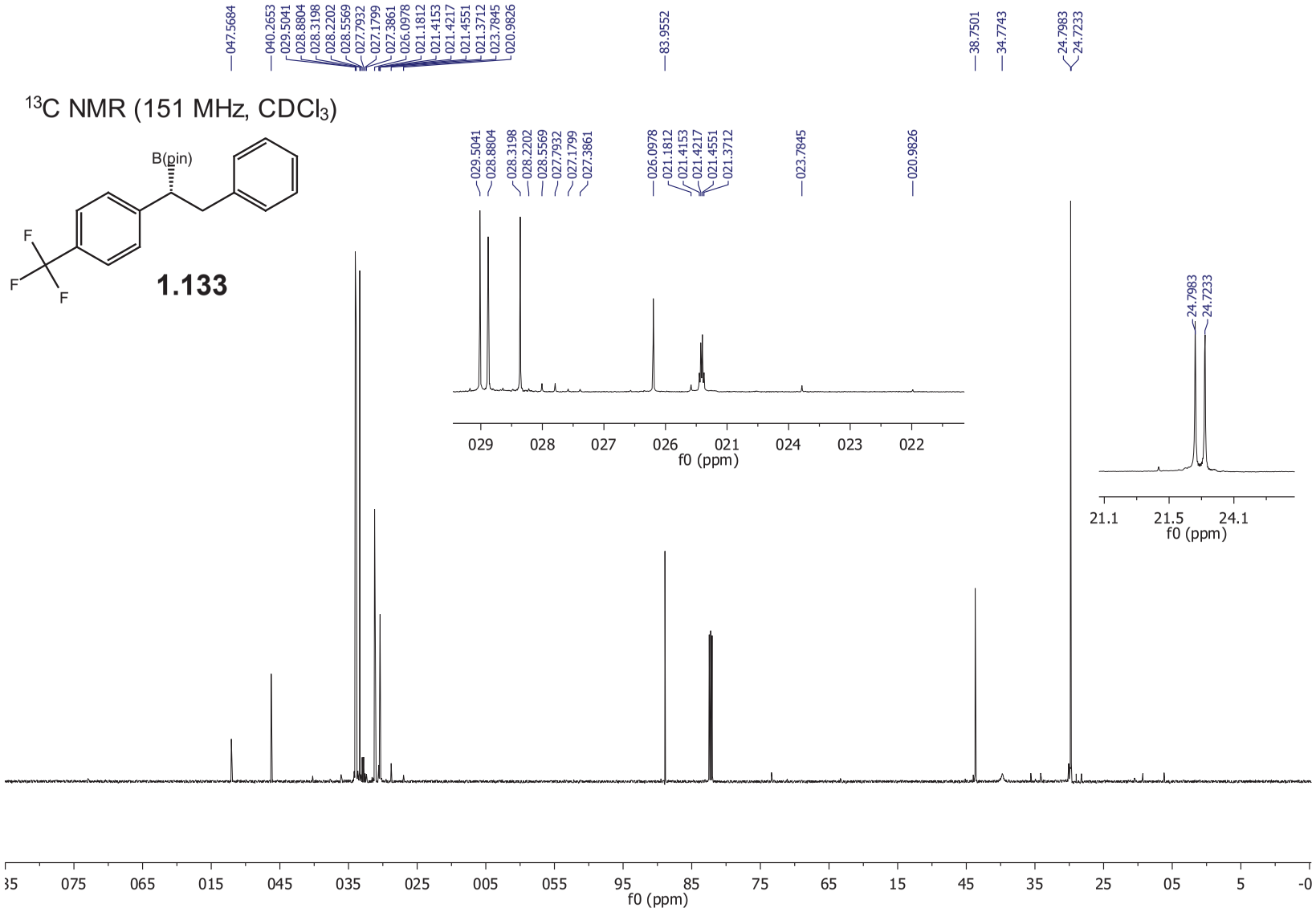
^{1}H NMR (600 MHz, $CDCl_3$)



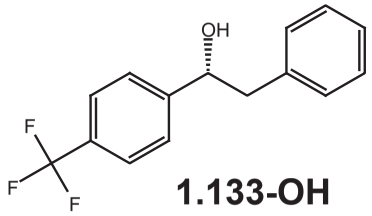
1.132


^{13}C NMR (151 MHz, CDCl$_3$)
Br
B(pin)
1.132
044.84
030.48
035.68
028.21
81.61
28.44
27.41
27.37
39.96
36.13
31.34
33.49
35.98
35.87
28.44
27.41
27.37
f0 (ppm)
f0 (ppm)

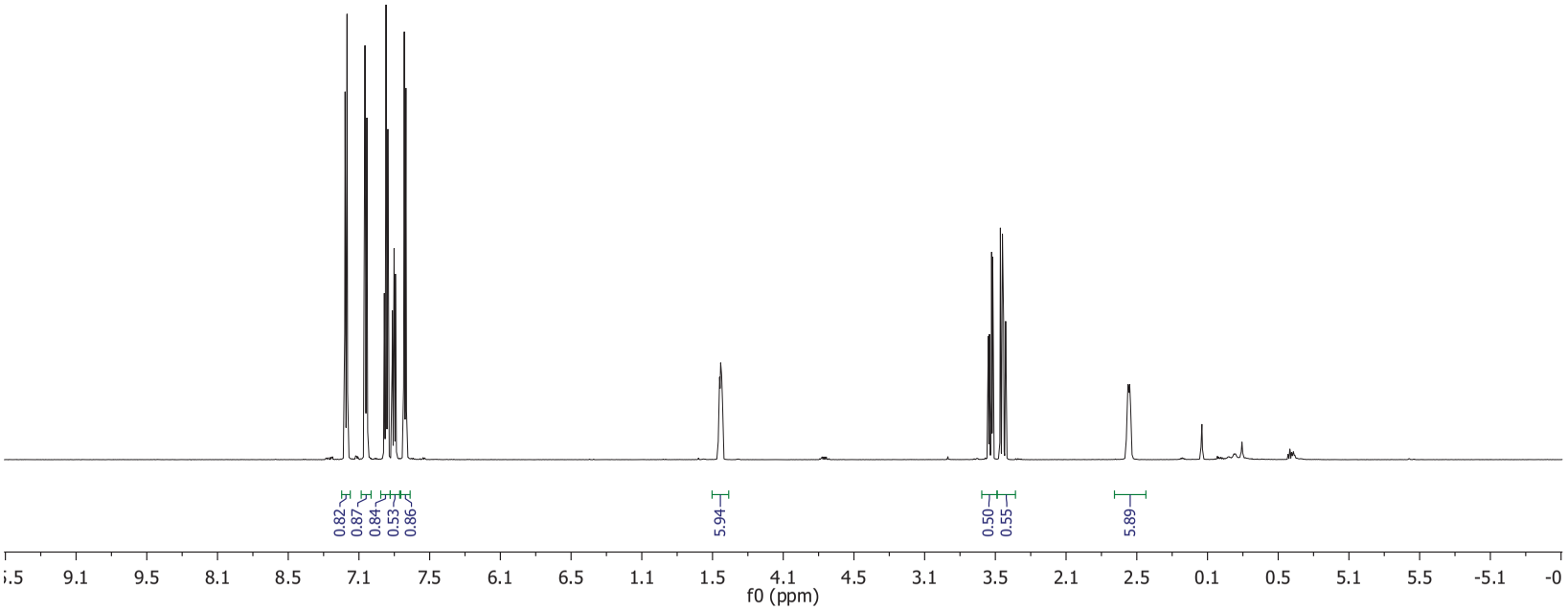

7.15
7.48
7.33
7.32
7.23
7.20
7.25
7.06
7.04
7.03
3.09
3.08
3.07
3.01
2.98
2.97
2.96
2.94
2.77
2.76
2.74
0.02
0.00
1H NMR (600 MHz, CDCl3)
B(pin)
F
F
F
1.133
0.02
0.00
1.88
1.97
0.06 0.01 0.04 0.03 0.02 0.00 0.05 0.59 0.58 0.57
f0 (ppm)
0.91
2.55
2.54
2.99
0.50
0.50
0.55
1.88
1.97
9.1 9.5 8.1 8.5 7.1 7.5 6.1 6.5 1.1 1.5 4.1 4.5 3.1 3.5 2.1 2.5 0.1 0.5 5.1 5.5 -5.1
f0 (ppm)

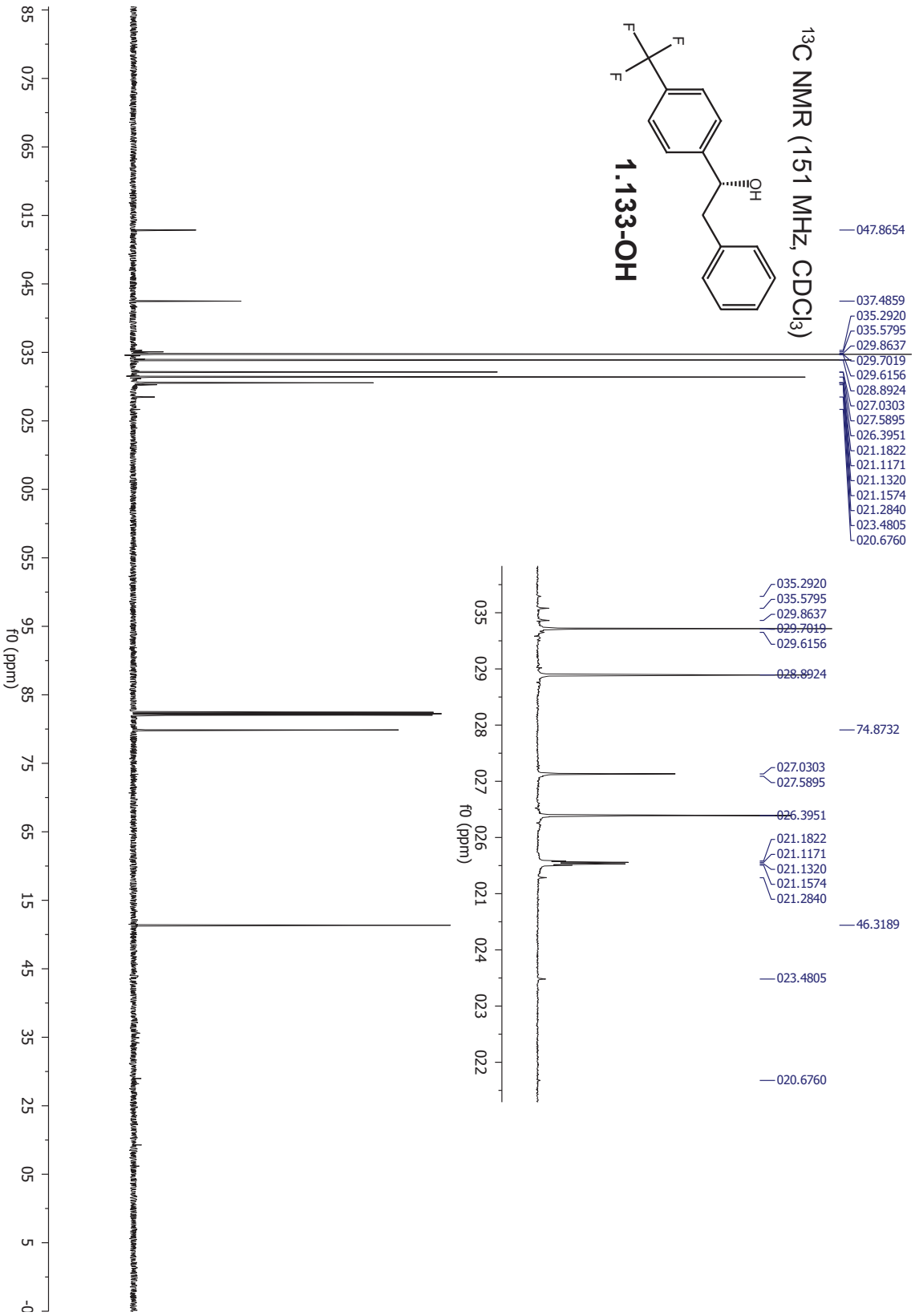

13C NMR (151 MHz, CDCl3)
B(pin)
F
F
F
1.133
047.5684
040.2653
029.5041
028.8804
028.3198
028.2202
028.5569
027.7932
027.1799
027.3861
026.0978
021.1812
021.4153
021.4217
021.4551
021.3712
023.7845
020.9826
83.9552
38.7501
34.7743
24.7983
24.7233
f0 (ppm)

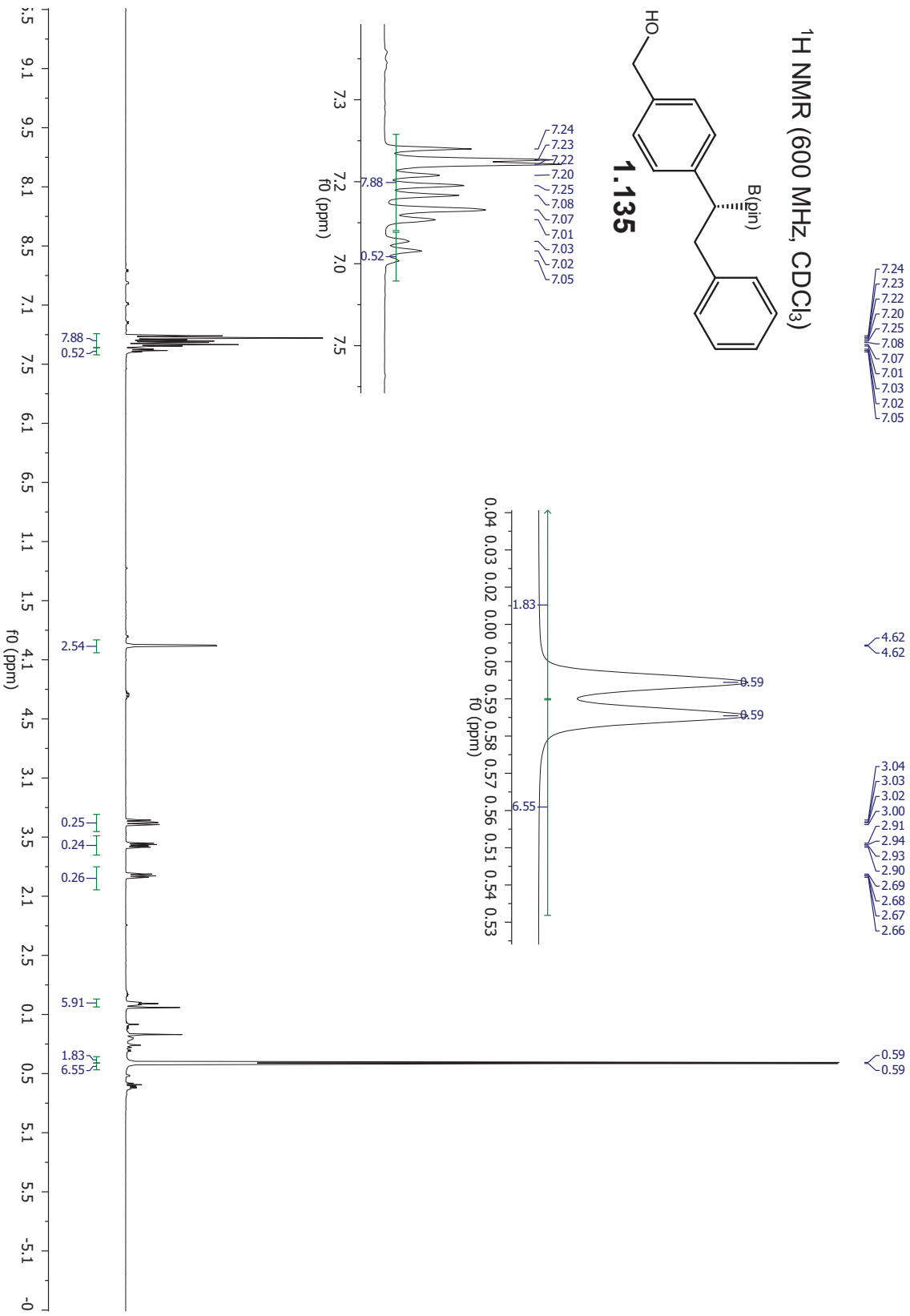
^{1}H NMR (600 MHz, $CDCl_3$)

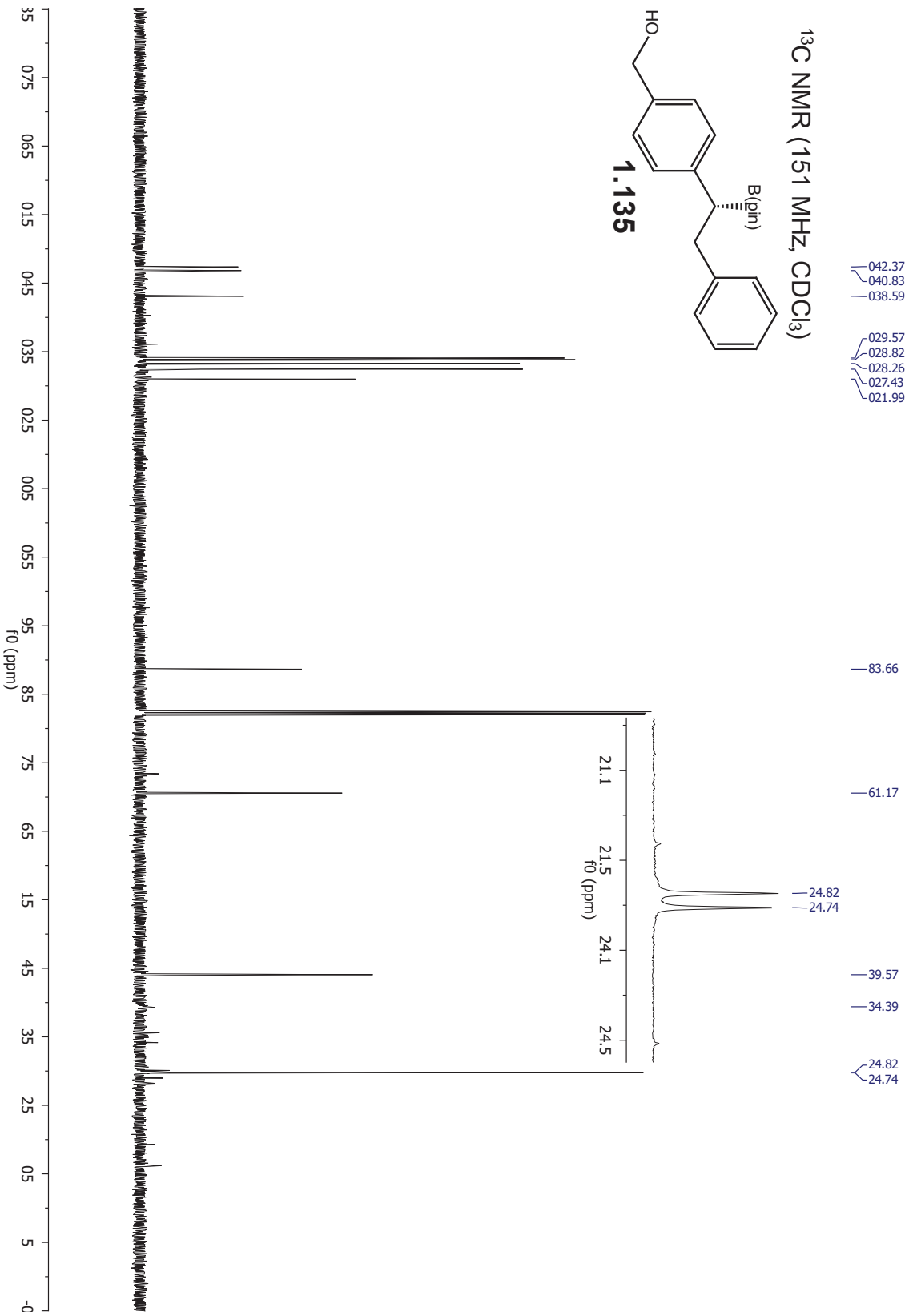


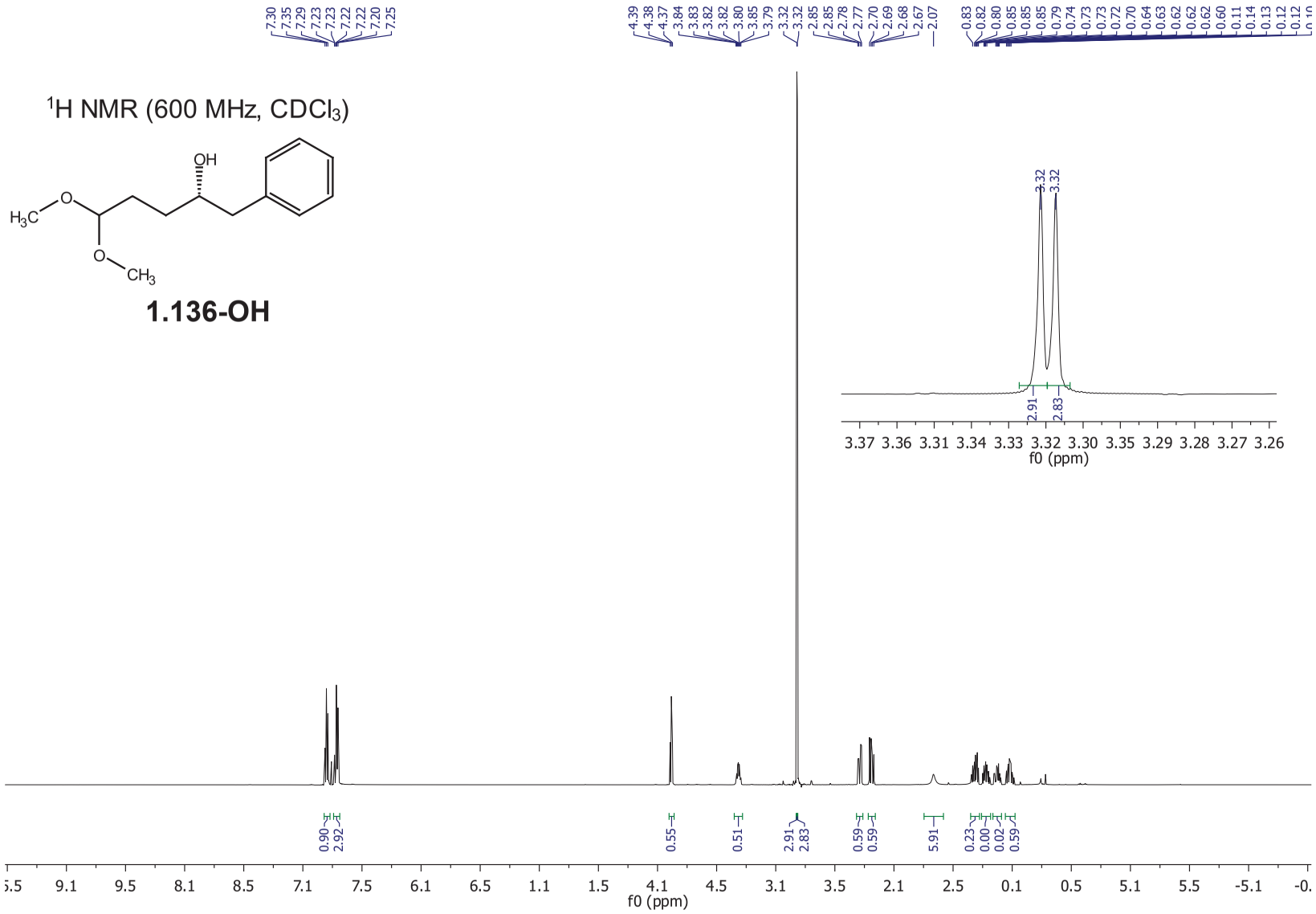
1.133-OH

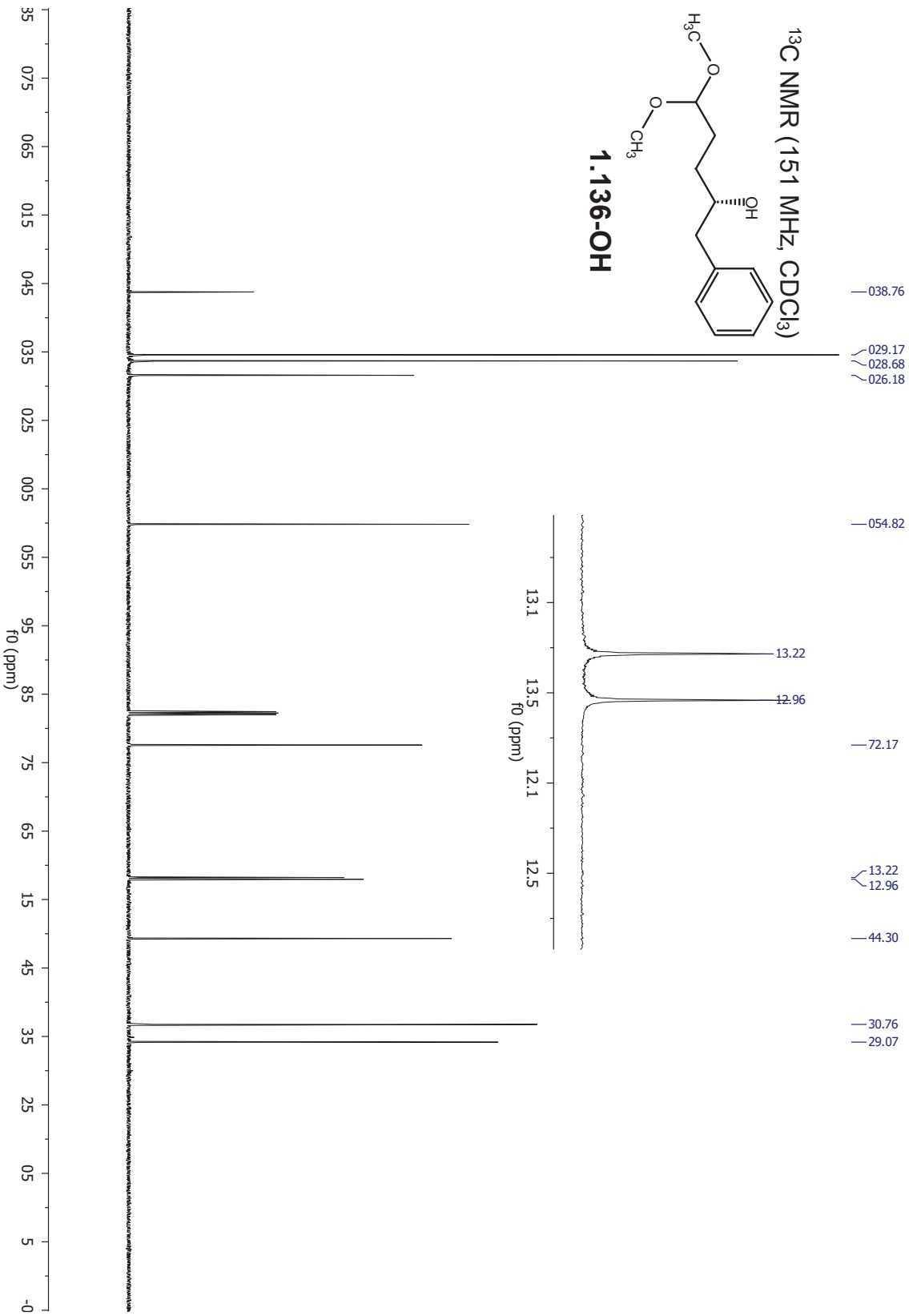


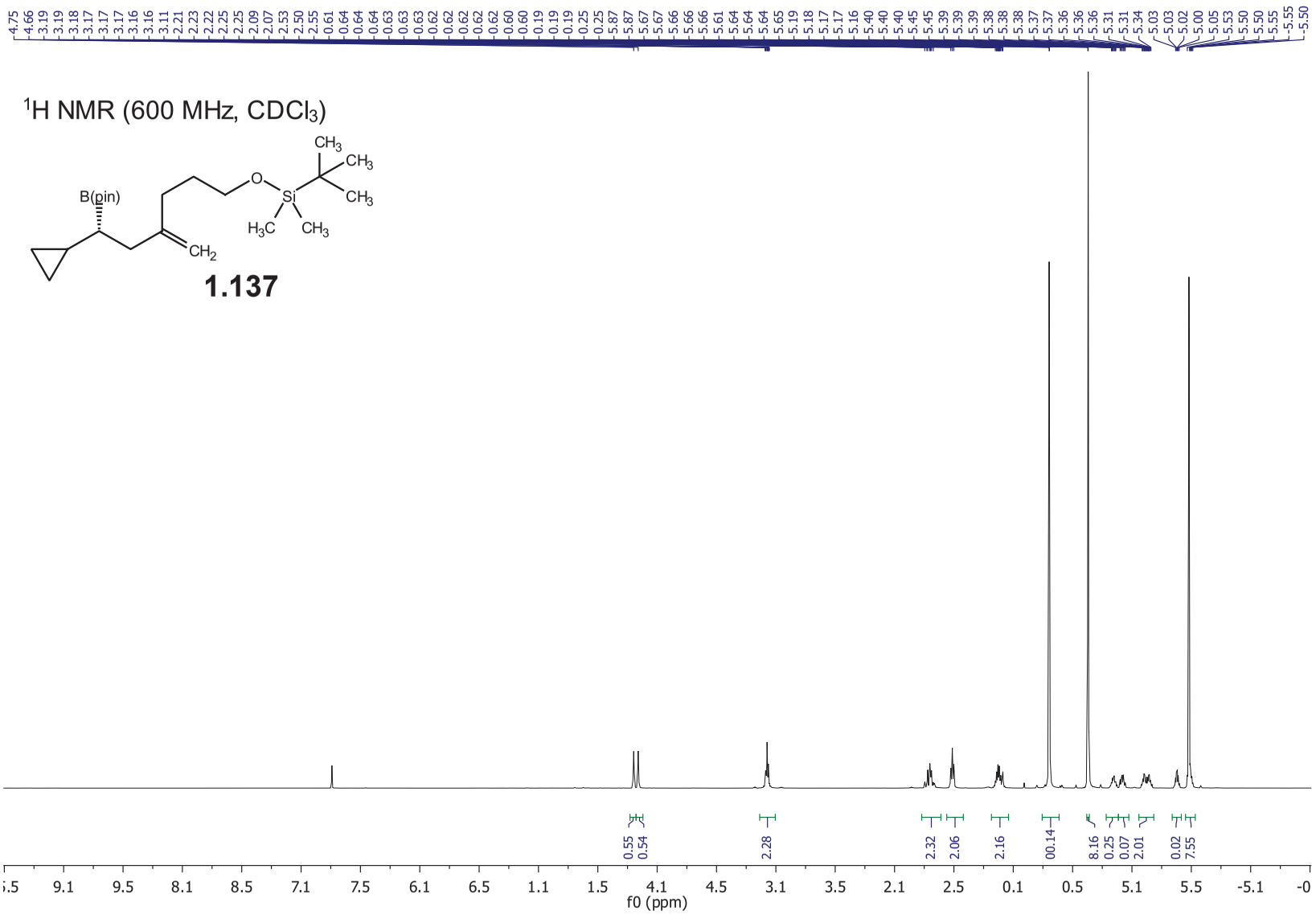

13C NMR (151 MHz, CDCl3)
1.133-OH
F
F
F
OH
047.8654
037.4859
035.2920
035.5795
029.8637
029.7019
029.6156
028.8924
027.0303
027.5895
026.3951
021.1822
021.1171
021.1320
021.1574
021.2840
023.4805
020.6760
74.8732
46.3189
f0 (ppm)

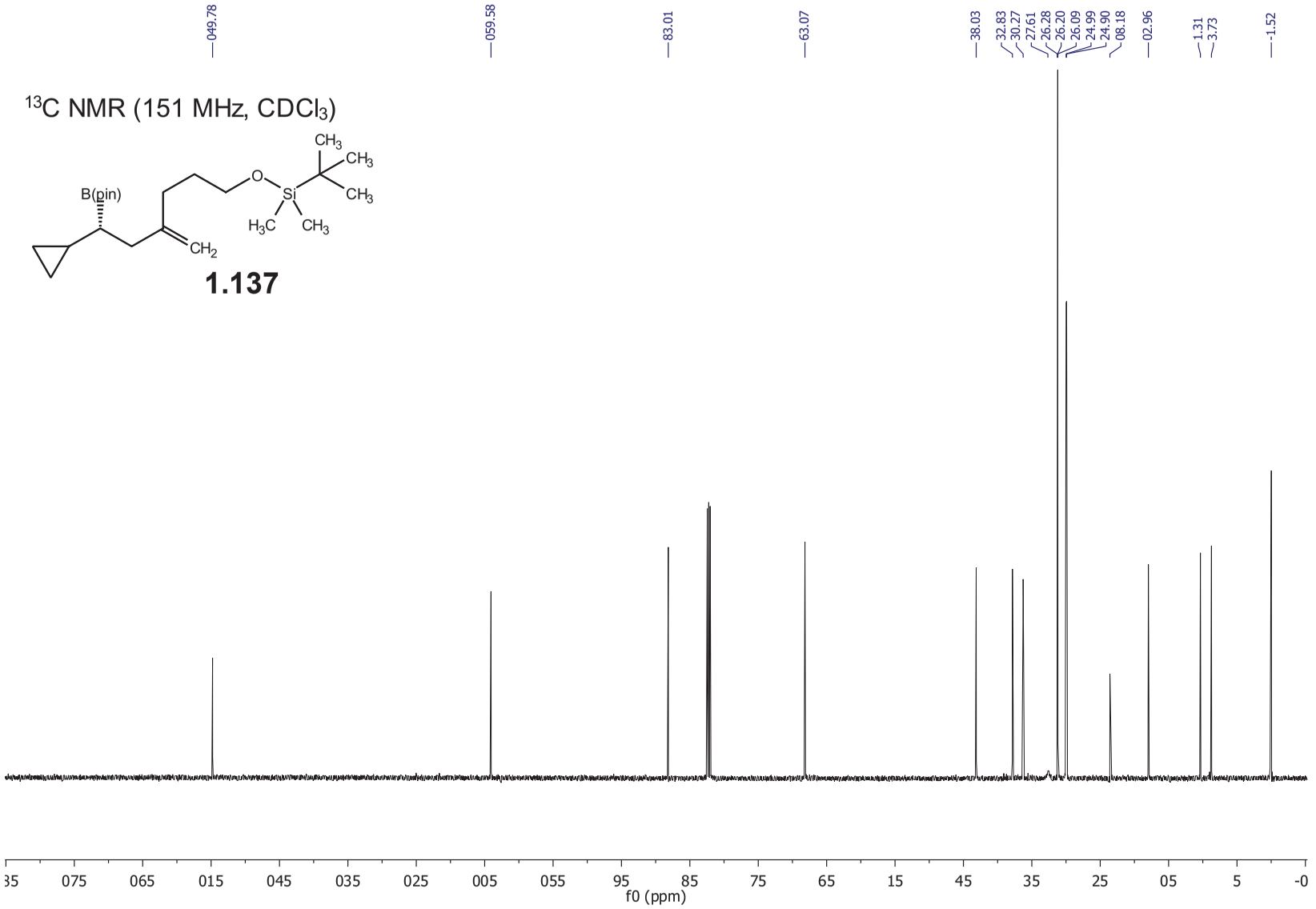

^{1}H NMR (600 MHz, CDCl$_3$)
1.135
HO
B(pin)
f0 (ppm)
7.88
0.52
1.83
6.55
0.59
0.59
2.54
0.25
0.24
0.26
5.91
1.83
6.55
7.24
7.23
7.22
7.20
7.25
7.08
7.07
7.01
7.03
7.02
7.05
4.62
4.62
3.04
3.03
3.02
3.00
2.91
2.94
2.93
2.90
2.69
2.68
2.67
2.66
0.59
0.59

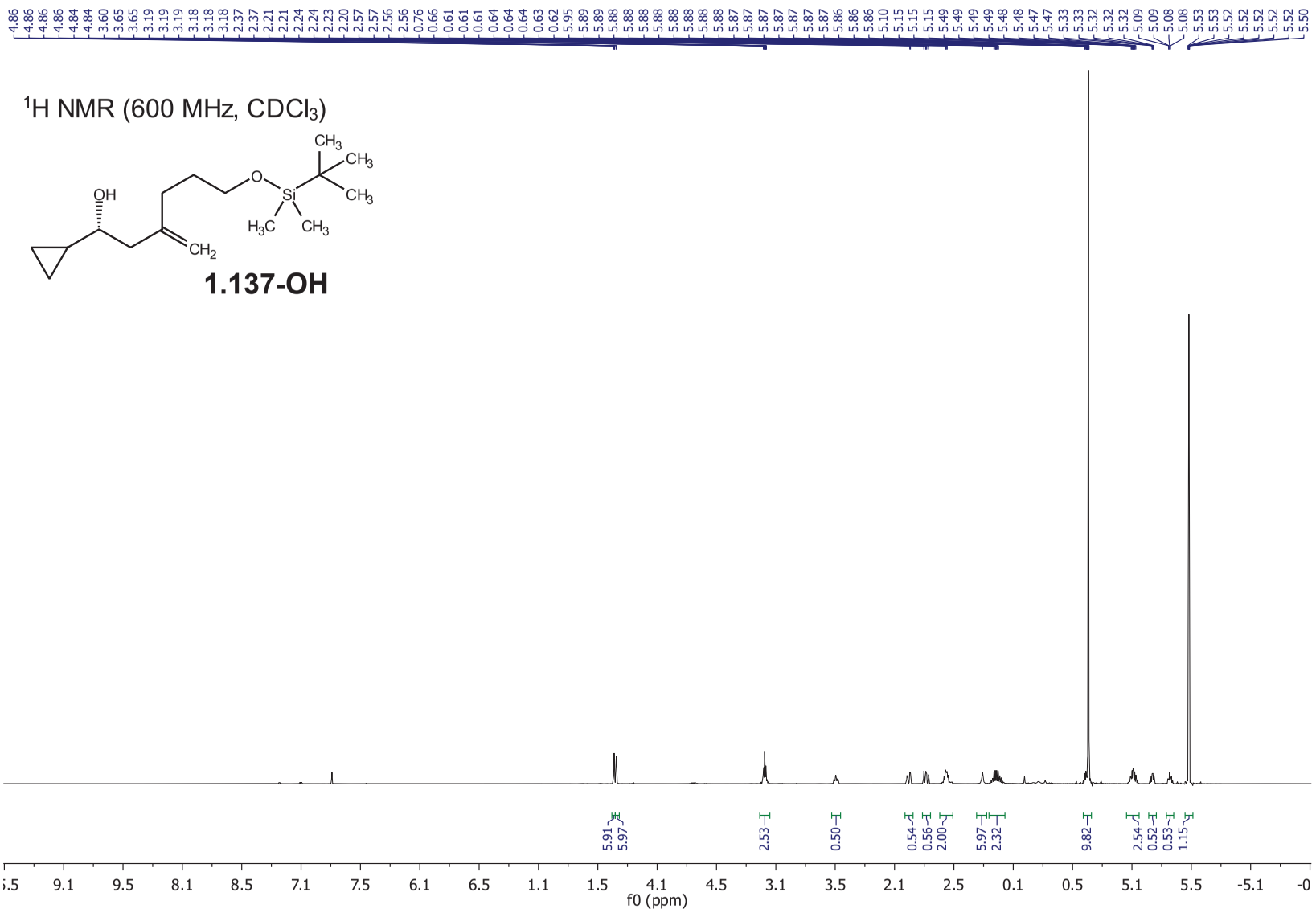

^{13}C NMR (151 MHz, CDCl$_3$)
HO
B(pin)
1.135
042.37
040.83
038.59
029.57
028.82
028.26
027.43
021.99
83.66
61.17
24.82
24.74
39.57
34.39
24.82
24.74
f0 (ppm)

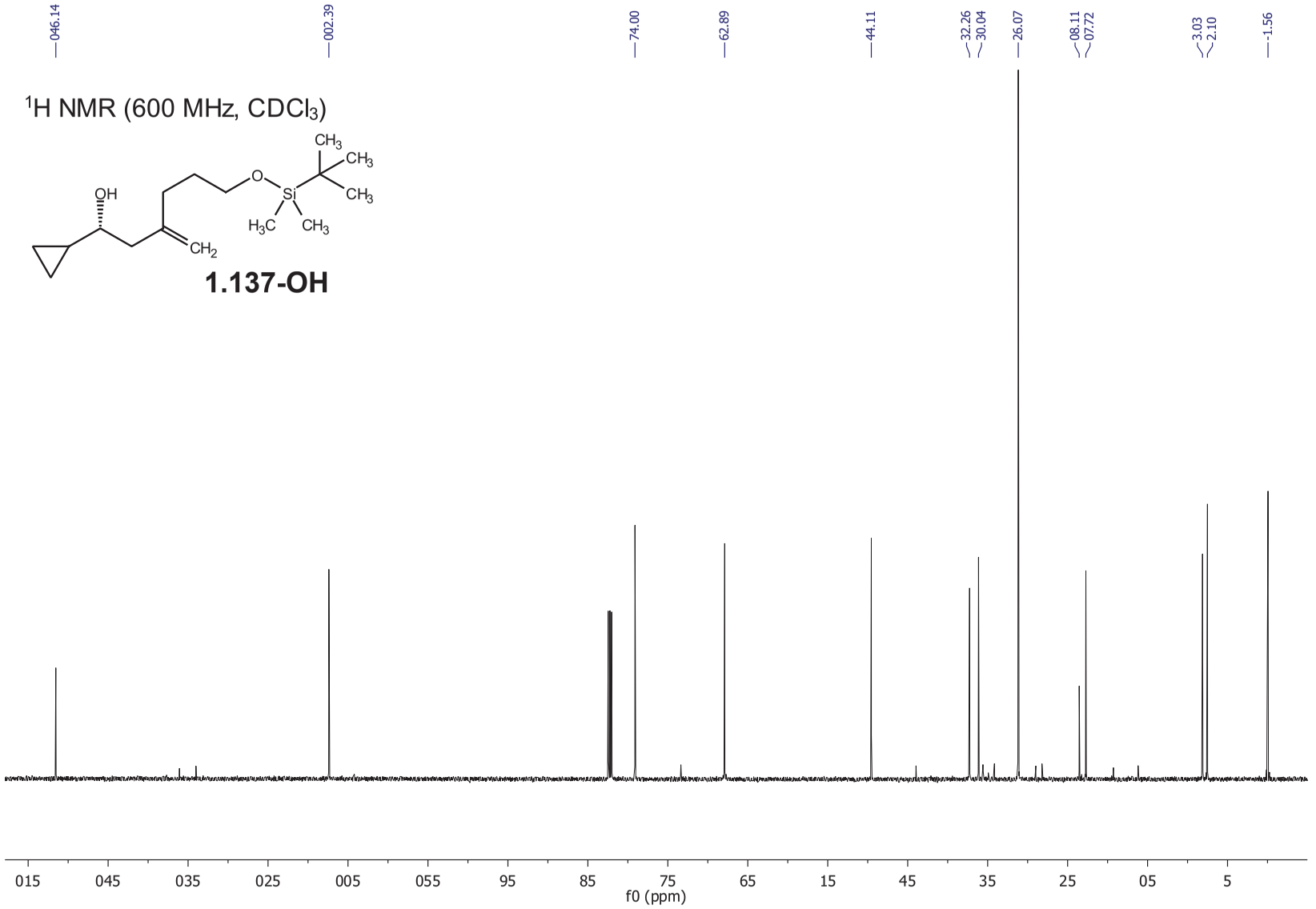

^{1}H NMR (600 MHz, $CDCl_3$)
OH
O
H_3C
O
CH_3
1.136-OH
f0 (ppm)

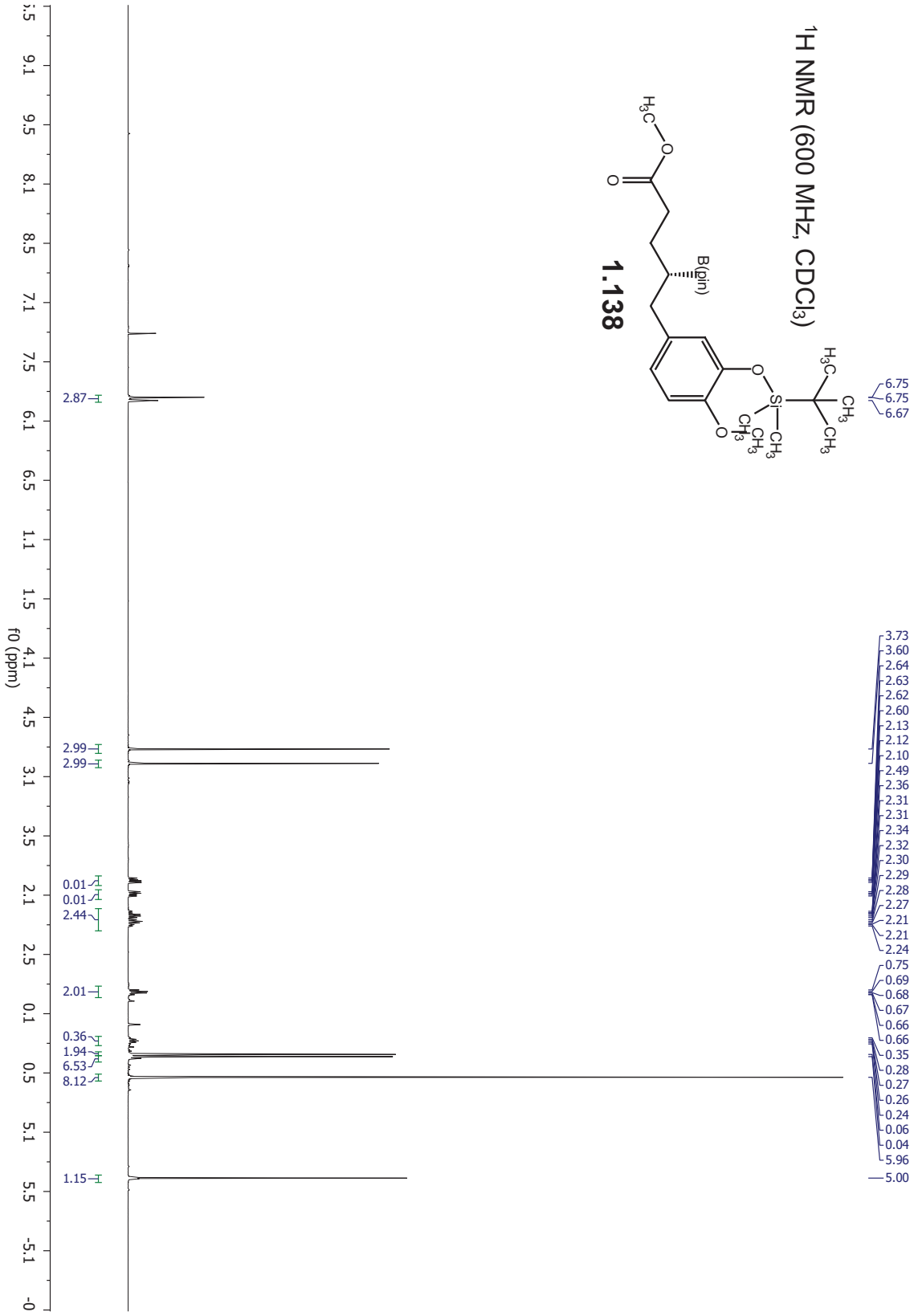

13C NMR (151 MHz, CDCl3)
1.136-OH
H3C
O
O
CH3
OH
038.76
029.17
028.68
026.18
054.82
13.22
12.96
72.17
13.22
12.96
44.30
30.76
29.07
f0 (ppm)
13.1
13.5
12.1
12.5

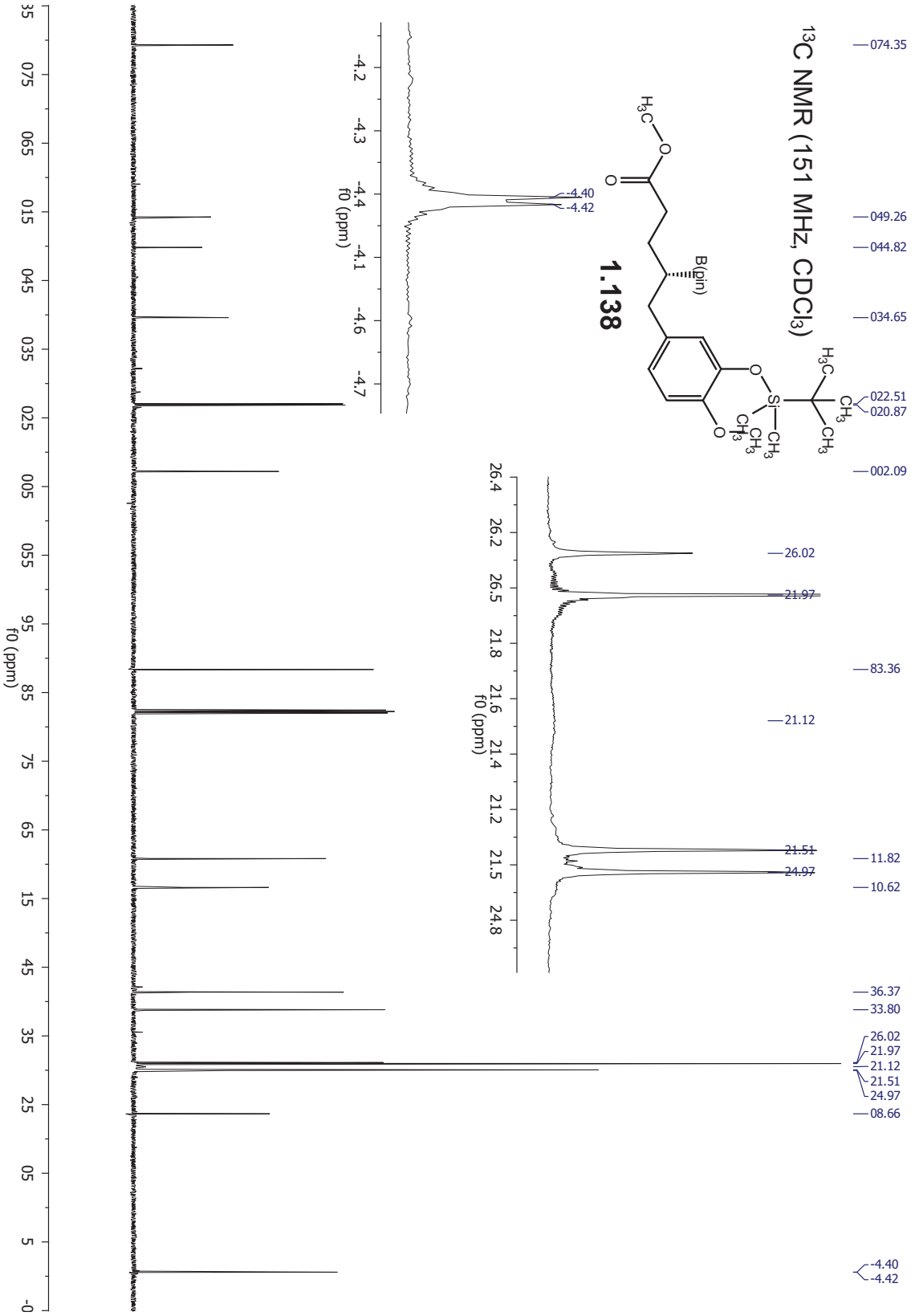

1H NMR (600 MHz, CDCl3)
B(pin)
O
Si
CH3
CH3
CH3
H3C
CH3
CH2
1.137
f0 (ppm)

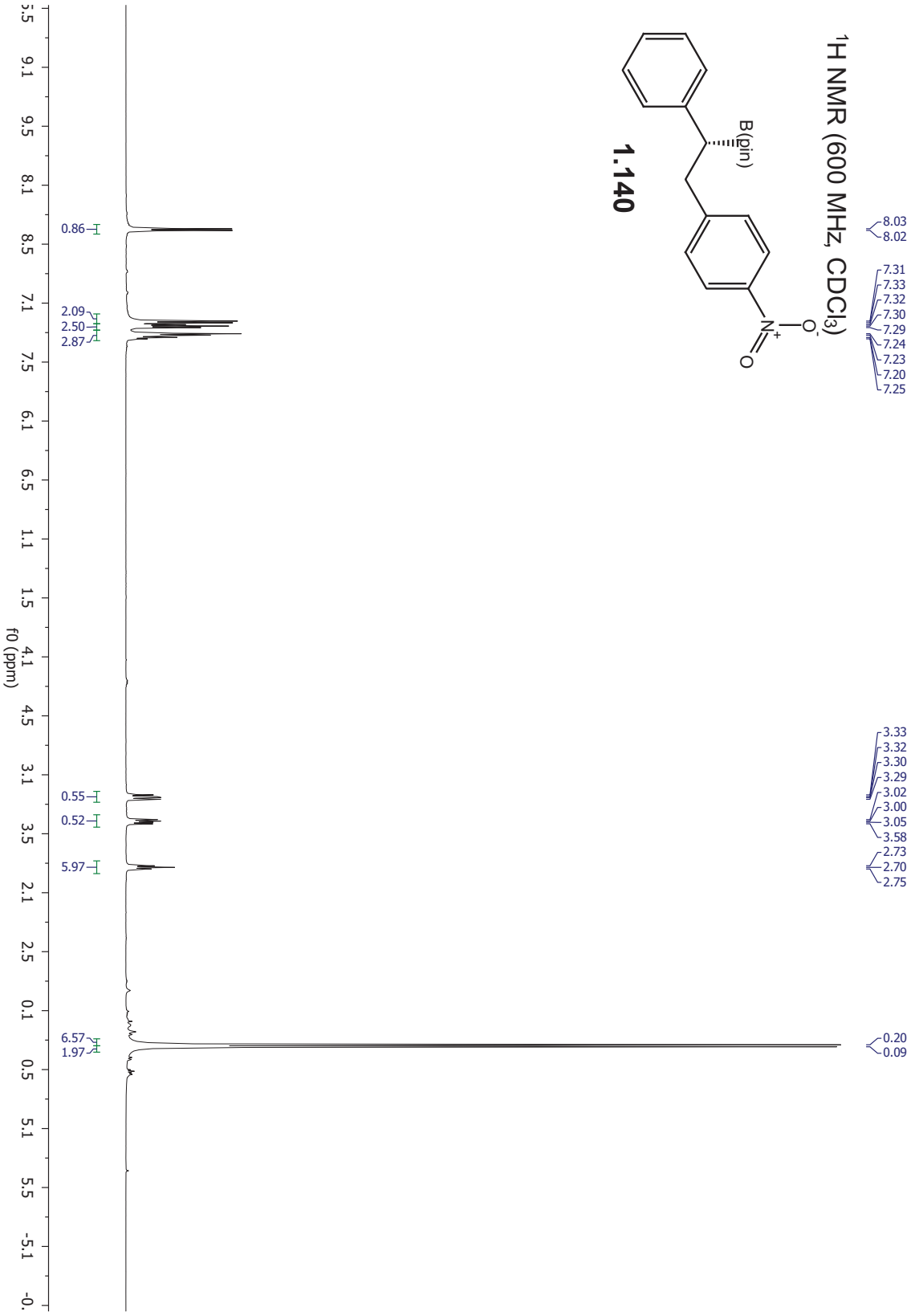

^{13}C NMR (151 MHz, $CDCl_3$)
B(pin)
O
Si
CH_3
CH_3
CH_3
H_3C
CH_3
CH_2
1.137
049.78
059.58
083.01
063.07
038.03
032.83
030.27
027.61
026.28
026.20
026.09
024.99
024.90
008.18
002.96
001.31
003.73
-01.52
f0 (ppm)

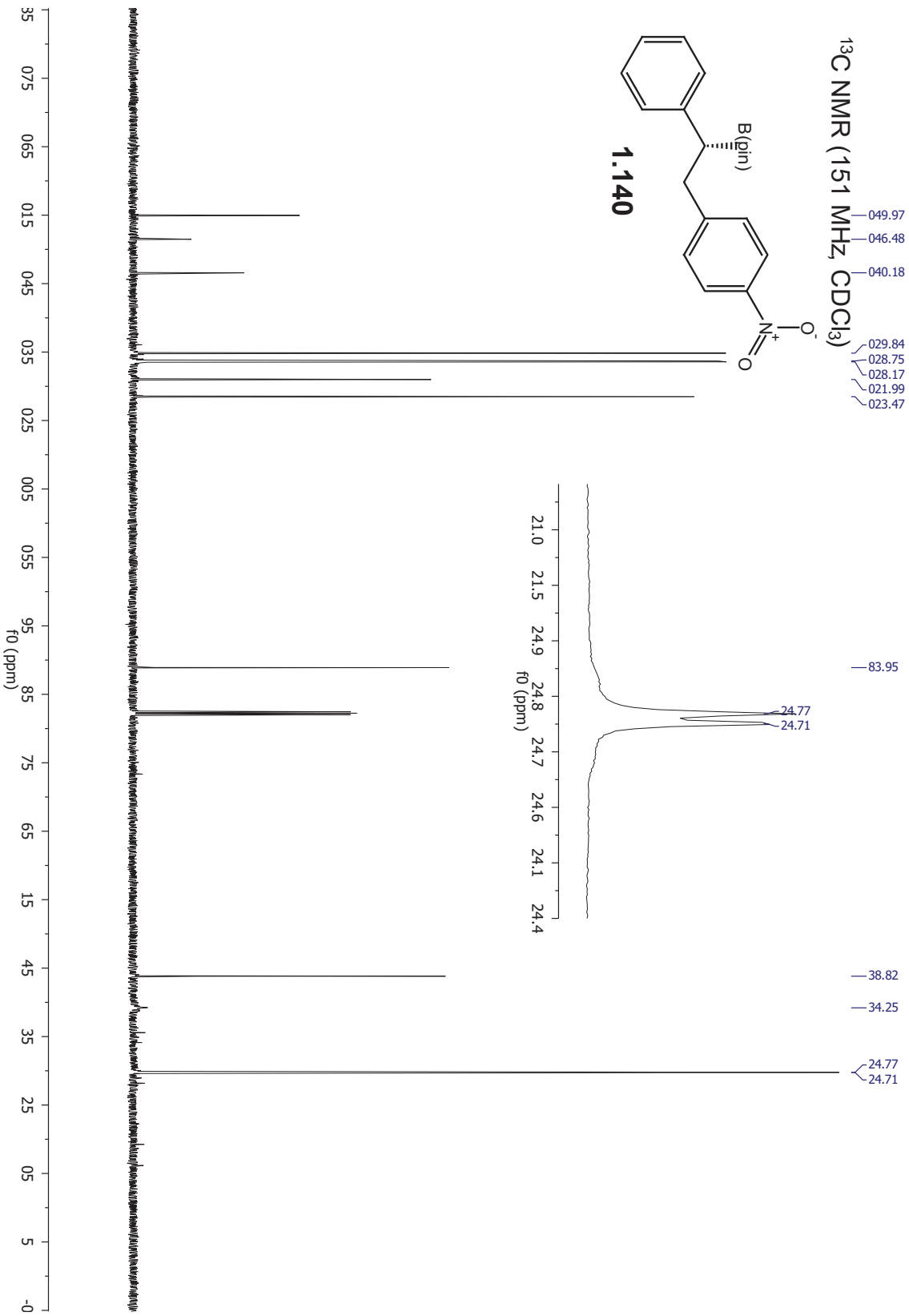

1H NMR (600 MHz, CDCl3)
OH
O
Si
CH3
CH3
CH3
H3C
CH3
CH2
1.137-OH
f0 (ppm)

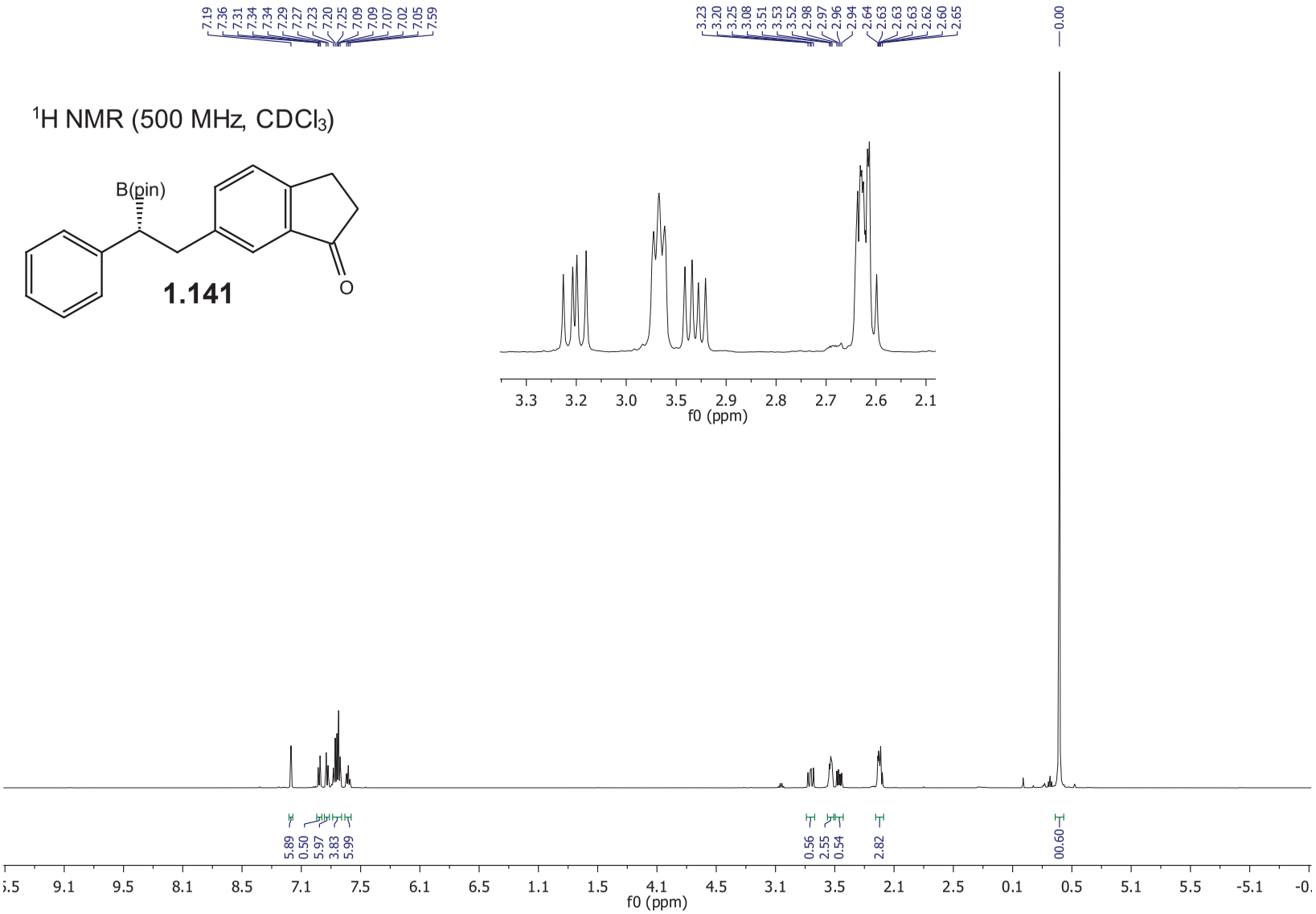

046.14
002.39
74.00
62.89
44.11
32.26
30.04
26.07
08.11
07.72
03.03
2.10
-1.56
1H NMR (600 MHz, CDCl3)
OH
O
Si
CH3
CH3
CH3
H3C
CH3
CH2
1.137-OH
015
045
035
025
005
055
95
85
75
65
15
45
35
25
05
5
f0 (ppm)

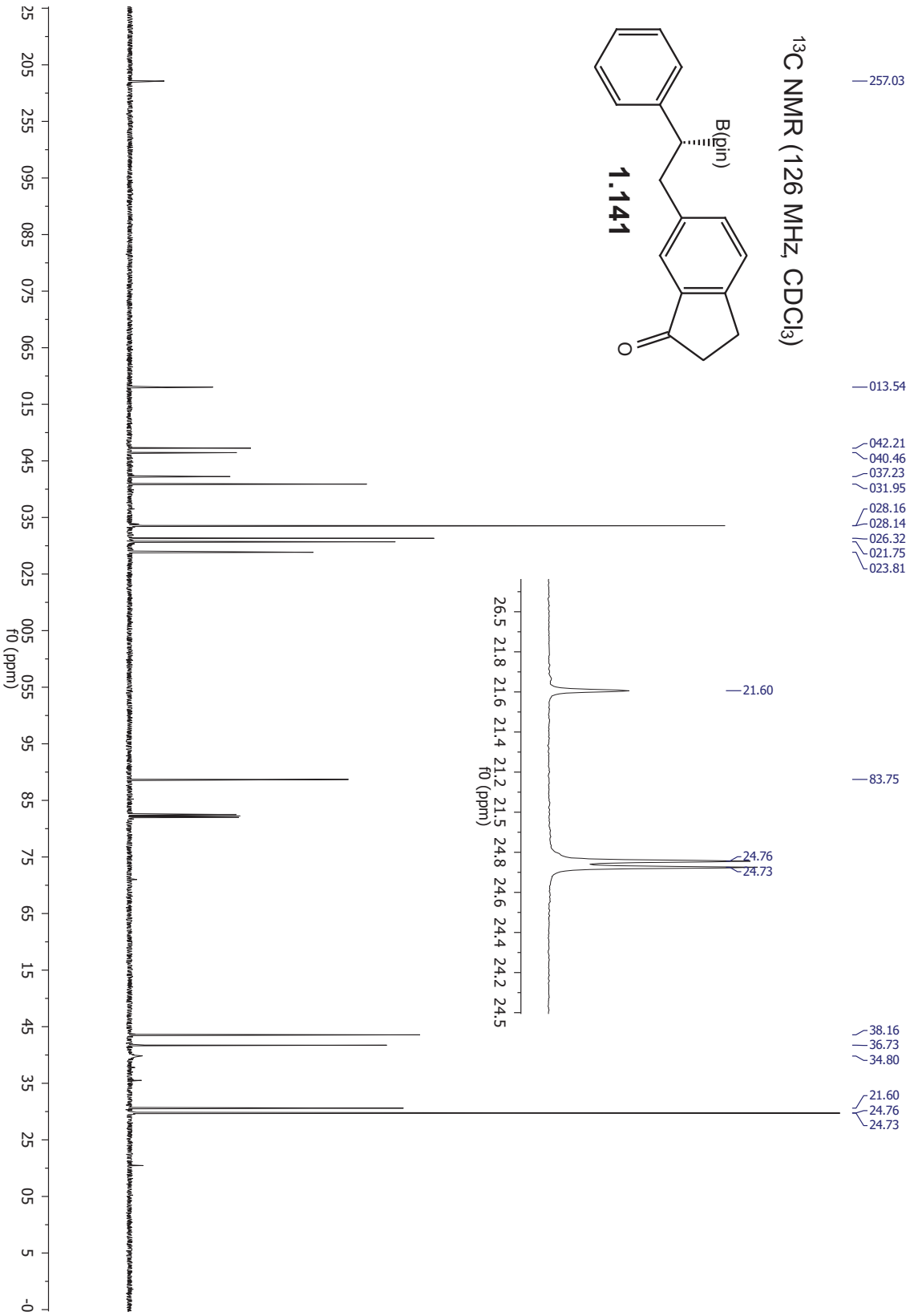

1H NMR (600 MHz, CDCl3)
1.138
B(pin)
f0 (ppm)
9.5
8.1
8.5
7.1
7.5
6.1
6.5
1.1
1.5
4.1
4.5
3.1
3.5
2.1
2.5
0.1
0.5
5.1
5.5
-5.1
-0
2.87
2.99
2.99
0.01
0.01
2.44
2.01
0.36
1.94
6.53
8.12
1.15
6.75
6.75
6.67
3.73
3.60
2.64
2.63
2.62
2.60
2.13
2.12
2.10
2.49
2.36
2.31
2.31
2.34
2.32
2.30
2.29
2.28
2.27
2.21
2.21
2.24
0.75
0.69
0.68
0.67
0.66
0.66
0.35
0.28
0.27
0.26
0.24
0.06
0.04
5.96
5.00


13C NMR (151 MHz, CDCl3)
1.138
B(pin)
f0 (ppm)
-4.40
-4.42
26.02
21.97
21.12
21.51
24.97
074.35
049.26
044.82
034.65
022.51
020.87
002.09
083.36
011.82
010.62
036.37
033.80
08.66


1H NMR (600 MHz, CDCl3)
1.140
B(pin)
8.03
8.02
7.31
7.33
7.32
7.30
7.29
7.24
7.23
7.20
7.25
3.33
3.32
3.30
3.29
3.02
3.00
3.05
3.58
2.73
2.70
2.75
0.20
0.09
0.86
2.09
2.50
2.87
0.55
0.52
5.97
6.57
1.97
f0 (ppm)


13C NMR (151 MHz, CDCl3)
1.140
B(pin)
049.97
046.48
040.18
029.84
028.75
028.17
021.99
023.47
83.95
38.82
34.25
24.77
24.71
f0 (ppm)


7.19
7.36
7.31
7.34
7.34
7.29
7.27
7.23
7.20
7.25
7.09
7.09
7.07
7.02
7.05
7.59
3.23
3.20
3.25
3.08
3.51
3.53
3.52
2.98
2.97
2.96
2.94
2.64
2.63
2.63
2.63
2.62
2.60
2.65
0.00
1H NMR (500 MHz, CDCl3)
B(pin)
O
1.141
3.3
3.2
3.0
3.5
2.9
2.8
2.7
2.6
2.1
f0 (ppm)
5.89
0.50
5.97
3.83
5.99
0.56
2.55
0.54
2.82
00.60
9.1
9.5
8.1
8.5
7.1
7.5
6.1
6.5
1.1
1.5
4.1
4.5
3.1
3.5
2.1
2.5
0.1
0.5
5.1
5.5
-5.1
f0 (ppm)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B(pin)
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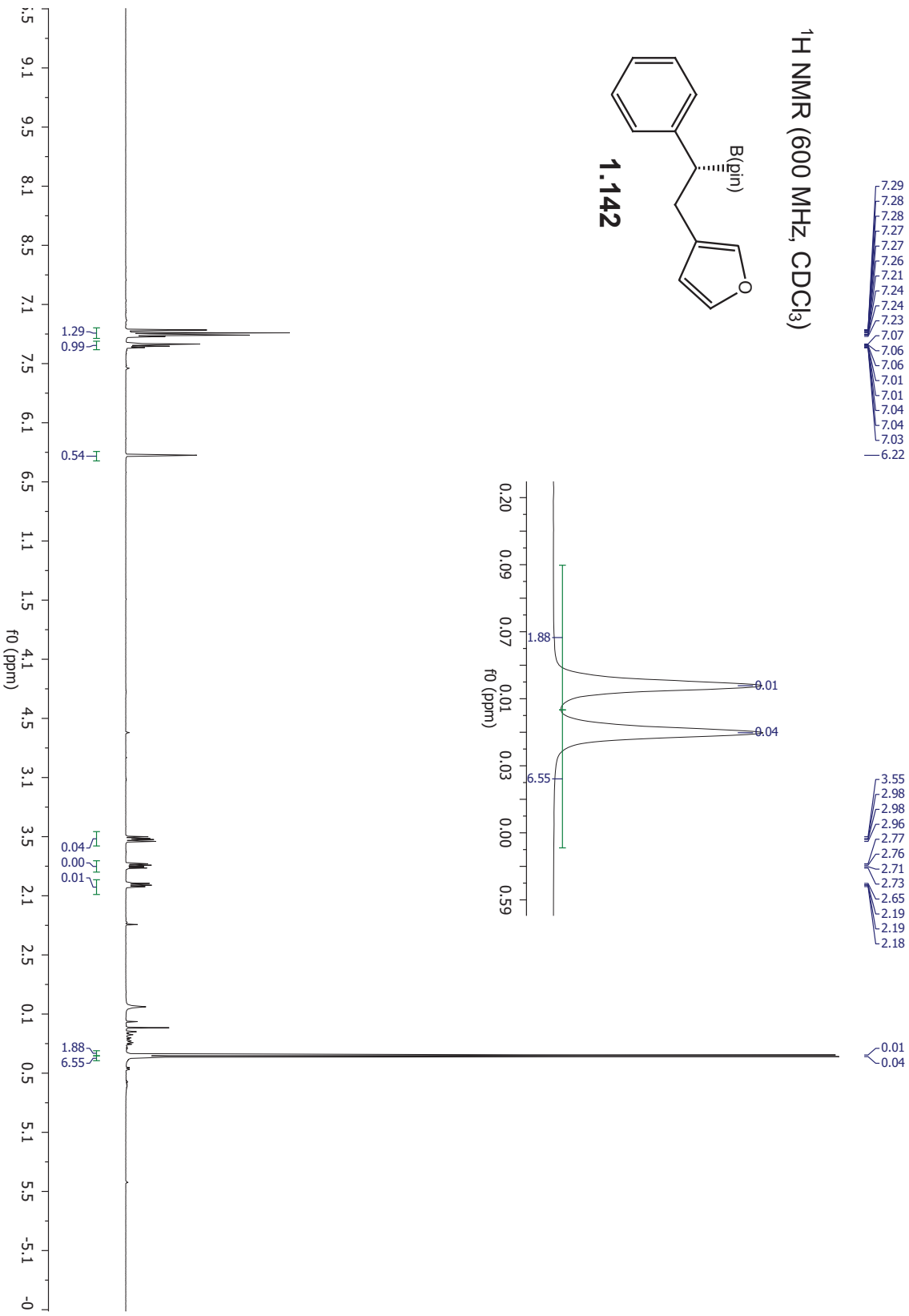
O
257.03
013.54
042.21
040.46
037.23
031.95
028.16
028.14
026.32
021.75
023.81
21.60
83.75
24.76
24.73
38.16
36.73
34.80
21.60
24.76
24.73
f0 (ppm)
f0 (ppm)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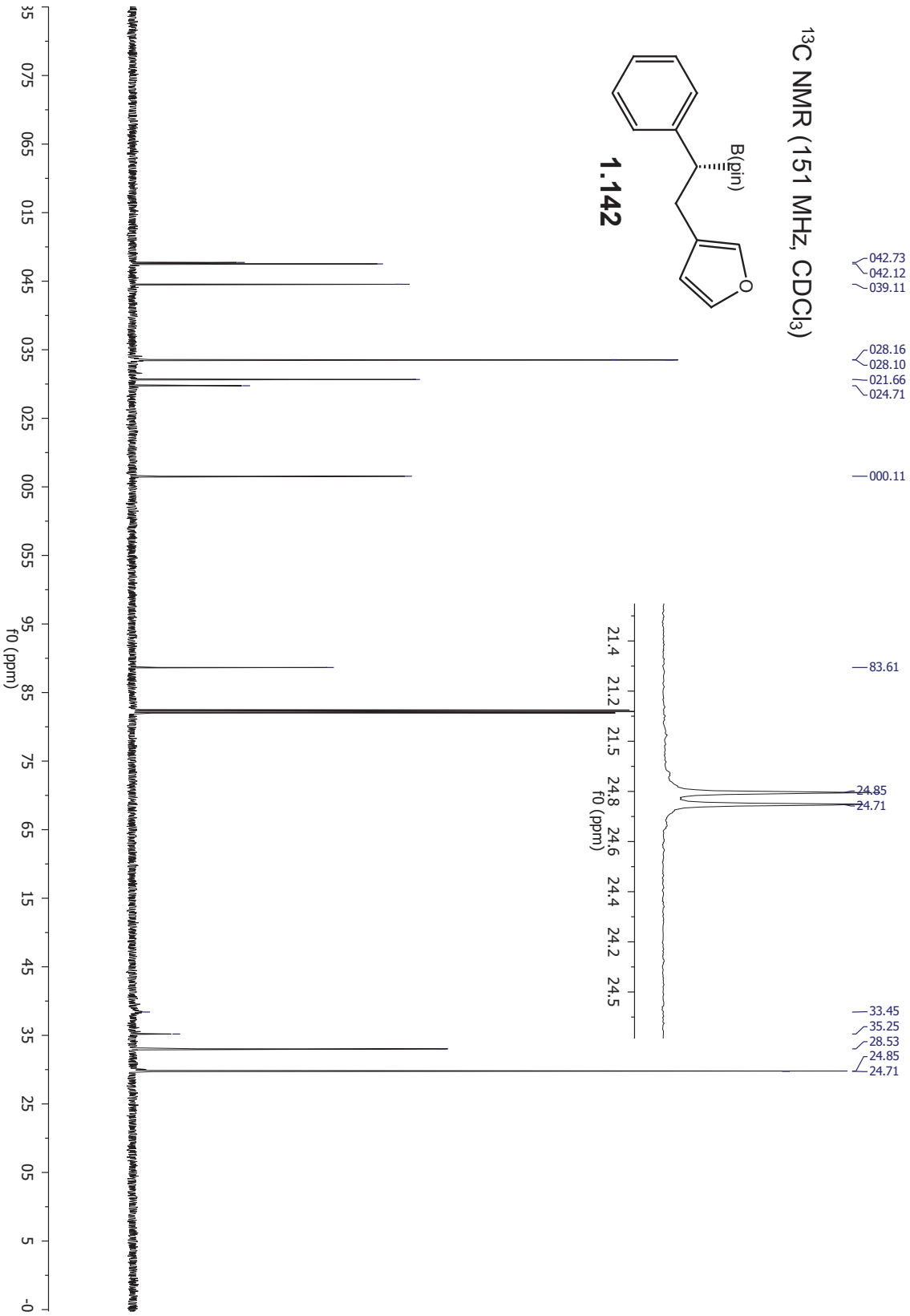
B(pin)
O
1.142
7.29
7.28
7.28
7.27
7.27
7.26
7.21
7.24
7.24
7.23
7.07
7.06
7.06
7.01
7.01
7.04
7.04
7.03
6.22
3.55
2.98
2.98
2.96
2.77
2.76
2.71
2.73
2.65
2.19
2.19
2.18
0.01
0.04
1.29
0.99
0.54
0.04
0.00
0.01
1.88
6.55
f0 (ppm)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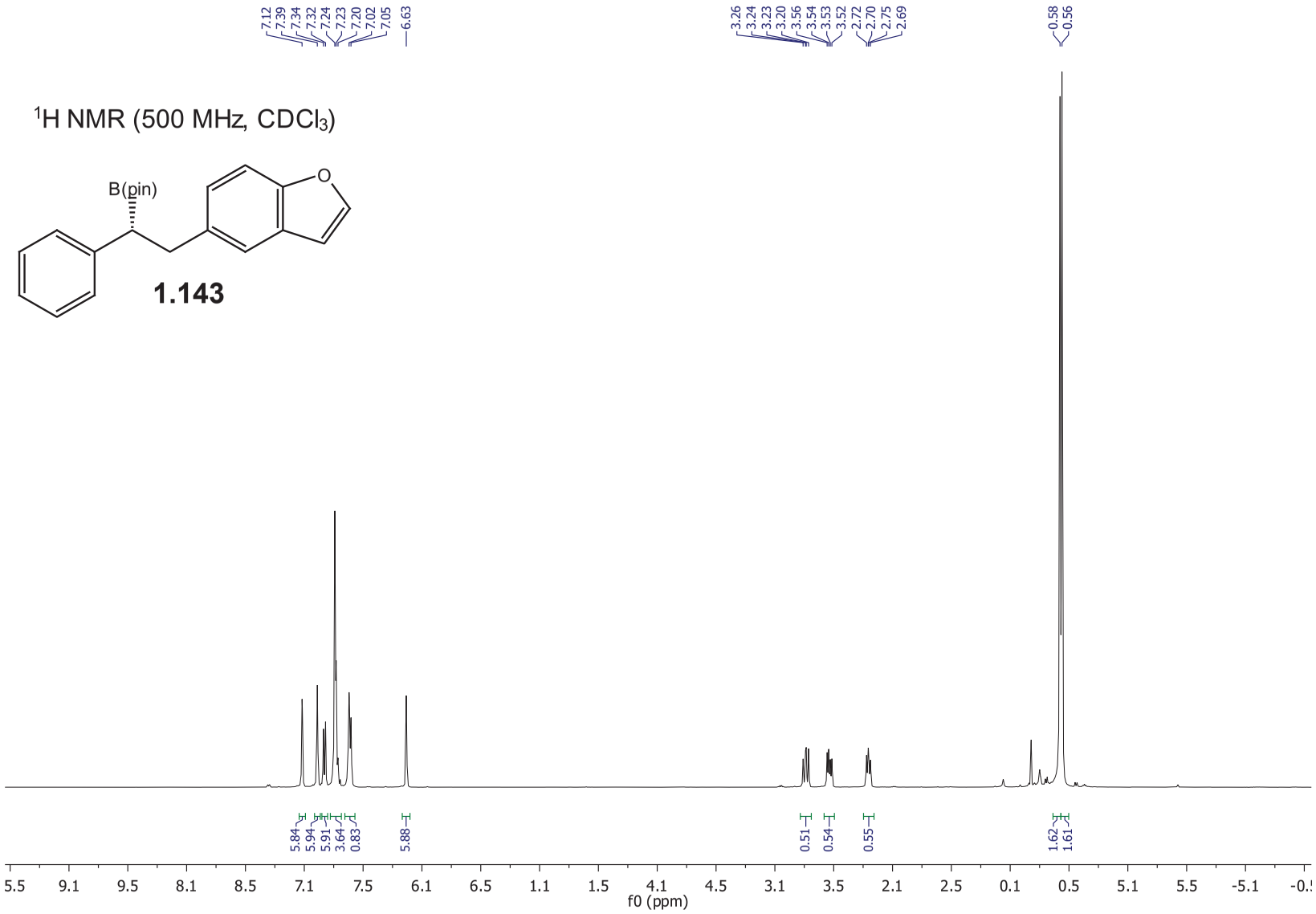
B(pin)
1.142
042.73
042.12
039.11
028.16
028.10
021.66
024.71
000.11
83.61
24.85
24.71
33.45
35.25
28.53
24.85
24.71
f0 (ppm)
f0 (ppm)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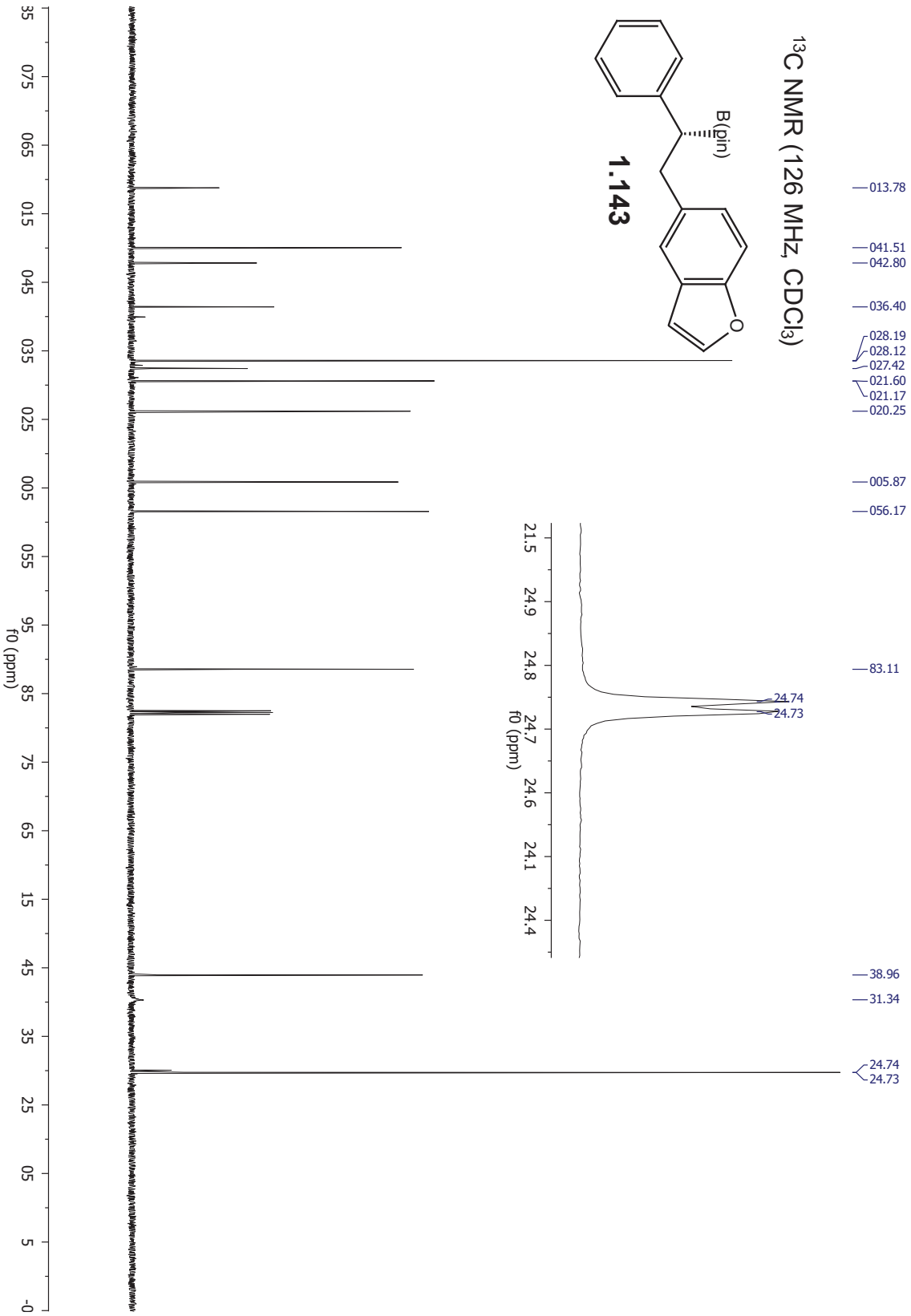
7.39
7.34
7.32
7.24
7.23
7.20
7.02
7.05
6.63
3.26
3.24
3.23
3.20
3.56
3.54
3.53
3.52
2.72
2.70
2.75
2.69
0.58
0.56
^{1}H NMR (500 MHz, $CDCl_3$)
B(pin)
O
1.143
5.84
5.94
5.91
3.64
0.83
5.88
0.51
0.54
0.55
1.62
1.61
5.5
9.1
9.5
8.1
8.5
7.1
7.5
6.1
6.5
1.1
1.5
4.1
4.5
3.1
3.5
2.1
2.5
0.1
0.5
5.1
5.5
-5.1
f0 (ppm)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B(pin)
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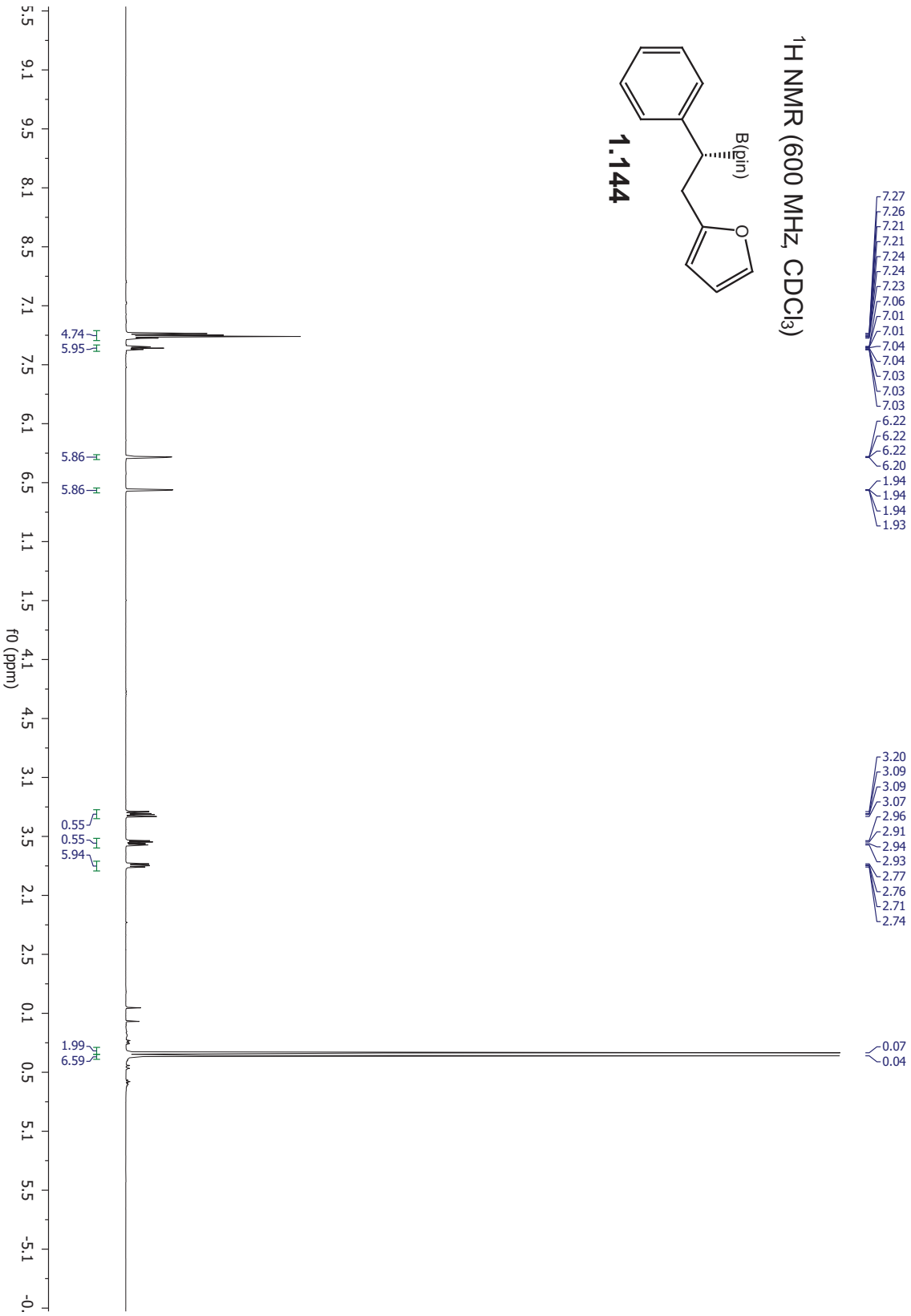
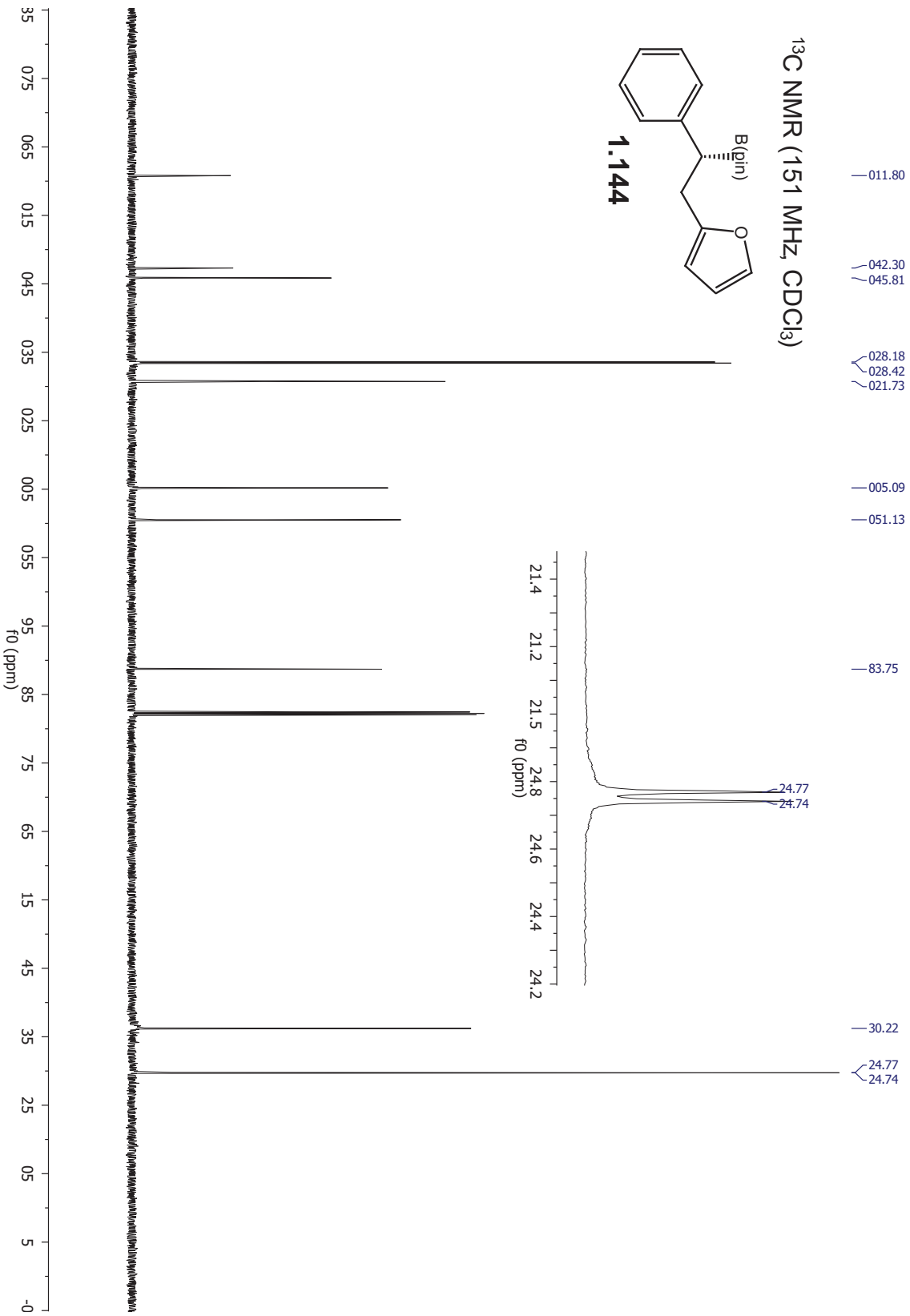
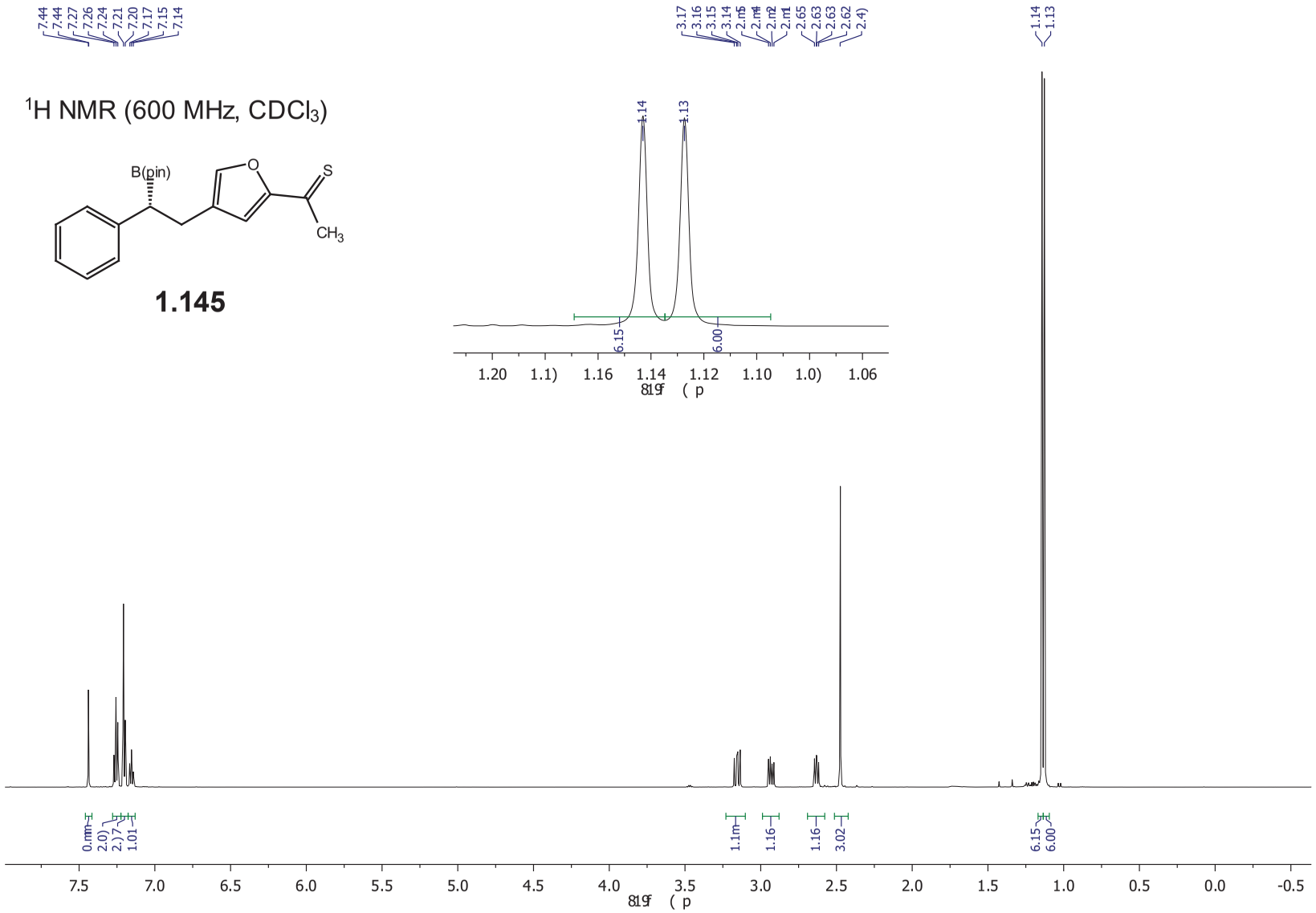
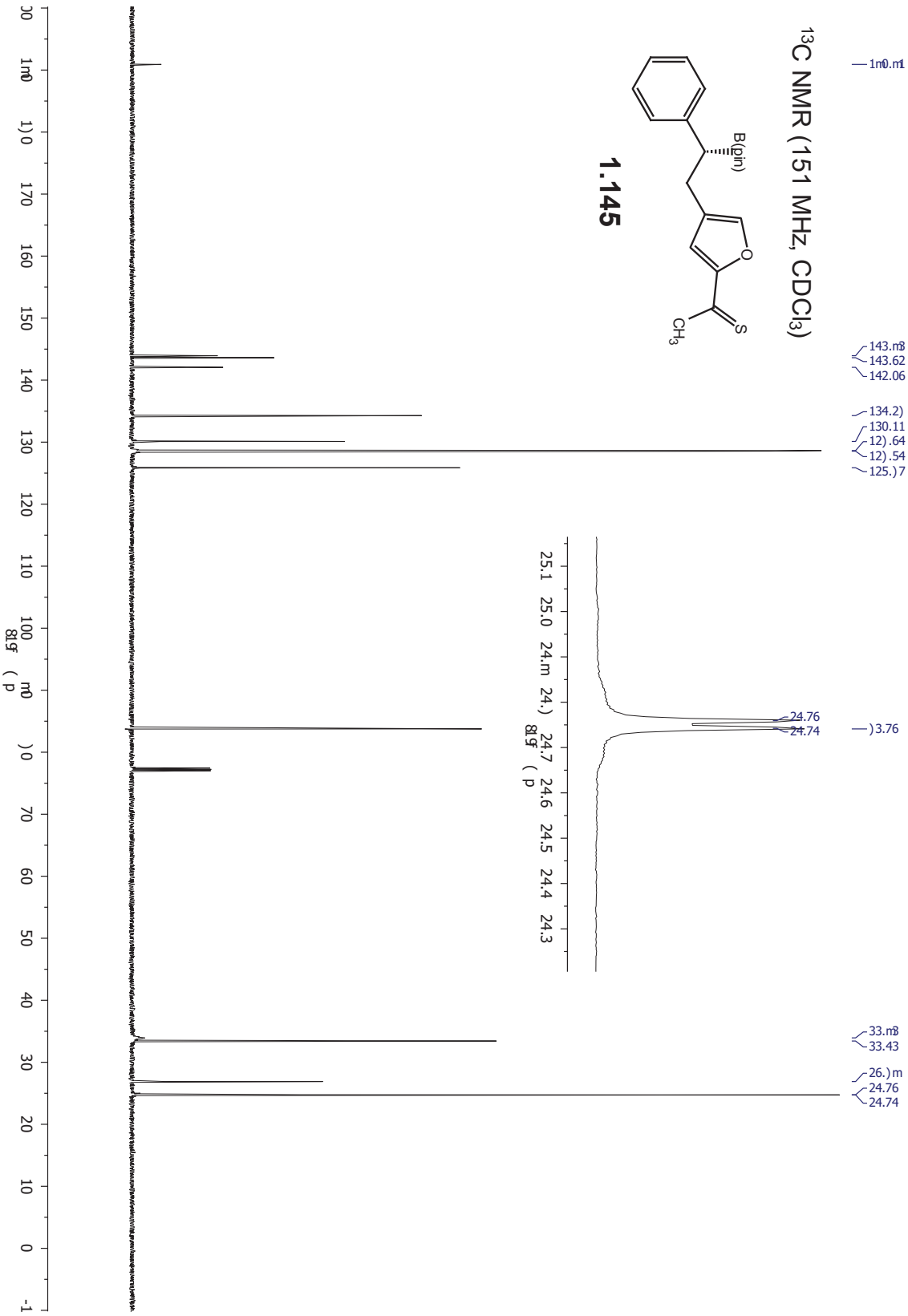
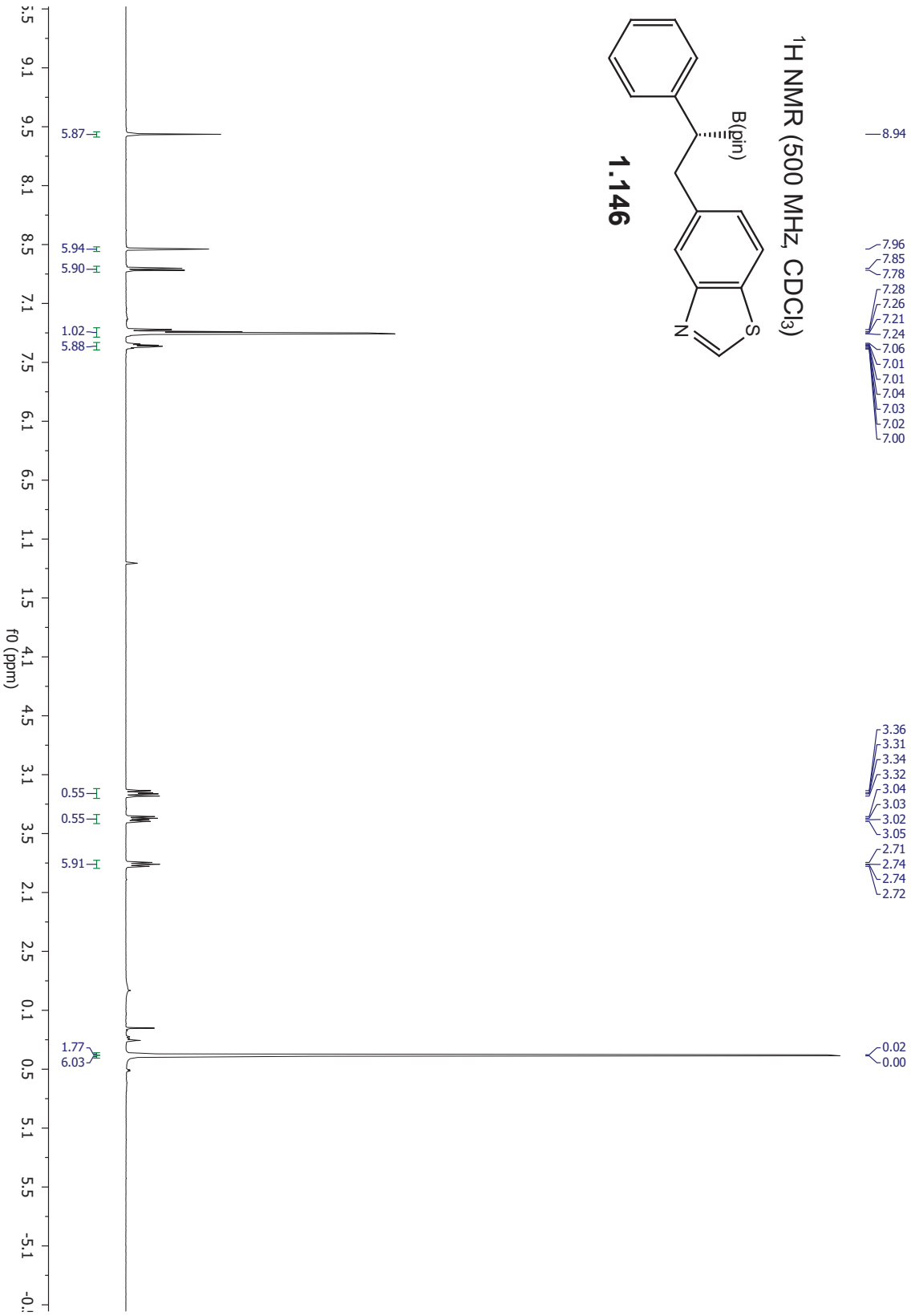
041.51
042.80
036.40
028.19
028.12
027.42
021.60
021.17
020.25
005.87
056.17
83.11
24.74
24.73
38.96
31.34
24.74
24.73
f0 (ppm)

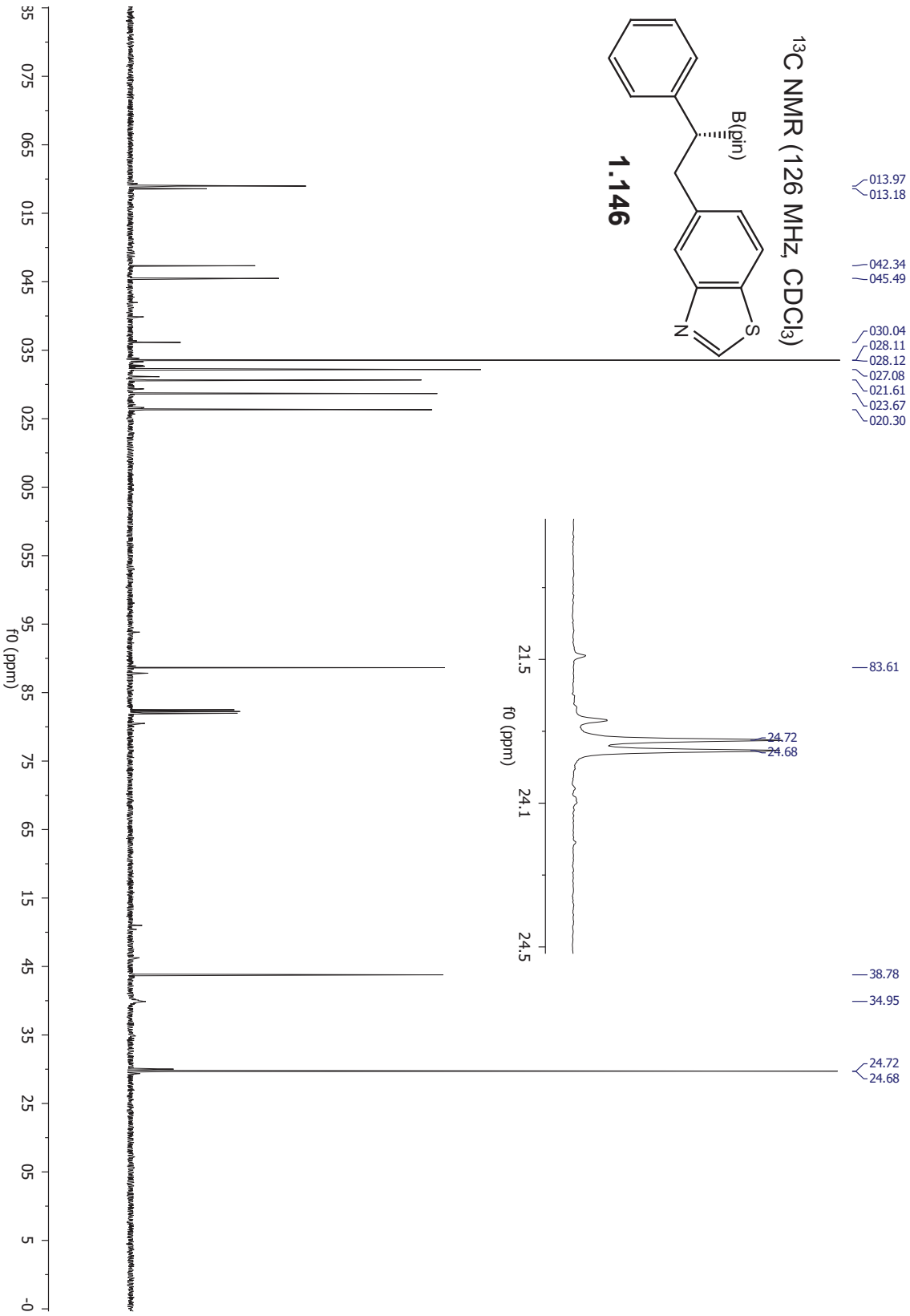

1H NMR (600 MHz, CDCl3)
1.144
B(pin)
O
f0 (ppm)
5.5 9.1 9.5 8.1 8.5 7.1 7.5 6.1 6.5 1.1 1.5 4.1 4.5 3.1 3.5 2.1 2.5 0.1 0.5 5.1 5.5 -5.1 -0.
4.74
5.95
5.86
5.86
0.55
0.55
5.94
1.99
6.59
7.27 7.26 7.21 7.21 7.24 7.24 7.23 7.06 7.01 7.01 7.04 7.04 7.03 7.03 7.03
6.22 6.22 6.22 6.20
1.94 1.94 1.94 1.93
3.20 3.09 3.09 3.07 2.96 2.91 2.94 2.93 2.77 2.76 2.71 2.74
0.07 0.04

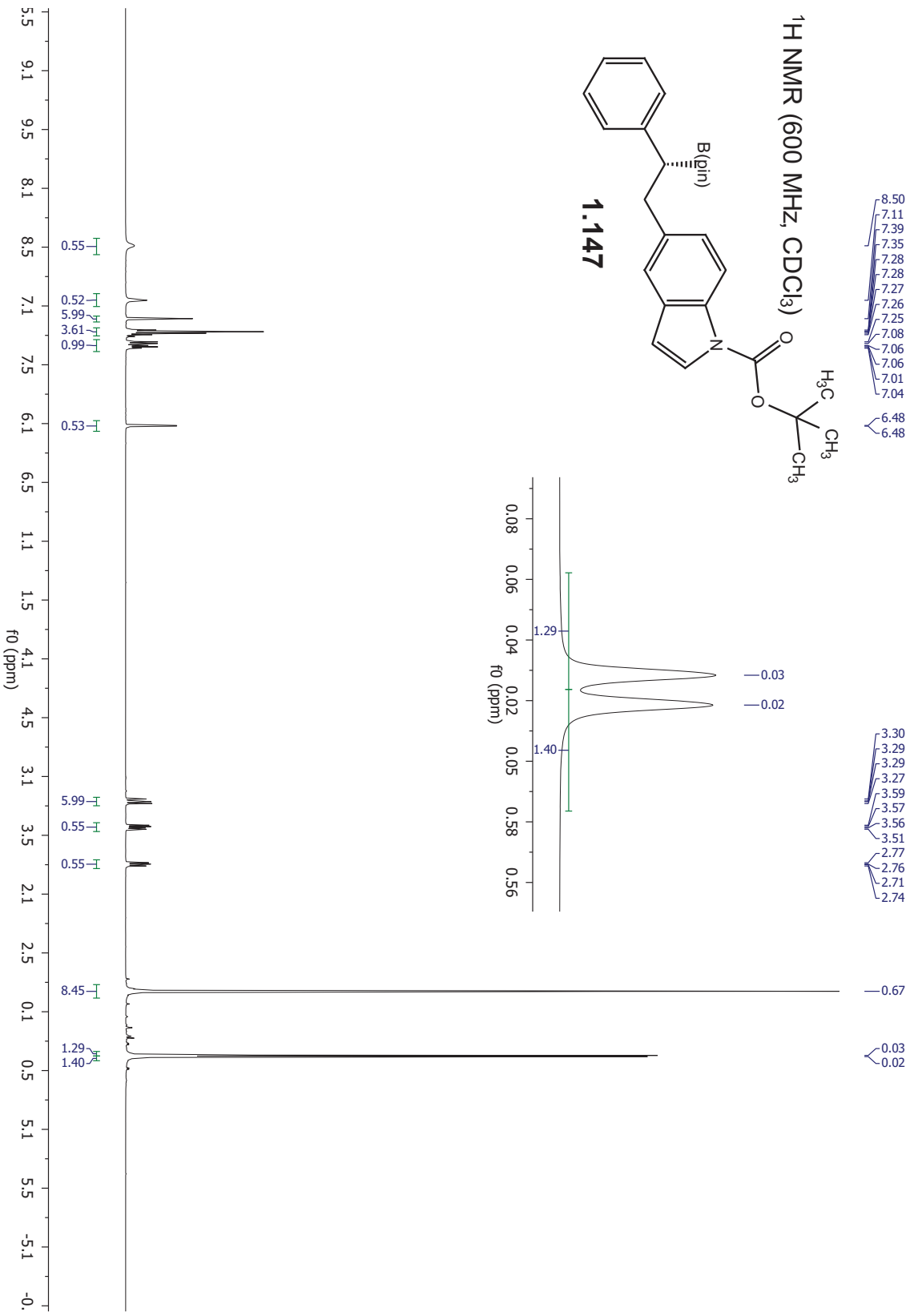

^{13}C NMR (151 MHz, CDCl$_3$)
B(pin)
O
1.144
011.80
042.30
045.81
028.18
028.42
021.73
005.09
051.13
83.75
24.77
24.74
30.22
24.77
24.74
f0 (ppm)
f0 (ppm)

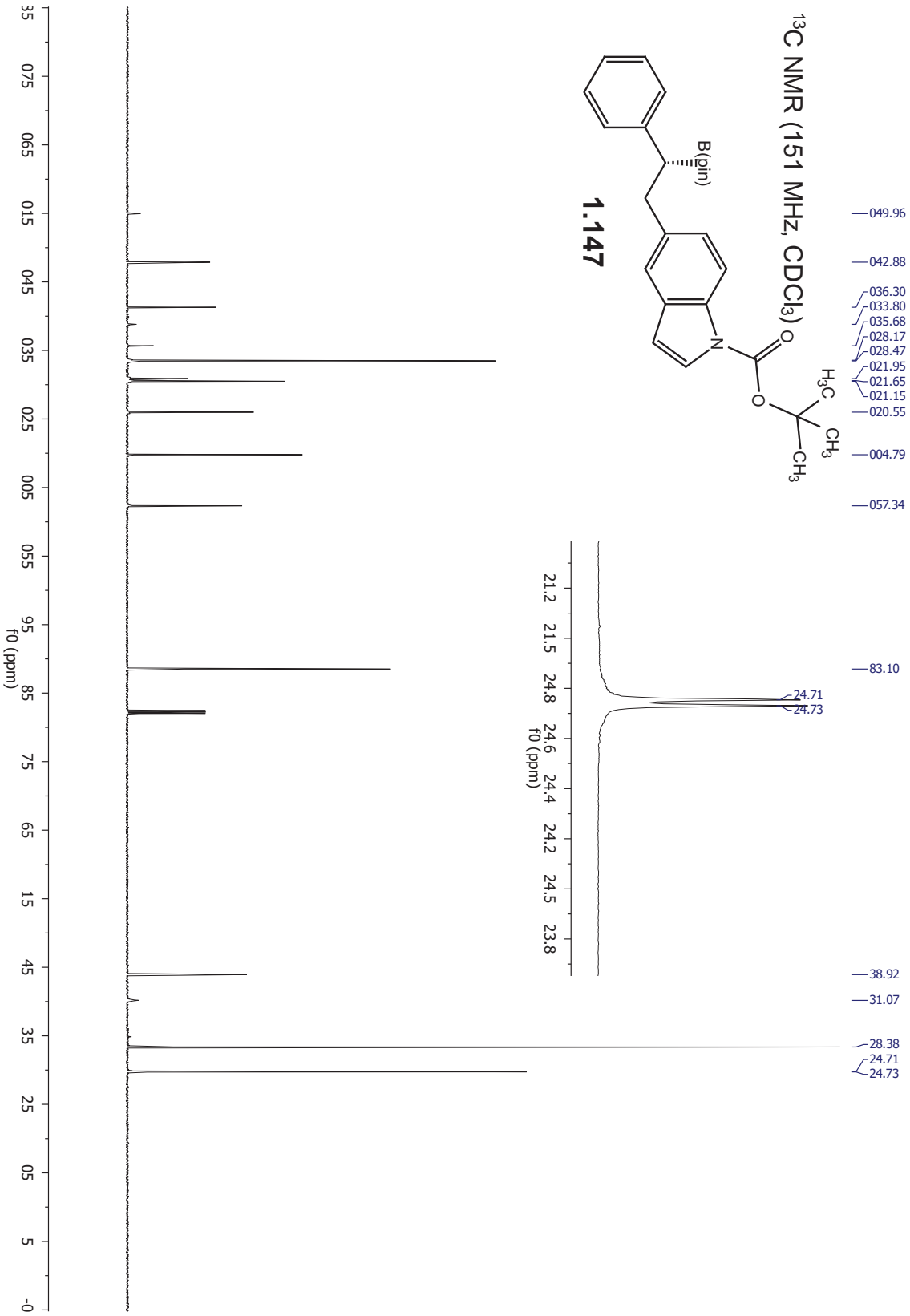

1H NMR (600 MHz, CDCl3)
B(pin)
O
S
CH3
1.145

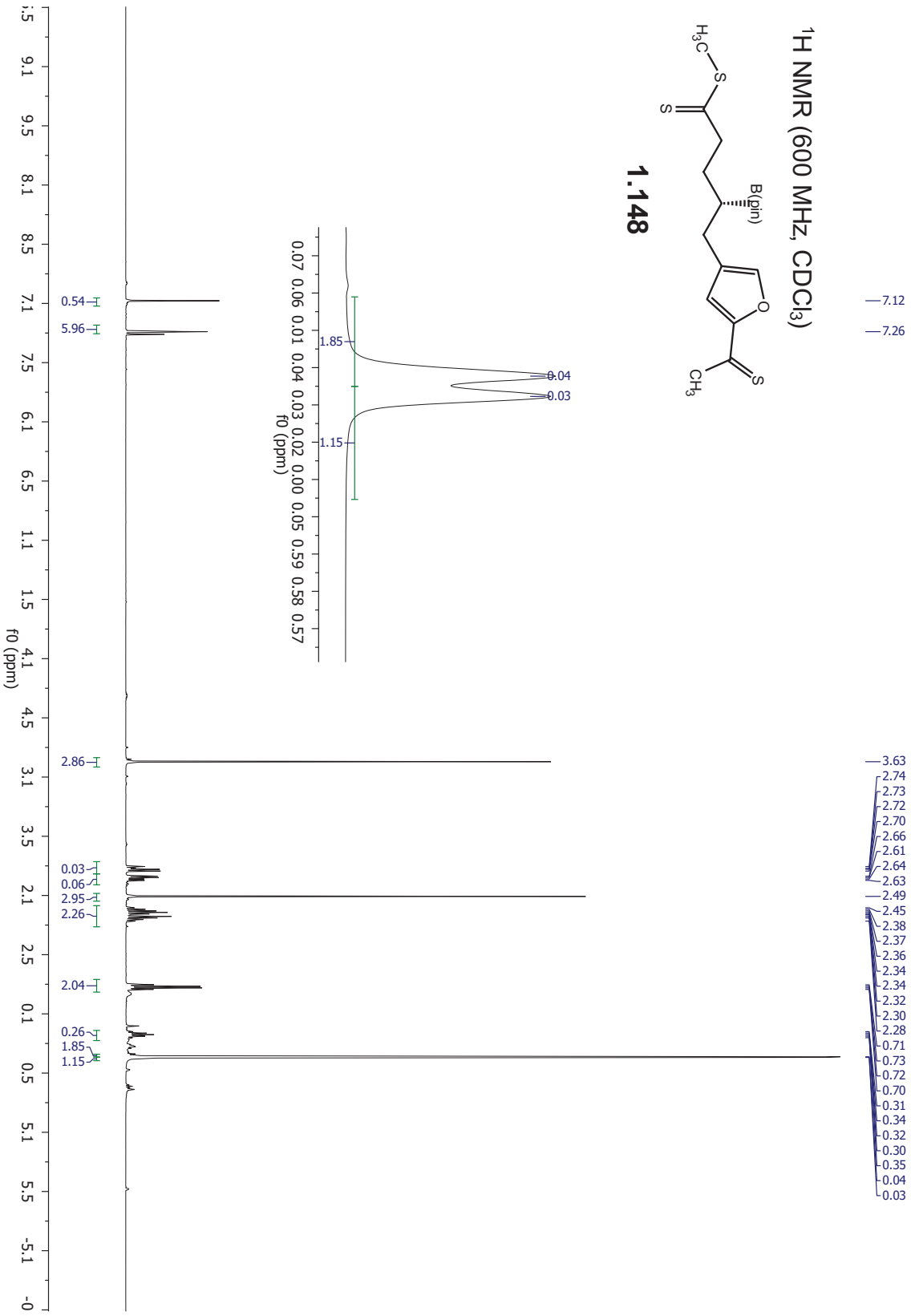

13C NMR (151 MHz, CDCl3)
B(pin)
O
S
CH3
1.145
143.62
142.06
134.2)
130.11
12).64
12).54
125.)7
24.76
24.74
)3.76
33.43
26.)m
24.76
24.74
f1 (ppm)

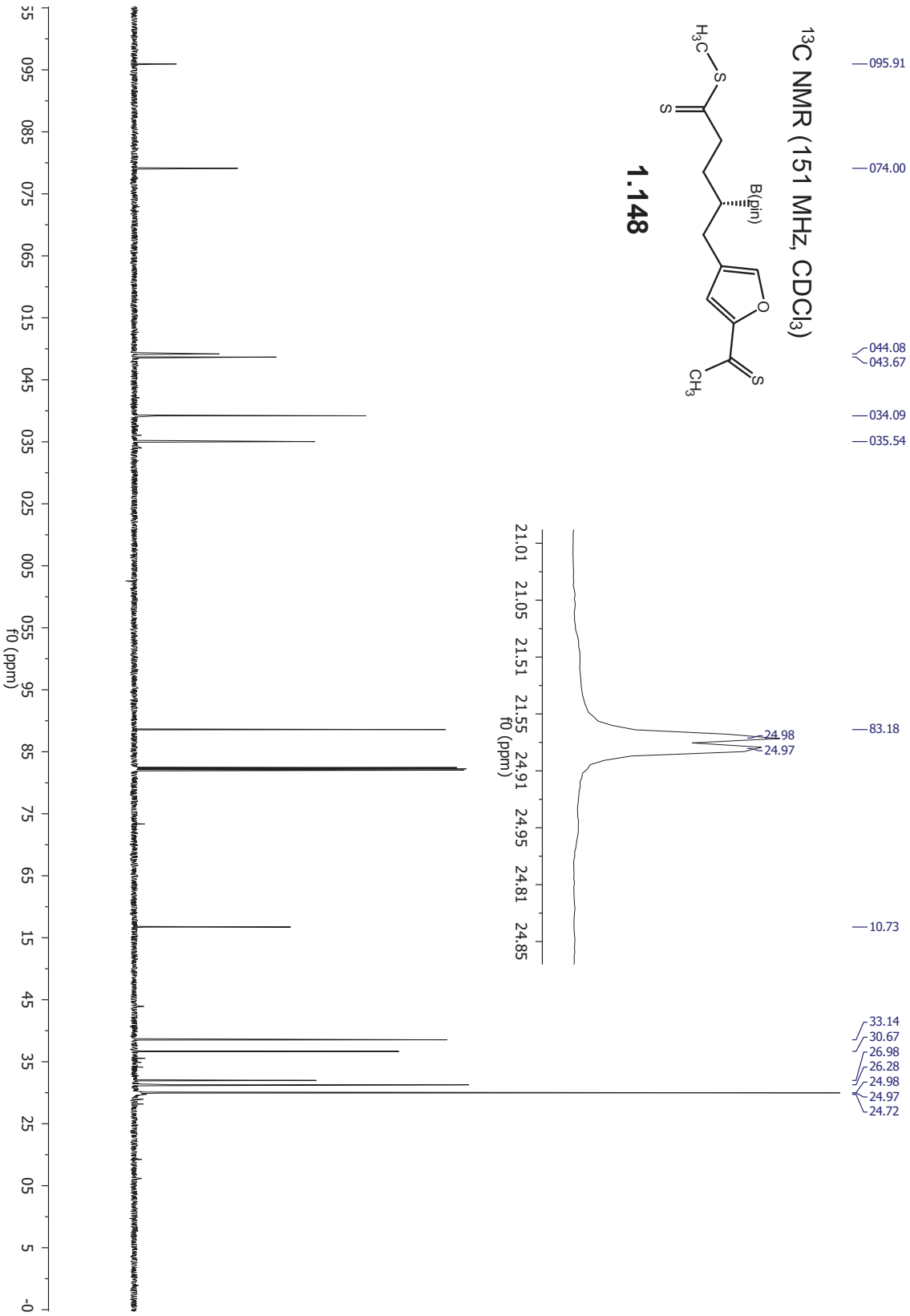

1H NMR (500 MHz, CDCl3)
B(pin)
1.146
N
S
f0 (ppm)
5.87
5.94
5.90
1.02
5.88
0.55
0.55
5.91
1.77
6.03
8.94
7.96
7.85
7.78
7.28
7.26
7.21
7.24
7.06
7.01
7.01
7.04
7.03
7.02
7.00
3.36
3.31
3.34
3.32
3.04
3.03
3.02
3.05
2.71
2.74
2.74
2.72
0.02
0.00

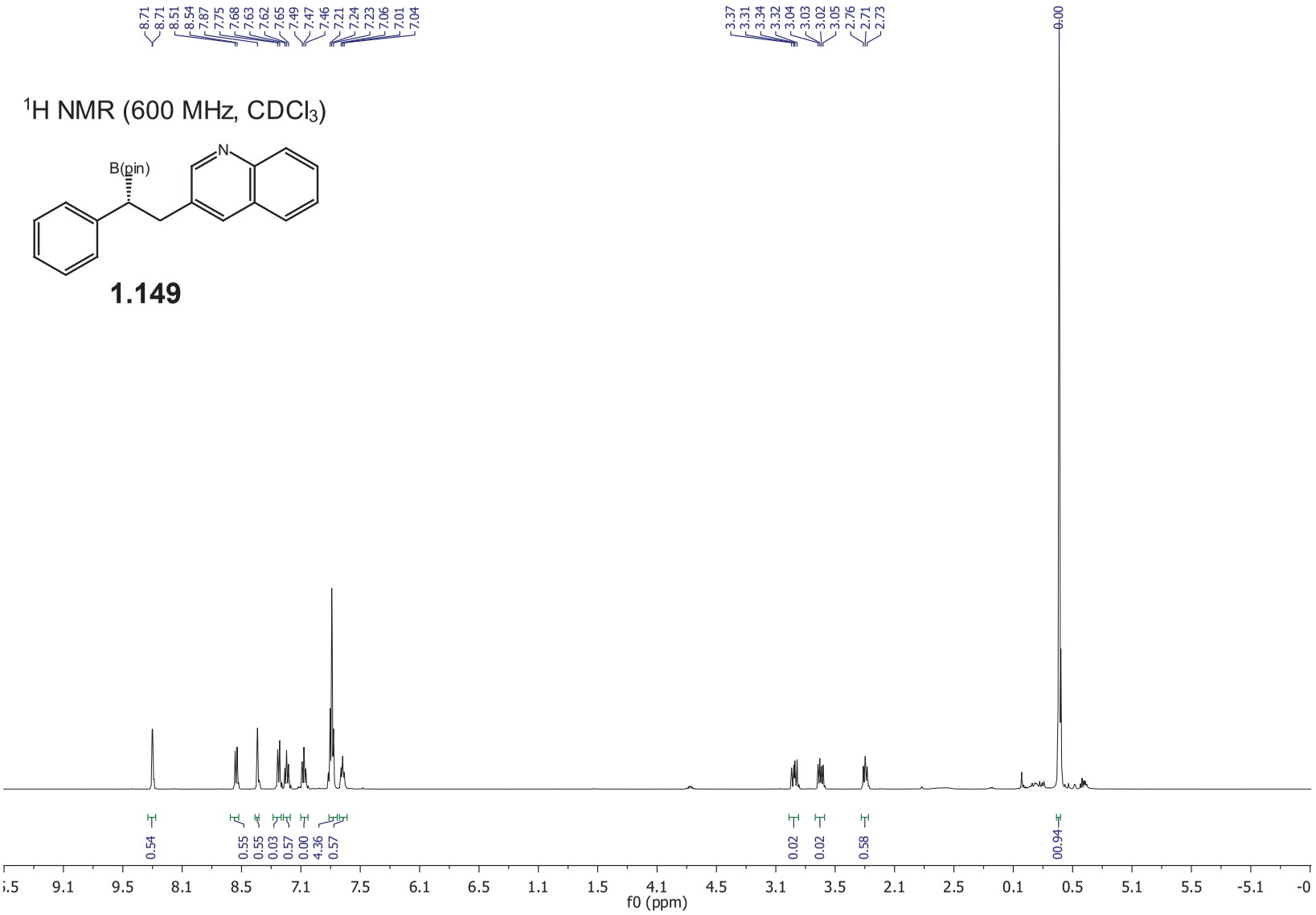

^{13}C NMR (126 MHz, CDCl$_3$)
B(pin)
1.146
N
S
013.97
013.18
042.34
045.49
030.04
028.11
028.12
027.08
021.61
023.67
020.30
83.61
24.72
24.68
38.78
34.95
24.72
24.68
f0 (ppm)
21.5
24.1
24.5
f0 (ppm)


1H NMR (600 MHz, CDCl3)
1.147
B(pin)
N
O
O
H3C
CH3
CH3
f0 (ppm)
8.50
7.11
7.39
7.35
7.28
7.28
7.27
7.26
7.25
7.08
7.06
7.06
7.01
7.04
6.48
6.48
3.30
3.29
3.29
3.27
3.59
3.57
3.56
3.51
2.77
2.76
2.71
2.74
0.67
0.03
0.02
1.29
1.40
0.55
0.52
5.99
3.61
0.99
0.53
5.99
0.55
0.55
8.45
1.29
1.40


^{13}C NMR (151 MHz, CDCl$_3$)
1.147
B(pin)
N
O
O
H$_3$C
CH$_3$
CH$_3$
049.96
042.88
036.30
033.80
035.68
028.17
028.47
021.95
021.65
021.15
020.55
004.79
057.34
83.10
24.71
24.73
38.92
31.07
28.38
24.71
24.73
f0 (ppm)


^{1}H NMR (600 MHz, CDCl$_3$)
1.148
B(pin)
H$_3$C
S
S
O
S
CH$_3$
f0 (ppm)
0.54
5.96
2.86
0.03
0.06
2.95
2.26
2.04
0.26
1.85
1.15
1.85
1.15
0.04
0.03
7.12
7.26
3.63
2.74
2.73
2.72
2.70
2.66
2.61
2.64
2.63
2.49
2.45
2.38
2.37
2.36
2.34
2.34
2.32
2.30
2.28
0.71
0.73
0.72
0.70
0.31
0.34
0.32
0.30
0.35
0.04
0.03


^{13}C NMR (151 MHz, CDCl$_3$)
1.148
095.91
074.00
044.08
043.67
034.09
035.54
083.18
24.98
24.97
10.73
33.14
30.67
26.98
26.28
24.98
24.97
24.72
f0 (ppm)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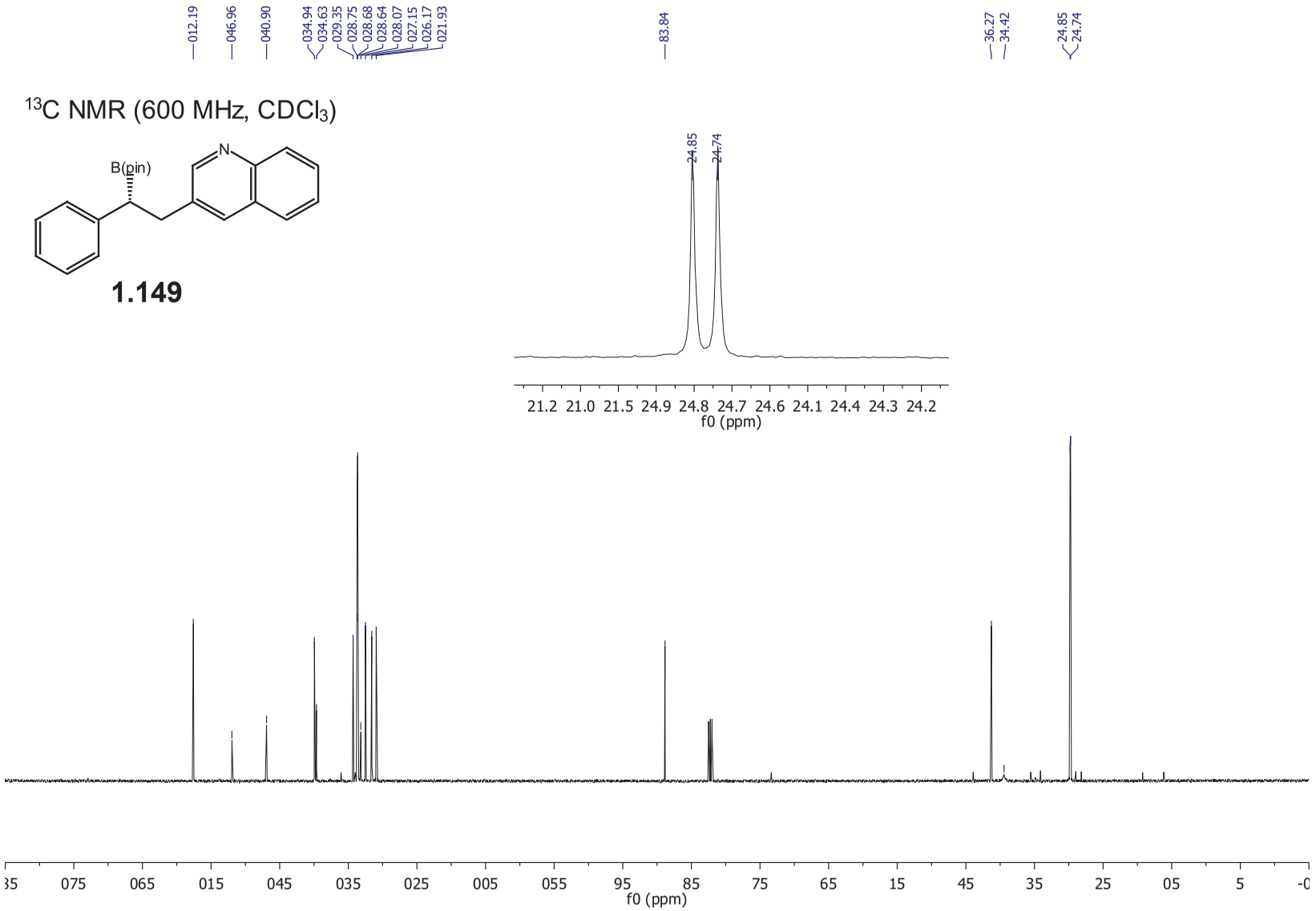
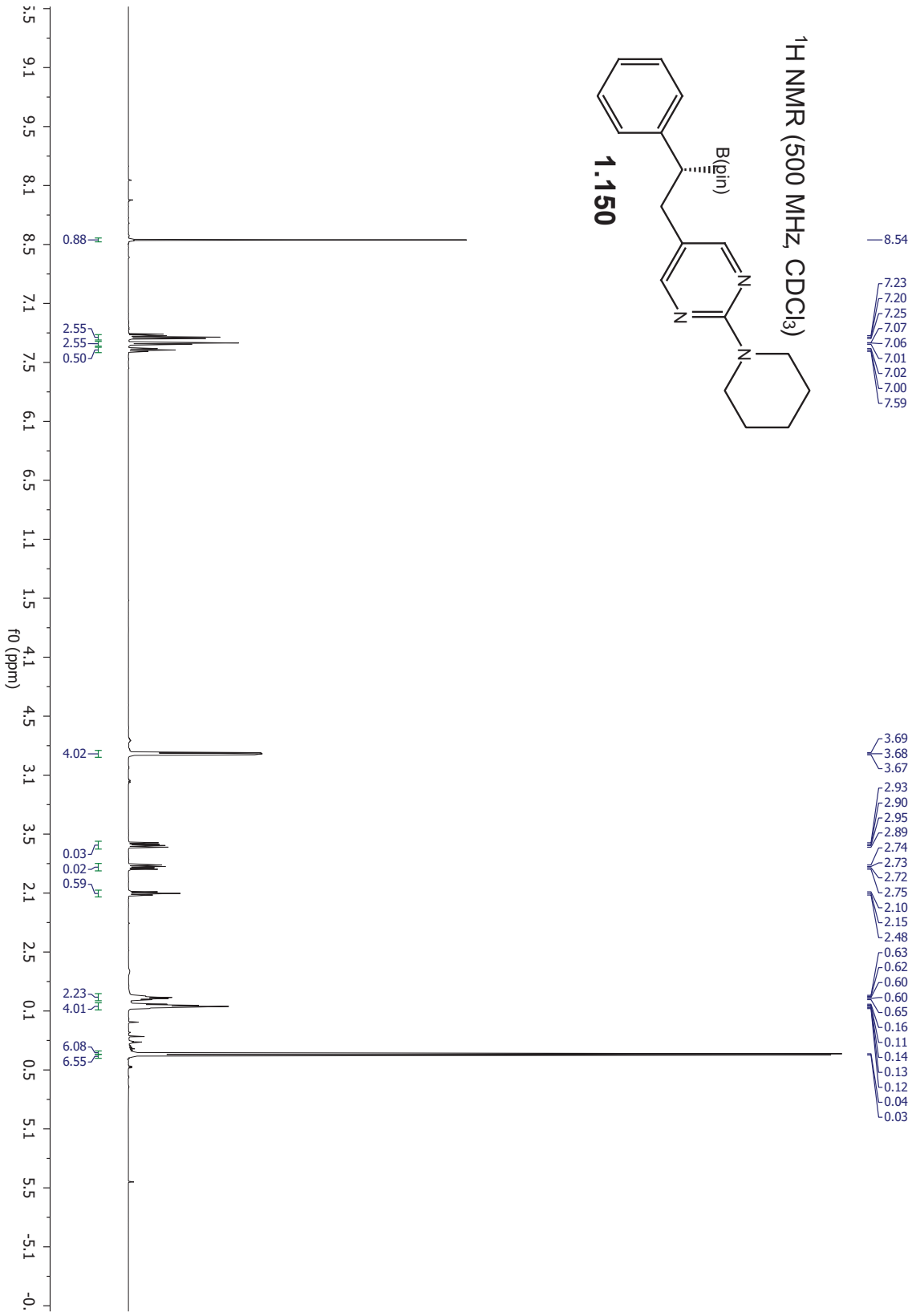
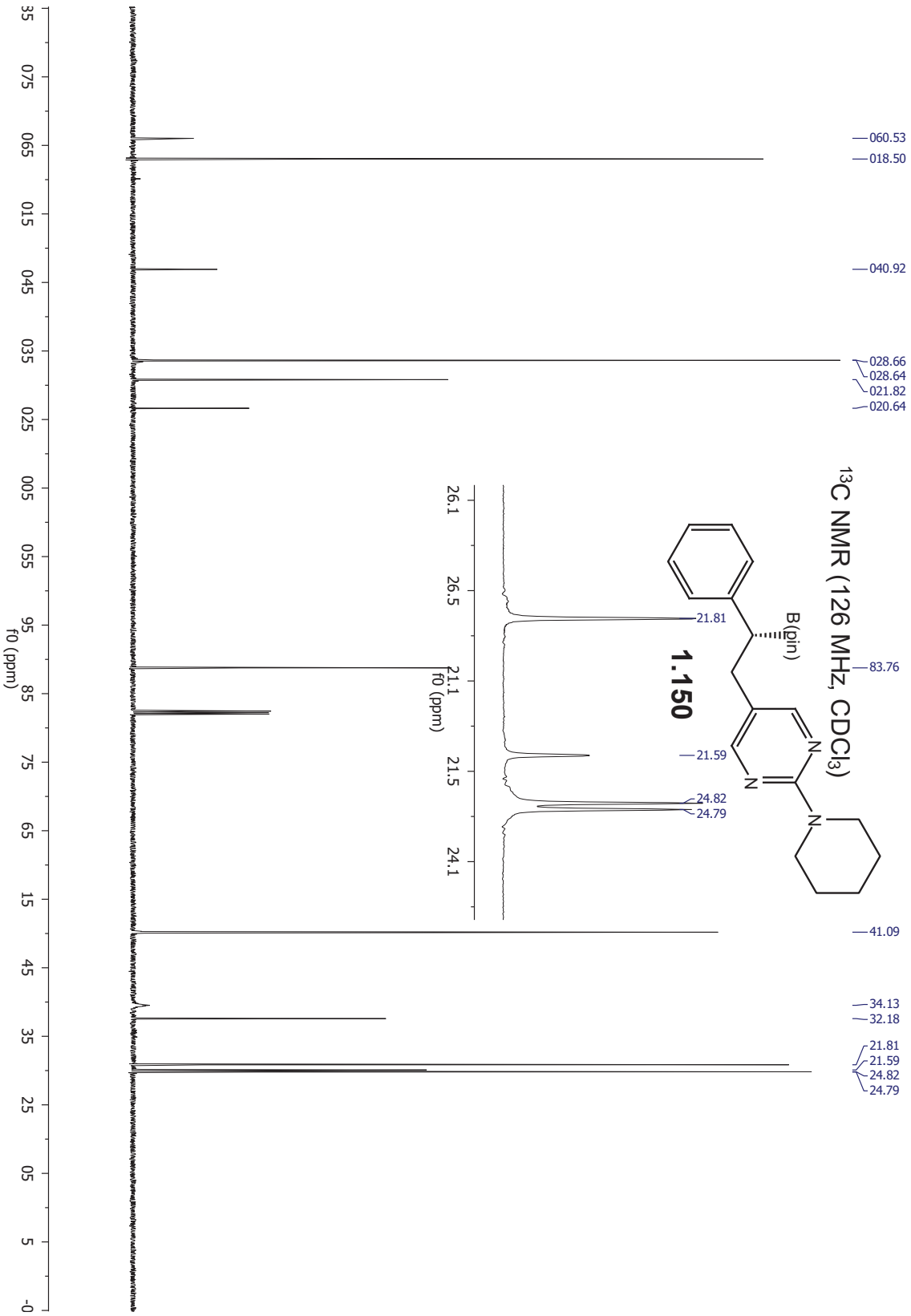
8.71
8.51
8.54
7.87
7.75
7.68
7.63
7.62
7.65
7.49
7.47
7.46
7.21
7.24
7.23
7.06
7.01
7.04
3.37
3.31
3.34
3.32
3.04
3.03
3.02
3.05
2.76
2.71
2.73
0.00
1H NMR (600 MHz, CDCl3)
B(pin)
N
1.149
0.54
0.55
0.55
0.03
0.57
0.00
4.36
0.57
0.02
0.02
0.58
00.94
f0 (ppm)


012.19
046.96
040.90
034.94
034.63
029.35
028.75
028.68
028.64
028.07
027.15
026.17
021.93
83.84
36.27
34.42
24.85
24.74
13C NMR (600 MHz, CDCl3)
B(pin)
N
1.149
24.85
24.74
21.2 21.0 21.5 24.9 24.8 24.7 24.6 24.1 24.4 24.3 24.2
f0 (ppm)
f0 (ppm)


1H NMR (500 MHz, CDCl3)
1.150
B(pin)
N
N
f0 (ppm)
0.88
2.55
2.55
0.50
4.02
0.03
0.02
0.59
2.23
4.01
6.08
6.55
8.54
7.23
7.20
7.25
7.07
7.06
7.01
7.02
7.00
7.59
3.69
3.68
3.67
2.93
2.90
2.95
2.89
2.74
2.73
2.72
2.75
2.10
2.15
2.48
0.63
0.62
0.60
0.60
0.65
0.16
0.11
0.14
0.13
0.12
0.04
0.03


13C NMR (126 MHz, CDCl3)
060.53
018.50
040.92
028.66
028.64
021.82
020.64
83.76
41.09
34.13
32.18
21.81
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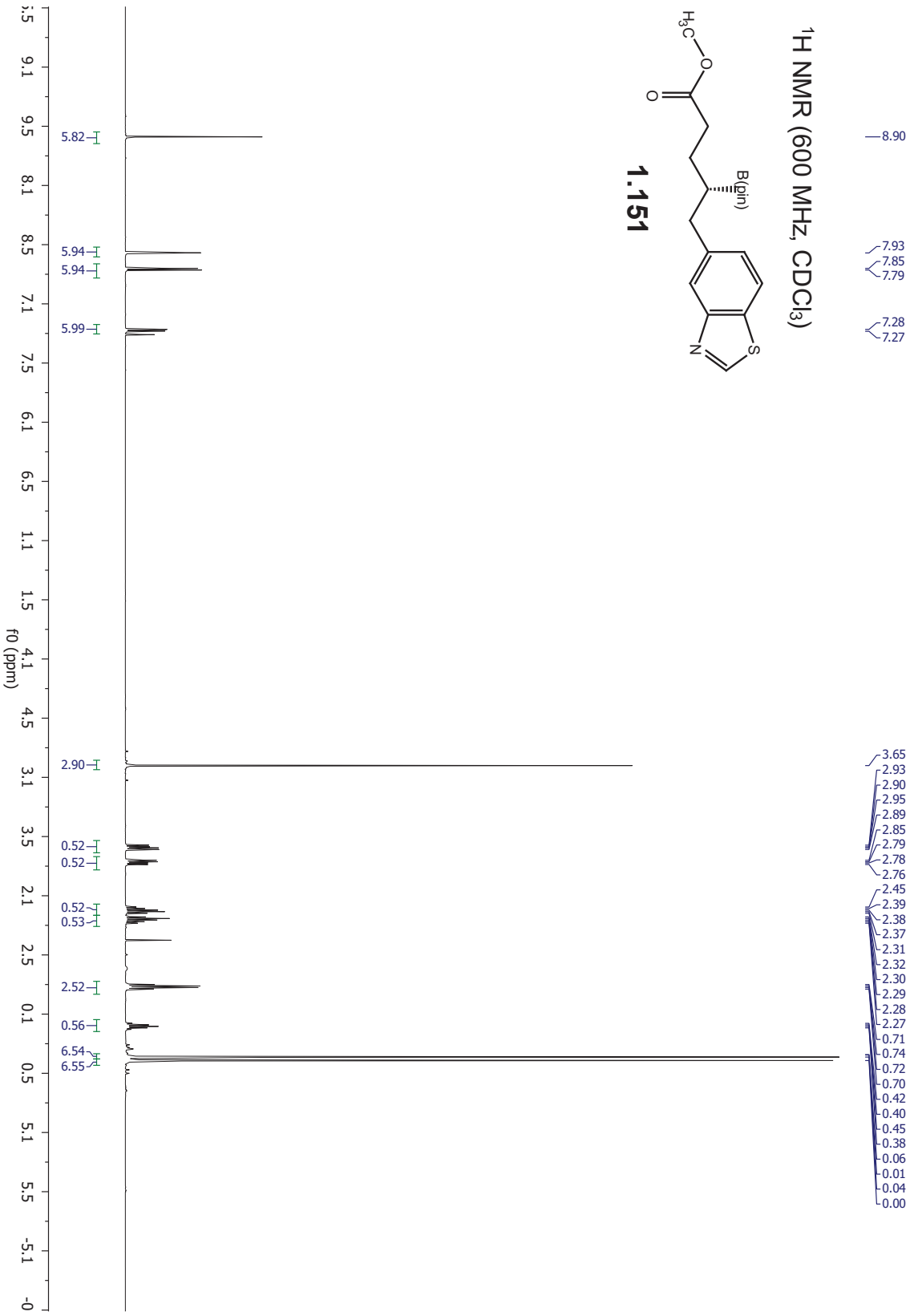
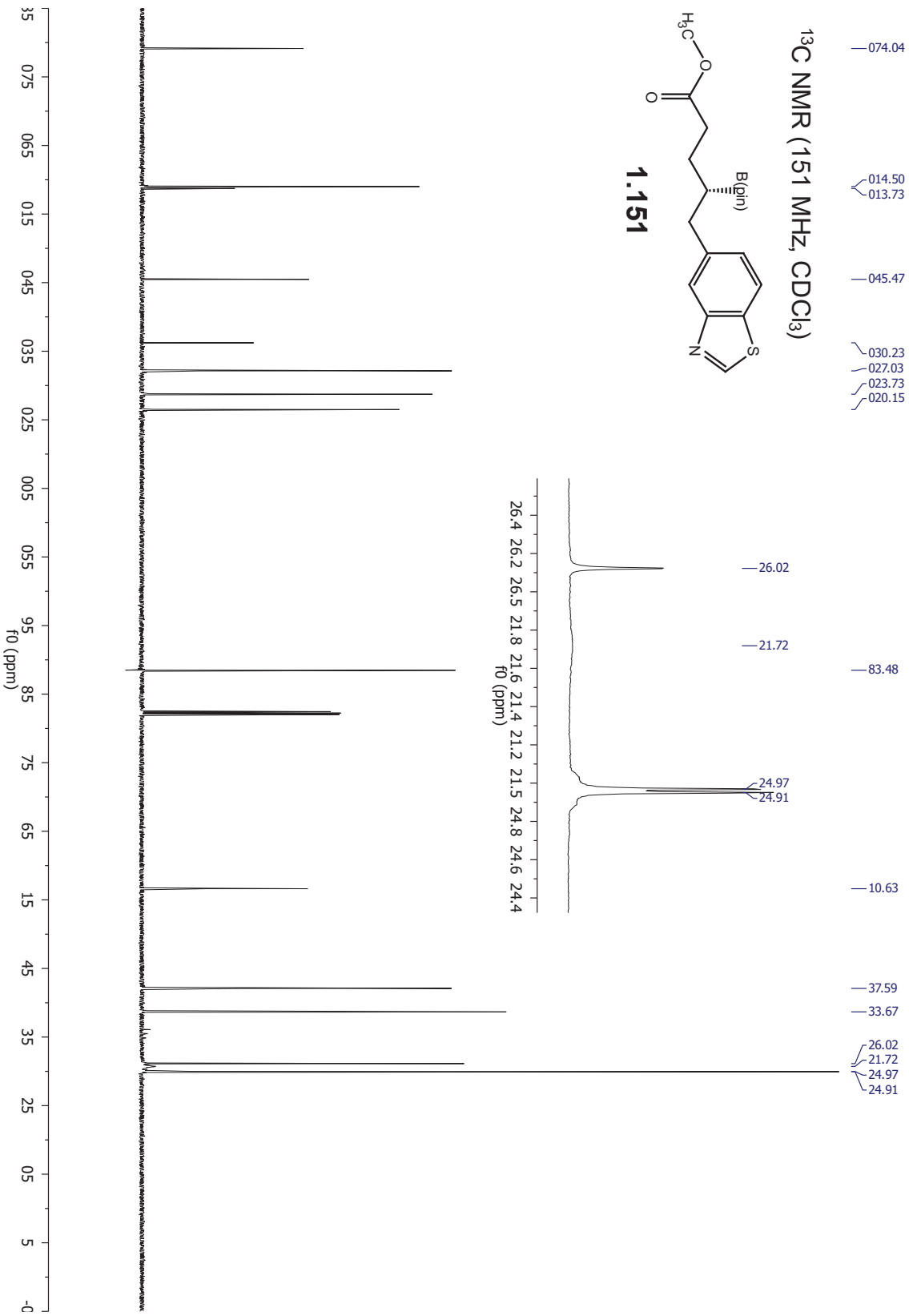
24.82
24.79
B(pin)
1.150
f0 (ppm)


1H NMR (600 MHz, CDCl3)
1.151
B(pin)
O
H3C
N
S
f0 (ppm)
8.90
7.93
7.85
7.79
7.28
7.27
5.82
5.94
5.94
5.99
2.90
0.52
0.52
0.52
0.53
2.52
0.56
6.54
6.55
3.65
2.93
2.90
2.95
2.89
2.85
2.79
2.78
2.76
2.45
2.39
2.38
2.37
2.31
2.32
2.30
2.29
2.28
2.27
0.71
0.74
0.72
0.70
0.42
0.40
0.45
0.38
0.06
0.01
0.04
0.00


13C NMR (151 MHz, CDCl3)
1.151
B(pin)
O
H3C
O
N
S
074.04
014.50
013.73
045.47
030.23
027.03
023.73
020.15
26.02
21.72
83.48
24.97
24.91
10.63
37.59
33.67
26.02
21.72
24.97
24.91
f0 (ppm)
f0 (ppm)

CHAPTER TWO

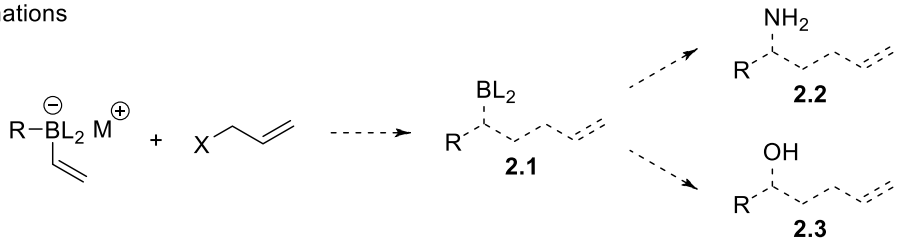
Allyl Electrophiles in the Conjunctive Cross-Coupling Reaction and the Discovery of the Vinylidenation of Boronic Esters

2.1. Introduction

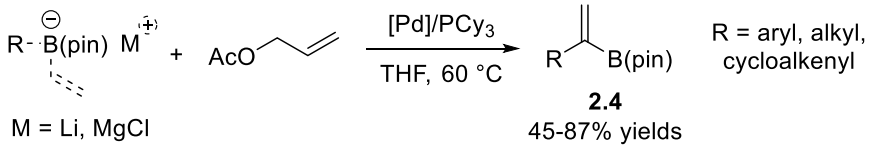
To expand the scope of conjunctive cross-coupling reactions, we investigated the possibility of using allyl electrophiles, which would give γ-boryl alkenes **2.1**. We envisioned that these compounds could be oxidized or aminated to the corresponding amine **2.2** or alcohol **2.3**, respectively (Scheme 2.1a), which are valuable intermediates in the synthesis of more complex structures. Although allyl electrophiles never gave the conjunctive cross-coupling products in greater than 15% yield, in some cases we observed products consistent with vinylidene insertion between the boron and the carbon of the migrating group **2.4** (Scheme 2.1b). In the presence of the large monodentate ligand tricyclohexylphosphine (PCy_3), the reaction favors this new homologation pathway.

Scheme 2.1. Reactions of boron "ate" complexes with allyl electrophiles

(a) Proposed synthesis of γ-boryl alkenes by conjunctive cross-coupling and subsequent transformations



(b) Vinylidenation of "ate" complexes



M = Li, MgCl

2.4

45-87% yields

2.2. Background

2.2.1. Utility of γ-Boryl Alkenes

γ-Boryl alkenes could be transformed to γ-amino or γ-hydroxyl alkenes, which are intermediates in the synthesis of pyrrolidine and tetrahydrofuran rings, respectively. Examples of pyrrolidine formation include aminoarylation,[1] aminoalkenylation,[2] aminoacylation,[3] and hydroamination[4] (Scheme 2.2). Examples of THF ring formation include oxyarylation;[5] oxyalkynylation;[6] oxy-,[7] amino-,[8] thio-,[9] and haloetherifications;[10] and oxidative lactonization to afford γ-butyrolactones[11] (Scheme 2.3). As for a medicinal chemistry application, Jaudzems and Jirgenson used the bromoetherification of γ-hydroxyl alkenes followed by Gabriel amine synthesis to access THF structures **2.5**, which have been used to synthesize a library of nonpeptidomimetic plasmepsin inhibitors **2.6** as potential treatment for malaria (Scheme 2.3f).[12]

---

[1] (a) Bertrand, M. B.; Wolfe, J. P. *Tetrahedron* **2005**, *61*, 6447. (b) Yang, Q.; Ney, J. E.; Wolfe, J. P. *Org. Lett.* **2005**, *7*, 2575. (c) Bertrand, M. B.; Neukom, J. D.; Wolfe, J. P. *J. Org. Chem.* **2008**, *73*, 8851. (d) Rosewall, C. F.; Sibbald, P. A.; Liskin, D. V.; Michael, F. E. *J. Am. Chem. Soc.* **2009**, *131*, 9488. (e) Brenzovich, W. E.; Benitez, D.; Lackner, A. D.; Shunatona, H. P.; Tkatchouk, E.; Goddard, W. A.; Toste, F. D. *Angew. Chem. Int. Ed.* **2010**, *49*, 5519. (f) Zhang, G.; Cui, L.; Wang, Y.; Zhang, L. *J. Am. Chem. Soc.* **2010**, *132*, 1474. (g) Peterson, L. J.; Wolfe, J. P. *Adv. Synth. Catal.* **2015**, *357*, 2339. (h) Sun, B.; Liu, S.; Zhang, M.; Zhao, J.; Zhang, Q. *Org. Chem. Front.* **2019**, *6*, 388.

[2] Ney, J. E.; Hay, M. B.; Yang, Q.; Wolfe, J. P. *Adv. Synth. Catal.* **2005**, *347*, 1614.

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[4] Crimmin, M. R.; Arrowsmith, M.; Barrett, A. G. M.; Casely, I. J.; Hill, M. S.; Procopiou, P. A. *J. Am. Chem. Soc.* **2009**, *131*, 9670.

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[6] (a) Nicolai, S.; Waser, J. *Org. Lett.* **2011**, *13*, 6324. (b) Nicolai, S.; Sedigh-Zadeh, R.; Waser, J. *J. Org. Chem.* **2013**, *78*, 3783.

[7] (a) Palmer, C.; Morra, N. A.; Stevens, A. C.; Bajtos, B.; Machin, B. P.; Pagenkopf, B. L. *Org. Lett.* **2009**, *11*, 5614. (b) Theodorou, A.; Kokotos, C. G. *Green Chem.* **2017**, *19*, 670.

[8] Sequeira, F. C.; Chemler, S. R. *Org. Lett.* **2012**, *14*, 4482.

[9] Fries, P.; Müller, M. K.; Hartung, J. *Org. Biomol. Chem.* **2013**, *11*, 2630.

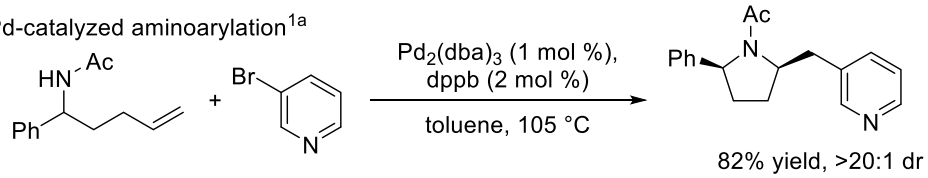
[10] (a) Lee, A. S.-Y.; Tsao, K.-W.; Chang, Y.-T.; Chu, S.-F. *Tetrahedron Lett.* **2007**, *48*, 6790. (b) Brücher, O.; Hartung, J. *Tetrahedron* **2014**, *70*, 7950. (c) Moriyama, K.; Nishinohara, C.; Togo, H. *Chem. Eur. J.* **2016**, *22*, 11934. (d) Tomizuka, A.; Moriyama, K. *Adv. Synth. Catal.* **2019**, *361* (6), 1447.

[11] Gao, R.; Fan, R.; Canney, D. *Synlett* **2015**, *26*, 661.

[12] Rasina, D.; Otikovs, M.; Leitans, J.; Recacha, R.; Borysov, O. V.; Kanepe-Lapsa, I.; Domraceva, I.; Pantelejevs, T.; Tars, K.; Blackman, M. J.; Jaudzems, K.; Jirgensons, A. *J. Med. Chem.* **2016**, *59*, 374.

Scheme 2.2. Synthesis of pyrrolidines from γ-amino alkenes

(a) Wolfe's Pd-catalyzed aminoarylation[1a]

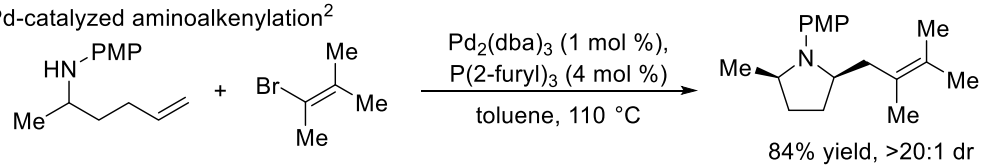


82% yield, >20:1 dr

(b) Zhang's Au-catalyzed aminoarylation[1f]

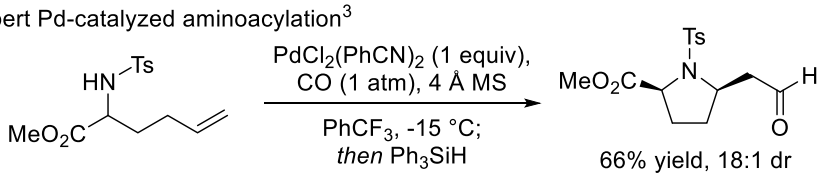
69% yield, ~1:1 dr

(c) Wolfe's Pd-catalyzed aminoalkenylation[2]



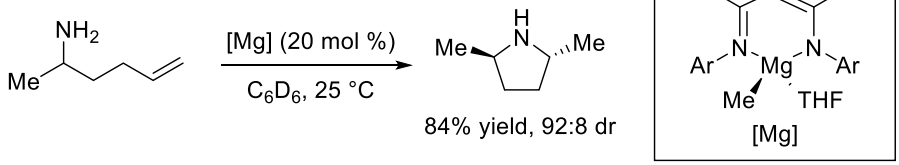
84% yield, >20:1 dr

(d) Lambert Pd-catalyzed aminoacylation[3]



66% yield, 18:1 dr

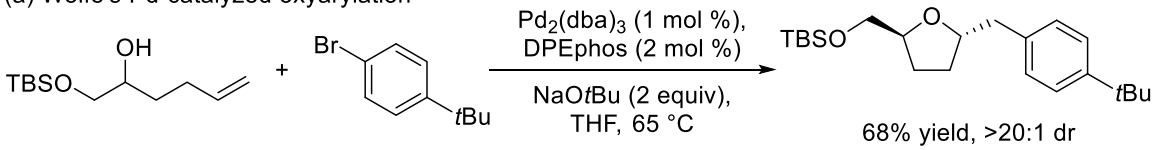
(e) Crimmin's Mg-catalyzed hydroamination[4]



84% yield, 92:8 dr

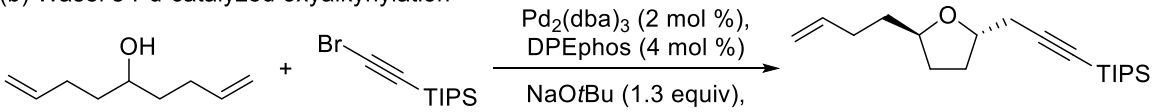
Scheme 2.3. Synthesis of THF rings from γ-hydroxyl alkenes

(a) Wolfe's Pd-catalyzed oxyarylation[5]



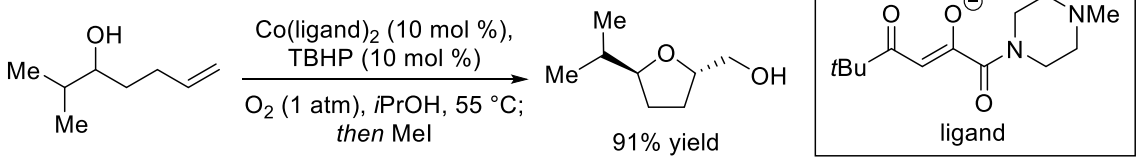
68% yield, >20:1 dr

(b) Waser's Pd-catalyzed oxyalkynylation[6a]

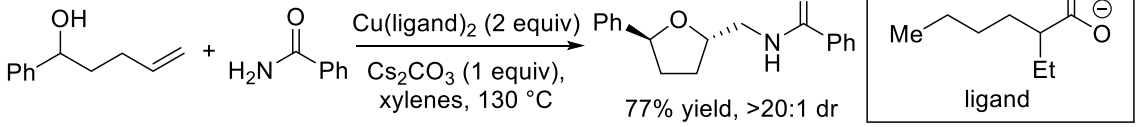


65% yield, >95:5 dr

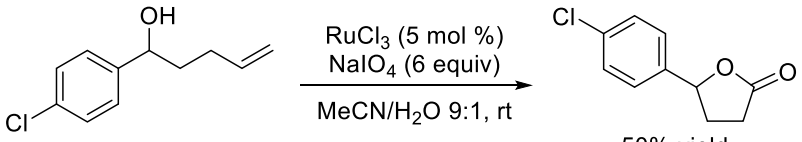
(c) Pagenkopf's Co-catalyzed oxyetherification[7a]



(d) Chemler's Cu-catalyzed aminoetherification[8]

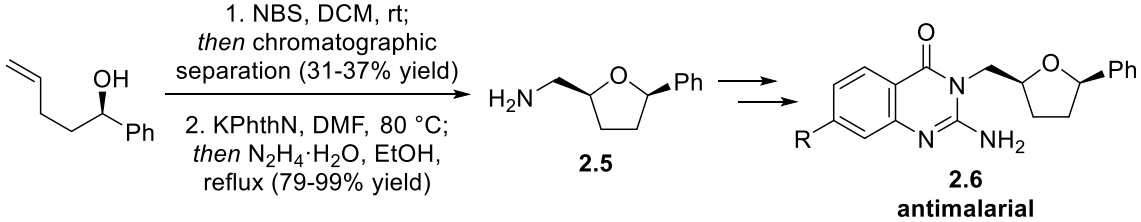


(e) Canney's oxidative lactonization[11]



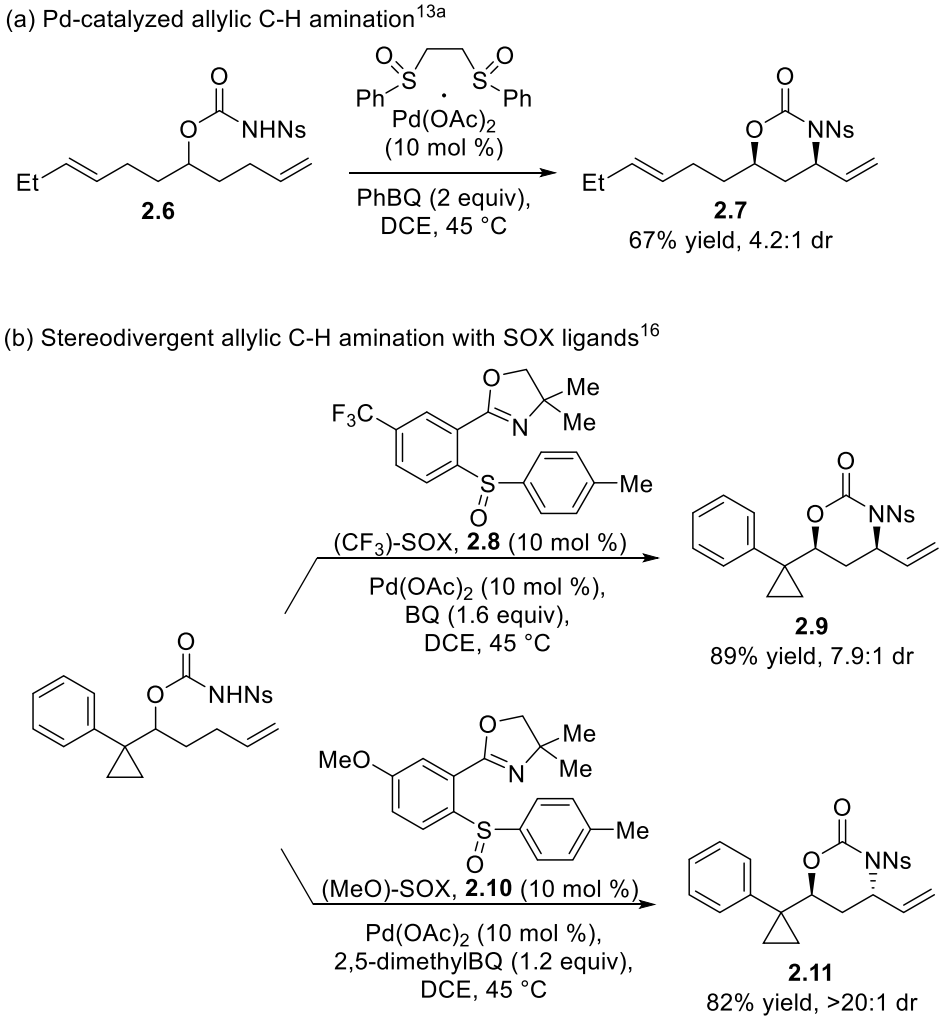
50% yield

(f) Jaudems and Jirgensons's synthesis of antimalarial plasmepsin inhibitors[12]



The laboratory of M. Christina White has found that the carbamates or sulfamates of γ-hydroxyl alkenes such as **2.6** could be utilized in the Pd-,[13] Fe-,[14] or Mn-catalyzed[15] C–H activation of the proximal allylic position to synthesize 1,3-amino alcohol motifs **2.7** (Scheme 2.4). Remarkably, they showed stereodivergent behavior with two different sulfoxide (SOX) ligands: the electron-deficient (CF_3)-SOX ligand **2.8** afforded the *syn*-1,3-

Scheme 2.4. White's allylic C-H amination



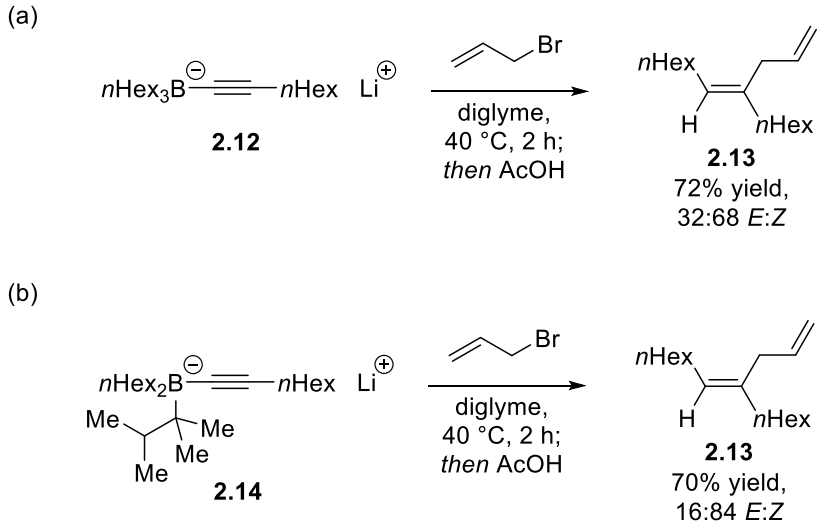
[13] (a) Rice, G. T.; White, M. C. *J. Am. Chem. Soc.* **2009**, *131*, 11707. (b) Qi, X.; Rice, G. T.; Lall, M. S.; Plummer, M. S.; White, M. C. *Tetrahedron* **2010**, *66*, 4816.
[14] Paradine, S. M.; White, M. C. *J. Am. Chem. Soc.* **2012**, *134*, 2036.
[15] Paradine, S. M.; Griffin, J. R.; Zhao, J.; Petronico, A. L.; Miller, S. M.; White, M. C. *Nat. Chem.* **2015**, *7*, 987.

amino alcohol motif **2.9** in high yield and diastereoselectivity, while the electron-rich (MeO)-SOX ligand **2.10** afforded the *anti*-1,3-amino alcohol **2.11** with comparable levels of yield and diastereoselectivity (Scheme 2.4b).[16]

2.2.2. Allylation of Organoboron "Ate" Complexes

Pelter and coworkers reported the earliest example of β-allylation of unsaturated organoboron "ate" complexes in which trialkylalkynylboron "ate" complexes such as **2.12** were treated with allyl bromide, followed by protodeborylation with AcOH, to afford trisubstituted alkenes **2.13** in moderate to excellent yields, albeit with low levels of diastereoselectivity (Scheme 2.5a).[17] Replacing one of the alkyl groups with a non-migrating thexyl group (**2.14**) resulted in improved diastereoselectivities (Scheme 2.5b). Deng and coworkers used palladium catalysts and allyl ethyl carbonates to facilitate alkyl group migration on alkynylboron "ate" complexes (Scheme 2.6a),[18] and twenty years later,

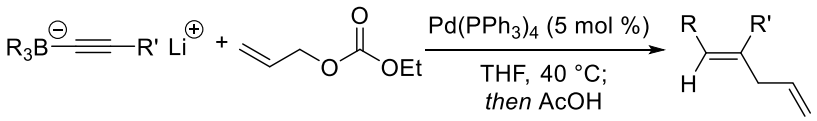
Scheme 2.5. Pelter's allylation of trialkylalkynylboron "ate" complexes[17]



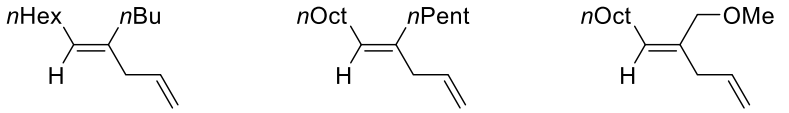
[16] Ma, R.; Young, J.; Promontorio, R.; Dannheim, F. M.; Pattillo, C. C.; White, M. C. *J. Am. Chem. Soc.* **2019**, *141*, 9468.
[17] Pelter, A.; Bentley, T. W.; Harrison, C. R.; Subrahmanyam, C.; Laub, R. J. *J. Chem. Soc. Perkin Trans. I* **1976**, 2419.
[18] Chen, Y.; Li, N.-S.; Deng, M.-Z. *Tetrahedron Lett.* **1990**, *31*, 2405.

Scheme 2.6. Pd-catalyzed allylation of alkynylboron "ate" complexes

(a) Deng's allylation of trialkylalkynylboron "ate" complexes[18]

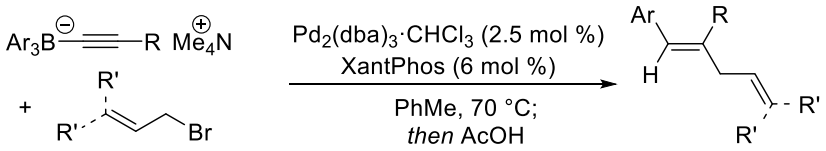


selected products:

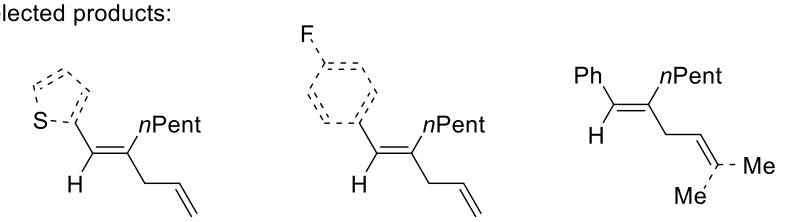


70% yield, 87:13 *E*:*Z* | 54% yield, 95:5 *E*:*Z* | 77% yield, 0:100 *E*:*Z*

(b) Murakami's allylation of triarylalkynylboron "ate" complexes[19]



selected products:



79% yield, 71:29 *E*:*Z* | 83% yield, 53:47 *E*:*Z* | 71% yield, 53:47 *E*:*Z*

Murakami and coworkers extended this reactivity to include aryl group migration (Scheme 2.6b).[19]

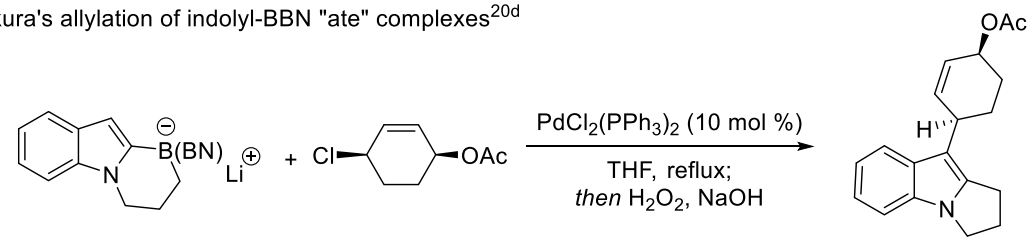
Although allyl electrophile-induced 1,2-metallate shifts of organoboron "ate" complexes with *sp*-hybridized migration termini are well-precedented, analogous examples with sp^2-hybridized migration termini are limited to 2-indolyl derivatives. As an example, the Ishikura group reported Pd(π-allyl)-induced 1,2-metallate shifts of

[19] Ishida, N.; Shinmoto, T.; Sawano, S.; Miura, T.; Murakami, M. *Bull. Chem. Soc. Jpn.* **2010**, *83*, 1380.

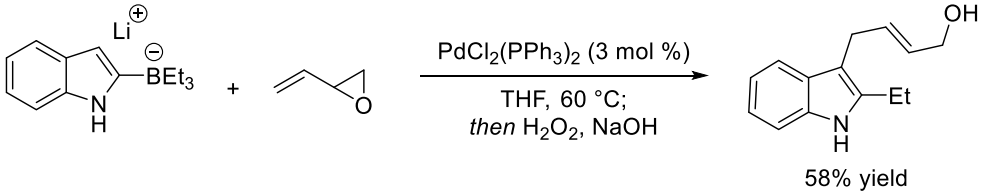
trialkylindolylboron "ate" complexes (Scheme 2.7a and b),[20] while the Ready group reported enantioselective variants of the same reaction using pinacol boron ester derivatives (Scheme 2.7c).[21]

Scheme 2.7. Pd-catalyzed allylation of 2-indolylboron "ate" complexes

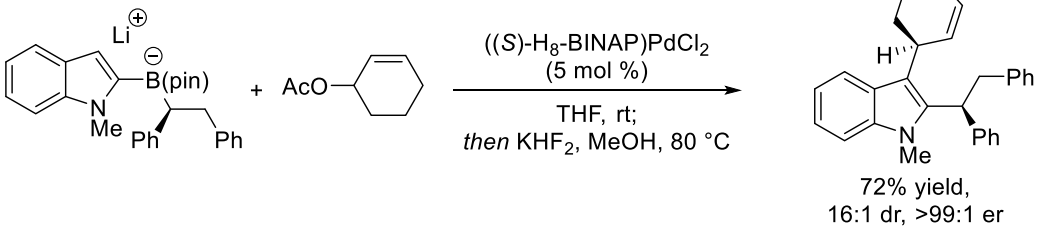
(a) Ishikura's allylation of indolyl-BBN "ate" complexes[20d]



(b) Ishikura's allylation of trialkylindolylboron "ate" complexes[20c]



(c) Ready's allylation of indolylboronic ester-derived "ate" complexes[21a]



[20] (a) Ishikura, M.; Terashima, M.; Okamura, K.; Date, T. *J. Chem. Soc., Chem. Commun.* **1991**, *20*, 1219. (b) Ishikura, M.; Agata, I. *Heterocycles* **1996**, *43*, 1591. (c) Ishikura, M.; Kato, H. *Tetrahedron* **2002**, *58*, 9827. (d) Ishikura, M.; Ida, W.; Yanada, K. *Tetrahedron* **2006**, *62*, 1015.

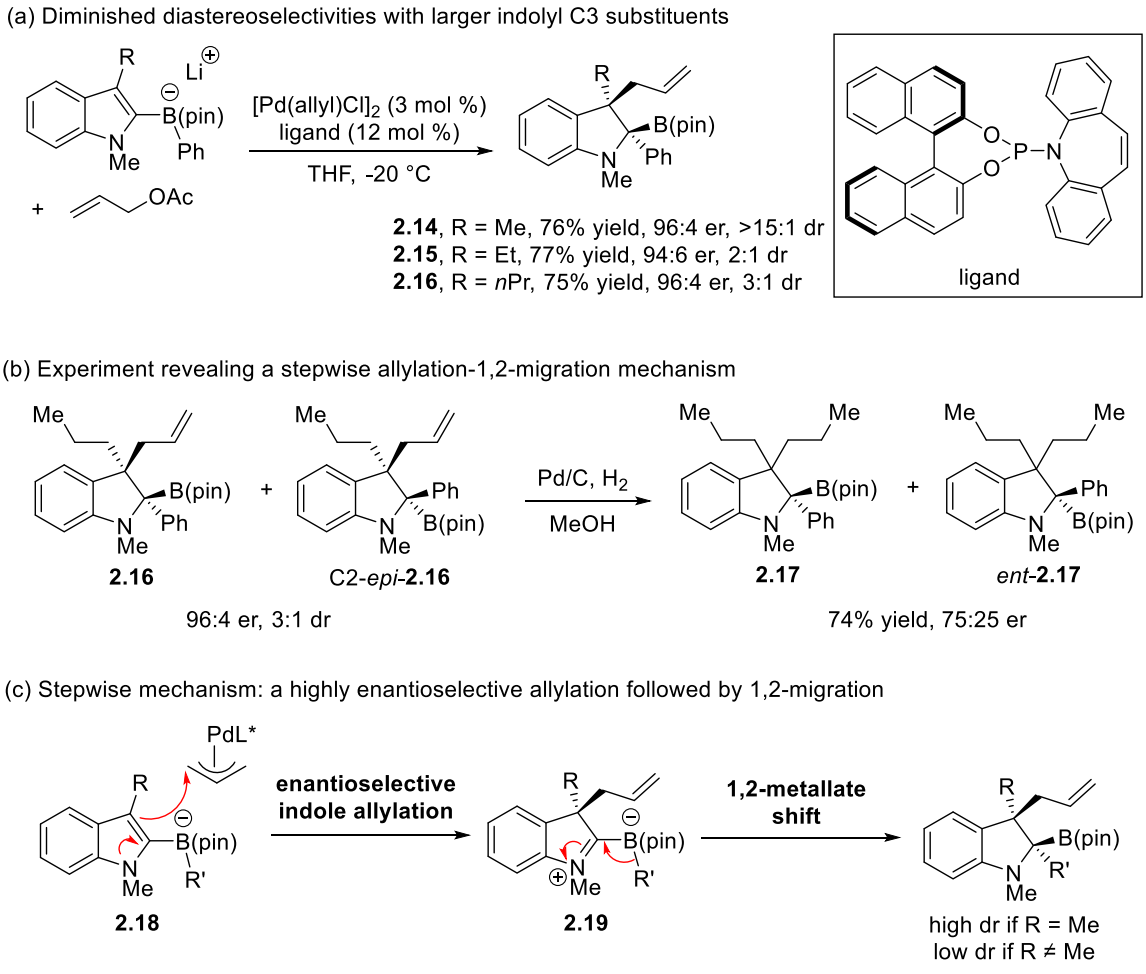
[21] (a) Panda, S.; Ready, J. M. *J. Am. Chem. Soc.* **2017**, *139*, 6038. (b) Panda, S.; Ready, J. M. *J. Am. Chem. Soc.* **2018**, *140*, 13242.

As stated in the introduction to this chapter, our attempts to engage non-indole-derived sp^2-hybridized migration termini such as olefins were met with failure. We speculated that the presence of the indole moiety in the examples by Ishikura and Ready was crucial to the success of those reactions. It was hypothesized that rather than a concerted 1,2-metallate shift triggered by electrophilic activation of the olefin by palladium, the indole first undergoes electrophilic allylation at the C3 position. The resulting iminium cation then triggers the 1,2-metallate shift from the boron "ate" at the C2 position. In other words, with more nucleophilic alkenes such as indoles, the allylation is mechanistically independent from the 1,2-metallate shift.

Indeed, the Ready group themselves proposes a concerted Pd-induced 1,2-metallate shift mechanism in their allylation of 2-indolylboron "ate" complexes.[21a] However, when they later expanded their Pd-catalyzed indole allylation reaction to synthesize enantioenriched quaternary centers using a phosphoramidite ligand, trends in the substrate scope caused them to doubt their initial mechanistic proposal.[21b] When they investigated substituents larger than a methyl group at the C3 position of the indole, they observed lower levels of diastereoselectivity, although the enantioselectivities of both diastereomers remained high (Scheme 2.8a, compare **2.14** vs. **2.15** and **2.16**). To probe the mechanism further, the *n*-propyl-bearing boronic ester product **2.16**, which was isolated with 96:4 er and 3:1 dr, was hydrogenated to give compound **2.17** as a pair of enantiomers bearing two *n*-propyl groups at the C3 position (Scheme 2.8b). This study shows that the pair of enantioenriched diastereomers **2.16** is epimeric at C2: hydrogenated compound **2.17** was isolated with 75:25 er, which is identical to the ratio of diastereomers for allyl compound **2.16**. Had **2.16** been epimeric at C3, the enantiomeric ratio of **2.17** should be *higher* than

96:4. These results are consistent with a stepwise mechanism in which a highly enantioselective Pd-catalyzed indole allylation (**2.18**) is followed by a 1,2-metallate shift (**2.19**): if R = Me, the faces of the iminium cation are well-differentiated and the migrating group adopts a position opposite to that of the allyl group; if R ≠ Me, steric discrimination between the R group and the allyl group is poorer, so 1,2-migration can occur on either face of the iminium (Scheme 2.8c).

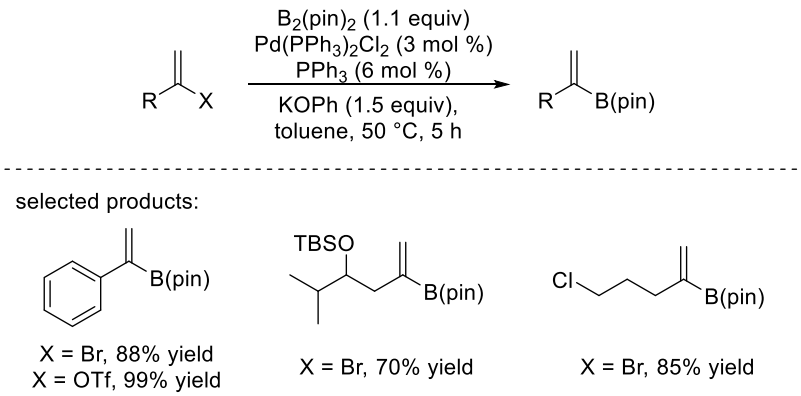
Scheme 2.8. Ready's allylation of indolylboronic ester-derived "ate" complexes to form quaternary stereogenic centers and mechanistic investigation[21b]



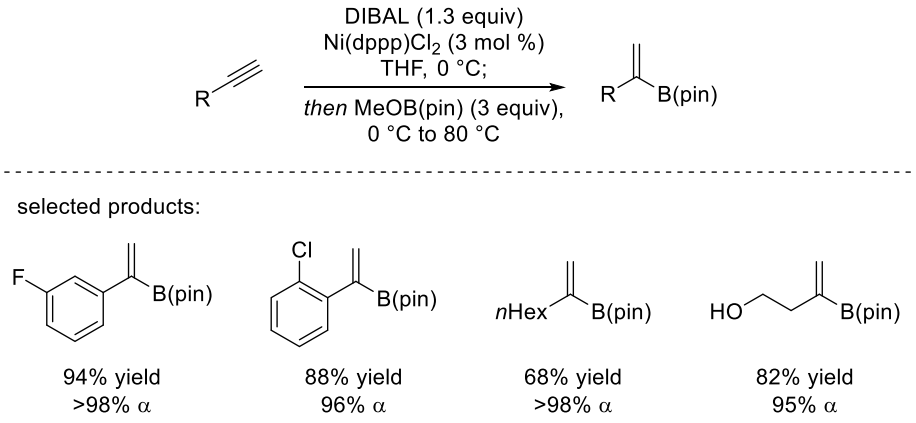
2.2.3. Previous Syntheses of 1,1-Disubstituted Boryl Alkenes

In 2002, Miyaura and coworkers reported the Pd-catalyzed borylation of C(sp^2) (pseudo)halides (Scheme 2.9),[22] an elaboration on a reaction first reported by Eastwood.[23] An alternative to the Miyaura borylation is the Markovnikov hydroboration of terminal alkynes. Hoveyda and coworkers reported a Ni-catalyzed hydroalumination of alkynes using DIBAL, followed by borylation with methoxyB(pin) (Scheme 2.10).[24]

Scheme 2.9. Miyaura's borylation of alkenyl bromides and triflates[22]



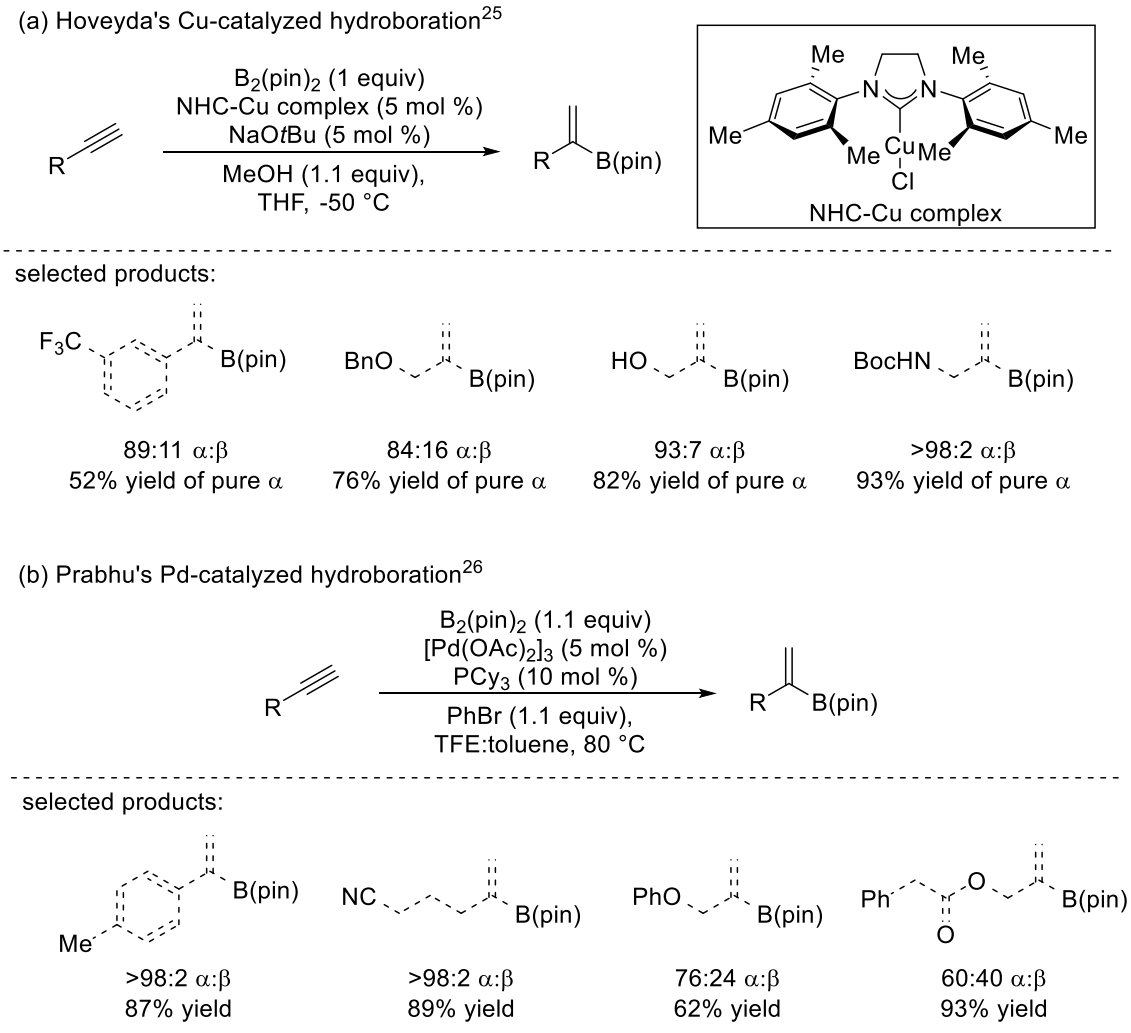
Scheme 2.10. Hoveyda's Ni-catalyzed hydroalumination-borylation of terminal alkynes[24]



[22] Takagi, J.; Takahashi, K.; Ishiyama, T.; Miyaura, N. *J. Am. Chem. Soc.* **2002**, *124*, 8001.
[23] Eastwood, P. R. *Tetrahedron Lett.* **2000**, *41*, 3705.
[24] Gao, F.; Hoveyda, A. H. *J. Am. Chem. Soc.* **2010**, *132*, 10961.

Methods have also been developed for the direct Markovnikov hydroboration of terminal alkynes using transition metal catalysis. The Hoveyda group reported a borylation protocol with $B_2(pin)_2$ catalyzed by an *N*-heterocyclic carbene (NHC)-Cu complex (Scheme 2.11a).[25] Prabhu and coworkers developed a Pd-catalyzed variant and found that employing PCy_3 as the ligand generally afforded Markovnikov products (Scheme 2.11b), while employing an NHC ligand afforded anti-Markovnikov products.[26] The Hoveyda

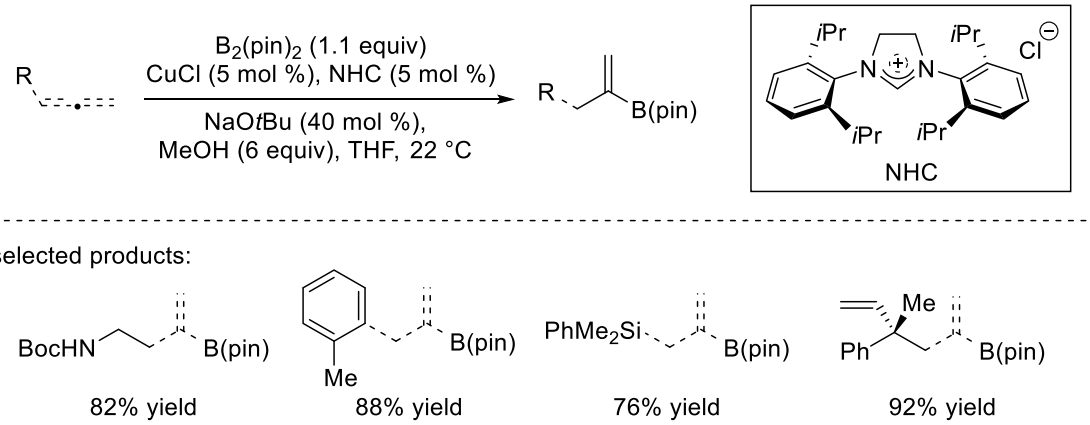
Scheme 2.11. Transition metal-catalyzed hydroboration of terminal alkynes



[25] Jang, H.; Zhugralin, A. R.; Lee, Y.; Hoveyda, A. H. *J. Am. Chem. Soc.* **2011**, *133*, 7859.
[26] Ojha, D. P.; Prabhu, K. R. *Org. Lett.* **2016**, *18*, 432.

group similarly developed a Cu-catalyzed hydroboration of monosubstituted allenes, affording a variety of products in good yields (Scheme 2.12).[27]

Scheme 2.12. Hoveyda's Cu-catalyzed hydroboration of monosubstituted allenes[27]

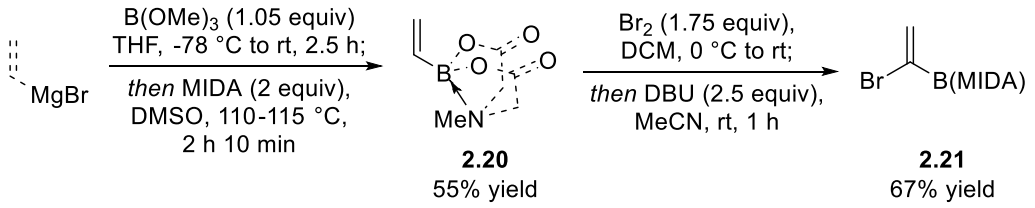


Burke and coworkers invented (1-bromovinyl)-MIDA boronate **2.21**, a versatile reagent to access 1,1-disubstituted alkenyl boronates.[28] Synthesis of this reagent began with nucleophilic attack of trimethylborate by vinylmagnesium bromide followed by transesterification with *N*-methyliminodiacetic acid (MIDA) to give vinyl-MIDA boronate **2.20**; treatment of **2.20** with molecular bromine followed by elimination gave **2.21** in good yield over two steps (Scheme 2.13a). The α-bromine atom could then be coupled to a number of organoboronic acids under standard Suzuki–Miyaura reaction conditions (Scheme 2.13b).

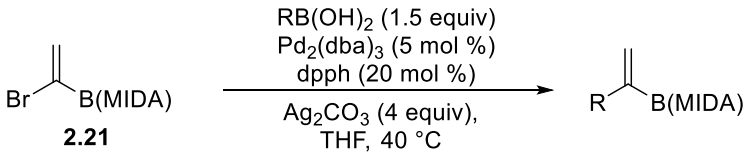
[27] Meng, F.; Jung, B.; Haeffner, F.; Hoveyda, A. H. *Org. Lett.* **2013**, *15*, 4.
[28] (45) Woerly, E. M.; Miller, J. E.; Burke, M. D. *Tetrahedron* **2013**, *69*, 7732.

Scheme 2.13. Burke's synthesis and application of (1-bromovinyl)-MIDA boronate[28]

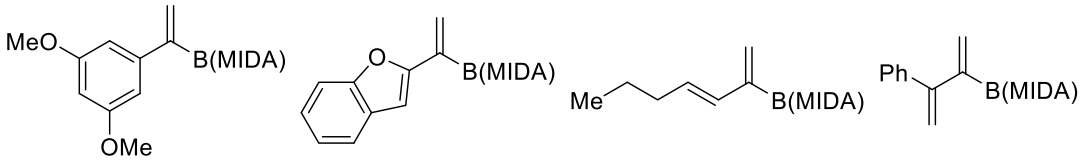
(a) Synthesis of (1-bromovinyl)-MIDA boronate **2.21**



(b) Suzuki-Miyaura cross-coupling of (1-bromovinyl)-MIDA boronate **2.21**



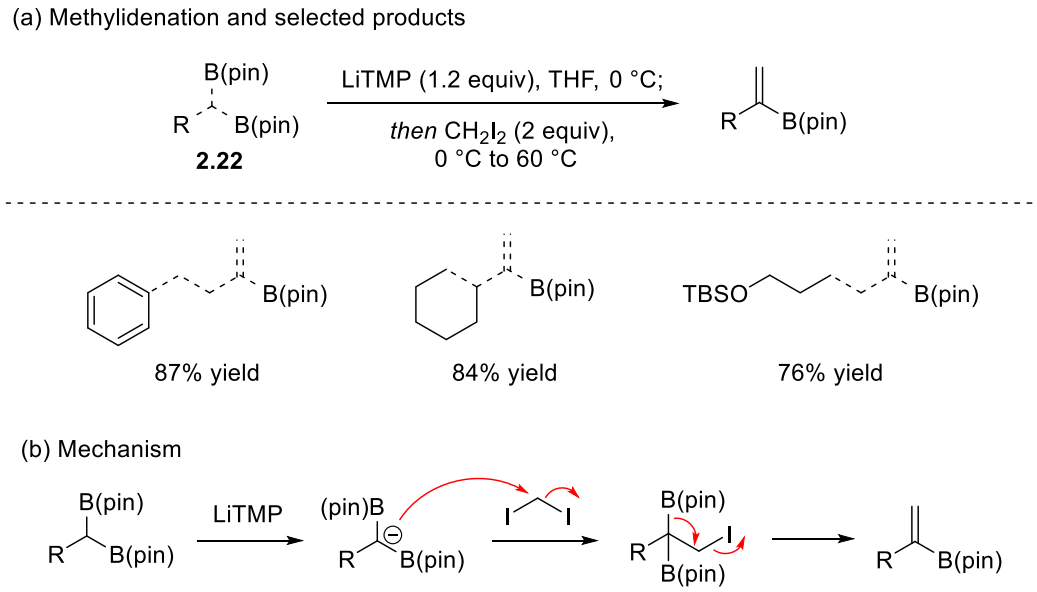
selected products:



The Morken group developed a boron–Wittig olefination of *gem*-bisboronates **2.22** to synthesize a variety of alkenyl boronates.[29] While alkyl, alkenyl, and alkynyl aldehydes gave *E*-trisubstituted alkenyl boronates, employing methylene iodide (CH_2I_2) as a formaldehyde equivalent gave 1,1-disubstituted alkenyl boronates (Scheme 2.14a). With respect to the mechanism, lithium tetramethylpiperidide (LiTMP) deprotonates the methine hydrogen α to both boron atoms. The resulting anion attacks CH_2I_2 in an S_N2 fashion followed by boron–iodine elimination to afford the alkenyl boronate product (Scheme 2.14b).

[29] Coombs, J. R.; Zhang, L.; Morken, J. P. *Org. Lett.* **2015**, *17*, 1708.

Scheme 2.14. Morken's boron-Wittig methylidenation of *gem*-diboronates[29]



Shortly after we reported our present Pd-catalyzed vinylidenation reaction, Aggarwal and coworkers reported their own vinylidenation reaction of organoboronic esters. Rather than employing transition metal catalysis, their reaction design involved the use of lithiated silyl epoxide **2.23** to form "ate" complex **2.24**, which would then undergo a 1,2-metallate shift to open the epoxide; the oxyanion and silyl groups on **2.25** would then undergo a Peterson-type silcon–oxygen elimination to forge the new carbon–carbon double bond (Scheme 2.15a).[30] Treating trimethylsilyl epoxide **2.26** with lithiation conditions reported previously by their group,[31] followed by addition of the organoboronic ester, gave a variety of vinylidenation products (Scheme 2.15b). Primary boronic esters such as those bearing sensitive functional groups like an azide were homologated successfully (**2.27**). Secondary (**2.28**) and tertiary boronic esters (**2.29** amd **2.30**) also fared well in the reaction;

[30] Fordham, J. M.; Grayson, M. N.; Aggarwal, V. K. *Angew. Chem. Int. Ed.* **2019**, *58*, 15268.
[31] Florio, S.; Aggarwal, V.; Salomone, A. *Org. Lett.* **2004**, *6*, 4191.

notably, compounds with defined relative stereochemical configurations such as **2.28** and **2.29** reacted with complete retention of configuration.

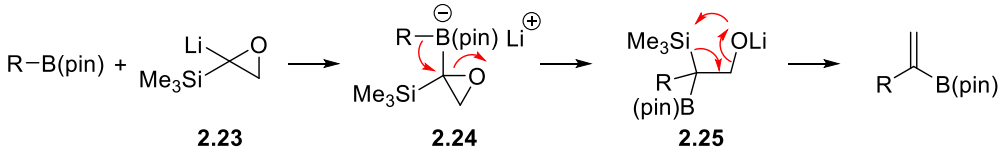
Examining the scope of aryl boronic esters in the Aggarwal vinylidenation revealed an interesting trend in chemoselectivity, namely that the electron-rich *p*-methoxyphenyl gave exclusively the homologated boronic ester **2.31**, whereas the electron-poor *p*-trifluoromethylphenyl yielded exclusively the 1,1-disubstituted alkenyl silane **2.36** with none of the expected boronic ester **2.35**. An arene of intermediate electron density such as *p*-chlorophenyl gave a mixture of alkenyl boronic ester **2.33** and alkenyl silane **2.34** products. Attempting the vinylidene homologation of either *trans*-1,2-disubstituted or 1,1-disubstituted alkenyl boronic esters gave exclusively alkenyl silane products (**2.38** and **2.40**).

One advantage the Aggarwal vinylidenation has over our method is that it accommodates more substituted alkenyl boronic esters. For example, the vinylidene homologation reaction of 2-phenylethylB(pin) **2.41** with *trans*-alkyl(trimethylsilyl) epoxides **2.42** and **2.43** gave *E*-trisubstituted alkenyl boronic esters **2.44** and **2.45**, respectively, with high diastereoselectivity, which was confirmed by NOESY (Scheme 2.15c). The Aggarwal group applied their method to the synthesis of the proposed structure of machillene **2.48**, a cytotoxic natural product isolated from the wood stem of the Taiwanese flowering plant *Machilus zuihoensis*.[32] Performing their vinylidenation on enantioenriched 1,3-bisboronate **2.46** gave the doubly-homologated compound **2.47**. Following a four-step sequence involving a Pd-catalyzed coupling of both boronic ester

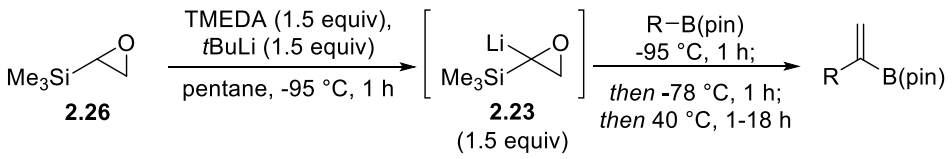
[32] Cheng, M.-J.; Tsai, I.-L.; Lee, S.-J.; Jayaprakasam, B.; Chen, I.-S. *Phytochemistry* **2005**, *66*, 1180.

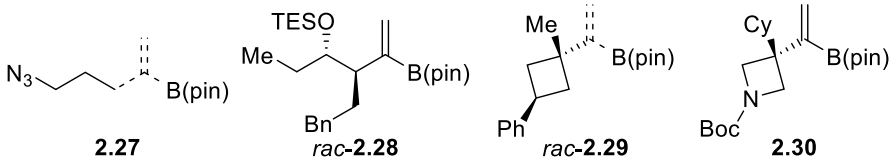
Scheme 2.15. Aggarwal's vinylidenation of organoboronic esters[30]

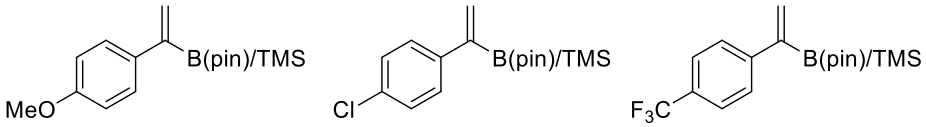
(a) Reaction design and mechanism



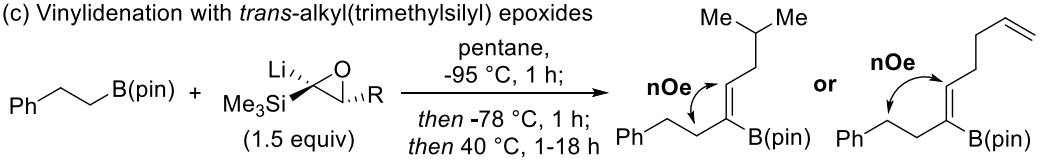
(b) Vinylidenation and selected products



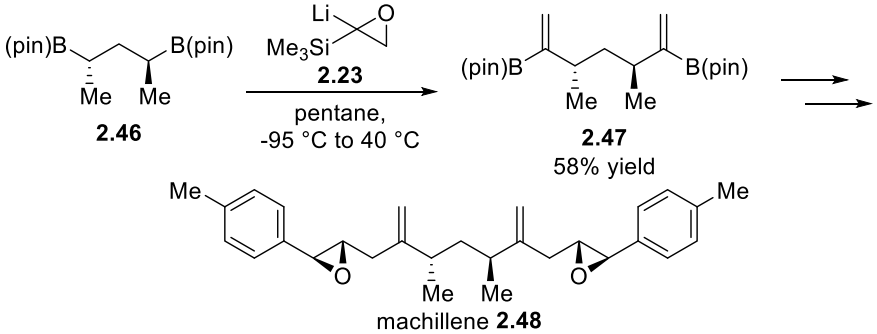




(c) Vinylidenation with *trans*-alkyl(trimethylsilyl) epoxides



(d) Application to the total synthesis of machillene



groups with a cinnamyl acetate derivative,[33] two sequential Sharpless dihydroxylations,[34] and epoxidation of both vicinal diol groups,[35] afforded **2.48** in 5% overall yield over six steps (Scheme 2.15d). Although the spectra of synthetic **2.48** did not match those of the isolated natural product, the synthesis was nevertheless a demonstration of their method's synthetic utility.

2.3. The Palladium-Catalyzed Vinylidenation of Organoboron "Ate" Complexes

2.3.1. Discovery of the Vinylidenation Reaction

Several attempts were made to promote the conjunctive cross-coupling of organoboron "ate" complexes with allyl electrophiles. Standard conjunctive cross-coupling conditions with $Pd(OAc)_2$ and MandyPhos failed to give any of the desired product with either allyl acetate or substituted electrophiles such as cinnamyl acetate. Surveying other ligands or other metals such as nickel,[36] copper,[37] and iridium[38] were likewise met with failure or low amounts of the desired product. In all of these cases, conversion of the "ate" complex back to the original organoboronic ester was observed, as was direct cross-coupling between one or both groups on the boron "ate" and the allyl electrophile.

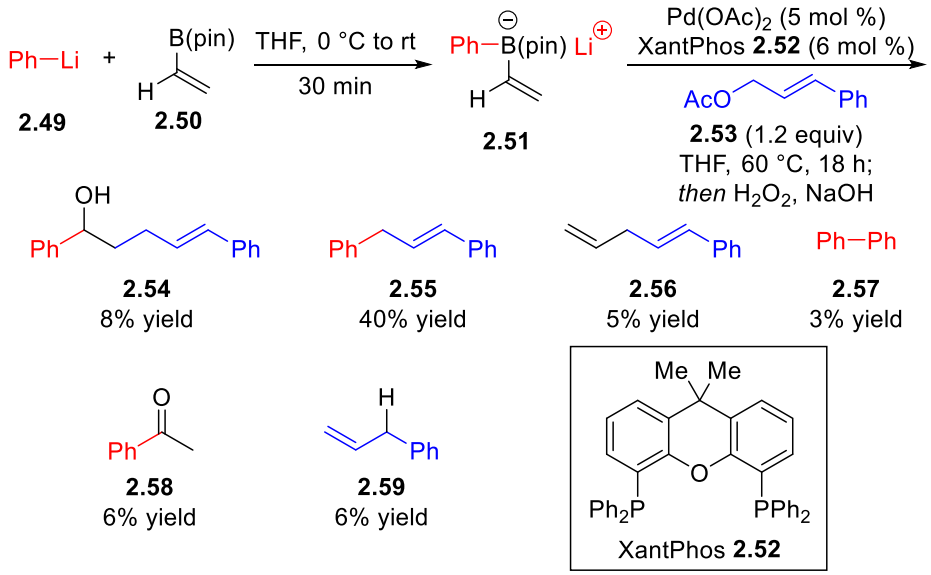
---

[33] Ortar, G. *Tetrahedron Lett.* **2003**, *44*, 4311.
[34] Kolb, H. C.; VanNieuwenhze, M. S.; Sharpless, K. B. *Chem. Rev.* **1994**, *94*, 2483.
[35] Kolb, H. C.; Sharpless, K. B. *Tetrahedron* **1992**, *48*, 10515.
[36] (a) Didiuk, M. T.; Morken, J. P.; Hoveyda, A. H. *J. Am. Chem. Soc.* **1995**, *117*, 7273. (b) Chung, K.-G.; Miyake, Y.; Uemura, S. *J. Chem. Soc. Perkin 1* **2000**, *1*, 15. (c) Kita, Y.; Kavthe, R. D.; Oda, H.; Mashima, K. *Angew. Chem. Int. Ed.* **2016**, *55*, 1098. (d) Ngamnithiporn, A.; Jette, C. I.; Bachman, S.; Virgil, S. C.; Stoltz, B. M. *Chem. Sci.* **2018**, *9*, 2547.
[37] (a) Malda, H.; van Zijl, A. W.; Arnold, L. A.; Feringa, B. L. *Org. Lett.* **2001**, *3*, 1169. (b) Van Veldhuizen, J. J.; Campbell, J. E.; Giudici, R. E.; Hoveyda, A. H. *J. Am. Chem. Soc.* **2005**, *127*, 6877. (c) Yoshikai, N.; Zhang, S.-L.; Nakamura, E. *J. Am. Chem. Soc.* **2008**, *130*, 12862. (d) Shi, Y.; Jung, B.; Torker, S.; Hoveyda, A. H. *J. Am. Chem. Soc.* **2015**, *137*, 8948. (e) You, H.; Rideau, E.; Sidera, M.; Fletcher, S. P. *Nature* **2015**, *517*, 351.
[38] (a) Takeuchi, R.; Kashio, M. *Angew. Chem. Int. Ed. Engl.* **1997**, *36*, 263. (b) Miyabe, H.; Takemoto, Y. *Synlett* **2005**, *11*, 1641. (c) Hartwig, J. F.; Stanley, L. M. *Acc. Chem. Res.* **2010**, *43*, 1461. (d) Hethcox, J. C.; Shockley, S. E.; Stoltz, B. M. *ACS Catal.* **2016**, *6*, 6207. (e) Qu, J.; Helmchen, G. *Acc. Chem. Res.* **2017**, *50*, 2539. (f) Cheng, Q.; Tu, H.-F.; Zheng, C.; Qu, J.-P.; Helmchen, G.; You, S.-L. *Chem. Rev.* **2019**, *119*, 1855.

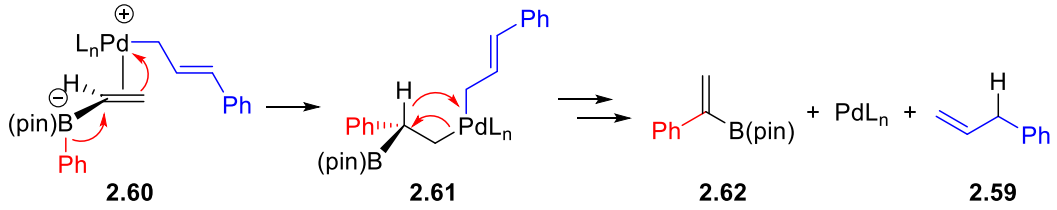
After careful analysis of the products of one of these low yielding reactions, namely the reaction of phenyl(vinyl)B(pin) "ate" complex **2.51**, formed from phenyllithium **2.49** and vinylB(pin) **2.50**, with cinnamyl acetate **2.53** catalyzed by $Pd(OAc)_2$ and XantPhos **2.52**, we identified two unexpected products that gave us insight into the mechanism of the reaction (Scheme 2.16a). In addition to the desired conjunctive cross-coupling product **2.54** (8% yield), the direct cross-coupling products **2.55** and **2.56** (40% and 5% yield, respectively), and a small amount of biphenyl **2.57**, acetophenone **2.58** and allyl benzene **2.59** were formed (6% yield each). The fact that these latter two compounds were formed in equal amounts indicates that following Pd-induced 1,2-metallate shift of **2.60** and

Scheme 2.16. Discovery of the vinylidenation of organoboronic esters

(a) Observation of β-hydride elimination products in the Pd/XantPhos-catalyzed conjunctive cross-coupling with cinnamyl acetate



(b) Proposed Pd(π-allyl)-induced 1,2-metallate shift/β-hydride elimination mechanism



formation of the carbon–palladium σ-bond to give **2.61**, a β-hydride elimination event occurred rather than reductive elimination to give 1-phenylvinylB(pin) **2.62** and allyl benzene, and **2.62** would be converted to acetophenone upon oxidation (Scheme 2.16b).

Since the results from this experiment suggested that Pd(π-allyl)-promoted β-hydride elimination[39] was a possible pathway following Pd-induced 1,2-metallate rearrangement, we decided to undertake a ligand survey in search of conditions that would favor this mechanism as the 1,1-disubstituted alkenyl boronate products are themselves valuable synthetic intermediates. We hypothesized that monodentate phosphine ligands would favor the desired reactivity over bidentate ligands as π-allyl ligands in their η^3 configuration on palladium would occupy a coordination site required for binding by the boron "ate."[40]

2.3.2. Optimization

We commenced our optimization studies by conducting a ligand survey using phenylB(pin) **2.63**, vinylmagnesium chloride, NaOTf, and allyl acetate **2.64** (Table 2.1). We found that, indeed, monodentate phosphine ligands provided higher yields of the vinylidenation products compared to bidentate ligands (Table 2.1, entries 1 and 2). The ratio of vinylidenation product to recovered phenylB(pin) starting material generally increases with increasing cone angle of the phosphine ligand (Table 2.1, entries 3–13).[41] Although $PPhCy_2$ gave the best yields in this series (Table 2.1, entry 11), we settled on PCy_3 as it is less expensive and gives similar results to $PPhCy_2$ (Table 2.1, entry 13).

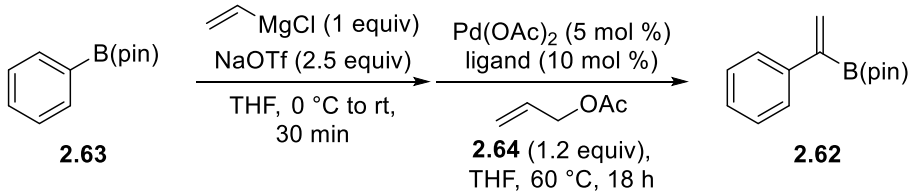
---

[39] (a) Shvo, Y.; Arisha, A. H. I. *J. Org. Chem.* **1998**, *63*, 5640. (b) Chen, Y.; Romaire, J. P.; Newhouse, T. R. *J. Am. Chem. Soc.* **2015**, *137*, 5875. (c) Chen, Y.; Turlik, A.; Newhouse, T. R. *J. Am. Chem. Soc.* **2016**, *138*, 1166. (d) Chen, Y.; Huang, D.; Zhao, Y.; Newhouse, T. R. *Angew. Chem. Int. Ed.* **2017**, *56*, 8258. (e) Huang, D.; Zhao, Y.; Newhouse, T. R. *Org. Lett.* **2018**, *20*, 684. (f) Murray, S. A.; Luc, E. C. M.; Meek, S. J. *Org. Lett.* **2018**, *20*, 469.

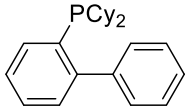
[40] Minami, I.; Takahashi, K.; Shimizu, I.; Kimura, T.; Tsuji, J. Tetrahedron **1986**, *42*, 2971.

[41] Tolman, C. A. *Chem. Rev.* **1977**, *77*, 313.

Table 2.1. The effect of ligands on the vinylidenation of phenylB(pin)[a]



2.63 **2.62**

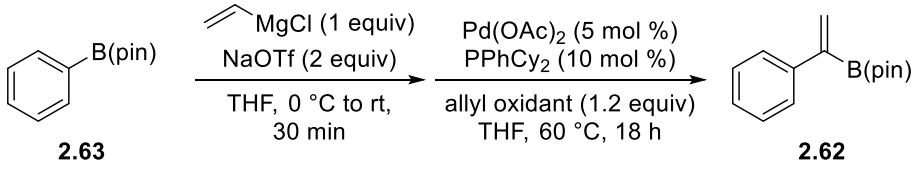
entry	ligand	cone angle (°)[74]	yield of product **2.62** (%)[b]	yield of starting material **2.63** (%)[b]
1	XantPhos **2.52**[c]	N/A	5	37
2	dppe[c]	125	0	72
3	PMe_2Ph	122	16	62
4	$PMePh_2$	136	24	61
5	PPh_3	145	49	39
6	$P(i\text{Pr})_3$	160	52	34
7	$PPh(t\text{Bu})_2$	170	40	44
8	$PPh_2(o\text{-Tol})$	---	41	39
9	$P(o\text{-Tol})_3$	194	35	46
10	PPh_2Cy	---	54	36
11	$PPhCy_2$	---	74 (61)	23
12	 CyJohnPhos	---	59	28
13	PCy_3	170	65 (58)	28 (20)
14[d]	PCy_3	170	70 (65)	25 (15)
15[d,e]	PCy_3	170	(72)	(15)
16[d,e,f]	**PCy_3**	**170**	**(76)**	**(17)**
17[d,e,g]	PCy_3	170	(67)	(19)

[a]Reactions conducted at 0.1 *M*. [b]Yields determined by ^{1}H NMR of the crude reaction mixture with 1,1,2,2-tetrachloroethane as an internal standard. Yields in parentheses represent isolated yields. [c]6 mol % of ligand used. [d]1.2 equiv of vinylmagnesium chloride used; reaction time = 1 h. [e]3 equiv of NaOTf used. [f]2.5 mol % of $Pd(OAc)_2$ and 5 mol % of PCy_3 used. [g]1 mol % of $Pd(OAc)_2$ and 2 mol % of PCy_3 used.

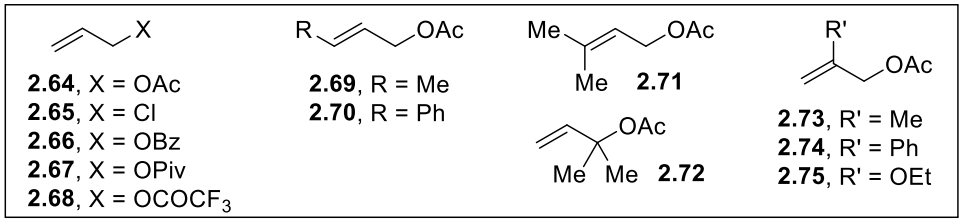
Further modifications were made by making minor changes to the equivalents of vinylmagnesium chloride and NaOTf, lowering the catalyst loading to 2.5 mol %, and shortening the reaction time from 18 hours to one hour (Table 2.1, entry 16).

We were also curious about the effect of the allyl oxidant on the reaction (Table 2.2). The nature of the leaving group did not significantly affect the reactivity (Table 2.2, entries 1–6). However, electrophiles with substituents at the position γ to the leaving group such as one or two methyl groups (**2.69** and **2.71**) or a phenyl group (**2.70**) diminished the yield of the reaction (Table 2.2, entries 7–9). In order to exclude the possibility of a more hindered S_N2' oxidative addition of Pd onto the more substituted γ-position of the allyl

Table 2.2. The effect of allyl oxidants on the vinylidenation of phenylB(pin)[a]



2.63 **2.62**



2.64, X = OAc
2.65, X = Cl
2.66, X = OBz
2.67, X = OPiv
2.68, X = $OCOCF_3$

2.69, R = Me
2.70, R = Ph

2.71

2.72

2.73, R' = Me
2.74, R' = Ph
2.75, R' = OEt

entry	allyl oxidant	yield of product **2.62** (%)[b]	yield of starting material **2.63** (%)[b]
1	**2.64**	66	27
2[c]	**2.64**	74 (61)	23
3	**2.65**	46	18
4	**2.66**	66	25
5	**2.67**	58	26
6	**2.68**	(50)	(14)
7	**2.69**	(34)	(19)
8	**2.70**	(28)	(43)
9	**2.71**	14	73
10	**2.72**	22	42
11	**2.73**	(52)	(16)
12	**2.74**	(57)	(19)
13	**2.75**	(60)	(19)

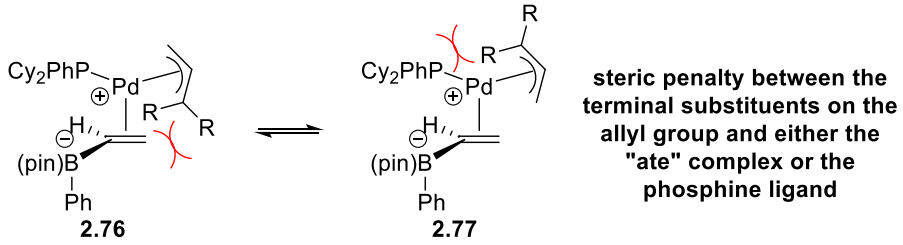
[a]Reactions conducted at 0.1 *M*. [b]Yields determined by ^{1}H NMR of the crude reaction mixture with 1,1,2,2-tetrachloroethane as an internal standard. Yields in parentheses represent isolated yields. [c]2.5 equiv of NaOTf used.

group, we synthesized α,α-dimethyl allyl acetate **2.72** and used it in the reaction. This oxidant would give the same Pd(π-allyl) complex as γ,γ-dimethyl allyl acetate **2.71** via a less hindered S_N2' oxidative addition. We found that **2.71** and **2.72** behaved similarly (Table 2.2, entries 9 and 10), showing that the nature of the oxidative addition is not responsible for the low yields when γ-substituted allyl oxidants are used. In contrast, having substituents at the β-position to the acetate leaving group did not significantly affect the yield of the reaction (Table 2.2, entries 11–13).

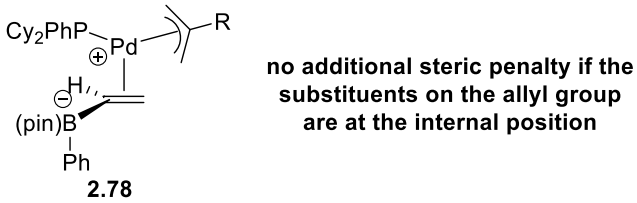
We hypothesized that the vinylidenation reaction is governed by steric interactions and that substituents on the allyl moiety of the $[(\eta^3\text{-allyl})Pd(PR_3)]^+$ complex could inhibit binding between the boron "ate" and the cationic palladium center. As shown in Scheme 2.17a, having substituents at either the α- or γ-positions on the allyl oxidant would lead to increased steric penalty with either the "ate" complex (**2.76**) or the phosphine ligand (**2.77**). However, β-substituents would not interact with either the "ate" complex or the phosphine

Scheme 2.17. Proposed effect of allyl substituents on organoboron "ate" olefin binding to Pd

(a) Substituents at the α- or γ-positions of the allyl oxidant



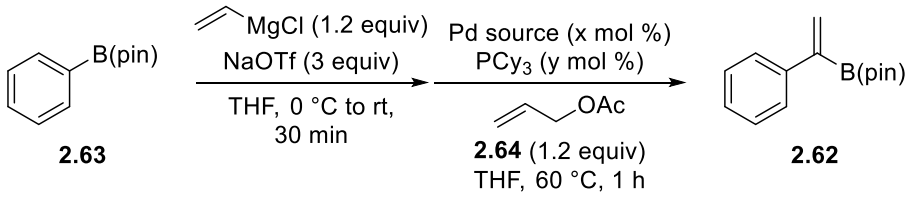
(b) Substituents at the β-position of the allyl oxidant



in any significant way, which explains why β-substituted allyl oxidants behave similarly to allyl acetate **2.64** (Scheme 2.17b).

We conducted additional experiments to investigate the effect of different palladium sources on the vinylidenation reaction of phenylB(pin) with PCy_3 as the ligand. $Pd(OAc)_2$ was found to be the best palladium source at 2.5 mol % catalyst loading (Table 2.3, entry 1). $Pd(P^tBu_3)_2$, $Pd_2(dba)_3$, and $[PdCl(allyl)]_2$ gave significantly lower yields (Table 2.3, entries 4–6).

Table 2.3. The effect of Pd sources on the vinylidenation of phenylB(pin)[a]



2.63 **2.62**

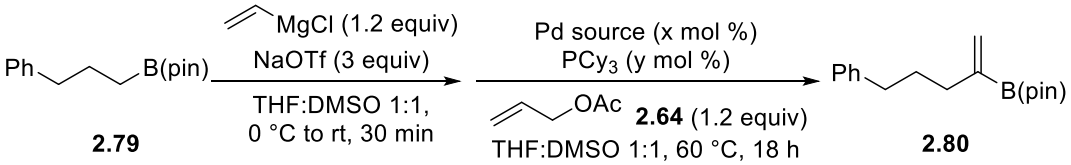
entry	Pd source	x : y	yield of product **2.62** (%)[b]	yield of starting material **2.63** (%)[b]
1	**$Pd(OAc)_2$**	**2.5 : 5**	**76**	**17**
2	$Pd(OAc)_2$	5 : 10	72	15
3	$Pd(OAc)_2$	1 : 2	67	19
4	$Pd(P^tBu_3)_2$	5 : 10	14	64
5	$Pd_2(dba)_3$	2.5 : 10	22	61
6	$[PdCl(allyl)]_2$	2.5 : 10	19	56

[a]Reactions conducted at 0.1 *M*. [b]Yields represent isolated yields.

When optimizing the reaction to encompass aliphatic migrating groups, 3-phenylpropylB(pin) **2.79** was used as a model substrate along with vinylmagnesium chloride. We used a 1:1 THF:DMSO solvent system and extended the reaction time to 18 hours, as in a previous study, we found that DMSO stabilizes alkyl(vinyl)B(pin) "ate" complexes generated from Grignard reagents, albeit at the price of retarding the rate of

conjunctive cross-coupling.[42] We found that 10% Pd loadings were required to give yields greater than 50% (Table 2.4 entry 1 vs. entries 2–5). The best conditions for the vinylidene homologation of aliphatic boronic esters used 5 mol % $Pd_2(dba)_3$ and 20 mol % PCy_3 (Table 2.4, entry 5). Attempts to change the Pd:ligand ratio and/or lower the catalyst loading resulted in inferior yields (Table 2.4 entries 6–8).

Table 2.4. The effect of Pd sources on the vinylidenation of 3-phenylpropylB(pin)[a]



2.79 **2.80**

entry	Pd source	x : y	yield of product **2.80** (%)[b]
1	$Pd(OAc)_2$	5 : 10	48
2	$Pd(OAc)_2$	10 : 20	62
3	$Pd(P^tBu_3)_2$	10 : 20	50
4	$[PdCl(allyl)]_2$	5 : 20	57
5	**$Pd_2(dba)_3$**	**5 : 20**	**70**
6	$Pd_2(dba)_3$	5 : 10	52
7	$Pd_2(dba)_3$	2.5 : 10	52
8	$Pd_2(dba)_3$	2.5 : 5	34

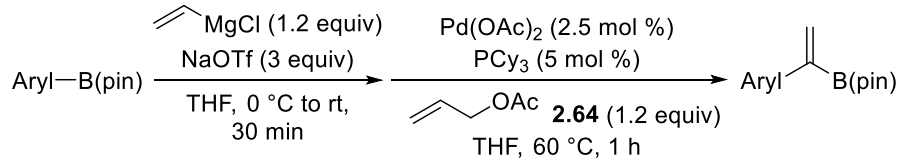
[a]Reactions conducted at 0.1 *M*. [b]Yields represent isolated yields.

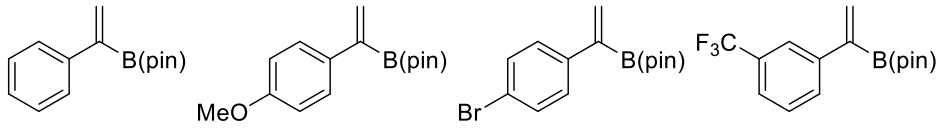
2.3.3. Substrate Scope and Demonstration of Synthetic Utility

Using the optimized conditions for phenylB(pin) **2.63** described in Table 2.3, entry 1, we tested the scope of the vinylidenation reaction with other aryl migrating groups. As shown in Scheme 2.18, *p*-methoxyphenyl **2.81** and *p*-bromophenyl **2.82** migrating groups performed well under these reaction conditions, although the reaction with *m*-trifluoromethylphenylB(pin) required three hours for full conversion to **2.83**.

[42] Lovinger, G. J.; Aparece, M. D.; Morken, J. P. *J. Am. Chem. Soc.* **2017**, *139*, 3153.

Scheme 2.18. Vinylidenation of aryl boronic esters with vinylmagnesium chloride[a]

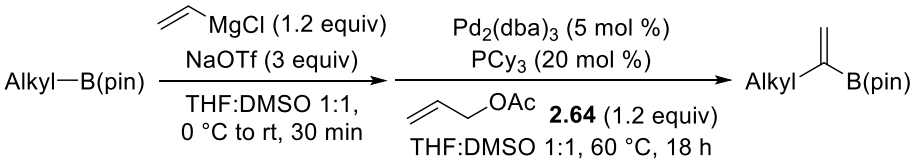


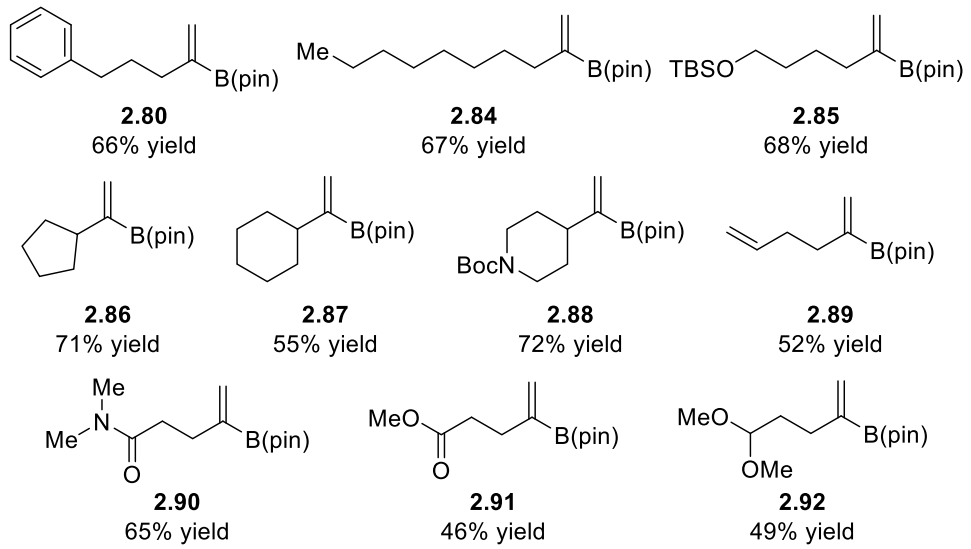


2.62 74% yield; **2.81** 66% yield; **2.82** 59% yield; **2.83** 54% yield[b]

[a]Reactions conducted at 0.1 *M*. Yields represent isolated yields and are the average of two trials.
[b]Reaction time = 3 h.

Scheme 2.19. Vinylidenation of alkyl boronic esters with vinylmagnesium chloride[a]





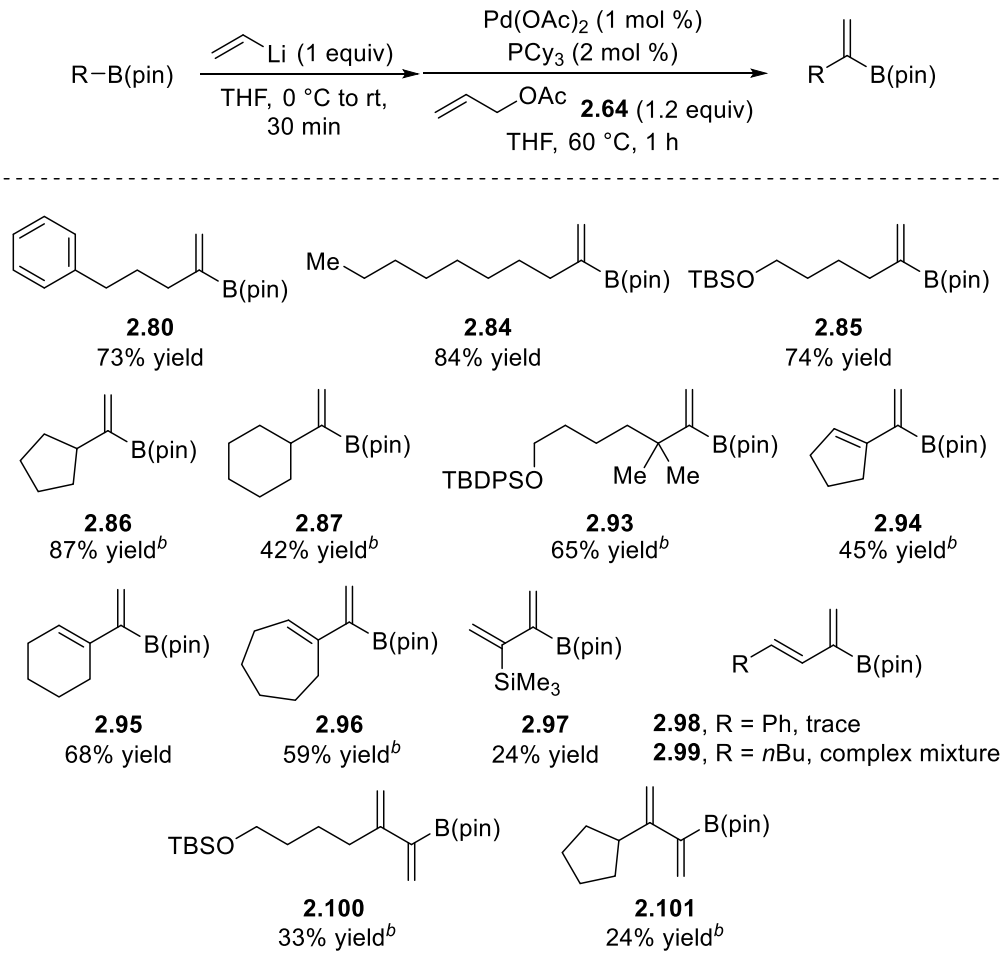
2.80 66% yield; **2.84** 67% yield; **2.85** 68% yield; **2.86** 71% yield; **2.87** 55% yield; **2.88** 72% yield; **2.89** 52% yield; **2.90** 65% yield; **2.91** 46% yield; **2.92** 49% yield

[a]Reactions conducted at 0.1 *M*. Yields represent isolated yields and are the average of two trials.

The scope of alkyl boronic esters was examined with vinylmagnesium chloride using the optimized conditions for 3-phenylpropylB(pin) **2.79** described in Table 2.4, entry 5. As shown in Scheme 2.19, we found that a variety of sp^3-hybridized boronic esters engaged in the reaction, including carbocyclic (**2.86** and **2.87**) and heterocyclic (**2.88**) migrating groups. Furthermore, migrating groups bearing sensitive functional groups such as terminal olefins (**2.89**), amides (**2.90**), esters (**2.91**), and acetals (**2.92**) were tolerated under the reaction conditions.

Although vinylmagnesium chloride is commercially available, we found that "ate" complexes generated from vinyllithium gave superior reactivity: yields were often higher compared to the analogous reactions with vinylmagnesium chloride, catalyst loadings could be reduced to 1 mol %, all reactions achieved full conversion in one hour, and DMSO and NaOTf additives were not required (Scheme 2.20). Furthermore, tertiary (**2.93**) and cycloalkenyl (**2.94**–**2.96**) boronic esters, which were unreactive in the Grignard-based protocol, could now undergo vinylidenation. Even an α-(trimethylsilyl)vinyl group (**2.97**) could participate in the reaction, although the yield is modest. Unfortunately, other acyclic alkenyl migrating groups such as *trans*-alkenyl boronic esters (**2.98** and **2.99**) were unsuccessful, and 1,1-disubstituted alkenyl boronates gave an inseparable ~1:1 mixture of vinylidenation product and starting material (**2.100** and **2.101**).

Scheme 2.20. Vinylidenation of organoboronic esters with vinyllithium[a]



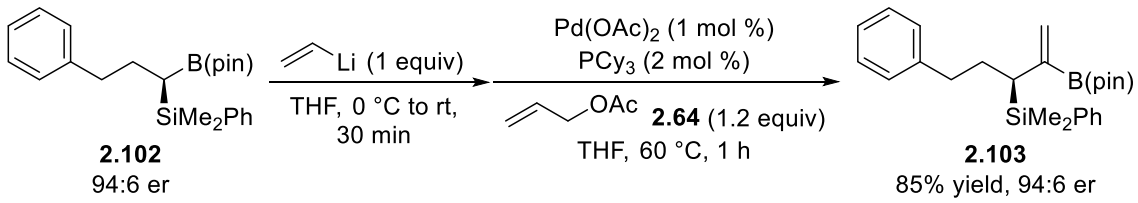
[a]Reactions conducted at 0.1 *M*. Yields represent isolated yields and are the average of two trials. [b]5 mol % of $Pd(OAc)_2$ and 10 mol % of PCy_3 used.

To demonstrate the stereospecificity of the vinylidenation, the enantioenriched substrate **2.102**, prepared by an enantioselective Pt-catalyzed hydrosilylation of *trans*-alkenyl boronic ester,[43] underwent vinylidenation to give **2.103** in good yield without loss of enantiopurity (Scheme 2.21a). To demonstrate the scalability of this reaction, the vinylidenation of cyclopentylB(pin) was conducted on gram scale and was found to occur in good yield (Scheme 2.21b).

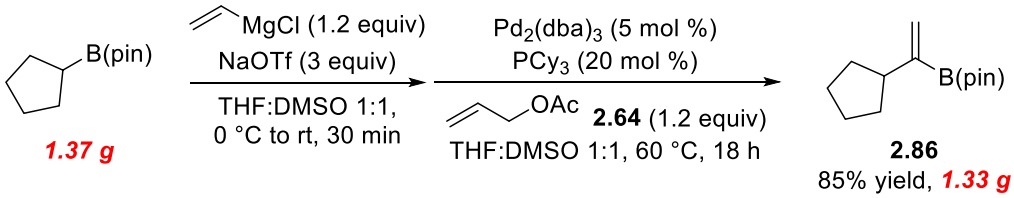
[43] Szymaniak, A. A.; Zhang, C.; Coombs, J. R.; Morken, J. P. *ACS Catal.* **2018**, *8*, 2897.

Scheme 2.21. Demonstration of stereospecificity and scalability

(a) Stereospecific vinylidenation of an enantioenriched α-silylboronic ester



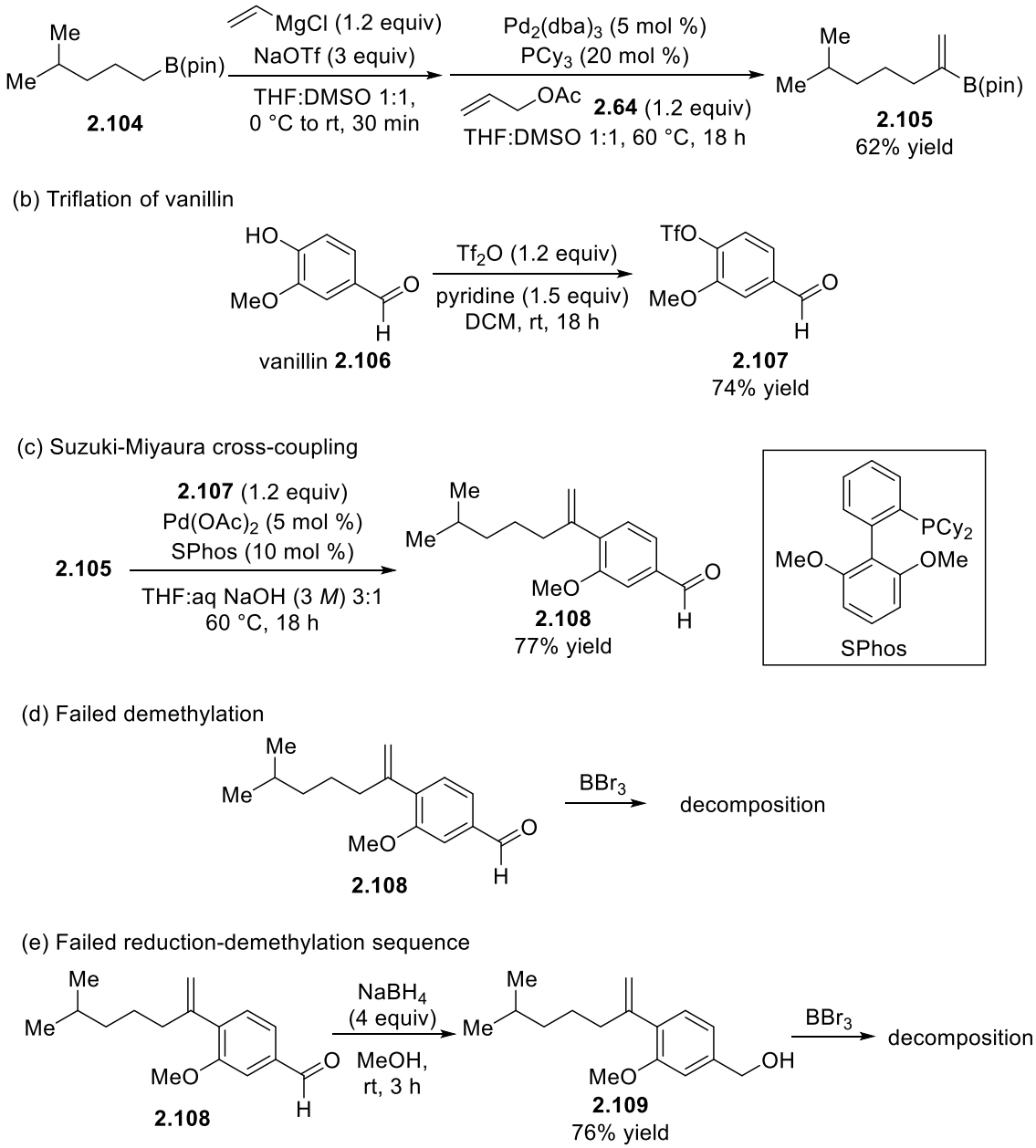
(b) Gram scale vinylidenation of cyclopentylB(pin)



We also sought to demonstrate the utility of this reaction by synthesizing 7-deoxy-7,14-didehydrosydonol **2.113**, a sesquiterpenoid natural product produced by the fungus *Aspergillus sydowii*.[44] Vinylidenation of 4-methylpentylB(pin) **2.104** with vinylmagnesium chloride gave alkenyl boronic ester **2.105** in 62% yield (Scheme 2.22a), which we then coupled with aryl triflate **2.107** via the Suzuki–Miyaura reaction to give **2.108** in 77% yield (Scheme 2.22c). We were eager to employ **2.107** because it can be derived from inexpensive, naturally abundant vanillin **2.106** in a single step in high yield (Scheme 2.22b). However, all attempts to demethylate the methoxy group in **2.108** led to decomposition of the starting material; reduction of the aldehyde prior to the demethylation step also led to decomposition (Scheme 2.22d and e).

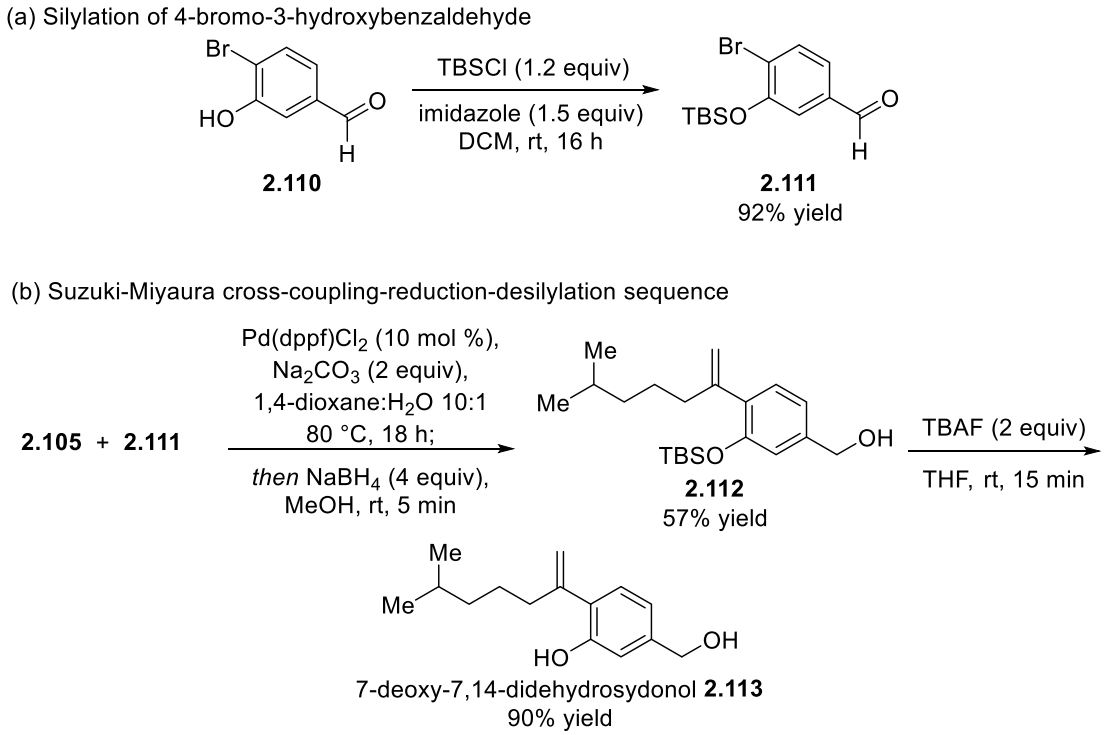
[44] Chung, Y.-M.; Wei, C.-K.; Chuang, D.-W.; El-Shazly, M.; Hsieh, C.-T.; Asai, T.; Oshima, Y.; Hsieh, T.-J.; Hwang, T.-L.; Wu, Y.-C.; Chang, F.-R. *Bioorg. Med. Chem.* **2013**, *21*, 3866.

Scheme 2.22. Attempted total synthesis of 7-deoxy-7,14-didehydrosydonol from 4-methylpentylB(pin) and vanillin



In lieu of vanillin-derived **2.107**, we decided to couple **2.105** with bromoarene **2.111**, which was synthesized in one step from commercially available 4-bromo-3-hydroxybenzaldehyde **2.110** (Scheme 2.23a). The Suzuki–Miyaura reaction was conducted at 80 °C for 18 hours, and following quenching with ammonium chloride, liquid–liquid extraction, silica gel filtration, and removal of the solvent under reduced pressure, the crude reaction mixture was immediately dissolved in methanol and treated with $NaBH_4$ to give **2.112** in 57% yield. Deprotection of the TBS ether with TBAF gave 7-deoxy-7,14-didehydrosydonol **2.113** in 90% yield (32% yield over three steps) (Scheme 2.23b), whose ^{1}H and ^{13}C NMR spectra are consistent with those reported for the isolated compound.

Scheme 2.23. Total synthesis of 7-deoxy-7,14-didehydrosydonol



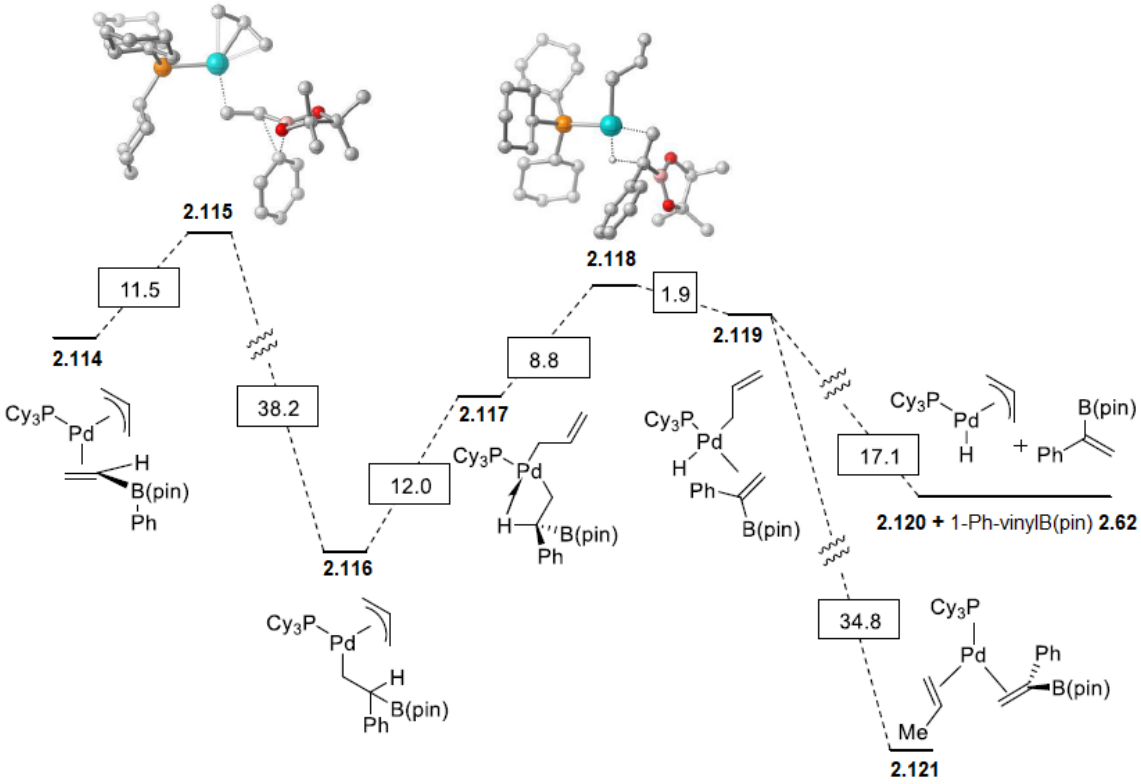
2.3.4. Mechanism

The mechanism of the first-generation conjunctive cross-coupling was studied by DFT calculations.[45] However, the vinylidenation reaction conditions are quite different from those of the conjunctive cross-coupling. Most notably, the use of a monodentate PCy_3 ligand rather than a chiral bidentate MandyPhos ligand, in conjunction with an allyl electrophile, means that the allyl ligand could fluctuate between η^1 and η^3 bonding modes. Therefore, we studied the kinetic and thermodynamic profile of the vinylidenation reaction by DFT calculations, which were conducted by former group member Gabriel Lovinger (Scheme 2.24).

Using the complex between (phenyl)(vinyl)B(pin) "ate" and $[(\eta^3\text{-allyl})Pd(PCy_3)]^+$ **2.114** as the starting point, calculations show that the reaction proceeds with a 1,2-metallate shift via transition state **2.115** (activation barrier of 11.5 kcal/mol), giving intermediate **2.116** in a process that is energetically downhill. The allyl ligand then changes its bonding mode from η^3 to η^1 (**2.116** → **2.117**), which, although 12 kcal/mol higher in energy, opens a coordination site on palladium to allow for an agostic interaction with the β-hydrogen of the substrate.[46] This agostic interaction is required for the subsequent β-hydride elimination via transition state **2.118** (activation barrier of 8.8 kcal/mol). Although these calculations show that the β-hydride elimination is endothermic, dissociation of complex **2.119** to give $(\eta^3\text{-allyl})PdH(PCy_3)$ **2.120** and the free vinylidenation product **2.62** is 17.1 kcal/mol downhill, presumably due to release of steric congestion around the palladium center in **2.119**. Alternatively, reductive elimination between the allyl and hydride ligands on palladium in **2.119** gives complex **2.121**, which is even more exothermic.

[45] Myhill, J. A.; Zhang, L.; Lovinger, G. J.; Morken, J. P. *Angew. Chem. Int. Ed.* **2018**, *57*, 12799.
[46] Brookhart, M.; Green, M. L. H.; Parkin, G. *Proc. Natl. Acad. Sci. U.S.A.* **2007**, *104*, 6908.

Scheme 2.24. DFT calculations for the Pd-induced vinylidenation reaction

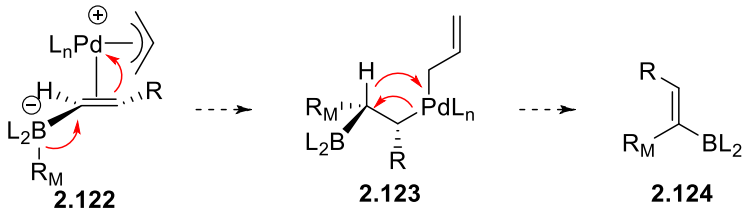


2.3.5. Outlook and Future Directions

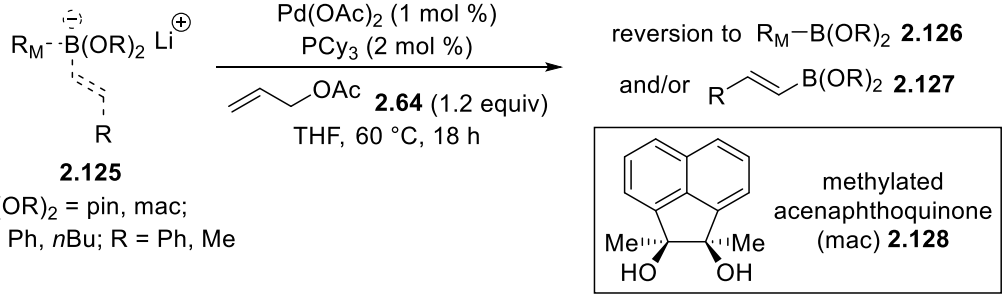
Based on what we learned from this vinylidenation reaction, we then attempted to expand this mode of reactivity to encompass β-substituted migration termini **2.122**: β-hydride elimination following Pd-induced 1,2-metallate shift (**2.123)** would give trisubstituted alkenyl boronic esters **2.124** (Scheme 2.25a). Subjecting organoboron "ate"

Scheme 2.25. Attempts to synthesize trisubstituted alkenyl boronic esters via Pd-induced 1,2-metallate shift/β-hydride elimination vinylidene homologation mechanism

(a) Proposed synthesis of trisubstituted alkenyl boronic esters from β-substituted migration termini

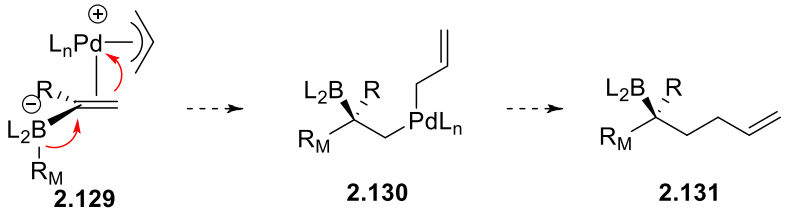


(b) Preliminary results

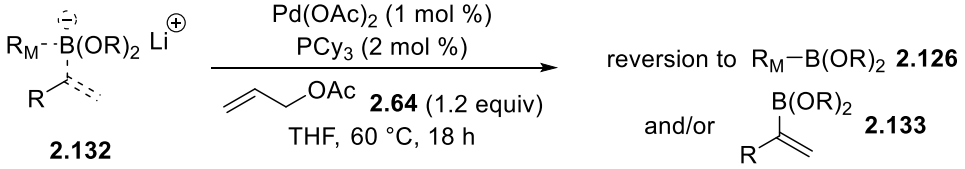


Scheme 2.26. Attempts to synthesize γ-boryl alkenes via Pd-induced 1,2-metallate shift/reductive elimination conjunctive cross-coupling mechanism

(a) Proposed conjunctive cross-coupling reaction with allyl electrophiles using α-substituted migration termini



(b) Preliminary results



complexes, derived from either phenyllithium or *n*-butyllithium and phenyl- or methyl-substituted alkenylB(pin) compounds **2.125**, to the optimized vinylidenation conditions resulted in recovery of boronic esters **2.126** and/or **2.127** (Scheme 2.25b). We also attempted to engage "ate" complexes derived from methylated acenaphthoquinone (mac, **2.128**). This boron ligand was developed in our laboratory to enhance palladium binding β to the boron atom on β-substituted olefins of the "ate" complex, which has the effect of promoting the Pd-induced 1,2-metallate shift while also retarding the Suzuki–Miyaura cross-coupling reaction.[47] Unfortunately, using mac-derived boron "ate" complexes did not give the desired trisubstituted alkenyl boronic esters; organoB(mac) and alkenylB(mac) compounds from "ate" complex decomposition resulted instead.

We also attempted to engage α-substituted migration termini **2.129**: if the Pd-induced 1,2-metallate shift were to occur with these boron "ate" complexes, we hypothesized that the lack of a hydrogen atom required for β-hydride elimination may force intermediate **2.130** to undergo reductive elimination to give γ-boryl alkene products **2.131** (Scheme 2.26a)—in other words, we had hoped that using boron "ate" complexes with α-substituted migration termini would be the solution to our failed conjunctive cross-coupling reaction with allyl electrophiles. Unfortunately, using "ate" complexes **2.132** derived from pinacol or mac, phenyllithium or *n*-butyllithium, and alkenylboronic esters with phenyl- or methyl-substitution at the α position did not result in the desired conjunctive cross-coupling products when treated with the optimized vinylidenation conditions, the outcome once again being reversion to boronic esters **2.126** and/or **2.133** (Scheme 2.26b).

[47] Myhill, J. A.; Wilhelmsen, C. A.; Zhang, L.; Morken, J. P. *J. Am. Chem. Soc.* **2018**, *140*, 15181.

We attribute the failure of both of these new directions to the acute sensitivity the $[Pd(\eta^3\text{-allyl})(PCy_3)]^+$ complex has to steric influences: the presence of an additional substituent on the migration terminus is enough to inhibit "ate" complex binding to the palladium center. The fact that we failed to observed products derived from the direct cross-coupling between the boron "ate" and the allyl electrophile fragment lends support to this hypothesis. Unfortunately, attempts to use smaller phosphine ligands such as those in Table 2.1 (*vide supra*) were not successful.

In conclusion, we have developed the Pd-catalyzed vinylidene homologation of organoboronic esters using allyl acetate as the oxidant. This reaction proceeds through a Pd-induced 1,2-metallate shift followed by β-hydride elimination, the energetics of which was studied by DFT calculations. We have shown that a variety of aryl, alkyl, and alkenyl boronates could undergo vinylidenation and have applied this method to the total synthesis of the sesquiterpenoid natural product 7-deoxy-7,14-didehydrosydonol **2.113**. Although we were unsuccessful in our attempts to engage "ate" complexes bearing α- or β-substituents, we have applied the lessons learned in this project to successfully couple to a related class of electrophiles, namely, propargyl electrophiles to synthesize β-boryl allenes from conjunctive cross-coupling, which is the subject of the following chapter.

2.4. Experimental

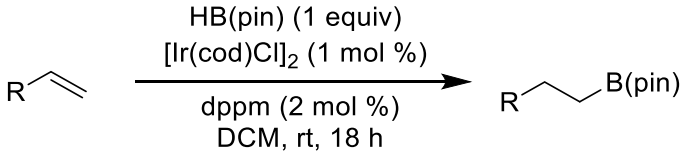
2.4.1. General Information

^{1}H NMR spectra were recorded on a Varian Gemini-400 (400 MHz), Varian Gemini-500 (500 MHz), or Varian Gemini-600 (600 MHz) spectrometer. Chemical shifts are reported in ppm with the solvent resonance as the internal standard ($CDCl_3$: 7.26 ppm). Data are reported as follows: chemical shift, multiplicity (s = singlet, d = doublet, t = triplet, q = quartet, p = pentet, m = multiplet, app = apparent), coupling constants (Hz), and integration. ^{13}C NMR spectra were recorded on a Varian Gemini-400 (100 MHz), Varian Gemini-500 (125 MHz), or Varian Gemini-600 (150 MHz) spectrometer with complete proton decoupling. Chemical shifts are reported in ppm with the solvent resonance as the internal standard ($CDCl_3$: 77.16 ppm). ^{11}B NMR spectra were recorded on a Varian Inova-500 (128 MHz) spectrometer. Chemical shifts are reported in ppm using boron trifluoride diethyl etherate as the external standard ($BF_3{\cdot}O(C_2H_5)_2$: 0.0 ppm). Infrared (IR) spectra were recorded on a Bruker Alpha-P Spectrometer. Frequencies are reported in wavenumbers (cm^{-1}) as follows: strong (s), broad (br), medium (m), and weak (w). Optical rotations were measured on a Rudolph Analytical Research Autopol IV Polarimeter and the values reported are averages of seven measurements. Direct analysis in real time-high resolution mass spectrometry (DART-HRMS) was performed at the Mass Spectrometry Facility, Boston College, Chestnut Hill, MA. Flash column chromatography was performed using silica gel (SiO_2, 230 x 450 Mesh, purchased from Silicycle). Thin layer chromatography (TLC) was performed on 25 μm silica gel aluminum backed plates from Silicycle. Visualization was performed using ultraviolet light (254 nm) and ceric ammonium molybdate (CAM) in ethanol.

Analytical chiral supercritical fluid chromatography (SFC) was performed on a TharSFC Method Station II equipped with Waters 2998 Photodiode Array Detector with isopropanol as the modifier.

Anhydrous tetrahydrofuran (THF), diethyl ether (Et_2O), and dichloromethane (DCM) were purified using a Pure Solv MD-4 solvent purification system, from Innovative Technology, Inc., by passing the solvent through two activated alumina columns after purging with argon. Anhydrous dimethyl sulfoxide (DMSO) and allyl acetate were purchased from Aldrich. Palladium (II) acetate ($Pd(OAc)_2$), tris(dibenzylideneacetone)dipalladium(0) ($Pd_2(dba)_3$), and tricyclohexylphosphine (PCy_3) purchased from Strem Chemicals, Inc. and used without further purification. Pinacol was purchased from Oakwood Chemicals. All pinacol boronic esters not synthesized in-house were purchased from Combi Blocks, Oakwood Chemicals, or Frontier Scientific and used without further purification. All other reagents were purchased from Aldrich, Alfa Aesar, or Acros and used without further purification.

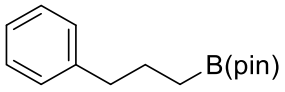
2.4.2. General Procedure for the Preparation of Pinacol Boronic Esters from Olefins



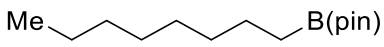
Following a literature procedure[48] with slight modification: In a glovebox filled with argon, a flame-dried round bottom flask equipped with a magnetic stir bar was charged with $[Ir(cod)Cl]_2$ (0.01 equiv) and 1,1-bis(diphenylphosphino)methane (dppm, 0.02 equiv) as solids. The solids were dissolved in anhydrous DCM (0.67 *M*) and allowed to stir for

[48] Yamamoto, Y.; Fujikawa, R.; Umemoto, T.; Miyaura, N. *Tetrahedron* **2004**, *60*, 10695.

five minutes. To this solution was added the olefin (1 equiv), followed by dropwise addition of 4,4,5,5-tetramethyl-1,3,2-dioxaborolane (pinacolborane, HB(pin), 1 equiv). The reaction flask was sealed with a septum, brought out of the glove box, and was allowed to stir at room temperature for 18 hours. Upon completion, the reaction was quenched with methanol and water and then partitioned between brine and DCM. The aqueous layer was extracted with DCM (4 x) and the combined organic phases were dried over Na_2SO_4, filtered, and concentrated *in vacuo*. The residue was then purified by silica gel column chromatography.

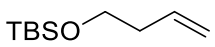


4,4,5,5-tetramethyl-2-(3-phenylpropyl)-1,3,2-dioxaborolane (2.79). Prepared according to the general procedure above with allylbenzene (355 mg, 3 mmol, 1 equiv). The crude product was purified by silica gel column chromatography (10% EtOAc in hexanes, stained in CAM) to afford a clear, colorless oil (572 mg, 77% yield). All spectroscopic data were in accord with the literature.[49]

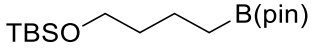


4,4,5,5-tetramethyl-2-octyl-1,3,2-dioxaborolane (2.134). Prepared according to the general procedure above with oct-1-ene (337 mg, 3 mmol, 1 equiv). The crude product was purified by silica gel column chromatography (10% EtOAc in hexanes, stained in CAM) to afford a clear, colorless oil (700 mg, 97% yield). All spectroscopic data were in accord with the literature.[48]

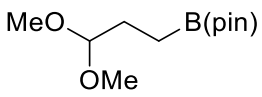
[49] Bose, S. K.; Brand, S.; Omoregie, H. O.; Haehnel, M.; Maier, J.; Bringmann, G.; Marder, T. B. *ACS Catal.* **2016**, *6*, 8332.



(but-3-enyloxy)(*tert*-butyl)dimethylsilane (2.135). The title compound was prepared according to the procedure reported in the literature, and all spectroscopic data were in accord with the literature.[50]



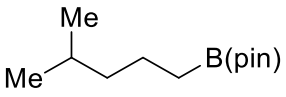
***tert*-butyldimethyl-[4-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl) butoxy]silane (2.136).** Prepared according to the general procedure above with (but-3-enyloxy)(*tert*-butyl)dimethylsilane **(2.135)** (410 mg, 2.2 mmol, 1 equiv). The crude product was purified by silica gel column chromatography (10% EtOAc in hexanes, stained in CAM) to afford a clear, colorless oil (627 mg, 91% yield). All spectroscopic data were in accord with the literature.[51]



2-(3,3-dimethoxypropyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (2.137). Prepared according to the general procedure above with 3,3-dimethoxyprop-1-ene (1.02 g, 10 mmol, 1 equiv). The crude product was purified by silica gel column chromatography (10% EtOAc in hexanes, stained in CAM) to afford a clear, colorless oil (660 mg, 29% yield). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 4.11 (t, J = 5.7 Hz, 1H), 3.11 (s, 6H), 1.51 (app q, J = 7.0 Hz, 2H), 1.05 (s, 12H), 0.59 (t, J = 7.8 Hz, 2H). **^{11}B NMR** (128 MHz, $CDCl_3$) δ 33.59. **^{13}C NMR** (150 MHz, $CDCl_3$) δ 105.6, 82.7, 52.4, 26.7, 24.6. **IR** (neat) ν_{max} 2978.20 (m), 2932.75 (m), 2829.35 (w), 1369.68 (s), 1324.19 (m), 1304.96 (m), 1214.91 (m), 1144.61 (s), 1121.35 (s), 1053.55 (s),

[50] Ghosh, A. K.; Li, J. *Org. Lett.*, **2009**, *11*, 4164.
[51] Fan, D.; Jarvest, R. L.; Lazarides, L.; Li, Q.; Li, X.; Liu, Y.; Liao, L.; Mordaunt, J. E.; Ni, Z.-J.; Plattner, J.; Qian, X.; Slater, M. J.; White, G. V.; Zhang, Y. K. Novel Cyclic Boronate Inhibitors of HCV Replication. WO2009046098A1, April 9, 2009.

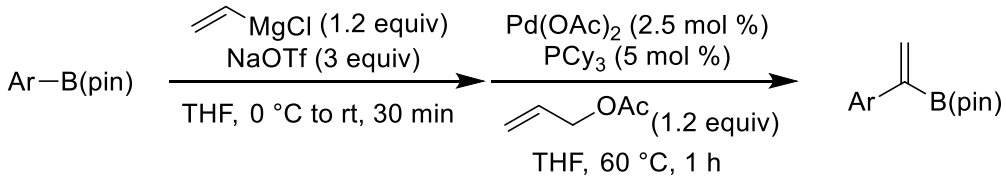
968.06 (m), 846.38 (m), 733.17 (m) cm^{-1}. **HRMS** (DART+) for $C_{11}H_{27}BNO_4$ $[M+NH_4]^+$ calculated: 248.2028, found: 248.2034.



2-(4-methylpentyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (2.104). Prepared according to the general procedure above with 4-methylpent-1-ene (505 mg, 6 mmol, 1 equiv). The crude product was purified by silica gel column chromatography (10% EtOAc in hexanes, stained in CAM) to afford a clear, colorless oil (1.20 g, 94% yield). All spectroscopic data were in accord with the literature.[52]

2.4.3. General Procedures for the Vinylidenation of Pinacol Boronic Esters

2.4.3.1. Method A: Vinylmagnesium Chloride with Aryl Boronic Esters

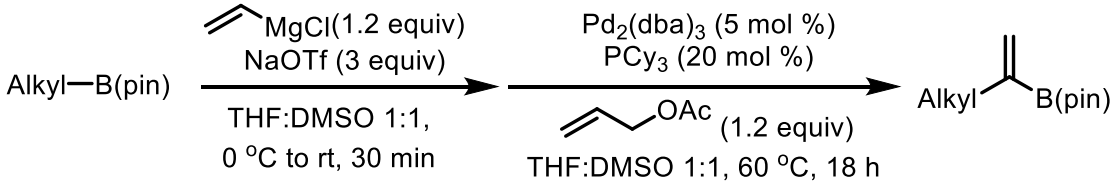


In a glovebox filled with argon, an oven-dried 2-dram vial equipped with a magnetic stir bar was charged with 2-aryl-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (0.3 mmol, 1 equiv), sodium trifluoromethanesulfonate (154.9 mg, 0.9 mmol, 3 equiv), and anhydrous THF (1 mL). The vial was sealed with a septum cap and removed from the glovebox. Under positive nitrogen pressure, the reaction vial was cooled to 0 ºC in an ice-water bath, and vinylmagnesium chloride solution in THF (0.36 mmol, 1.2 equiv) was added dropwise with stirring. The reaction vial was allowed to warm to room temperature and stir for 30 minutes before being brought back into the glovebox. In the glovebox, a

[52] Pang, M.; Wu, C.; Zhuang, X.; Zhang, F.; Su, M.; Tong, Q.; Tung, C.-H.; Wang, W. *Organometallics* **2018**, *37*, 1462.

second oven-dried 2-dram vial equipped with a magnetic stirbar was charged with $Pd(OAc)_2$ solution in anhydrous THF (0.75 mL, 0.01 *M*, 0.0075 mmol, 0.025 equiv) and PCy_3 (4.2 mg, 0.015 mmol, 0.05 equiv). The $Pd(OAc)_2/PCy_3$ solution was allowed to stir for 10 minutes at room temperature inside the glovebox. The $Pd(OAc)_2/PCy_3$ solution was then transferred into the reaction vial, followed by allyl acetate (36.0 mg, 0.36 mmol, 1.2 equiv) and anhydrous THF (1.25 mL, used to rinse the $Pd(OAc)_2/PCy_3$ vial). The reaction vial was sealed with a polypropylene cap and electrical tape, brought out of the glovebox, and stirred at 60 ºC for 1 hour. After cooling to room temperature, the reaction solution was filtered through a silica gel plug with Et_2O washing, concentrated *in vacuo*, and purified by silica gel column chromatography to provide the desired products.

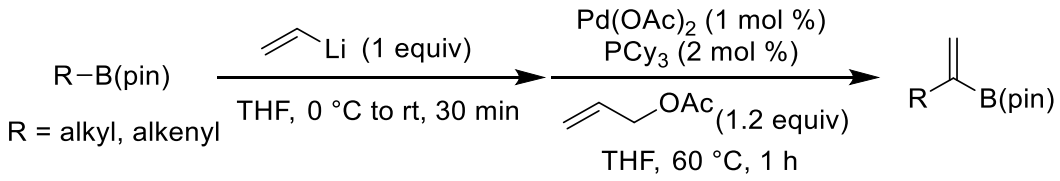
2.4.3.2. Method B: Vinylmagnesium Chloride with Alkyl Boronic Esters



In a glovebox filled with argon, an oven-dried 2-dram vial equipped with a magnetic stir bar was charged with 2-alkyl-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (0.3 mmol, 1 equiv), sodium trifluoromethanesulfonate (154.9 mg, 0.9 mmol, 3 equiv), anhydrous THF (0.5 mL), and anhydrous DMSO (0.5 mL). The vial was sealed with a septum cap and removed from the glovebox. Under positive nitrogen pressure, the reaction vial was cooled to 0 ºC in an ice-water bath, and vinylmagnesium chloride solution in THF (0.36 mmol, 1.2 equiv) was added dropwise with stirring. The reaction vial was allowed to warm to room temperature and stir for 30 minutes before being brought back into the glovebox. In the glovebox, a second oven-dried 2-dram vial equipped with a magnetic

stirbar was charged with $Pd_2(dba)_3$ (13.7 mg, 0.015 mmol, 0.05 equiv), PCy_3 (16.8 mg, 0.06 mmol, 0.2 equiv), anhydrous DMSO (1 mL), and anhydrous THF (0.5 mL). The $Pd_2(dba)_3/PCy_3$ solution was allowed to stir for 10 minutes at room temperature inside the glovebox. The $Pd_2(dba)_3/PCy_3$ solution was then transferred into the reaction vial, followed by allyl acetate (36.0 mg, 0.36 mmol, 1.2 equiv) and anhydrous THF (0.5 mL, used to rinse the $Pd_2(dba)_3/PCy_3$ vial). The reaction vial was sealed with a polypropylene cap and electrical tape, brought out of the glovebox, and stirred at 60 ºC for 18 hours. After cooling to room temperature, the resulting mixture was transferred to a separatory funnel with the aid of EtOAc (5 mL). The organic phase was washed with water (2 x 10 mL), and the combined aqueous phases were extracted with EtOAc (20 mL). The combined organic phases were dried over Na_2SO_4, filtered, concentrated *in vacuo*, filtered through a silica gel plug with EtOAc, re-concentrated, and purified by silica gel column chromatography to provide the desired products.

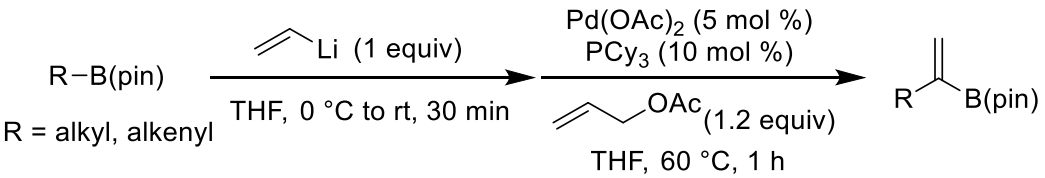
2.4.3.3. Method C: Halide-free Vinyllithium with Alkyl/Alkenyl Boronic Esters at 1 mol % Pd/PCy₃ Loading



In a glovebox filled with argon, an oven-dried 2-dram vial equipped with a magnetic stir bar was charged with 2-alkyl(or alkenyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (0.3 mmol, 1 equiv) and anhydrous THF (1 mL). The vial was sealed with a septum cap and removed from the glovebox. Under positive nitrogen pressure, the reaction vial was cooled to 0 ºC in an ice-water bath, and vinyllithium solution in THF

(0.36 mmol, 1 equiv) was added dropwise with stirring. The reaction vial was allowed to warm to room temperature and stir for 30 minutes before being brought back into the glovebox. In the glovebox, a second oven-dried 2-dram vial equipped with a magnetic stirbar was charged with $Pd(OAc)_2$ solution in anhydrous THF (0.3 mL, 0.01 *M*, 0.003 mmol, 0.01 equiv) and PCy_3 (1.7 mg, 0.006 mmol, 0.02 equiv). The $Pd(OAc)_2/PCy_3$ solution was allowed to stir for 10 minutes at room temperature inside the glovebox. The $Pd(OAc)_2/PCy_3$ solution was then transferred into the reaction vial, followed by allyl acetate (36.0 mg, 0.36 mmol, 1.2 equiv) and anhydrous THF (1.7 mL, used to rinse the $Pd(OAc)_2/PCy_3$ vial). The reaction vial was sealed with a polypropylene cap and electrical tape, brought out of the glovebox, and stirred at 60 ºC for 1 hour. After cooling to room temperature, the reaction solution was filtered through a silica gel plug with Et_2O washing, concentrated *in vacuo*, and purified by silica gel column chromatography to provide the desired products.

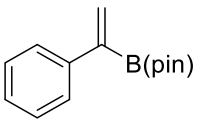
2.4.3.4. Method D: Halide-free Vinyllithium with Alkyl/Alkenyl Boronic Esters at 5 mol % Pd/PCy₃ Loading



In a glovebox filled with argon, an oven-dried 2-dram vial equipped with a magnetic stir bar was charged with 2-alkyl(or alkenyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (0.3 mmol, 1 equiv) and anhydrous THF (1 mL), sealed with a septum cap, and removed from the glovebox. Under positive nitrogen pressure, the reaction vial was cooled to 0 ºC in an ice-water bath, and vinyllithium solution in THF (0.36 mmol, 1 equiv)

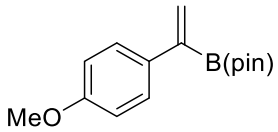
was added dropwise. The reaction vial was allowed to warm to room temperature and stir for 30 minutes before being brought back into the glovebox. In the glovebox, a second oven-dried 2-dram vial equipped with a magnetic stirbar was charged with $Pd(OAc)_2$ solution in anhydrous THF (1.5 mL, 0.01 *M*, 0.015 mmol, 0.05 equiv) and PCy_3 (8.4 mg, 0.03 mmol, 0.1 equiv). The $Pd(OAc)_2/PCy_3$ solution was allowed to stir for 10 minutes at room temperature inside the glovebox. The $Pd(OAc)_2/PCy_3$ solution was then transferred into the reaction vial, followed by allyl acetate (36.0 mg, 0.36 mmol, 1.2 equiv) and anhydrous THF (0.5 mL, used to rinse the $Pd(OAc)_2/PCy_3$ vial). The reaction vial was sealed with a polypropylene cap and electrical tape, brought out of the glovebox, and stirred at 60 ºC for 1 hour. After cooling to room temperature, the reaction solution was filtered through a silica gel plug with Et_2O washing, concentrated *in vacuo*, and purified by silica gel column chromatography to provide the desired products.

2.4.4. Characterization of Vinylidenation Products

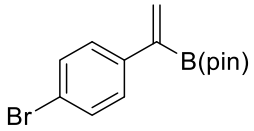


4,4,5,5-tetramethyl-2-(1-phenylvinyl)-1,3,2-dioxaborolane (2.62). The reaction was performed according to the general procedures outlined in ***Method A*** with 4,4,5,5-tetramethyl-2-phenyl-1,3,2-dioxaborolane **(2.63)** (61.2 mg, 0.3 mmol). The crude product was purified by silica gel column chromatography (0% → 15% DCM in hexanes, stained in CAM) to afford a clear, colorless oil (62.2 mg, 76% yield + 16% unreacted starting material). All spectroscopic data were in accord with the literature.[53]

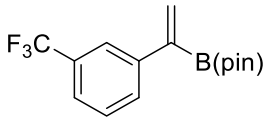
[53] Guan, W.; Michael, A. K.; McIntosh, M. L.; Koren-Selfridge, L.; Scott, J. P.; Clark, T. B. *J. Org. Chem.* **2014**, *79*, 7199.



2-[1-(4-methoxyphenyl)vinyl]-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (2.81). The reaction was performed according to the general procedures outlined in ***Method A*** with 2-(4-methoxyphenyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (70.2 mg, 0.3 mmol). The crude product was purified by silica gel column chromatography (0% → 15% DCM in hexanes, stained in CAM) to afford a clear, colorless oil (66.0 mg, 68% yield + 19% unreacted starting material). All spectroscopic data were in accord with the literature.[53]

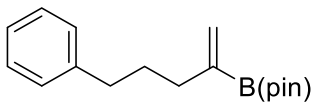


2-[1-(4-bromophenyl)vinyl]-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (2.82). The reaction was performed according to the general procedures outlined in ***Method A*** with 2-(4-bromophenyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane **(S-1)** (84.9 mg, 0.3 mmol). The crude product was purified by silica gel column chromatography (0% → 15% DCM in hexanes, stained in CAM) to afford a clear, colorless oil (73.8 mg, 62% yield + 19% unreacted starting material). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.44 (d, *J* = 9.0 Hz, 2H), 7.36 (d, *J* = 8.4 Hz, 2H), 6.09 – 6.08 (m, 2H), 1.33 (s, 12H). **^{11}B NMR** (128 MHz, $CDCl_3$) δ 30.17. **^{13}C NMR** (150 MHz, $CDCl_3$) δ 140.4, 131.6, 131.4, 129.0, 121.2, 84.0, 24.9; carbon α to boron was not observed.

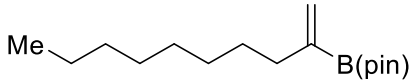


4,4,5,5-tetramethyl-2-[1-[3-(trifluoromethyl)phenyl]vinyl]-1,3,2-dioxaborolane (2.83). The reaction was performed according to the general procedures outlined in ***Method A*** with 4,4,5,5-tetramethyl-2-[3-(trifluoromethyl)phenyl]-1,3,2-dioxaborolane (81.6 mg, 0.3 mmol) with the modification that the reaction was run for 3 hours. The crude product was purified by silica gel column

chromatography (0% → 15% DCM in hexanes, stained in CAM) to afford a clear, colorless oil (64.1 mg, 55% yield + 19% unreacted starting material). All spectroscopic data were in accord with the literature.[54]



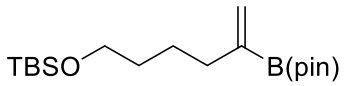
4,4,5,5-tetramethyl-2-(1-methylene-4-phenylbutyl)-1,3,2-dioxaborolane (2.80). The reaction was performed according to the general procedures outlined in either ***Method B*** or ***Method C*** with 4,4,5,5-tetramethyl-2-(3-phenylpropyl)-1,3,2-dioxaborolane **(2.79)** (73.9 mg, 0.3 mmol). The crude product was purified by silica gel column chromatography (0% → 15% DCM in hexanes, stained in CAM) to afford a clear, colorless oil (***Method B:*** 56.8 mg, 70% yield; ***Method C:*** 59.5 mg, 73% yield). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.31 – 7.26 (m, 2H), 7.22 – 7.17 (m, 3H), 5.83 (d, *J* = 3.2 Hz, 1H), 5.65 (app s, 1H), 2.63 (t, *J* = 7.8 Hz, 2H), 2.24 (t, *J* = 7.4 Hz, 2H), 1.79 (app p, *J* = 7.7 Hz, 2 H), 1.29 (s, 12H). **^{11}B NMR** (128 MHz, $CDCl_3$) δ 29.88. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 142.9, 129.4, 128.5, 128.3, 125.7, 83.4, 35.6, 35.2, 31.0, 24.9; carbon α to boron was not observed. **IR** (neat) ν_{max} 3062.21 (w), 3026.23 (w), 2977.75 (m), 2930.28 (m), 2859.03 (w), 1614.55 (w), 1425.20 (m), 1368.34 (s), 1307.52 (s), 1213.03 (m), 1188.99 (m), 1142.28 (s), 968.66 (m), 940.65 (m), 858.25 (m), 741.46 (m), 698.55 (s) cm^{-1}. **HRMS** (DART+) for $C_{17}H_{29}BNO_2$ $[M+NH_4]^+$ calculated: 290.2291, found: 290.2297.



4,4,5,5-tetramethyl-2-(1-methylenenonyl)-1,3,2-dioxaborolane (2.84). The reaction was performed according to the general procedures

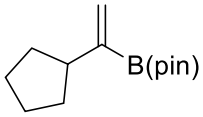
[54] Zhang, P.; Suárez, J. M.; Driant, T.; Derat, E.; Zhang, M.; Ménand, M.; Roland, S.; Sollogoub, M. *Angew. Chem. Int. Ed.* **2017**, *56*, 10821.

outlined in either ***Method B*** or ***Method C*** with 4,4,5,5-tetramethyl-2-octyl-1,3,2-dioxaborolane **(2.134)** (72.1 mg, 0.3 mmol). The crude product was purified by silica gel column chromatography (0% → 15% DCM in hexanes, stained in CAM) to afford a clear, colorless oil (***Method B:*** 54.2 mg, 68% yield; ***Method C:*** 68.0 mg, 85% yield). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 5.74 (d, *J* = 3.6 Hz, 1H), 5.58 (app s, 1H), 2.13 (t, *J* = 7.4 Hz, 2H), 1.41 – 1.38 (m, 2H), 1.26 (app s, 22H), 0.87 (t, *J* = 7.0 Hz, 3H). **^{11}B NMR** (128 MHz, $CDCl_3$) δ 29.88. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 128.8, 83.4, 35.5, 32.1, 29.7, 29.43, 29.36, 24.9, 22.8, 14.3; carbon α to boron was not observed. **IR** (neat) ν_{max} 2977.91 (m), 2958.10 (m), 2924.00 (s), 2854.43 (m), 1615.14 (w), 1425.63 (m), 1306.47 (s), 1141.72 (s), 969.23 (m), 938.38 (m), 862.26 (m) cm^{-1}. **HRMS** (DART+) for $C_{16}H_{32}BO_2$ $[M+H]^+$ calculated: 267.2495, found: 267.2500.

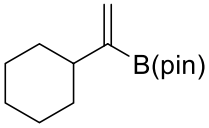


tert*-butyldimethyl-[5-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)hex-5-enoxy]silane (2.85).** The reaction was performed according to the general procedures outlined in either ***Method B or ***Method C*** with *tert*-butyldimethyl-[4-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)butoxy]silane **(2.136)** (94.3 mg, 0.3 mmol). The crude product was purified by silica gel column chromatography (0% → 50% DCM in hexanes, stained in CAM) to afford a clear, yellow oil (***Method B:*** 70.0 mg, 69% yield; ***Method C:*** 78.7 mg, 77% yield). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 5.75 (d, *J* = 3.6 Hz, 1H), 5.58 (d, *J* = 2.8 Hz, 1H), 3.59 (t, *J* = 6.2 Hz, 2H), 2.14 (t, *J* = 7.2 Hz, 2H), 1.52 – 1.40 (m, 4H), 1.25 (s, 12H), 0.88 (s, 9H), 0.03 (s, 6H). **^{11}B NMR** (128 MHz, $CDCl_3$) δ 29.88. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 129.1, 83.4, 63.3, 35.3, 32.7, 26.1, 25.6, 24.9, 18.5, –5.1; carbon α to boron was not observed. **IR** (neat) ν_{max} 2978.23

(w), 2954.63 (m), 2929.20 (m), 2857.28 (m), 1615.85 (w), 1370.04 (s), 1308.57 (s), 1254.62 (m), 1142.31 (s), 1101.93 (s), 968.46 (w), 939.38 (w), 835.37 (s), 774.74 (s) cm^{-1}. **HRMS** (DART+) for $C_{18}H_{38}BO_3Si$ $[M+H]^+$ calculated: 341.2683, found: 341.2698.

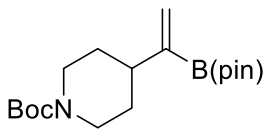


2-(1-cyclopentylvinyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (2.86). The reaction was performed according to the general procedures outlined in either ***Method B*** or ***Method D*** with 2-cyclopentyl-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (58.8 mg, 0.3 mmol). The crude product was purified by silica gel column chromatography (0% → 15% DCM in hexanes, stained in CAM) to afford a clear, colorless oil (***Method B:*** 48.0 mg, 72% yield; ***Method D:*** 58.8 mg, 88% yield). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 5.70 (d, J = 3.2 Hz, 1H), 5.58 (app s, 1H), 2.55 (p, J = 8.4 Hz, 1H), 1.82 – 1.75 (m, 2H), 1.68 – 1.62 (m, 2H), 1.60 – 1.52 (m, 2H), 1.43 – 1.36 (m, 2H), 1.26 (s, 12H). **^{11}B NMR** (128 MHz, $CDCl_3$) δ 30.17. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 126.1, 83.3, 45.7, 32.2, 25.2, 24.9; carbon α to boron was not observed. **IR** (neat) ν_{max} 2977.45 (m), 2952.89 (m), 2867.84 (w), 1607.71 (w), 1370.13 (s), 1304.77 (s), 1139.61 (s), 965.63 (m), 936.84 (m), 877.55 (w), 848.05 (w), 690.05 (w) cm^{-1}. **HRMS** (DART+) for $C_{13}H_{24}BO_2$ $[M+H]^+$ calculated: 223.1864, found: 223.1871.

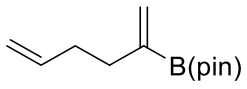


2-(1-cyclohexylvinyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (2.87). The reaction was performed according to the general procedures outlined in either ***Method B*** or ***Method D*** with 2-cyclohexyl-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (63.0 mg, 0.3 mmol). The crude product was purified by silica gel column chromatography (0% → 15% DCM in hexanes, stained in CAM) to afford a clear, colorless

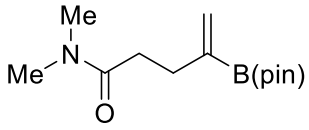
oil (***Method B:*** 39.0 mg, 55% yield; ***Method D:*** 30.0 mg, 42% yield). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 5.70 (d, *J* = 3.2 Hz, 1H), 5.54 (d, *J* = 2.0 Hz, 1H), 2.09 (app t, *J* = 11.6 Hz, 1H), 1.76 – 1.64 (m, 5H), 1.35 – 1.09 (m, 17H). **^{11}B NMR** (128 MHz, $CDCl_3$) δ 30.17. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 126.0, 83.3, 42.9, 32.6, 26.8, 26.5, 24.9; carbon α to boron was not observed. **IR** (neat) ν_{max} 2977.69 (m), 2923.13 (s), 2851.60 (m), 1609.50 (w), 1429.69 (m), 1410.55 (m), 1369.56 (s), 1354.33 (s), 1304.86 (s), 1184.18 (m), 1143.17 (s), 968.38 (m), 940.45 (m), 868.62 (m), 846.61 (m), 689.32 (m) cm^{-1}. **HRMS** (DART+) for $C_{14}H_{26}BO_2$ $[M+H]^+$ calculated: 237.2026, found: 237.2019.



tert*-butyl 4-[1-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)vinyl] piperidine-1-carboxylate (2.88).** The reaction was performed according to the general procedures outlined in ***Method B with *tert*-butyl 4-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)piperidine-1-carboxylate (93.4 mg, 0.3 mmol). The crude product was purified by silica gel column chromatography (25% → 50% DCM in hexanes, stained in CAM) to afford a clear, yellow oil (74.1 mg, 73% yield). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 5.77 (d, *J* = 2.8 Hz, 1H), 5.57 (d, *J* = 1.6 Hz, 1H), 4.12 (br app s, 2H), 2.70 (t, *J* = 11.4 Hz, 2H), 2.22 (t, *J* = 12.0 Hz, 1H), 1.65 (d, *J* = 13.2 Hz, 2H), 1.45 (s, 9H), 1.38 (td, *J* = 12.8, 4.7 Hz, 2H), 1.25 (s, 12H). **^{11}B NMR** (128 MHz, $CDCl_3$) δ 29.78. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 155.1, 127.4, 83.5, 79.3, 41.2, 31.4, 28.6, 24.9; carbon α to boron was not observed. **IR** (neat) ν_{max} 2976.91 (w), 2931.23 (w), 2854.55 (w), 1693.75 (s), 1417.61 (m), 1365.37 (m), 1307.72 (m), 1163.73 (s), 1141.11 (s), 1036.38 (w), 968.80 (w), 940.12 (w), 865.50 (w) cm^{-1}. **HRMS** (DART+) for $C_{18}H_{33}BNO_4$ $[M+H]^+$ calculated: 338.2503, found: 338.2494.

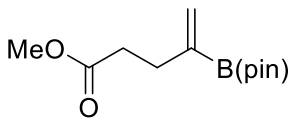


4,4,5,5-tetramethyl-2-(1-methylenepent-4-enyl)-1,3,2-dioxaborolane (2.89). The reaction was performed according to the general procedures outlined in ***Method B*** with 2-but-3-enyl-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (54.6 mg, 0.3 mmol). The crude product was purified by silica gel column chromatography (0% → 15% DCM in hexanes, stained in CAM) to afford a clear, colorless oil (34.4 mg, 55% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 5.86 – 5.78 (m, 2H), 5.61 (app s, 1H), 5.00 (dq, *J* = 17.4, 1.6 Hz, 1H), 4.93 (dq, *J* = 10.8, 1.3 Hz, 1H), 2.26 – 2.23 (m, 2H), 2.21 – 2.17 (m, 2H), 1.27 (s, 12H). **^{11}B NMR** (128 MHz, $CDCl_3$) δ 29.78. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 138.9, 129.5, 114.5, 83.5, 34.9, 33.7, 24.9; carbon α to boron was not observed. **IR** (neat) ν_{max} 3075.17 (w), 2977.74 (s), 2925.60 (s), 2853.27 (m), 1640.31 (w), 1617.20 (w), 1429.14 (m), 1370.05 (s), 1308.78 (s), 1142.37 (s), 909.22 (w), 862.27 (w) cm^{-1}. **HRMS** (DART+) for $C_{12}H_{22}BO_2$ $[M+H]^+$ calculated: 209.1713, found: 209.1713.

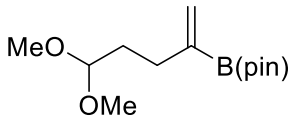


N*,*N*-dimethyl-4-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)pent-4-enamide (2.90).** The reaction was performed according to the general procedures outlined in ***Method B with *N*,*N*-dimethyl-3-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)propanamide (68.1 mg, 0.3 mmol). The crude product was purified by silica gel column chromatography (25% → 50% DCM in hexanes, stained in CAM) to afford a clear, colorless oil (50.7 mg, 67% yield). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 5.76 (d, *J* = 3.2 Hz, 1H), 5.63 (d, *J* = 2.8 Hz, 1H), 2.99 (s, 3H), 2.90 (s, 3H), 2.42 (app s, 4H), 1.23 (s, 12H). **^{11}B NMR** (128 MHz, $CDCl_3$) δ 29.68. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 173.0, 130.0, 83.5, 37.4, 35.4, 33.5, 31.4, 24.91, 24.86; carbon α to boron was not observed.

IR (neat) ν_{max} 2977.19 (w), 2929.57 (w), 1647.69 (s), 1368.72 (s), 1308.95 (s), 1267.66 (w), 1138.21 (s), 941.73 (w), 864.69 (w), 683.88 (w) cm^{-1}. **HRMS** (DART+) for $C_{13}H_{25}BNO_3$ $[M+H]^+$ calculated: 254.1927, found: 254.1936.

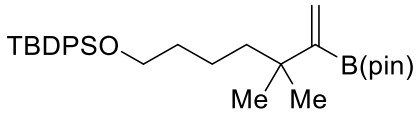


methyl 4-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)pent-4-enoate (2.91). The reaction was performed according to the general procedures outlined in ***Method B*** with methyl 3-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)propanoate (64.2 mg, 0.3 mmol). The crude product was purified by silica gel column chromatography (25% → 50% DCM in hexanes, stained in CAM) to afford a clear, colorless oil (34.7 mg, 48% yield). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 5.80 (d, *J* = 3.2 Hz, 1H), 5.63 (d, *J* = 2.8 Hz, 1H), 3.65 (s, 3H), 2.46 (app s, 4H), 1.26 (s, 12H). **^{11}B NMR** (128 MHz, $CDCl_3$) δ 29.59. **^{13}C NMR** (100 MHz, $CDCl_3$) δ 173.9, 130.2, 83.6, 51.5, 33.9, 30.8, 24.9; carbon α to boron was not observed. **IR** (neat) ν_{max} 2978.69 (m), 2950.10 (w), 2930.31 (w), 1740.06 (s), 1618.37 (w), 1436.44 (m), 1371.02 (s), 1311.60 (s), 1139.37 (s), 858.02 (w) cm^{-1}. **HRMS** (DART+) for $C_{12}H_{22}BO_4$ $[M+H]^+$ calculated: 241.1611, found: 241.1609.



2-(4,4-dimethoxy-1-methylenebutyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (2.92). The reaction was performed according to the general procedures outlined in ***Method B*** with 2-(3,3-dimethoxypropyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane **(2.137)** (69.0 mg, 0.3 mmol). The crude product was purified by silica gel column chromatography (0% → 15% DCM in hexanes, stained in CAM) to afford a clear, colorless oil (38.8 mg, 51% yield). **^{1}H NMR** (500 MHz, $CDCl_3$)

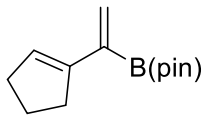
δ 5.76 (d, J = 3.5 Hz, 1H), 5.61 (app s, 1H), 4.36 (t, J = 6.0 Hz, 1H), 3.30 (s, 6H), 2.18 (t, J = 7.8 Hz, 2H), 1.75 – 1.70 (m, 2H), 1.25 (s, 12H). **^{11}B NMR** (128 MHz, $CDCl_3$) δ 29.78. **^{13}C NMR** (125 MHz, $CDCl_3$) δ 129.4, 104.3, 83.5, 52.6, 31.9, 30.7, 24.9; carbon α to boron was not observed. **IR** (neat) ν_{max} 2977.96 (m), 2930.15 (m), 2853.79 (w), 2829.22 (w), 1616.58 (w), 1434.38 (m), 1368.91 (s), 1308.83 (s), 1214.52 (m), 1193.39 (m), 1141.16 (s), 1125.45 (s), 1060.07 (s), 966.87 (m), 939.51 (m), 860.23 (m) cm^{-1}. **HRMS** (DART+) for $C_{13}H_{29}BNO_4$ $[M+NH_4]^+$ calculated: 274.2190, found: 274.2204.



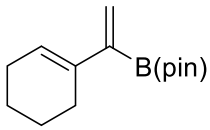
tert*-butyl-[5,5-dimethyl-6-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)hept-6-enoxy]-diphenyl-silane (2.93).** The reaction was performed according to the general procedures outlined in ***Method D with *tert*-butyl-[5-methyl-5-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)hexoxy]diphenylsilane[55] (144.2 mg, 0.3 mmol). The crude product was purified by silica gel column chromatography (0% → 30% DCM in hexanes, stained in CAM) to afford a clear, colorless oil (99.0 mg, 65% yield). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.71 (d, J = 7.2 Hz, 4H), 7.45 – 7.38 (m, 6H), 5.78 (d, J = 1.2 Hz, 1H), 5.55 (d, J = 1.8 Hz, 1H), 3.68 (t, J = 6.9 Hz, 2H), 1.57 (app p, J = 7.2 Hz, 2H), 1.52 – 1.49 (m, 2H), 1.26 (s, 12H), 1.22 – 1.16 (m, 2H), 1.09 (s, 15H). **^{11}B NMR** (128 MHz, $CDCl_3$) δ 30.27. **^{13}C NMR** (150 MHz, $CDCl_3$) δ 136.4, 135.7, 134.4, 129.6, 129.3, 127.7, 125.7, 83.1, 64.3, 41.5, 38.6, 33.7, 27.8, 27.6, 27.0, 24.8, 21.4, 19.4; carbon α to boron was not observed. **IR** (neat) ν_{max} 3070.93 (w), 3051.46 (w), 2957.67 (m), 2930.19 (m), 2858.25 (m), 1601.25 (w), 1472.15 (m), 1427.34 (m), 1410.54 (m), 1361.76 (m), 1298.26 (m), 1146.40 (m), 1106.85 (s), 864.77 (m), 822.14

[55] Edelstein, E. K.; Grote, A.; Palkowitz, M. D. *Synlett* **2018**, *29*, 1749.

(m), 738.70 (m), 699.48 (s), 612.25 (m), 502.72 (s) cm^{-1}. **HRMS** (DART+) for $C_{31}H_{48}BO_3Si$ $[M+H]^+$ calculated: 507.3460, found: 507.3467.

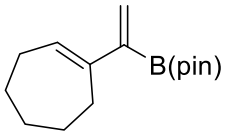


2-[1-(cyclopenten-1-yl)vinyl]-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (2.94). The reaction was performed according to the general procedures outlined in ***Method D*** with 2-(cyclopenten-1-yl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane[90] (58.2 mg, 0.3 mmol). The crude product was purified by silica gel column chromatography (0% → 15% DCM in hexanes, stained in CAM) to afford a clear, colorless oil (30.0 mg, 45% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 6.22 (app s, 1H), 5.78 (d, *J* = 3.0 Hz, 1H), 5.62 (d, *J* = 2.5 Hz, 1H), 2.46 (app t, *J* = 7.8 Hz, 4H), 1.87 (app p, *J* = 7.8 Hz, 2H), 1.30 (s, 12H). **^{11}B NMR** (128 MHz, $CDCl_3$) δ 29.98. **^{13}C NMR** (150 MHz, $CDCl_3$) δ 144.2, 131.5, 127.4, 83.5, 33.7, 32.3, 24.9, 22.7; carbon α to boron was not observed. **IR** (neat) ν_{max} 2977.45 (m), 2928.70 (w), 2843.18 (w), 1410.54 (s), 1370.82 (m), 1305.74 (s), 1253.43 (m), 1214.16 (m), 1142.39 (s), 967.36 (m), 927.01 (m), 861.12 (m), 731.00 (w), 685.92 (w) cm^{-1}. **HRMS** (DART+) for $C_{13}H_{22}BO_2$ $[M+H]^+$ calculated: 221.1707, found: 221.1702.



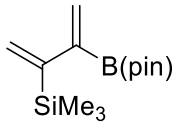
2-[1-(cyclohexen-1-yl)vinyl]-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (2.95). The reaction was performed according to the general procedures outlined in ***Method C*** with 2-(cyclohexen-1-yl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane[90] (62.4 mg, 0.3 mmol). The crude product was purified by silica gel column chromatography (0% → 15% DCM in hexanes, stained in CAM) to afford a clear, colorless oil (49.7 mg, 71% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 6.18 (app s, 1H), 5.65

(app s, 1H), 5.59 (d, J = 2.5 Hz, 1H), 2.17 – 2.15 (m, 4H), 1.68 (app p, J = 2.9 Hz, 2H), 1.57 (app p, J = 2.9 Hz, 2H), 1.29 (s, 12H). **^{11}B NMR** (128 MHz, $CDCl_3$) δ 30.66. **^{13}C NMR** (125 MHz, $CDCl_3$) δ 137.4, 128.9, 123.6, 83.5, 26.2, 25.6, 24.93, 24.87, 22.9, 22.4; carbon α to boron was not observed. **IR** (neat) ν_{max} 2981.13 (w), 2928.39 (w), 1298.87 (w), 1264.59 (m), 1191.95 (w), 1142.87 (m), 905.82 (s), 858.09 (w), 726.46 (s), 649.27 (m) cm^{-1}. **HRMS** (DART+) for $C_{14}H_{24}BO_2$ $[M+H]^+$ calculated: 235.1864, found: 235.1857.

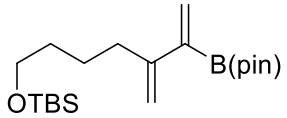


2-[1-(cyclohepten-1-yl)vinyl]-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (2.96). The reaction was performed according to the general procedures outlined in ***Method D*** with 2-(cyclohepten-1-yl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane[56] (66.6 mg, 0.3 mmol). The crude product was purified by silica gel column chromatography (0% → 15% DCM in hexanes, stained in CAM) to afford a clear, colorless oil (44.0 mg, 59% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 6.09 (t, J = 6.5 Hz, 1H), 5.63 (app s, 1H), 5.57 (d, J = 2.5 Hz, 1H), 2.34 – 2.32 (m, 2H), 2.22 – 2.19 (m, 2H), 1.75 (app p, J = 5.9 Hz, 2H), 1.53 – 1.47 (m, 5H), 1.29 (s, 12H). **^{11}B NMR** (128 MHz, $CDCl_3$) δ 30.37. **^{13}C NMR** (125 MHz, $CDCl_3$) δ 145.9, 131.8, 124.0, 83.6, 32.6, 29.8, 28.8, 26.8, 26.4, 24.9; carbon α to boron was not observed. **IR** (neat) ν_{max} 2977.66 (m), 2919.83 (s), 2849.31 (m), 1629.25 (w), 1576.08 (w), 1445.41 (m), 1404.81 (m), 1351.65 (s), 1300.79 (s), 1223.40 (m), 1138.06 (s), 966.60 (m), 850.84 (m) cm^{-1}. **HRMS** (DART+) for $C_{15}H_{26}BO_2$ $[M+H]^+$ calculated: 249.2026, found: 249.2030.

[56] Rauniyar, V.; Zhai, H.; Hall, D. G. *Synth. Commun.* **2008**, *38*, 3984.



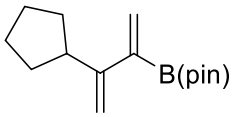
trimethyl-[1-methylene-2-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)allyl] silane (2.97). The reaction was performed according to the general procedures outlined in ***Method C*** with trimethyl-[1-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)vinyl]silane[57] (67.86 mg, 0.3 mmol). The crude product was purified by silica gel column chromatography (0% → 15% DCM in hexanes, stained in CAM) to afford a clear, colorless oil (27.8 mg, 37% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 5.76 (d, *J* = 3.5 Hz, 1H), 5.70 (d, *J* = 3.0 Hz, 1H), 5.56 (d, *J* = 2.5 Hz, 1H), 5.40 (d, *J* = 3.5 Hz, 1H), 1.28 (s, 12H), 0.12 (s, 9H). **^{11}B NMR** (128 MHz, $CDCl_3$) δ 29.78. **^{13}C NMR** (150 MHz, $CDCl_3$) δ 154.5, 128.8, 125.9, 83.7, 24.9, –0.8; carbon α to boron was not observed. **IR** (neat) ν_{max} 2978.78 (w), 1345.48 (m), 1308.78 (m), 1245.94 (m), 1146.26 (m), 968.97 (w), 931.87 (w), 835.20 (s), 757.18 (w), 644.54 (w) cm^{-1}. **HRMS** (DART+) for $C_{13}H_{26}BO_2Si$ $[M+H]^+$ calculated: 253.1790, found: 253.1811.



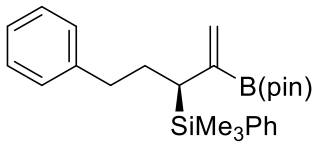
tert*-butyl-dimethyl-[5-methylene-6-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)hept-6-enoxy]silane (2.100).** The reaction was performed according to the general procedures outlined in ***Method D with *tert*-butyl-dimethyl-[5-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)hex-5-.3enoxy]silane **(2.85)** (102.1 mg, 0.3 mmol). The crude product was purified by silica gel column chromatography (0% → 15% DCM in hexanes, stained in CAM) to afford a clear, colorless oil (77.4 mg, 33% yield + 40% unreacted starting material). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 5.78 (app s, 2H), 5.27 (d, *J* = 1.5 Hz, 1H), 4.95 (s, 1H), 3.60 (t, *J* = 6.3 Hz, 2H), 2.26 (t, *J* = 7.3 Hz, 2H), 1.54 – 1.42 (m, 4H), 1.28 (s, 12H), 0.88 (s, 9H), 0.03 (s, 6H). **^{11}B NMR**

[57] Edelstein, E. K.; Namirembe, S.; Morken, J. P. *J. Am. Chem. Soc.* **2017**, *139*, 5027.

(128 MHz, $CDCl_3$) δ 29.88. **^{13}C NMR** (150 MHz, $CDCl_3$) δ 149.1, 128.0, 114.2, 83.6, 63.3, 34.0, 32.8, 25.6, 24.9, 24.6, 18.5, –5.1; carbon α to boron was not observed. **IR** (neat) ν_{max} 2977.60 (w), 2929.45 (m), 2856.79 (m), 1742.64 (w), 1370.05 (s), 1307.81 (s), 1252.74 (m), 1142.40 (s), 1101.46 (s), 835.14 (s), 774.65 (s) cm^{-1}. **HRMS** (DART+) for $C_{20}H_{40}BO_3Si$ $[M+H]^+$ calculated: 367.2834, found: 367.2840.



2-(2-cyclopentyl-1-methylene-allyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (2.101). The reaction was performed according to the general procedures outlined in ***Method D*** with 2-(1-cyclopentylvinyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane **(2.86)** (66.6 mg, 0.3 mmol). The crude product was purified by silica gel column chromatography (0% → 15% DCM in hexanes, stained in CAM) to afford a clear, colorless oil (22.3 mg, 24% yield + 7% unreacted starting material). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 5.77 (app s, 2H), 5.14 (s, 1H), 4.94 (s, 1H), 2.77 (p, J = 8.3 Hz, 1H), 1.85 – 1.77 (m, 2H), 1.70 – 1.63 (m, 2H), 1.60 – 1.54 (m, 2H), 1.44 – 1.36 (m, 2H), 1.29 (s, 12H). **^{11}B NMR** (128 MHz, $CDCl_3$) δ 30.17. **^{13}C NMR** (125 MHz, $CDCl_3$) δ 128.1, 126.1, 110.5, 83.6, 43.2, 32.0, 25.1, 24.8; carbon α to boron was not observed. **IR** (neat) ν_{max} 2977.57 (m), 2953.71 (m), 2869.15 (w), 1618.23 (w), 1406.23 (w), 1378.31 (m), 1306.59 (s), 1131.48 (m), 967.60 (w), 859.65 (w) cm^{-1}. **HRMS** (DART+) for $C_{15}H_{26}BO_2$ $[M+H]^+$ calculated: 249.2020, found: 249.2026.



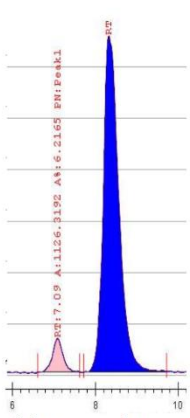
dimethylphenyl-[(1*S*)-1-(2-phenylethyl)-2-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)allyl]silane (2.103). The reaction was performed according to the general procedures outlined in ***Method C*** with dimethylphenyl-[(1*R*)-3-phenyl-1-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl) propyl] silane **(2.102)**[43] (114.1 mg, 0.3 mmol). The crude product was purified by silica gel column chromatography (15% → 30% DCM in hexanes, stained in CAM) to afford a clear, colorless oil (106.5 mg, 87% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.52 – 7.50 (m, 2H), 7.37 – 7.33 (m, 3H), 7.28 (t, *J* = 7.3 Hz, 2H), 7.19 (t, *J* = 7.3 Hz, 1H), 7.14 (d, *J* = 7.5 Hz, 2H), 5.97 (d, *J* = 3.0 Hz, 1H), 5.50 (d, *J* = 3.0 Hz, 1H), 2.74 (ddd, *J* = 13.5, 10.0, 4.0 Hz, 1H), 2.42 (ddd, *J* = 13.5, 9.5, 6.5 Hz, 1H), 2.20 (dd, *J* = 12.5, 3.5 Hz, 1H), 2.04 (dddd, *J* = 18.5, 10.5, 10.5, 4.5 Hz, 1H), 1.82 (dddd, *J* =17.5, 7.0, 7.0, 3.5 Hz, 1H), 1.27 (s, 12H), 0.32 (s, 3H), 0.28 (s, 3H). **^{11}B NMR** (128 MHz, $CDCl_3$) δ 29.78. **^{13}C NMR** (125 MHz, $CDCl_3$) δ 143.2, 138.5, 134.4, 128.8, 128.7, 128.2, 127.6, 127.4, 125.6, 83.4, 35.4, 33.6, 31.1, 24.94, 24.92, –3.6, –5.0; carbon α to boron was not observed. **IR** (neat) ν_{max} 3067.26 (w), 3025.09 (w), 2976.59 (m), 2928.61 (w), 2859.19 (w), 1601.81 (w), 1426.12 (m), 1360.60 (m), 1305.56 (s), 1246.81 (m), 1133.88 (s), 967.74 (m), 926.81 (m), 828.71 (s), 809.01 (s), 733.56 (s), 698.13 (s), 662.58 (m) cm^{-1}. **HRMS** (DART+) for $C_{25}H_{36}BO_2Si$ $[M+H]^+$ calculated: 407.2572, found: 407.2566. $[\alpha]_D^{20}$ = –23.023 (*c* = 4.56, CHCl3, *l* = 50 mm).

Analysis of Stereochemistry:

Racemic compound was prepared according to the general procedure (***Method C***) with *rac*-dimethylphenyl-[3-phenyl-1-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)propyl]silane **(2.102)**.[43]

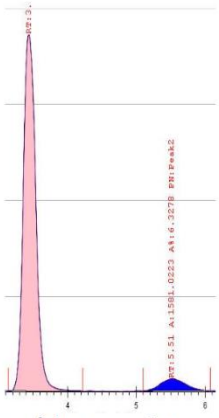
Chiral SFC (Chiracel OJ-H, 5% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of dimethyl-phenyl-[(1*S*)-1-(2-phenylethyl)-2-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)allyl]silane **(2.103)**.

Enriched starting material **(2.102)**



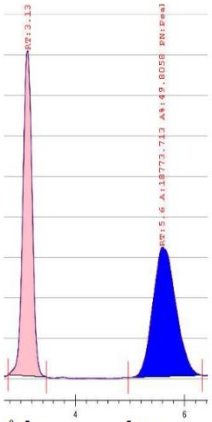
Peak No	% Area	Area	RT (min)
1	6.2165	1126.3192	7.09
2	93.7835	16991.7778	8.33
Total:	100	18118.097	

Enriched product **(2.103)**



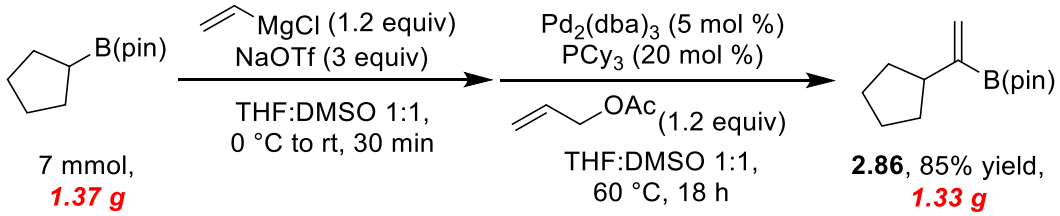
Peak No	% Area	Area	RT (min)
1	93.6722	23404.5106	3.44
2	6.3278	1581.0223	5.51
Total:	100	24985.5329	

Racemic product **(2.103)**



Peak No	% Area	Area	RT (min)
1	50.1942	18920.0916	3.13
2	49.8058	18773.713	5.6
Total:	100	37693.8046	

2.4.5. Procedure for the Gram-Scale Vinylidenation of Pinacol Boronic Esters

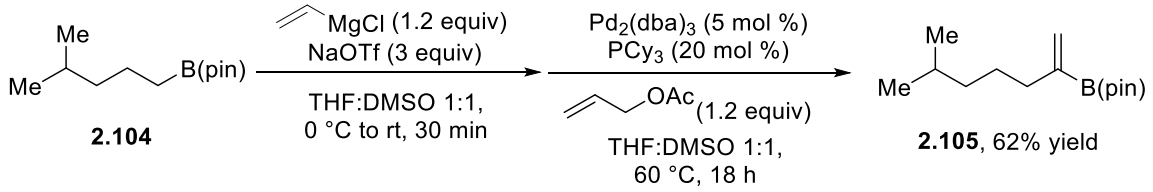


In a glovebox filled with argon, an oven-dried 100-mL round-bottom flask equipped with a magnetic stir bar was charged with 4,4,5,5-tetramethyl-2-cyclopentyl-1,3,2-dioxaborolane (1.37 g, 7 mmol, 1 equiv), sodium trifluoromethanesulfonate (3.61 g, 21 mmol, 3 equiv), anhydrous THF (8 mL), and anhydrous DMSO (8 mL), sealed with a septum, and removed from the glovebox. Under positive nitrogen pressure, the reaction vial was cooled to 0 ºC in an ice-water bath, and vinylmagnesium chloride solution in THF (8.4 mmol, 1.2 equiv) was added dropwise with stirring. The reaction vial was allowed to warm to room temperature and stir for 30 minutes before being brought back into the glovebox. In the glovebox, an oven-dried 20-mL scintillation vial equipped with a magnetic stirbar was charged with $Pd_2(dba)_3$ (320.5 mg, 0.35 mmol, 0.05 equiv), PCy_3 (392.6 mg, 1.4 mmol, 0.2 equiv), anhydrous DMSO (8 mL), and anhydrous THF (4 mL). The $Pd_2(dba)_3$/PCy_3 solution was allowed to stir for 10 minutes at room temperature inside the glovebox. The $Pd_2(dba)_3$/PCy_3 solution was then transferred into the round-bottom flask, followed by allyl acetate (841.0 mg, 8.4 mmol, 1.2 equiv) and anhydrous THF (4 mL, used to rinse the $Pd_2(dba)_3$/PCy_3 vial). The round-bottom flask was sealed with the septum and electrical tape, brought out of the glovebox, and stirred at 60 ºC for 18 hours. After cooling to room temperature, the resulting mixture was transferred to a separatory funnel with the aid of EtOAc (25 mL). The organic phase was washed with water (2 x 50 mL), and the combined aqueous phases were extracted with EtOAc (100 mL). The

combined organic phases were dried over Na_2SO_4, filtered, concentrated *in vacuo*, filtered through a silica gel plug with EtOAc, re-concentrated, and purified by silica gel column chromatography (0% → 15% DCM in hexanes, stained in CAM) to afford **2.86** as a clear, colorless oil (1.33 g, 85% yield).

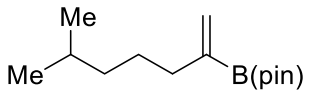
2.4.6. Total Synthesis of 7-Deoxy-7,14-didehydrosydonol

2.4.6.1. Vinylidenation of 4-MethylpentylB(pin)



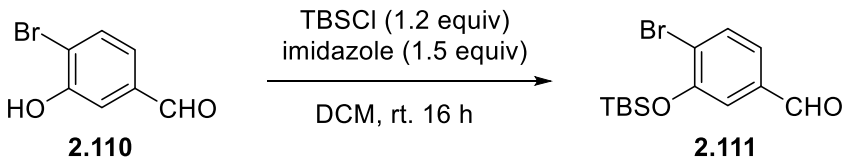
In a glovebox filled with argon, an oven-dried 25-mL round-bottom flask equipped with a magnetic stir bar was charged with 2-(4-methylpentyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane **2.104** (212.1 mg, 1 mmol, 1 equiv), sodium trifluoromethanesulfonate (516.2 mg, 3 mmol, 3 equiv), anhydrous THF (2 mL), and anhydrous DMSO (2 mL), sealed with a septum, and removed from the glovebox. Under positive nitrogen pressure, the reaction vial was cooled to 0 ºC in an ice-water bath, and vinylmagnesium chloride solution in THF (1.2 mmol, 1.2 equiv) was added dropwise with stirring. The reaction vial was allowed to warm to room temperature and stir for 30 minutes before being brought back into the glovebox. In the glovebox, an oven-dried 2-dram vial equipped with a magnetic stirbar was charged with $Pd_2(dba)_3$ (45.8 mg, 0.05 mmol, 0.05 equiv), PCy_3 (56.1 mg, 0.2 mmol, 0.2 equiv), anhydrous DMSO (3 mL), and anhydrous THF (2 mL). The $Pd_2(dba)_3$/PCy_3 solution was allowed to stir for 10 minutes at room temperature inside the glovebox. The $Pd_2(dba)_3$/PCy_3 solution was then transferred into the round-bottom flask, followed by allyl acetate (120.1 mg, 1.2 mmol, 1.2 equiv) and anhydrous THF (1 mL, used

to rinse the $Pd_2(dba)_3/PCy_3$ vial). The round-bottom flask was sealed with the septum and electrical tape, brought out of the glovebox, and stirred at 60 ºC for 18 hours. After cooling to room temperature, the resulting mixture was transferred to a separatory funnel with the aid of EtOAc (5 mL). The organic phase was washed with water (2 x 10 mL), and the combined aqueous phases were extracted with EtOAc (20 mL). The combined organic phases were dried over Na_2SO_4, filtered, concentrated *in vacuo*, filtered through a silica gel plug with EtOAc, re-concentrated, and purified by silica gel column chromatography (0% → 15% DCM in hexanes, stained in CAM) to afford **4,4,5,5-tetramethyl-2-(5-methyl-1-methylenehexyl)-1,3,2-dioxaborolane (2.105)** as a clear, colorless oil (148.1 mg, 62% yield).



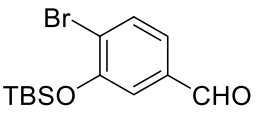
4,4,5,5-tetramethyl-2-(5-methyl-1-methylenehexyl)-1,3,2-dioxaborolane (2.105). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 5.75 (s, 1H), 5.59 (s, 1H), 2.12 (t, *J* = 7.2 Hz, 2H), 1.56 – 1.50 (m, 1H), 1.41 (app p, *J* = 7.7 Hz, 2H), 1.26 (s, 12H), 1.16 (app q, *J* = 7.6 Hz, 2H), 0.86 (d, *J* = 6.6 Hz, 6H). **^{11}B NMR** (128 MHz, $CDCl_3$) δ 30.37. **^{13}C NMR** (150 MHz, $CDCl_3$) δ 128.8, 83.4, 38.7, 35.8, 28.0, 27.1, 24.9, 22.8; carbon α to boron was not observed. **IR** (neat) ν_{max} 2955.43 (m), 2927.87 (m), 2858.37 (w), 1697.06 (w), 1463.11 (m), 1368.61 (m), 1306.98 (m), 1142.42 (s), 1098.05 (m), 937.43 (m), 833.92 (s), 776.12 (m), 698.66 (m) cm^{-1}. **HRMS** (DART+) for $C_{14}H_{28}BO_2$ $[M+H]^+$ calculated: 239.2177, found: 239.2185.

2.4.6.2. Silylation of 4-Bromo-3-hydroxybenzaldehyde



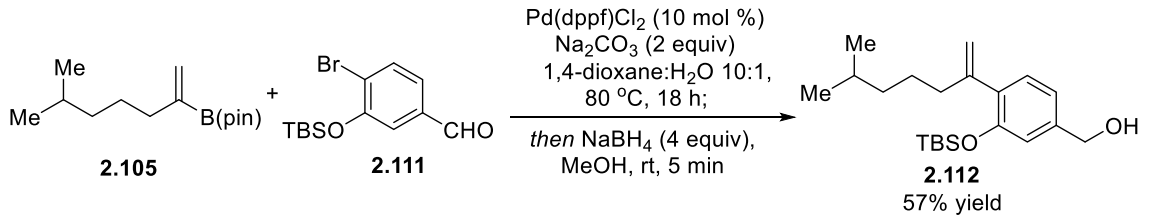
2.110 **2.111**

A flame-dried 25 mL round-bottom flask equipped with a magnetic stir bar was charged with 4-bromo-3-hydroxybenzaldehyde **2.110** (500.0 mg, 2.49 mmol, 1 equiv), *tert*-butylchlorodimethylsilane (449.9 mg, 2.98 mmol, 1.2 equiv), imidazole (254.0 mg, 3.73 mmol, 1.5 equiv), and anhydrous DCM (5 mL). The solution was stirred at room temperature for 16 hours. Water (5 mL) was added, the phases were separated, and the aqueous phase was extracted with pentanes (10 mL x 2). The combined organic phases were dried over Na_2SO_4, filtered, concentrated *in vacuo*, filtered through a silica gel plug with EtOAc, re-concentrated, and purified by silica gel column chromatography (30% EtOAc in hexanes, stained in $KMnO_4$) to afford **4-bromo-3-(*tert*-butyldimethylsilyl)oxybenzaldehyde (2.111)** as a yellow oil (718.1 mg, 92% yield).



4-bromo-3-(*tert*-butyldimethylsilyl)oxybenzaldehyde (2.111). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 9.91 (s, 1H), 7.71 (d, J = 8.5 Hz, 1H), 7.33 – 7.32 (m, 2H), 1.06 (s, 9H), 0.29 (s, 6H). **^{13}C NMR** (125 MHz, $CDCl_3$) δ 191.1, 153.6, 136.9, 134.3, 124.2, 123.4, 119.1, 25.8, 18.5, –4.1. **IR** (neat) ν_{max} 2930.04 (w), 2858.14 (w), 1704.63 (s), 1585.23 (m), 1568.81 (w), 1473.28 (m), 1422.16 (m), 1386.59 (w), 1294.50 (w), 1279.38 (w), 1262.00 (w), 1035.69 (w), 852.72 (m) cm^{-1}. **HRMS** (DART+) for $C_{13}H_{20}O_2SiBr$ $[M+H]^+$ calculated: 315.0411, found: 315.0410.

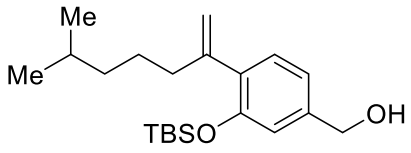
2.4.6.3. Suzuki–Miyaura Cross-Coupling and Reduction



Following a literature procedure:[58] In a glovebox filled with argon, an oven-dried 2-dram vial equipped with a magnetic stir bar was charged with 4,4,5,5-tetramethyl-2-(5-methyl-1-methylenehexyl)-1,3,2-dioxaborolane **(2.105)** (47.6 mg, 0.2 mmol, 1 equiv), 4-bromo-3-(*tert*-butyldimethylsilyl)oxybenzaldehyde **(2.111)** (63.1 mg, 0.2 mmol, 1 equiv), $Pd(dppf)Cl_2$ (16.3 mg, 0.02 mmol, 0.1 equiv), Na_2CO_3 (42.4 mg, 0.4 mmol, 2 equiv), and anhydrous 1,4-dioxane (2 mL). The vial was sealed with a septum cap and removed from the glovebox. Under positive nitrogen pressure, water (0.2 mL) was added. The septum cap was quickly replaced with a polypropylene cap, sealed with electrical tape, and stirred at 80°C for 18 hours. The reaction was allowed to cool to room temperature, partitioned with saturated aqueous ammonium chloride (2 mL) and EtOAc (2 mL), and the phases separated. The aqueous phase was extracted with EtOAc (2 mL), and the combined organic phases were washed with brine (4 mL), dried over Na_2SO_4, filtered through a silica plug, and concentrated *in vacuo*. The residue was dissolved in methanol (2 mL), sodium borohydride (30.3 mg, 0.8 mmol, 4 equiv) was added, and the mixture was stirred for 5 minutes. The reaction was quenched with water (2 mL), partitioned with EtOAc (2 mL), and the phases separated. The aqueous phase was extracted with EtOAc (2 mL), and the combined organic phases were washed with brine (4 mL) dried over Na_2SO_4, filtered,

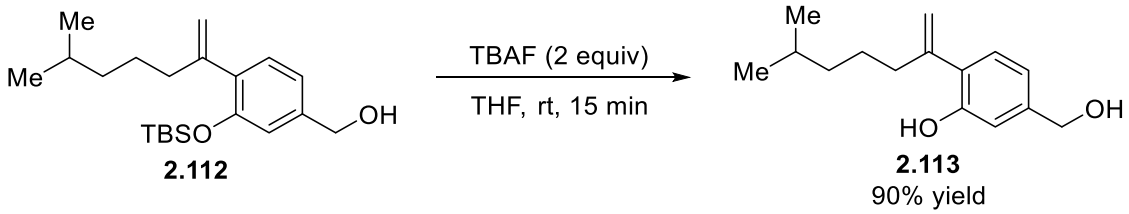
[58] Higuchi, R. I.; Roach, S. L.; Zhi, L.; Adams, M. E.; Liu, Y.; Karanewsky, D. S.; Hudson, A. Intracellular Receptor Modulator Compounds and Methods. WO2006019716A1, February 23, 2006.

concentrated *in vacuo*, and purified by silica gel column chromatography (30% EtOAc/hexanes, stained in $KMnO_4$) to afford **[3-(*tert*-butyldimethylsilyl)oxy-4-(5-methyl-1-methylenehexyl)phenyl]methanol (2.112)** as a clear, colorless oil (40.0 mg, 57% yield).



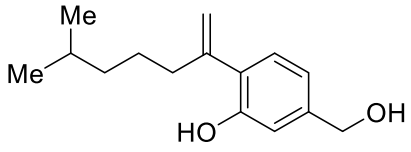
[3-(*tert*-butyldimethylsilyl)oxy-4-(5-methyl-1-methylene-hexyl)phenyl]methanol (2.112). ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.09 (d, *J* = 7.2 Hz, 1H), 6.89 (d, *J* = 7.8 Hz, 1H), 6.80 (s, 1H), 5.08 (s, 1H), 4.94 (d, *J* = 1.2 Hz, 1H), 4.63 (d, *J* = 4.8 Hz, 2H), 2.41 (t, *J* = 7.8 Hz, 2H), 1.57 (s, 1H), 1.53 – 1.46 (m, 1H), 1.33 (app p, *J* = 7.8 Hz, 2H), 1.16 (app q, *J* = 7.4 Hz, 2H), 0.98 (s, 9H), 0.83 (d, *J* = 6.6 Hz, 6H), 0.18 (d, 6H). **^{13}C NMR** (150 MHz, $CDCl_3$) δ 152.9, 149.2, 141.0, 134.6, 130.6, 119.6, 118.1, 114.0, 65.3, 38.8, 36.8, 28.0, 25.9, 22.8, 22.7, 18.3, –4.0. **IR** (neat) ν_{max} 3293.20 (m, br), 2953.27 (s), 2928.55 (s), 2857.99 (s), 1609.68 (w), 1561.18 (w), 1498.27 (m), 1471.28 (m), 1417.71 (s), 1363.41 (w), 1283.03 (m), 1254.25 (m), 1166.44 (w), 972.39 (w), 852.60 (m), 782.07 (m) cm^{-1}. **HRMS** (DART+) for $C_{21}H_{37}O_2Si$ $[M+H]^+$ calculated: 349.2557, found: 349.2542.

2.4.6.4. TBAF Desilylation



A 2-dram vial equipped with a magnetic stir bar was charged with [3-(*tert*-butyldimethylsilyl) oxy-4-(5-methyl-1-methylenehexyl)phenyl]methanol **(2.112)** (27.1 mg, 0.08 mmol, 1 equiv) and THF (0.8 mL). A 1 *M* solution of tetrabutylammonium

fluoride in THF (155 uL, 2 equiv) was added, and the mixture was stirred for 15 minutes. The reaction was partitioned with water (1 mL) and EtOAc (1 mL), and the phases separated. The aqueous phase was extracted with EtOAc (1 mL), and the combined organic phases were washed with brine (2 mL) dried over Na_2SO_4, filtered, concentrated *in vacuo*, and purified by silica gel column chromatography (0% → 30% Et_2O in pentanes, stained in $KMnO_4$) to afford **7-deoxy-7,14-didehydrosydonol (2.113)** as a clear, colorless oil (16.4 mg, 90% yield). The spectral data were in accord with the literature.[44]



7-deoxy-7,14-didehydrosydonol (2.113). ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.08 (d, *J* = 7.8 Hz, 1H), 6.95 (s, 1H), 6.89 (d, *J* = 7.8 Hz, 1H), 5.67 (s, 1H), 5.38 (d, *J* = 1.8 Hz, 1H), 5.12 (s, 1H), 4.65 (d, *J* = 6.0 Hz, 2H), 2.38 (t, *J* = 7.6 Hz, 2H), 1.54 – 1.48 (m, 1H), 1.43 (s, 1H), 1.42 – 1.37 (m, 2H), 1.20 – 1.16 (m, 2H), 0.84 (d, *J* = 6.6 Hz, 6H). **^{13}C NMR** (150 MHz, $CDCl_3$) δ 152.6, 146.7, 141.8, 128.2, 127.8, 118.7, 115.2, 114.0, 65.2, 38.7, 38.2, 27.9, 25.8, 22.7. **IR** (neat) ν_{max} 3343.42 (m, br), 2952.94 (s), 2927.65 (m), 2868.62 (w), 1617.44 (w), 1570.55 (w), 1423.98 (s), 1383.80 (m), 1366.18 (m), 1289.02 (m), 1168.35 (w), 1016.96 (m), 822.42 (m) cm^{-1}. **HRMS** (DART+) for $C_{15}H_{23}O_2$ $[M+H]^+$ calculated: 235.1693, found: 235.1685.

2.4.7. Density Functional Theory (DFT) Calculations

All calculations were performed using the Gaussian09 package of programs.[59] Geometry optimizations were carried out using the density functional BP86 in conjunction with the def2-SVP[60] basis set in tetrahydrofuran as solvent using the IEFPCM model.[61] Very tight convergence criteria and an ultrafine integration grid were applied. Stationary points were assessed through vibrational analysis and Gibbs free energy corrections were performed under standard conditions (298.15 K, 1.0 atm). Intrinsic Reaction Coordinate (IRC)[62] calculations were performed followed by subsequent optimization of the end points with the previously mentioned optimization method. Gibbs free energies have been assessed through single point calculations with the density functional PBE0-D3BJ[63] applying the larger def2-TZVPP[64] basis set and the SMD[65] solvent model, followed by addition of thermal corrections obtained at the level of geometry optimization (denoted as PBE0-D3BJ /def2-TZVPP$_{THF(SMD)}$//BP86/def2-SVP)$_{THF(PCM)}$).

[59] Frisch, M. J.; Trucks, G. W.; Schlegel, H. B.; Scuseria, G. E.; Robb, M. A.; Cheeseman, J. R.; Scalmani, G.; Barone, V.; Mennucci, B.; Petersson, G. A.; Nakatsuji, H.; Caricato, M.; Li, X.; Hratchian, H. P.; Izmaylov, A. F.; Bloino, J.; Zheng, G.; Sonnenberg, J. L.; Hada, M.; Ehara, M.; Toyota, K.; Fukuda, R.; Hasegawa, J.; Ishida, M.; Nakajima, T.; Honda, Y.; Kitao, O.; Nakai, H.; Vreven, T.; Montgomery, Jr., J. A.; Peralta, J. E.; Ogliaro, F.; Bearpark, M.; Heyd, J. J.; Brothers, E.; Kudin, K. N.; Staroverov, V. N.; Kobayashi, R.; Normand, J.; Raghavachari, K.; Rendell, A.; Burant, J. C.; Iyengar, S. S.; Tomasi, J.; Cossi, M.; Rega, N.; Millam, J. M.; Klene, M.; Knox, J. E.; Cross, J. B.; Bakken, V.; Adamo, C.; Jaramillo, J.; Gomperts, R.; Stratmann, R. E.; Yazyev, O.; Austin, A. J.; Cammi, R.; Pomelli, C.; Ochterski, J. W.; Martin, R. L.; Morokuma, K.; Zakrzewski, V. G.; Voth, G. A.; Salvador, P.; Dannenberg, J. J.; Dapprich, S.; Daniels, A. D.; Farkas, Ö.; Foresman, J. B.; Ortiz, J. V.; Cioslowski, J.; Fox, D. J. Gaussian 09, Revision D.01, Gaussian, Inc., Wallingford CT, 2009.

[60] Weigend, F.; Ahlrichs, R. *Phys. Chem. Chem. Phys.* **2005**, *7*, 3297.

[61] Scalmani, G.; Frisch, M. J. *J. Chem. Phys.* **2010**, *132*, 114110.

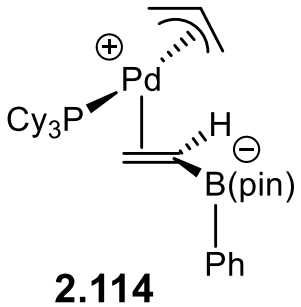
[62] (a) Page, M.; McIver Jr., J. W. *J. Chem. Phys.* **1988**, *88*, 922. (b) Page, M.; Doubleday Jr., C.; McIver Jr., J. W. *J. Chem. Phys.* **1990**, *93*, 5634.

[63] (a) Grimme, S.; Ehrlich, S.; Goerigk, L. *J. Comp. Chem.* **2011**, *32*, 1456. (b) Adamo, C.; Barone, V. *J. Chem. Phys.* **1999**, *110*, 6158.

[64] Weigend, F. *Phys. Chem. Chem. Phys.* **2006**, *8*, 1057.

[65] Marenich, A. V.; Cramer, C. J.; Truhlar, D. G. *J. Phys. Chem. B* **2009**, *113*, 6378.

Scheme 2.24. Calculated reaction coordinate for metal-induced metallate shift/β-hydrogen elimination involved in the vinylidenation reaction. Optimized geometries calculated using DFT (BP86/Def2-SVP; PCM solvent model with THF). ΔG Values are in kcal/mol, calculated using DFT (PBE0-D3BJ/def2-TZVPP//BP86/def2-SVP; SMD solvent model with THF). Hydrogen atoms removed from structures for clarity.



2.114

BP86 Optimization and Frequency Calculation:
Sum of electronic and thermal Free Energies= -2011.429186
Thermal correction to Gibbs Free Energy= 0.762606
Lowest frequency= 10.50 cm^{-1}
PB86-D3BJ Single Point Calculation:
Electronic Energy= -2012.066354

0 1

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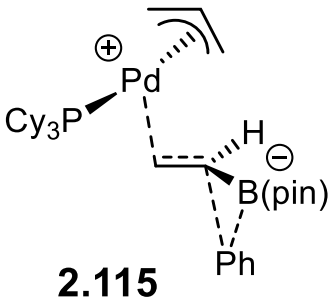
C	0.85358400	-1.38468900	0.34876300
C	1.91998000	-1.12473700	-0.51759300
H	2.08596300	-1.89746500	-1.29368300
H	0.30476200	-2.34417400	0.32440700
H	0.79296800	-0.82078500	1.29493800
B	3.20096400	-0.15251300	-0.15041400
O	3.60523300	0.76157200	-1.25444400
O	2.97223300	0.73590600	1.02039700
C	4.34136900	-1.31327800	0.20826900
C	4.65671600	-1.65276600	1.54642900
C	5.02520800	-2.02774600	-0.80698400
C	5.61172000	-2.63862200	1.86182500
H	4.14490800	-1.10770300	2.35842600
C	5.98479600	-3.01452400	-0.50907000
H	4.81252200	-1.79369000	-1.86570500
C	6.28191900	-3.32622100	0.83168600
H	5.83897200	-2.87255600	2.91630400

H	6.50639100	-3.54415400	-1.32485400
H	7.03126300	-4.09879600	1.07166100
C	1.20050900	0.00112900	-3.01919400
H	1.76161400	0.88455900	-2.66878000
H	1.82417000	-0.84529100	-3.34330800
C	-1.04138000	0.99900700	-2.84839200
H	-0.66387800	2.00409400	-2.59335000
H	-2.11407200	0.94082900	-3.09029900
C	-0.15776900	0.03337500	-3.40341000
H	-0.58032700	-0.82219500	-3.96098500
C	-2.37233000	-0.56353000	1.86088500
C	-2.12373300	-2.06208000	2.15331200
C	-1.52773600	0.32370200	2.80597900
H	-3.44679100	-0.35870200	2.07712600
C	-2.39926700	-2.39165200	3.63378700
H	-1.07121800	-2.32055400	1.91592800
H	-2.75832300	-2.70145500	1.50644400
C	-1.78756700	-0.02164200	4.28534600
H	-0.44824900	0.18736100	2.57612800
H	-1.74471500	1.39762100	2.63553800
C	-1.56100700	-1.51352900	4.57630900
H	-2.19551100	-3.46856900	3.81743200
H	-3.48177500	-2.23657700	3.84890300
H	-1.13812500	0.60692400	4.93180900
H	-2.83835800	0.24724500	4.54167600
H	-1.80148000	-1.74224900	5.63698700
H	-0.48202600	-1.75522500	4.44006800
C	-2.94402400	1.68404100	-0.03761900
C	-4.15899100	1.98239700	0.87293300
C	-1.88410600	2.79931900	0.12759600
H	-3.29886700	1.72227900	-1.09433300
C	-4.75596500	3.37043000	0.55962300
H	-3.84074700	1.96029400	1.93881900
H	-4.94725600	1.21088500	0.76398600
C	-2.47541400	4.18491000	-0.19156100
H	-1.50426300	2.80054900	1.17300000
H	-1.00308400	2.59467700	-0.51263900
C	-3.70741200	4.48804800	0.67685600
H	-5.61369400	3.56632300	1.23873400
H	-5.17175300	3.36084800	-0.47419300
H	-1.69676400	4.96526300	-0.05143200
H	-2.76363200	4.21972900	-1.26771300
H	-4.15187700	5.46702200	0.39538600
H	-3.39019900	4.58248800	1.74088900
C	-3.44535000	-1.13639200	-0.91495300
C	-2.79887900	-2.43715800	-1.45342000

C	-4.79925300	-1.44772900	-0.23546700
H	-3.65364900	-0.48762400	-1.79895900
C	-3.74795700	-3.18738000	-2.40609400
H	-2.53307000	-3.10377800	-0.60286600
H	-1.84177900	-2.19594600	-1.96545900
C	-5.74321900	-2.20386500	-1.19360400
H	-4.62982700	-2.07164200	0.66955400
H	-5.29642300	-0.51980900	0.11108500
C	-5.10052100	-3.48826400	-1.74027200
H	-3.26440500	-4.12594200	-2.75295500
H	-3.91565000	-2.56647100	-3.31633100
H	-6.69518000	-2.43489800	-0.66868300
H	-6.00975700	-1.53455100	-2.04381500
H	-5.78523200	-3.98860700	-2.45856000
H	-4.94552800	-4.20699000	-0.90285700
C	3.24525200	2.09116500	0.66016400
C	4.12666400	1.95242500	-0.65989500
C	3.95763300	2.79163100	1.82997500
H	4.24680600	3.83196500	1.56849800
H	3.27861100	2.84081000	2.70748400
H	4.86702600	2.24130300	2.13962400
C	1.90608000	2.80841300	0.38805300
H	1.25737900	2.70563000	1.28220000
H	2.02840900	3.89143700	0.17514800
H	1.38105800	2.33372000	-0.46635200
C	3.97004800	3.11033000	-1.65869400
H	4.28328400	4.07727500	-1.21120700
H	4.60942000	2.92738000	-2.54803300
H	2.92459000	3.21097600	-2.01019100
C	5.63037200	1.77353300	-0.34488100
H	6.15581100	1.46958600	-1.27432200
H	6.09636800	2.71186000	0.02236100
H	5.79424500	0.97971800	0.40985100



2.115

BP86 Optimization and Frequency Calculation:
Sum of electronic and thermal Free Energies = -2011.421128
Thermal correction to Gibbs Free Energy= 0.760387
Lowest frequency: -329.77 cm^{-1}

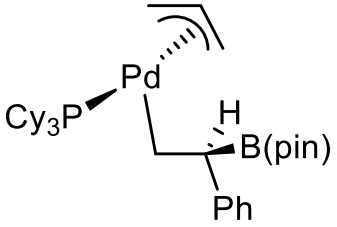
PB86-D3BJ Single Point Calculation:
Electronic Energy: -2012.045885

0 1

Pd	-0.43759900	-0.66064900	1.08696200
P	-2.39669400	-0.05291400	-0.07687300
C	0.89064400	0.76112900	0.15292700
C	2.11278300	0.55549900	0.89027900
H	2.14429900	1.00971800	1.89806300
H	0.38032900	1.73456900	0.29271600
H	0.92977200	0.46276800	-0.91243100
B	3.43018700	-0.08407400	0.38511700
O	4.37329900	-0.68914900	1.29320700
O	3.52691400	-0.75009100	-0.89415300
C	3.72086700	1.70170400	0.17464500
C	3.57665100	2.28246700	-1.10385700
C	4.40289300	2.43146300	1.17245600
C	4.13747300	3.53863500	-1.39455200
H	3.03176200	1.73058600	-1.88795300
C	4.95766200	3.69499800	0.89363800
H	4.52058000	1.99400500	2.17886000
C	4.82837800	4.25089500	-0.39329100
H	4.03491200	3.96940600	-2.40475100
H	5.49349500	4.24942700	1.68226900
H	5.26084400	5.24001100	-0.61568000
C	0.99840800	-1.80310800	2.35717900
H	1.34724900	-2.53138000	1.60506600
H	1.79006400	-1.30316300	2.93311000
C	-1.38192700	-2.41874100	2.10445800
H	-1.18446400	-3.21002600	1.36052500
H	-2.40821500	-2.38207100	2.50287800
C	-0.31780300	-1.88988900	2.88042600
H	-0.55605900	-1.35188400	3.81670400
C	-2.53716800	1.43132700	-1.24009300
C	-2.31319200	2.78142400	-0.51799800
C	-1.62013900	1.32133500	-2.48114200
H	-3.59389600	1.40770400	-1.59532500
C	-2.49642100	3.97422400	-1.47647800
H	-1.28539500	2.80475900	-0.09338700
H	-3.00600800	2.88780800	0.34160700
C	-1.81048500	2.51908400	-3.43209200
H	-0.55997400	1.27836100	-2.15216600
H	-1.81520400	0.37787600	-3.03090200
C	-1.59011000	3.85902300	-2.71228800
H	-2.29807900	4.92268900	-0.93206600
H	-3.56096400	4.01835600	-1.80383600

H	-1.11920600	2.42074200	-4.29681000
H	-2.84260400	2.49230600	-3.85202900
H	-1.77067500	4.70791200	-3.40674100
H	-0.52489700	3.93419600	-2.39448700
C	-2.95137800	-1.55872500	-1.09356200
C	-4.09388600	-1.35422400	-2.11477500
C	-1.75565300	-2.28213500	-1.76093300
H	-3.33040100	-2.23334100	-0.28952500
C	-4.52145600	-2.69415200	-2.74908600
H	-3.75557700	-0.66633800	-2.92128000
H	-4.97361300	-0.87347200	-1.64078200
C	-2.18775800	-3.61924800	-2.39087100
H	-1.31821500	-1.63209400	-2.55109200
H	-0.94743100	-2.44206800	-1.01487800
C	-3.33575600	-3.42803200	-3.39600600
H	-5.32405000	-2.51294600	-3.49646900
H	-4.96924500	-3.34202400	-1.96062600
H	-1.31536600	-4.10287800	-2.88104800
H	-2.51752500	-4.31300000	-1.58313700
H	-3.66349900	-4.40849000	-3.80437900
H	-2.96707200	-2.83480300	-4.26446500
C	-3.79856200	0.17748300	1.18876100
C	-3.31252500	0.88588400	2.47711700
C	-5.11652500	0.81531300	0.69233300
H	-4.01729000	-0.88172100	1.46317100
C	-4.39255700	0.86192200	3.57466900
H	-3.05155000	1.94294800	2.24633600
H	-2.37496600	0.41072000	2.83716300
C	-6.19650900	0.79288300	1.79398900
H	-4.93150300	1.87071700	0.39295700
H	-5.49880300	0.29608100	-0.20975600
C	-5.71456800	1.47538200	3.08439100
H	-4.02401300	1.39714600	4.47642500
H	-4.57035700	-0.19288900	3.88804000
H	-7.12253100	1.27878300	1.41727600
H	-6.46698200	-0.26524800	2.01577900
H	-6.49351900	1.40479400	3.87413200
H	-5.56391700	2.56235800	2.88975000
C	4.50098600	-1.80566800	-0.79045400
C	5.34568800	-1.39398600	0.49679000
C	5.31182800	-1.86515400	-2.09292200
H	6.11886800	-2.62528800	-2.03213300
H	4.64635900	-2.14517400	-2.93603500
H	5.76781000	-0.88558400	-2.33344100
C	3.74528400	-3.13646400	-0.59920400
H	3.02373900	-3.26316100	-1.43250300

H	4.42612200	-4.01274300	-0.59726900
H	3.17424400	-3.13581200	0.35087200
C	5.87860500	-2.57554100	1.31866800
H	6.56286400	-3.20899700	0.71640200
H	6.44901900	-2.19670800	2.19229900
H	5.05637900	-3.20969900	1.70203600
C	6.51269900	-0.44327200	0.15794000
H	6.92557200	-0.03092000	1.10168200
H	7.33268900	-0.96605300	-0.37634200
H	6.17459400	0.40867200	-0.46393200



2.116

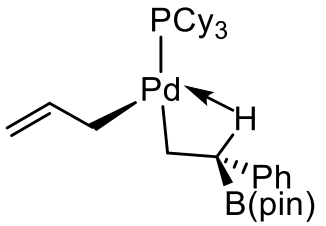
BP86 Optimization and Frequency Calculation:
Sum of electronic and thermal Free Energies= -2011.476634
Thermal correction to Gibbs Free Energy= 0.762371
Lowest frequency= 9.33 cm^{-1}
PB86-D3BJ Single Point Calculation:
Electronic Energy: -2012.108684

0 1

P	2.07776100	0.06804600	0.09698600
C	-0.91348600	1.01251400	-0.75338400
C	-2.42805000	0.94154900	-1.09118100
H	-2.56146900	0.87768000	-2.19146300
H	-0.50697200	1.97692000	-1.13392100
H	-0.79689200	1.03262900	0.35170200
B	-3.16840400	-0.31470600	-0.46498300
O	-4.16831200	-1.00613800	-1.12347100
O	-2.94715300	-0.79224000	0.81641500
C	-3.16598400	2.20661600	-0.64026700
C	-3.22861000	2.57976600	0.72547200
C	-3.79315400	3.05669900	-1.58172100
C	-3.88607200	3.75425200	1.13036600
H	-2.75747600	1.93081000	1.48093700
C	-4.45409300	4.23238900	-1.18110100

H	-3.75923700	2.78798800	-2.65121900
C	-4.50263400	4.58858700	0.17860200
H	-3.92097700	4.01940700	2.19997900
H	-4.93205100	4.87567300	-1.93818300
H	-5.01811000	5.50947000	0.49551500
C	-0.96333300	-1.24631700	-2.97574700
H	-1.63605800	-1.92897200	-2.42760300
H	-1.47507800	-0.53588900	-3.64466700
C	1.11789800	-2.49726300	-2.46333600
H	0.62057300	-3.17044600	-1.74428800
H	2.16367700	-2.73077800	-2.70868200
C	0.36157500	-1.67457200	-3.31372400
H	0.87628800	-1.18379300	-4.16147500
Pd	0.38541600	-0.49191200	-1.46213800
C	1.92693900	-0.95071700	1.67996600
C	0.66685000	-0.59760300	2.50299100
C	1.94430100	-2.46363200	1.36186700
H	2.81950400	-0.71400200	2.30156900
C	0.58940600	-1.44373800	3.78973900
H	-0.24191300	-0.77668400	1.88582900
H	0.65727100	0.48038600	2.76929700
C	1.86889900	-3.31335600	2.64409600
H	1.07323500	-2.69333700	0.70726900
H	2.84912100	-2.73535200	0.77703200
C	0.63641000	-2.95110900	3.48900200
H	-0.33568200	-1.18800300	4.35068900
H	1.44197900	-1.17515500	4.45575700
H	1.85722400	-4.39335100	2.38037200
H	2.79169500	-3.14951100	3.24741600
H	0.62664200	-3.53648200	4.43412100
H	-0.28422000	-3.23919500	2.93188200
C	3.91241200	-0.07718100	-0.42684600
C	4.90842700	-0.49271800	0.68138200
C	4.13719200	-0.93024800	-1.69186000
H	4.15192800	0.97495800	-0.70634400
C	6.36624600	-0.39372700	0.18704100
H	4.70500100	-1.54263300	0.98908600
H	4.78200800	0.13085000	1.58983800
C	5.59274100	-0.83406600	-2.18671400
H	3.89549800	-1.99285900	-1.46450300
H	3.43264200	-0.61660000	-2.48990100
C	6.59530700	-1.22192000	-1.08748100
H	7.05749400	-0.71958000	0.99455500
H	6.60849500	0.67440800	-0.01922800
H	5.72947700	-1.47623200	-3.08388000
H	5.79613100	0.21087500	-2.51740300

H	7.63900600	-1.09725000	-1.44932800
H	6.47473600	-2.30361400	-0.84706900
C	1.99830300	1.86599900	0.68239800
C	2.91176700	2.26191900	1.86321300
C	2.19035900	2.85361800	-0.49299900
H	0.94206400	1.96836200	1.01912500
C	2.63823800	3.71277300	2.31080900
H	3.97797300	2.17882000	1.55393500
H	2.77689800	1.57335500	2.72403700
C	1.91751200	4.30469500	-0.05264200
H	3.23692400	2.78669100	-0.87033200
H	1.53238200	2.57330300	-1.34233200
C	2.79165600	4.70692800	1.14742400
H	3.31909400	3.98379600	3.14696600
H	1.60266100	3.77766800	2.71710500
H	2.08694600	4.99634500	-0.90630800
H	0.84235400	4.40374200	0.22168000
H	2.54151100	5.73696400	1.48247300
H	3.85965700	4.73308500	0.82886600
C	-4.03771800	-1.71454200	1.14645700
C	-4.56926800	-2.14191300	-0.29006900
C	-5.06641400	-0.91296400	1.96064300
H	-5.48450300	-0.07079400	1.37354300
H	-5.90393700	-1.55296400	2.30369200
H	-4.56795100	-0.48940600	2.85587900
C	-3.47829400	-2.86103200	1.99111100
H	-2.63123000	-3.36788400	1.49144700
H	-3.11835600	-2.46926700	2.96395300
H	-4.26533100	-3.61443500	2.19997400
C	-6.08793200	-2.30624300	-0.39280900
H	-6.36401200	-2.58814000	-1.42923700
H	-6.44474600	-3.10936400	0.28422700
H	-6.62144600	-1.37022000	-0.14109600
C	-3.86442300	-3.38549900	-0.85467700
H	-4.17907000	-4.30854900	-0.32764200
H	-4.12707900	-3.49422800	-1.92625300
H	-2.76192700	-3.29905100	-0.77861400



2.117

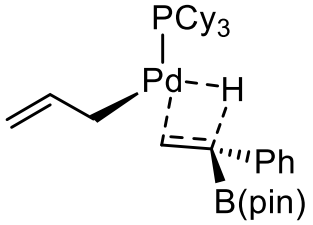
BP86 Optimization and Frequency Calculation:
Sum of electronic and thermal Free Energies= -2011.462496
Thermal correction to Gibbs Free Energy= 0.756593
Lowest frequency= 6.32 cm^{-1}
PB86-D3BJ Single Point Calculation:
Electronic Energy= -2012.08376

0 1

P	-2.00307200	-0.06951300	0.30498500
C	1.70895900	0.43005400	-2.02248600
C	2.17933100	0.72811300	-0.59448900
H	1.32024700	0.44177100	0.13765900
H	1.77925200	1.29127100	-2.71605500
H	2.12850400	-0.48632900	-2.48348700
B	3.31360200	-0.31653500	-0.19664900
O	4.66025700	-0.03972800	-0.21597800
O	3.02045800	-1.61758800	0.15220200
C	2.52701300	2.17675200	-0.29854200
C	3.42754900	2.88589100	-1.12783600
C	1.98991500	2.84852100	0.82294200
C	3.77819000	4.21685900	-0.84355100
H	3.86407200	2.38328600	-2.00557900
C	2.33935300	4.17985900	1.11144900
H	1.27942200	2.31817000	1.47887500
C	3.23615100	4.87161500	0.27790700
H	4.48262300	4.74716200	-1.50482500
H	1.90229800	4.68071100	1.99044900
H	3.50888400	5.91592900	0.49870200
C	-1.04937800	-0.12593300	-3.09404700
H	-0.93417300	0.89702700	-3.51475100
H	-2.12314500	-0.34875100	-2.94388200
Pd	-0.15526900	0.09587800	-1.20619600
C	-3.18298600	1.40315600	0.19479200
C	-2.46738600	2.72637500	0.55222900
C	-3.81283200	1.50888400	-1.21356200
H	-3.99844700	1.23505200	0.93450800
C	-3.41242700	3.93810600	0.43103200
H	-1.59762500	2.85856000	-0.13319000

H	-2.05227300	2.68641900	1.58129100
C	-4.77066400	2.71019600	-1.32209200
H	-2.99475600	1.62294000	-1.95869800
H	-4.34735000	0.57191600	-1.47913300
C	-4.06288400	4.02578600	-0.95914800
H	-2.85427400	4.87175300	0.66037500
H	-4.21073600	3.85415000	1.20432600
H	-5.19077600	2.76377700	-2.34992400
H	-5.63668700	2.55488900	-0.63776800
H	-4.77615100	4.87749300	-1.00056900
H	-3.27598600	4.23831200	-1.71902000
C	-3.10263300	-1.62448900	0.31914100
C	-4.56859400	-1.44198300	0.77473200
C	-3.04616700	-2.39796000	-1.01681600
H	-2.59280400	-2.26220700	1.07966700
C	-5.29310200	-2.79987700	0.87868400
H	-5.10825800	-0.80381900	0.03989100
H	-4.62283500	-0.91277700	1.74802600
C	-3.77028900	-3.75298300	-0.91367300
H	-3.52588900	-1.78839800	-1.81639700
H	-1.99047400	-2.53900700	-1.33039800
C	-5.22421200	-3.58735100	-0.44035700
H	-6.35051800	-2.63841600	1.18204700
H	-4.82353700	-3.40118200	1.69121500
H	-3.73621000	-4.27557600	-1.89430800
H	-3.22148500	-4.40429700	-0.19440900
H	-5.71266200	-4.57939700	-0.32551300
H	-5.80340000	-3.04257900	-1.22156900
C	-1.36179700	0.00790200	2.09004600
C	-2.41614100	0.08802600	3.21502600
C	-0.35315500	-1.12829000	2.37806000
H	-0.78539100	0.96305200	2.09371000
C	-1.75094900	0.26648600	4.59517800
H	-3.01410600	-0.85082200	3.22655800
H	-3.13189800	0.91760300	3.03248500
C	0.30871100	-0.95920300	3.75927500
H	-0.88081200	-2.10957700	2.34923300
H	0.42279400	-1.17224100	1.58351300
C	-0.73455800	-0.85078000	4.88379600
H	-2.53007500	0.29947200	5.38752900
H	-1.23332500	1.25299200	4.62480700
H	1.00144500	-1.80710200	3.95067700
H	0.93686600	-0.03862100	3.74986800
H	-0.23534400	-0.67845900	5.86198300
H	-1.27523200	-1.82118200	4.97567100
C	4.28680500	-2.36479800	0.15731600

C	5.35869700	-1.20533800	0.34504700
C	-0.88975500	-2.34660800	-4.31188900
H	-0.31589600	-3.03976100	-4.94901000
H	-1.89223400	-2.67741000	-3.98832800
C	-0.38424700	-1.14233800	-3.93904100
H	0.62518500	-0.87817000	-4.30964200
C	4.38880100	-3.07169500	-1.20289400
H	5.29111400	-3.71268700	-1.26177000
H	3.49814000	-3.71636600	-1.34414500
H	4.42068200	-2.34449700	-2.03924800
C	4.24225500	-3.39229900	1.28926500
H	3.45545100	-4.14514000	1.08051100
H	5.21076800	-3.92690700	1.37089200
H	4.01628700	-2.92250300	2.26507400
C	5.64891900	-0.87649300	1.81753500
H	6.24314200	-1.67590700	2.30364500
H	6.23001800	0.06614100	1.86918900
H	4.71368900	-0.73352700	2.39535200
C	6.66602600	-1.40377500	-0.42371200
H	7.33769300	-0.53902700	-0.24878800
H	7.19041200	-2.31723700	-0.07600200
H	6.49538600	-1.48878900	-1.51351200



2.118

BP86 Optimization and Frequency Calculation:
Sum of electronic and thermal Free Energies= -2011.446985
Thermal correction to Gibbs Free Energy= 0.756808
Lowest frequency= -448.75 cm^{-1}
PB86-D3BJ Single Point Calculation:
Electronic Energy= -2012.069914

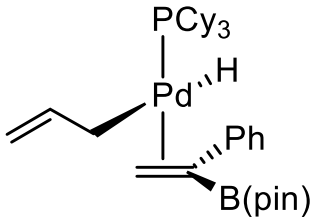
0 1

P	-1.78410600	-0.13134400	0.33212000
C	1.69374900	0.72000200	-2.36219300
C	2.14737200	0.88291700	-1.00611300
H	0.95248600	0.24694900	0.10354100
H	1.45278700	1.60734200	-2.97133000

H	2.01776700	-0.16993100	-2.92486300
B	3.11460400	-0.24506700	-0.45998500
O	4.18919700	0.01588400	0.36088700
O	3.01617600	-1.57079100	-0.83151000
C	2.31037700	2.26991300	-0.42686800
C	2.63813600	3.36707400	-1.25775100
C	2.22050300	2.50290800	0.96695300
C	2.85438100	4.64877100	-0.71859900
H	2.74541400	3.21412400	-2.34284200
C	2.43832200	3.77860500	1.50844700
H	1.96209600	1.66428100	1.63350500
C	2.75432500	4.86239100	0.66628000
H	3.10914800	5.48433800	-1.39040600
H	2.35719400	3.93039700	2.59689400
H	2.92229200	5.86561100	1.08935500
C	-1.19087600	0.15322800	-3.04160800
H	-1.15665400	1.22274900	-3.34621000
H	-2.23869000	-0.12177300	-2.81912700
Pd	-0.02784800	0.20674600	-1.19427700
C	-2.94966600	1.35485800	0.39412900
C	-2.20636900	2.62878000	0.85997800
C	-3.65100400	1.61740600	-0.95767200
H	-3.73022500	1.10891600	1.14962200
C	-3.14899800	3.84651500	0.92708600
H	-1.37259500	2.83442300	0.14922300
H	-1.73675000	2.47386800	1.85384400
C	-4.60981100	2.82001800	-0.87195400
H	-2.87700100	1.82115500	-1.72823700
H	-4.20146500	0.71584300	-1.30064700
C	-3.87691000	4.08820000	-0.40511300
H	-2.57183500	4.74817400	1.22631700
H	-3.90262200	3.67790300	1.73080900
H	-5.08855700	2.98791600	-1.86101900
H	-5.43522300	2.58598300	-0.16036000
H	-4.58749800	4.93782400	-0.31008700
H	-3.13371600	4.38584700	-1.18023100
C	-2.87611600	-1.68582400	0.20148900
C	-4.34417700	-1.54393200	0.66843100
C	-2.81755400	-2.36681900	-1.18168600
H	-2.36711100	-2.37470800	0.91603000
C	-5.05169500	-2.91486500	0.68833800
H	-4.88983400	-0.86692900	-0.02568700
H	-4.40580200	-1.07852700	1.67323400
C	-3.51682800	-3.73821600	-1.15782400
H	-3.31908000	-1.71763700	-1.93346000
H	-1.76407500	-2.46514600	-1.51731700

C	-4.97229500	-3.62283700	-0.67432300
H	-6.11109100	-2.78384400	0.99912700
H	-4.57581600	-3.55711800	1.46499300
H	-3.47689000	-4.19949300	-2.16840800
H	-2.95602900	-4.42291300	-0.48001500
H	-5.44597100	-4.62690100	-0.61666000
H	-5.56047700	-3.04231400	-1.42219600
C	-1.14192500	-0.24552600	2.11574000
C	-2.20166200	-0.23795000	3.23912900
C	-0.17197600	-1.43275000	2.30393900
H	-0.53597900	0.68584700	2.20448300
C	-1.53824500	-0.20055800	4.63128200
H	-2.82523800	-1.15714600	3.16748600
H	-2.89311900	0.62437000	3.13223800
C	0.48791800	-1.40755500	3.69611100
H	-0.72587000	-2.39264600	2.18689100
H	0.60216600	-1.41685700	1.50606300
C	-0.55709500	-1.36803400	4.82367900
H	-2.32073900	-0.21412500	5.42072600
H	-0.99259400	0.76401300	4.74833600
H	1.15232800	-2.29088300	3.81358100
H	1.14441900	-0.51022700	3.77062900
H	-0.05753400	-1.29701600	5.81412500
H	-1.12614000	-2.32639900	4.82857500
C	4.25951600	-2.23515900	-0.42446700
C	4.80214900	-1.26979500	0.71826700
C	-1.08635500	-1.90657600	-4.54234900
H	-0.55360900	-2.47801900	-5.32066200
H	-2.01878800	-2.34841900	-4.14947300
C	-0.60996900	-0.71756100	-4.08580200
H	0.32805500	-0.35156500	-4.54919600
C	5.16479000	-2.27755100	-1.66584300
H	6.10857900	-2.82280200	-1.46483400
H	4.63105600	-2.80249900	-2.48352100
H	5.41754600	-1.25839400	-2.02176600
C	3.92690800	-3.65523100	0.03732100
H	3.53877600	-4.24532100	-0.81738900
H	4.83486600	-4.16585200	0.41864200
H	3.15863500	-3.66133800	0.83329600
C	4.28788400	-1.63096700	2.11943200
H	4.75246600	-2.56394400	2.49619400
H	4.54289200	-0.81119400	2.82081400
H	3.18706800	-1.75884600	2.12855300
C	6.32148500	-1.09010300	0.74211700
H	6.60218800	-0.38707800	1.55234000
H	6.82725400	-2.05714000	0.94042600

H	6.70402700	-0.68114500	-0.21201300



2.119

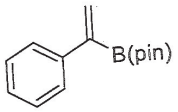
BP86 Optimization and Frequency Calculation:
Sum of electronic and thermal Free Energies= -2011.448913
Thermal correction to Gibbs Free Energy= 0.757938
Lowest frequency= 7.85 cm^{-1}
PB86-D3BJ Single Point Calculation:
Electronic Energy= -2012.074021

0 1

P	-1.74990600	-0.18219400	0.29071800
C	1.79926200	0.93705800	-2.30970100
C	2.28110200	1.00343400	-0.98207500
H	0.78431500	-0.08189000	0.37791600
H	1.48824900	1.84532800	-2.84981800
H	2.06639200	0.07047200	-2.93378000
B	3.12883800	-0.22207600	-0.46895000
O	4.03721700	-0.14661400	0.56919700
O	3.14411300	-1.45054600	-1.11016700
C	2.37153200	2.31977700	-0.25869000
C	2.54930000	3.53085400	-0.97206600
C	2.34778200	2.38951900	1.15724000
C	2.68346300	4.75997300	-0.30172900
H	2.60639900	3.51072100	-2.07168500
C	2.48465900	3.61393500	1.82832500
H	2.20924300	1.46127900	1.73170700
C	2.65020200	4.80951400	1.10236000
H	2.82355800	5.68456600	-0.88490600
H	2.45871100	3.63704100	2.92990000
H	2.75576600	5.77139600	1.62910100
C	-1.01880200	0.62468100	-2.90819100
H	-0.91806600	1.72586300	-3.02292500
H	-2.08120200	0.38712200	-2.71691800
Pd	0.13003100	0.27866100	-1.03901400

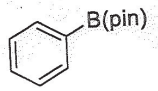
C	-2.74562300	1.39772600	0.58434500
C	-1.91549100	2.45436500	1.35068000
C	-3.31361200	2.01542500	-0.71281200
H	-3.60290900	1.09530100	1.22762400
C	-2.74159500	3.72409100	1.63700200
H	-1.01953700	2.71518000	0.74170600
H	-1.53254200	2.04322600	2.30782800
C	-4.16015400	3.26721400	-0.41343600
H	-2.46808100	2.29759800	-1.37549600
H	-3.91766900	1.27374700	-1.27646600
C	-3.34798900	4.32091100	0.35670500
H	-2.10344600	4.47355900	2.15317100
H	-3.56193400	3.47050800	2.34766600
H	-4.54748200	3.69191900	-1.36481000
H	-5.05357700	2.97592600	0.18597900
H	-3.98185100	5.20063500	0.60172800
H	-2.52741000	4.69745300	-0.29628000
C	-2.98661900	-1.55467800	-0.18273600
C	-4.47103600	-1.28752500	0.16073800
C	-2.85573300	-2.06581300	-1.63131900
H	-2.64337500	-2.38655100	0.47554100
C	-5.32113500	-2.55585500	-0.05980000
H	-4.86157600	-0.47253400	-0.48788100
H	-4.58791300	-0.94016800	1.20752600
C	-3.69476500	-3.33921700	-1.84518700
H	-3.20932500	-1.27928900	-2.33303000
H	-1.78988100	-2.24644200	-1.88359900
C	-5.17260400	-3.10762500	-1.48735900
H	-6.38708900	-2.33340200	0.16405700
H	-5.00466000	-3.33515900	0.67135500
H	-3.59771100	-3.68120700	-2.89834300
H	-3.28469400	-4.15967100	-1.21168300
H	-5.75403900	-4.04827400	-1.60046900
H	-5.61237400	-2.37981000	-2.20775900
C	-1.27446500	-0.71202300	2.05180600
C	-2.43095400	-0.79828700	3.07198500
C	-0.45128300	-2.01846500	2.06265100
H	-0.58819700	0.10684400	2.36736000
C	-1.90363300	-1.11666400	4.48645700
H	-3.13788200	-1.60251600	2.76791900
H	-3.01475300	0.14577100	3.09773100
C	0.07098300	-2.34414200	3.47518200
H	-1.08172200	-2.86634400	1.70867100
H	0.39443900	-1.93072000	1.34630400
C	-1.06915300	-2.40711500	4.50501300
H	-2.75664200	-1.19226300	5.19512000

H	-1.27689500	-0.26617600	4.84063100
H	0.63233800	-3.30324000	3.45572500
H	0.80108200	-1.56040600	3.78164300
H	-0.66358800	-2.59277000	5.52313000
H	-1.72951400	-3.27335500	4.26866600
C	4.30612200	-2.19250400	-0.61857200
C	4.59541700	-1.48571500	0.77624700
C	-1.07583900	-1.13890300	-4.75454300
H	-0.59148200	-1.58848800	-5.63738400
H	-2.02919200	-1.58858800	-4.42792200
C	-0.51611400	-0.08385400	-4.10456000
H	0.43498800	0.29714800	-4.52624400
C	5.43142000	-1.98839500	-1.64655000
H	6.33609600	-2.57345200	-1.38584500
H	5.07673600	-2.32684600	-2.64100200
H	5.71679200	-0.92034300	-1.73109700
C	3.93939000	-3.67525700	-0.52468500
H	3.73739500	-4.07594000	-1.53877700
H	4.77550900	-4.25967600	-0.08865100
H	3.03580900	-3.83845400	0.09248100
C	3.82722700	-2.11413000	1.94840100
H	4.22986700	-3.11211600	2.21357400
H	3.92171900	-1.45751500	2.83669300
H	2.74922300	-2.22090000	1.71473300
C	6.07722100	-1.34284100	1.13118900
H	6.18043900	-0.82512100	2.10635600
H	6.55656300	-2.33902100	1.22262700
H	6.62801200	-0.75462400	0.37309500

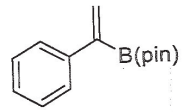


2.62

The peaks marked with an asterisk correspond to inseparable co-eluting starting material:

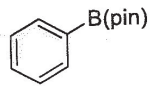


2.63

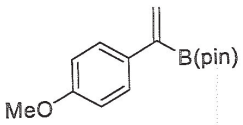


2.62

The peaks marked with an asterisk correspond to inseparable co-eluting starting material:

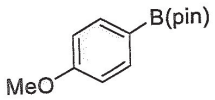


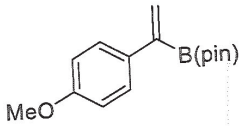
2.63



2.81

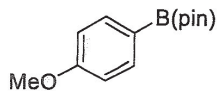
The peaks marked with an asterisk correspond to inseparable co-eluting starting material:

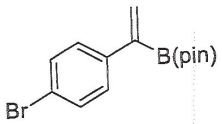




2.81

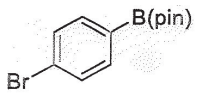
The peaks marked with an asterisk correspond to inseparable co-eluting starting material:

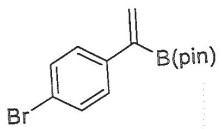




2.82

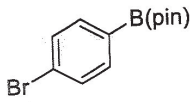
The peaks marked with an asterisk correspond to inseparable co-eluting starting material:

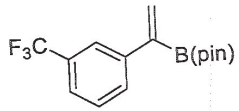




2.82

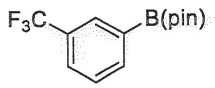
The peaks marked with an asterisk correspond to inseparable co-eluting starting material:

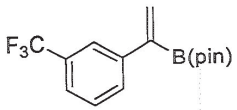




2.83

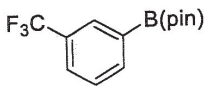
The peaks marked with an asterisk correspond to inseparable co-eluting starting material:

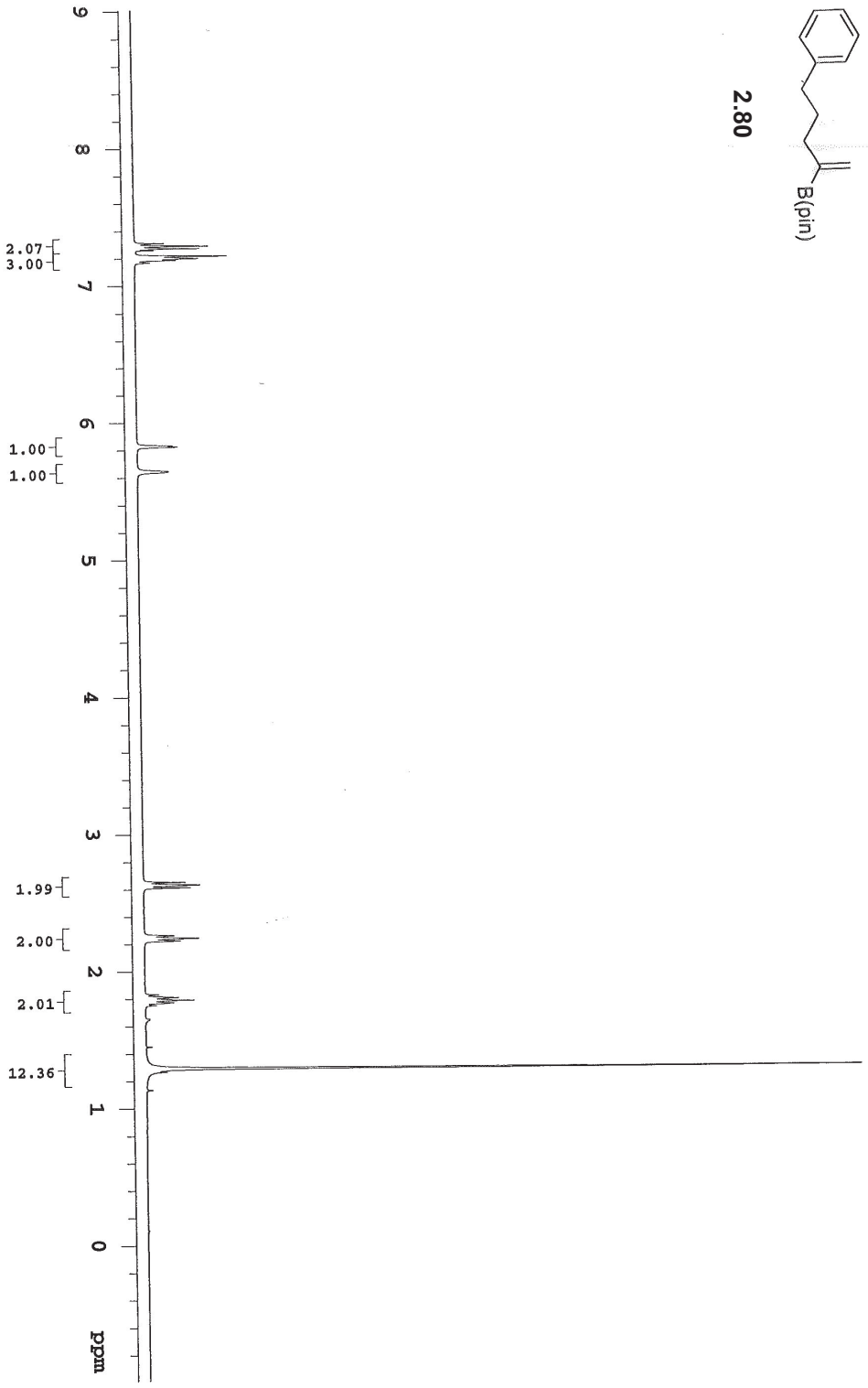




2.83

The peaks marked with an asterisk correspond to inseparable co-eluting starting material:

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6
5
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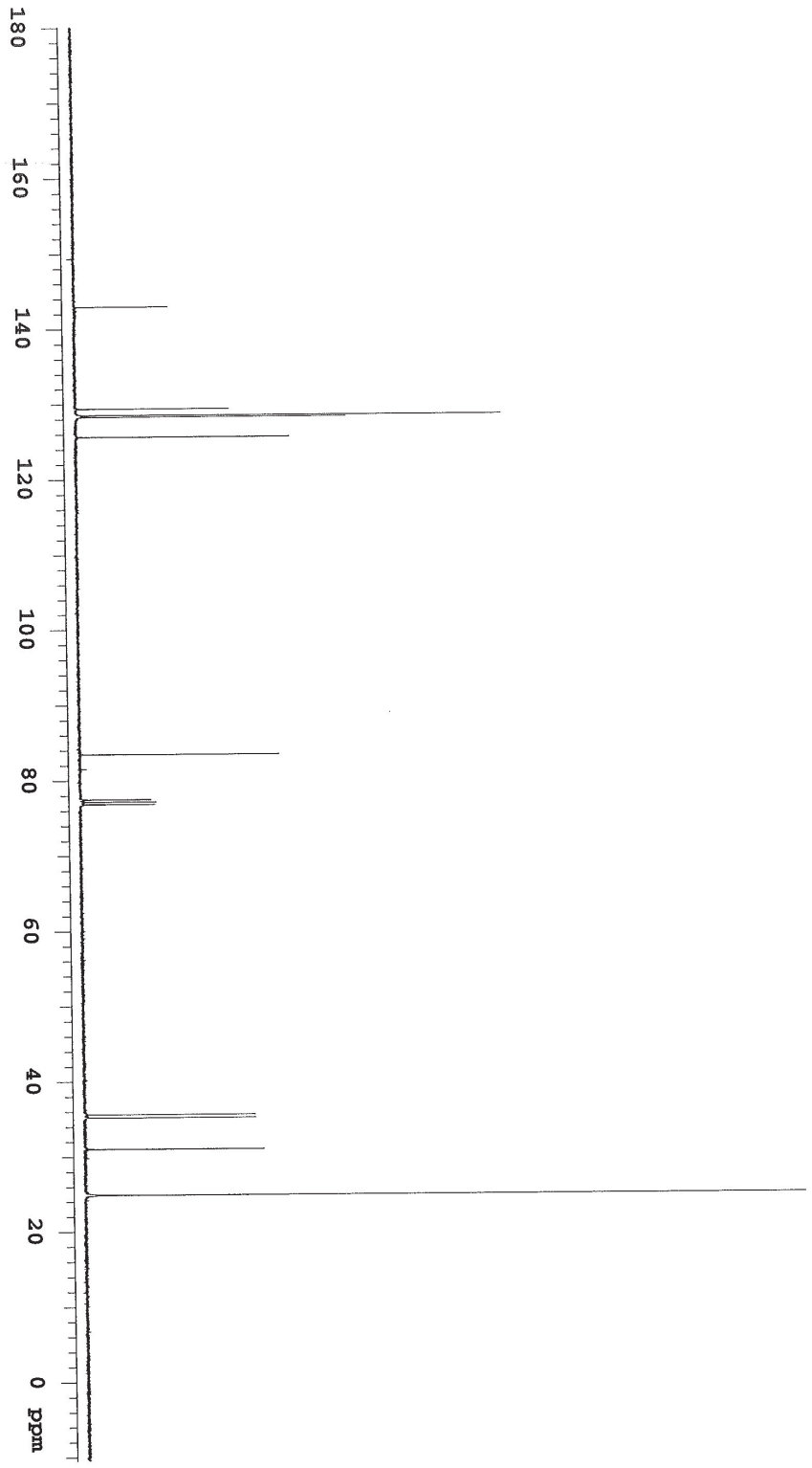
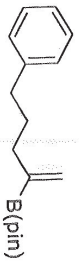
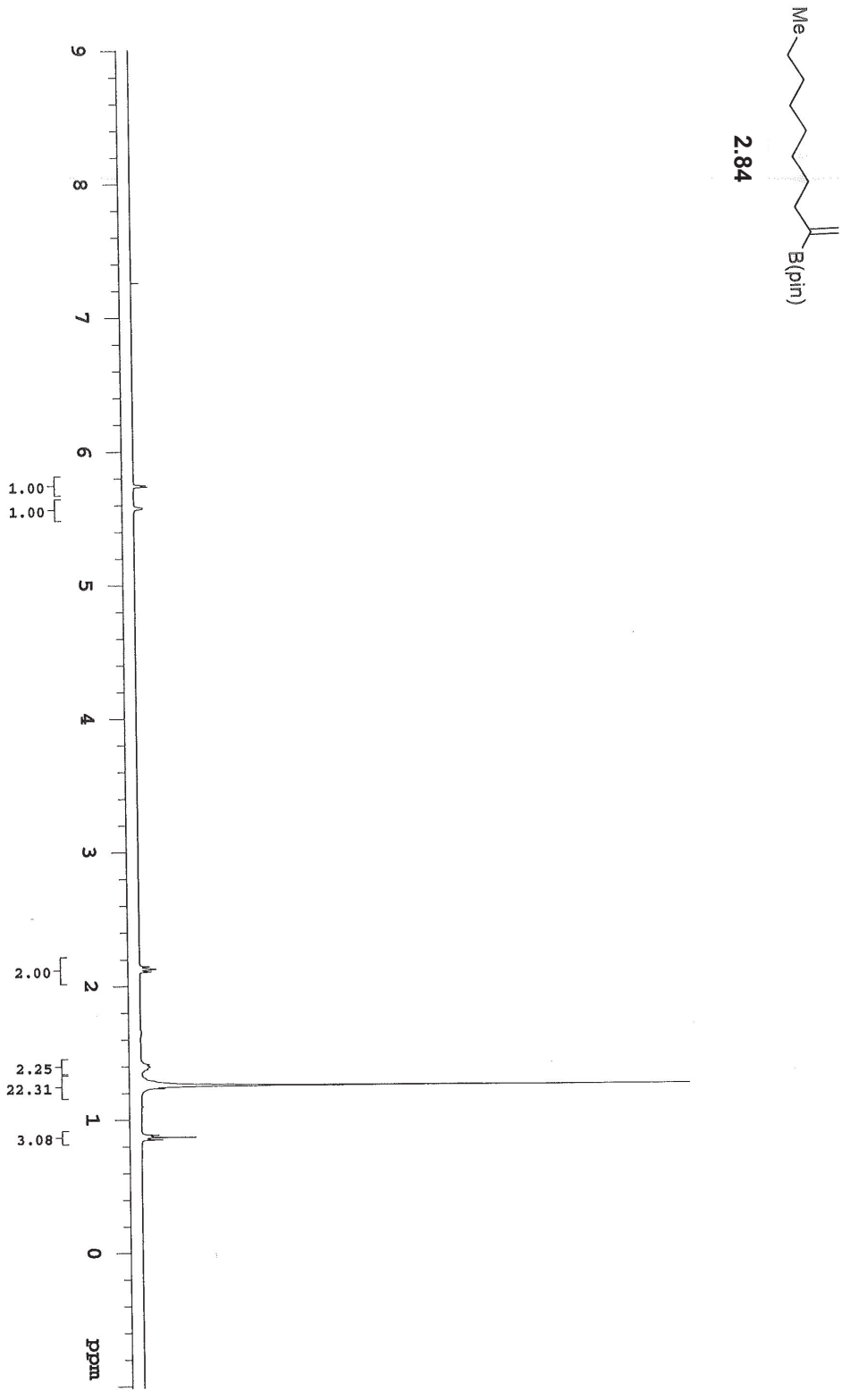
3
2
1
0
ppm



2.80

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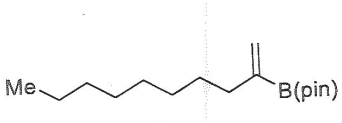
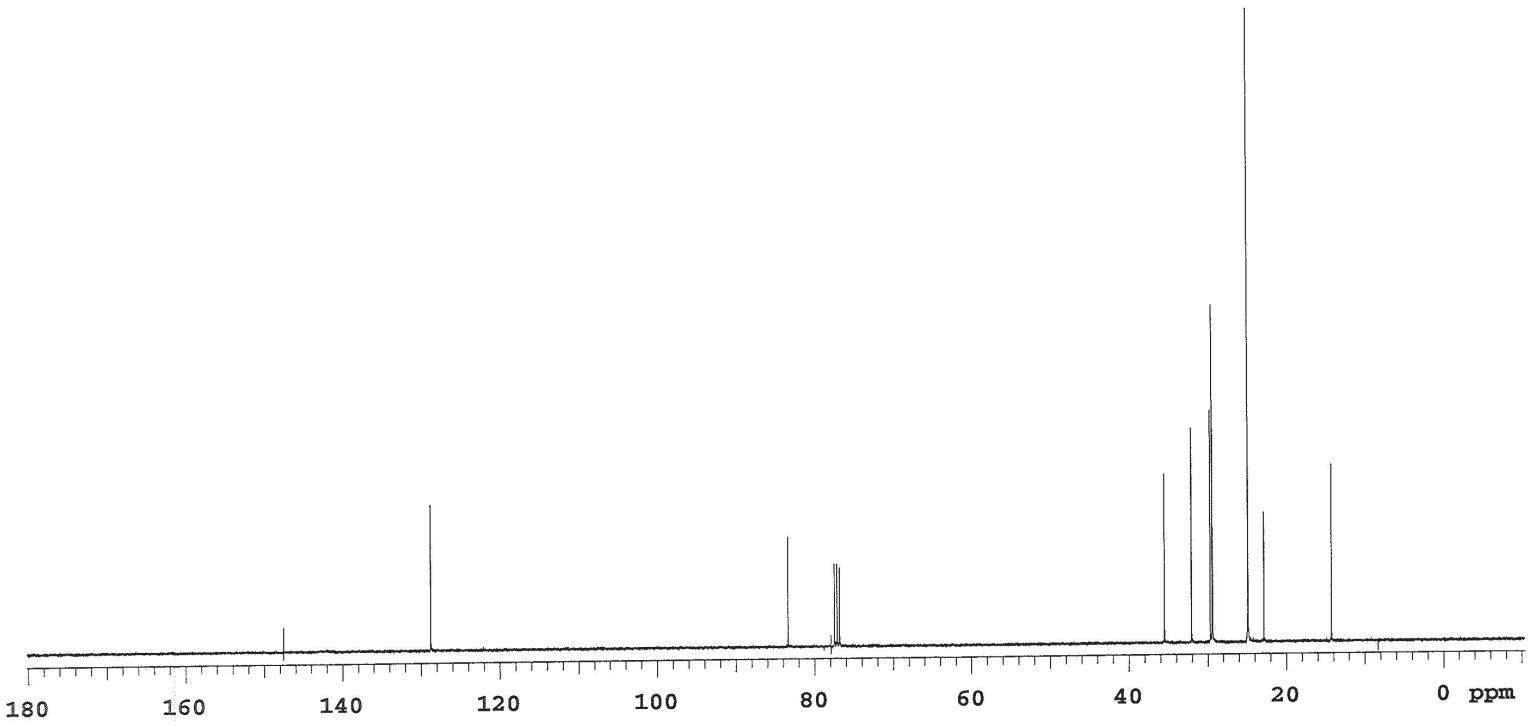
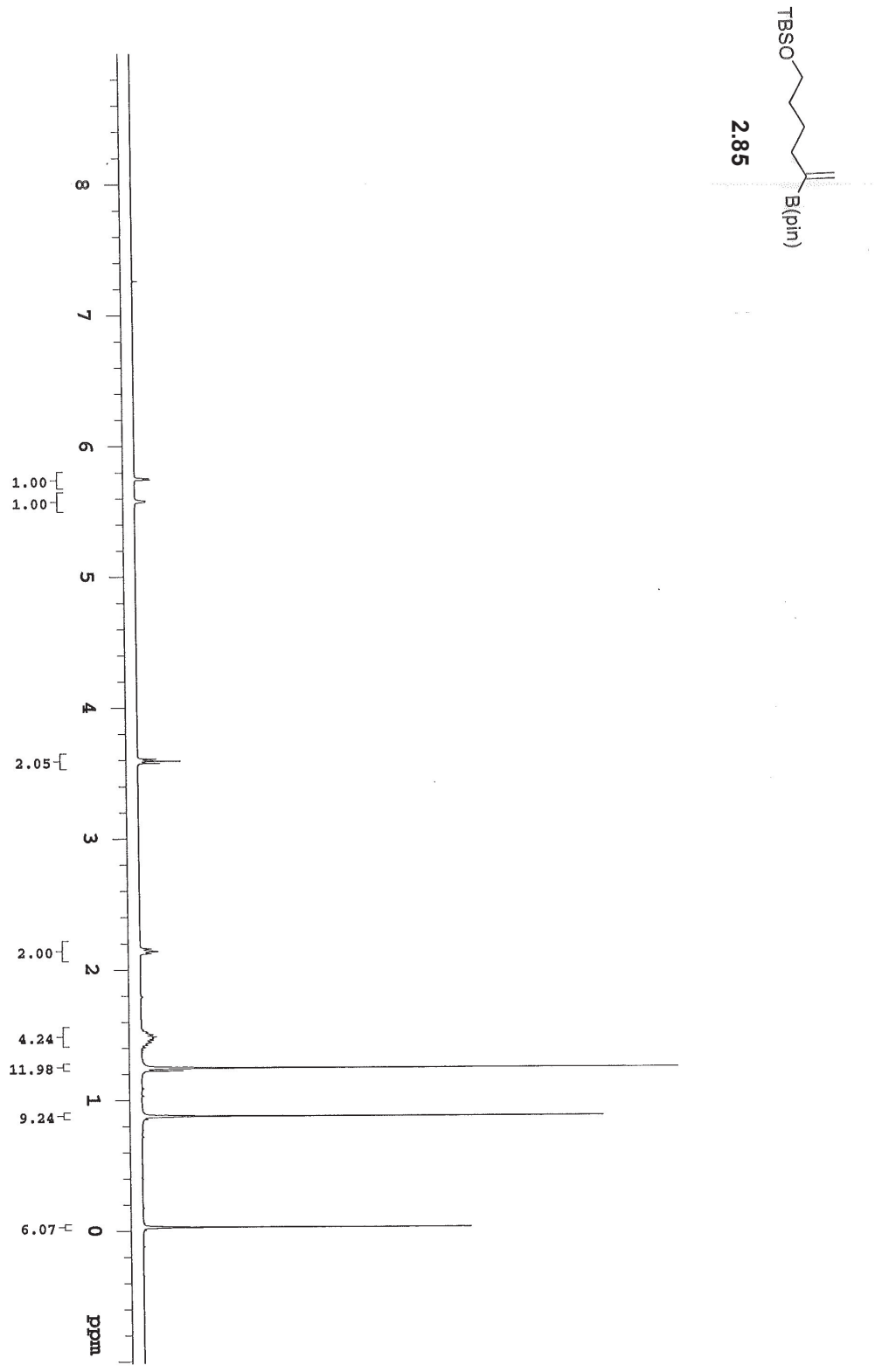
3.08



2.84

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6
5
4
3
2
1
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ppm
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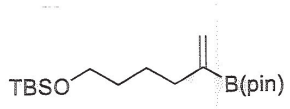
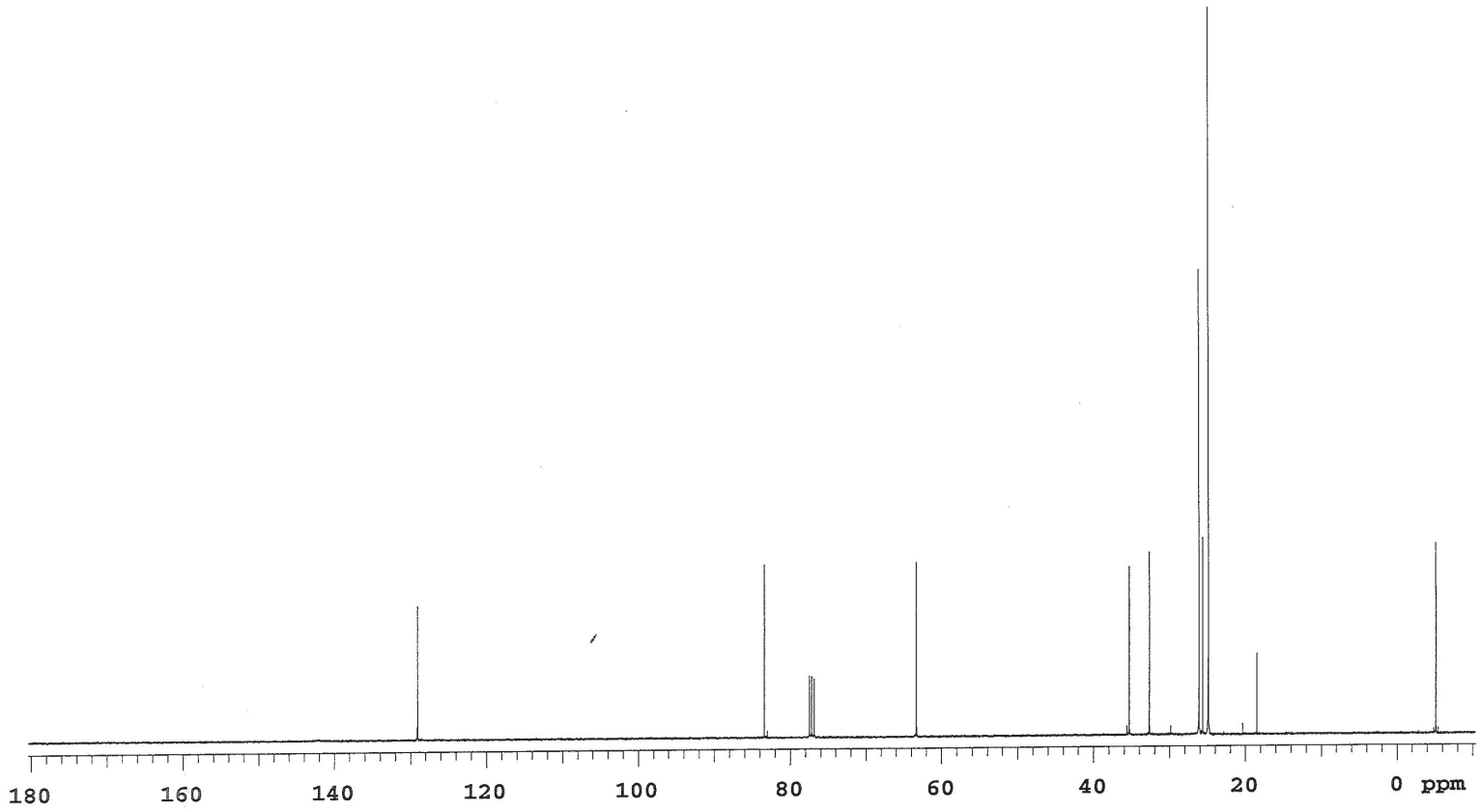
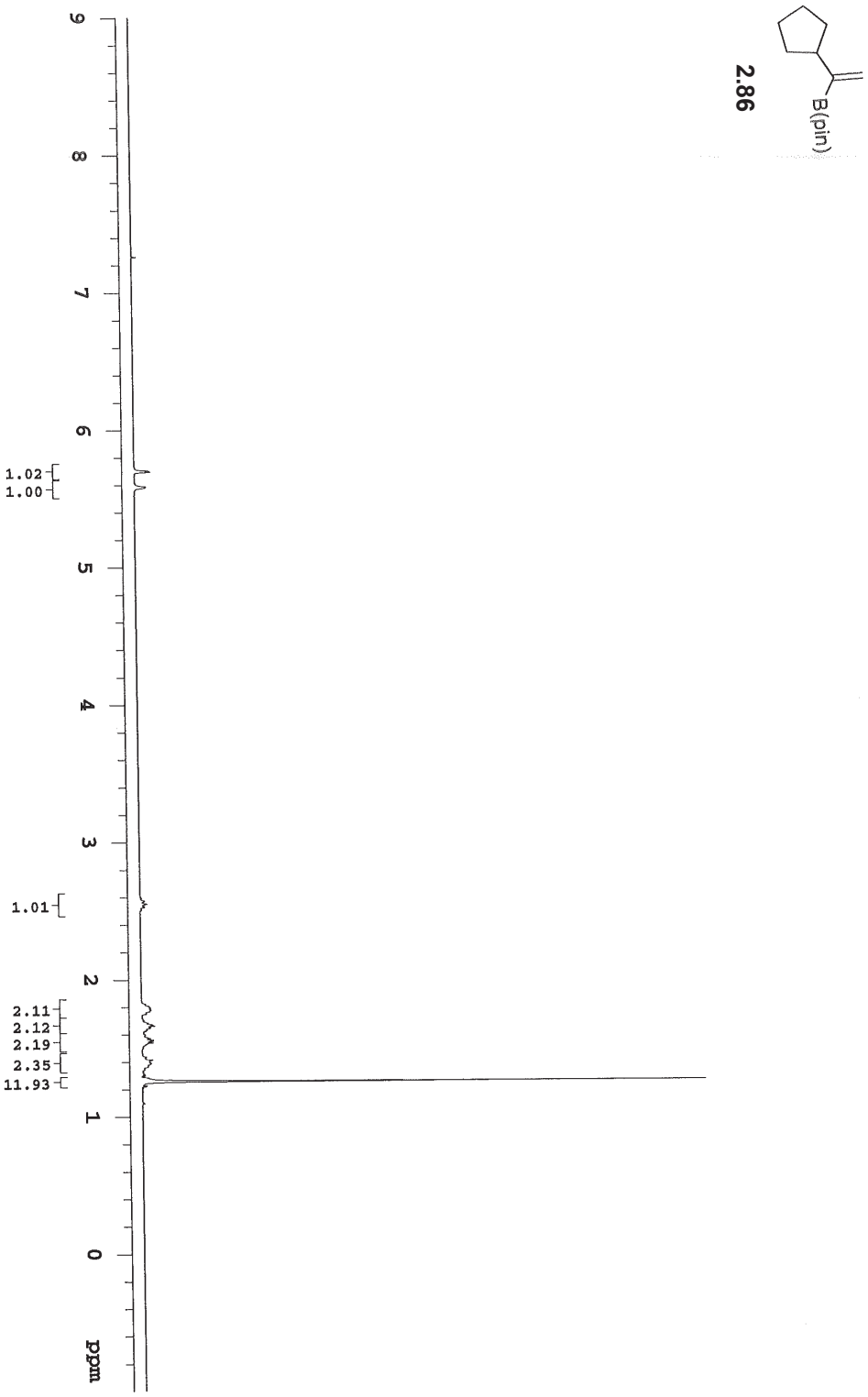
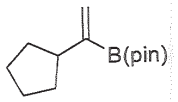
2.00
4.24
11.98
9.24
6.07



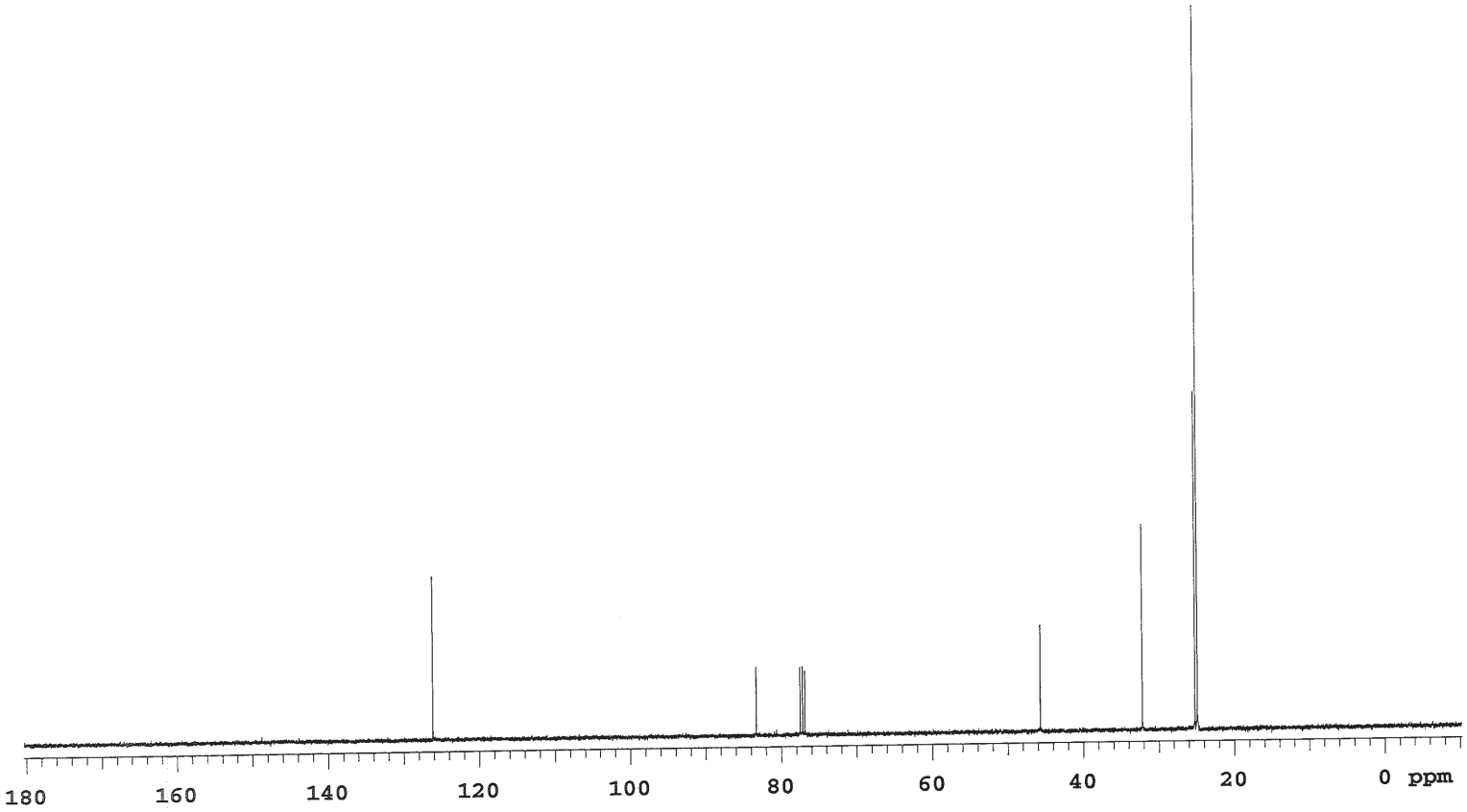
2.85

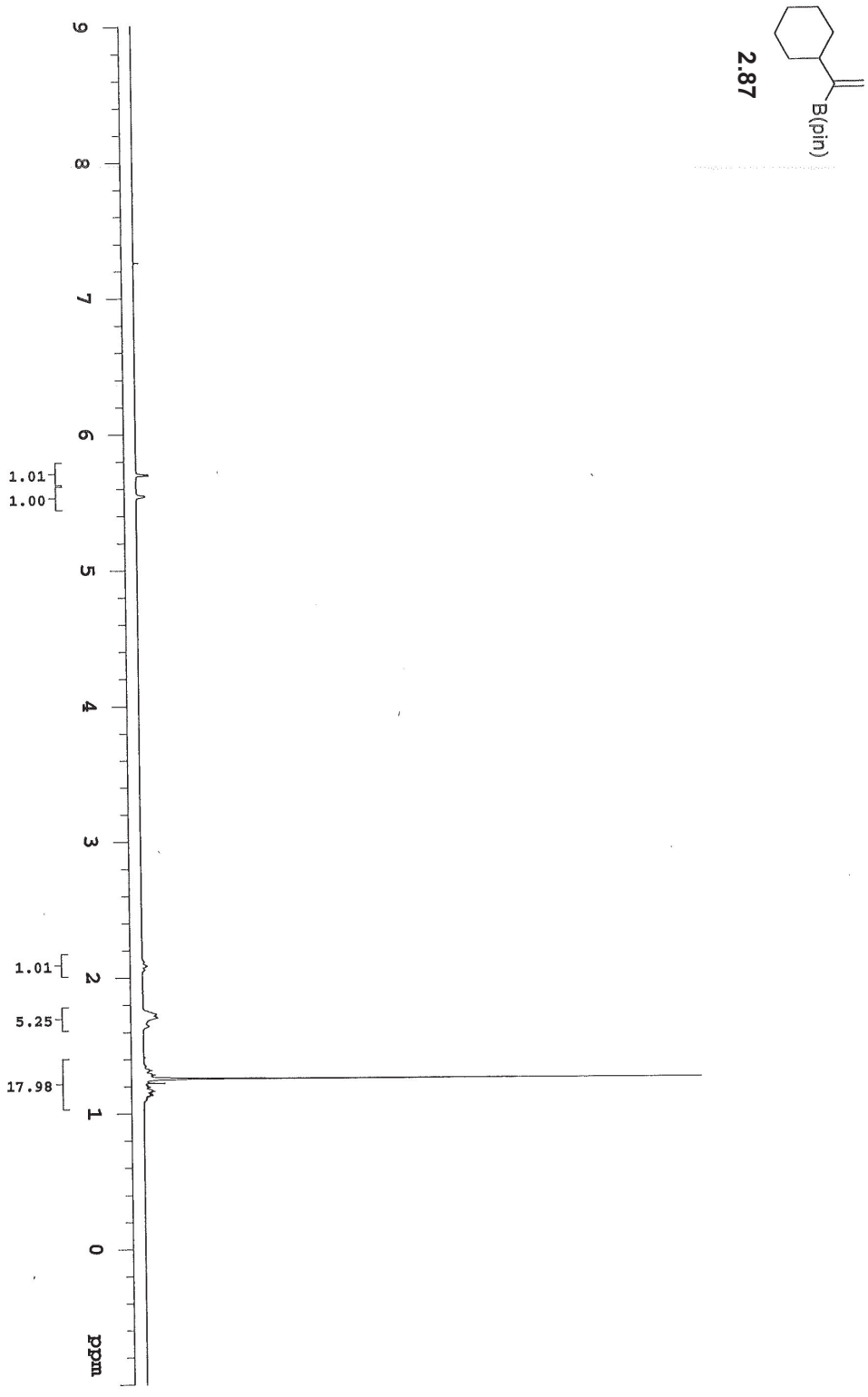



B(pin)
2.86
1.02
1.00
1.01
2.11
2.12
2.19
2.35
11.93
9
8
7
6
5
4
3
2
1
0
ppm



2.86

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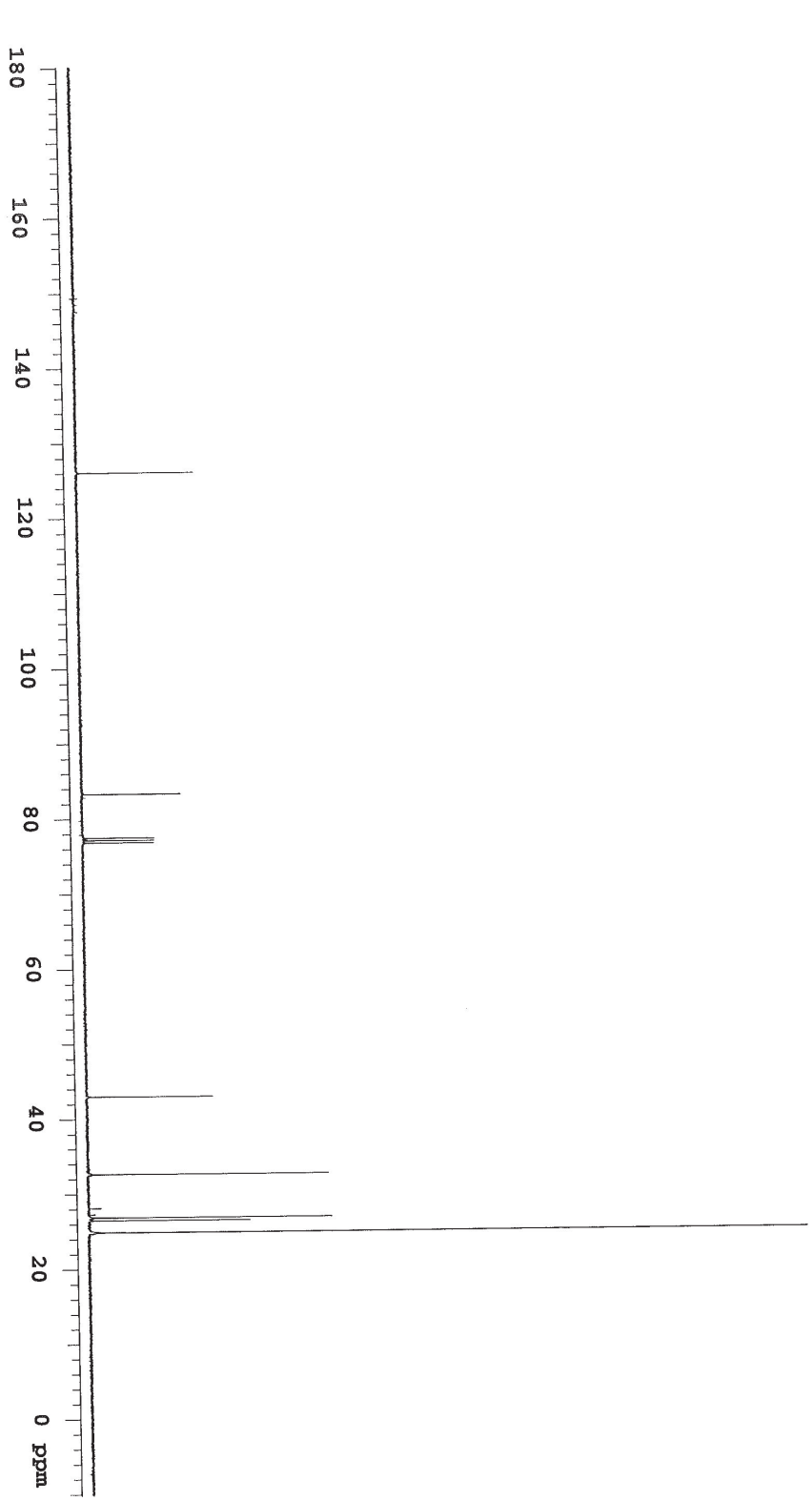
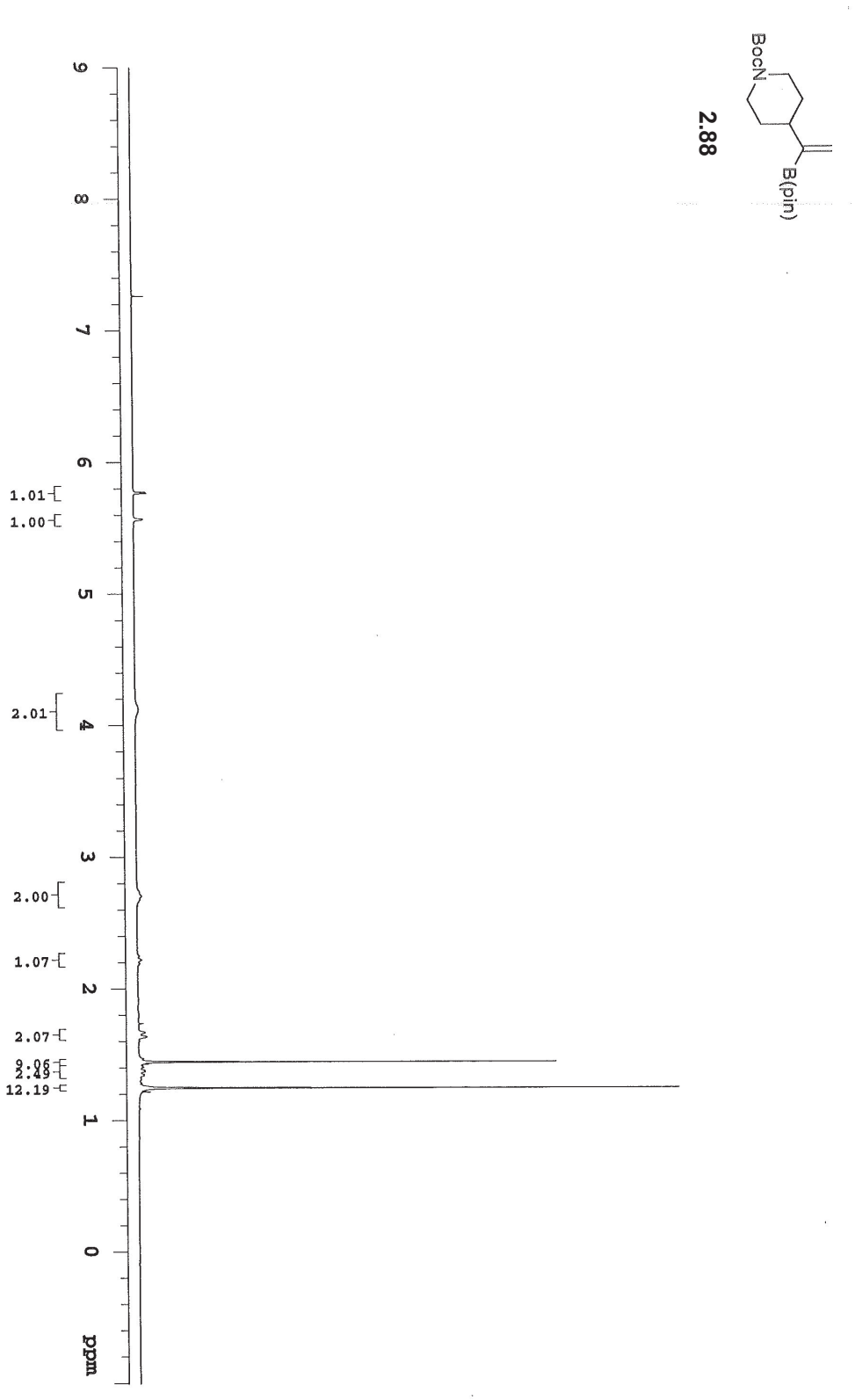
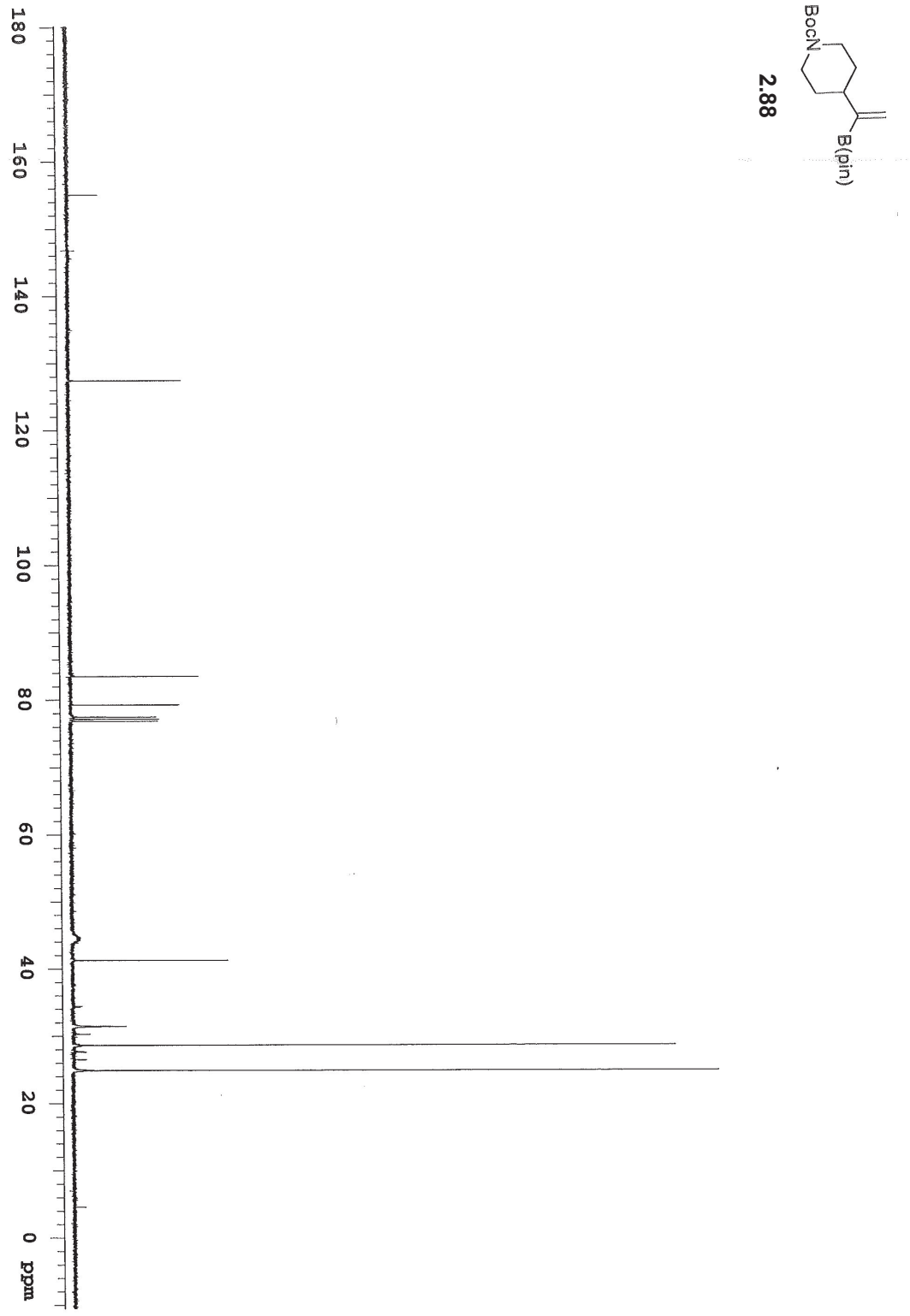
17.98
ppm


B(pin)
2.87
180
160
140
120
100
80
60
40
20
0 ppm


BocN
B(pin)
2.88
9
8
7
6
5
4
3
2
1
0
ppm
1.01
1.00
2.01
2.00
1.07
2.07
9.06
2.49
12.19


BocN
B(pin)
2.88
180
160
140
120
100
80
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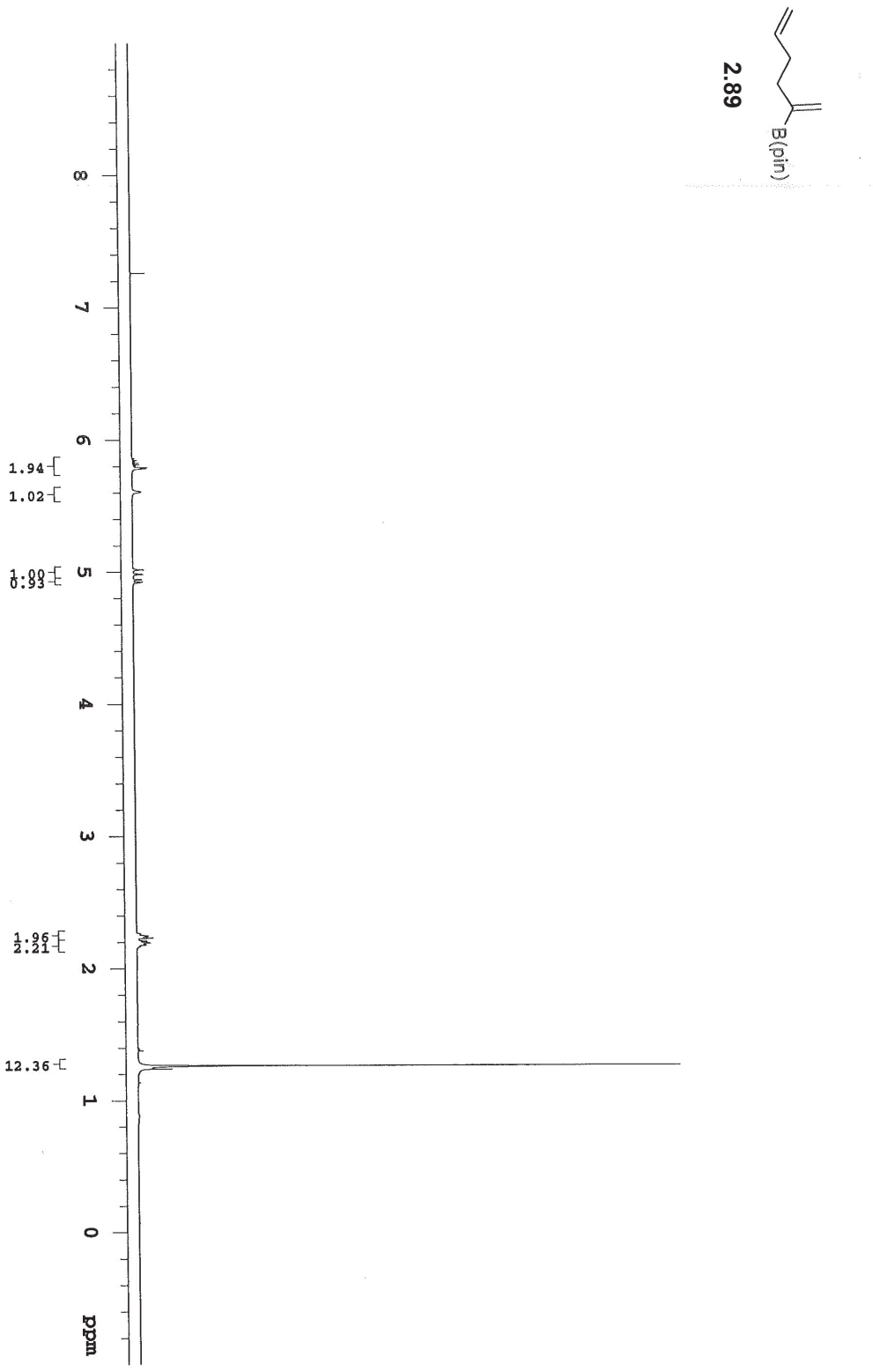
40
20
0 ppm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6
5
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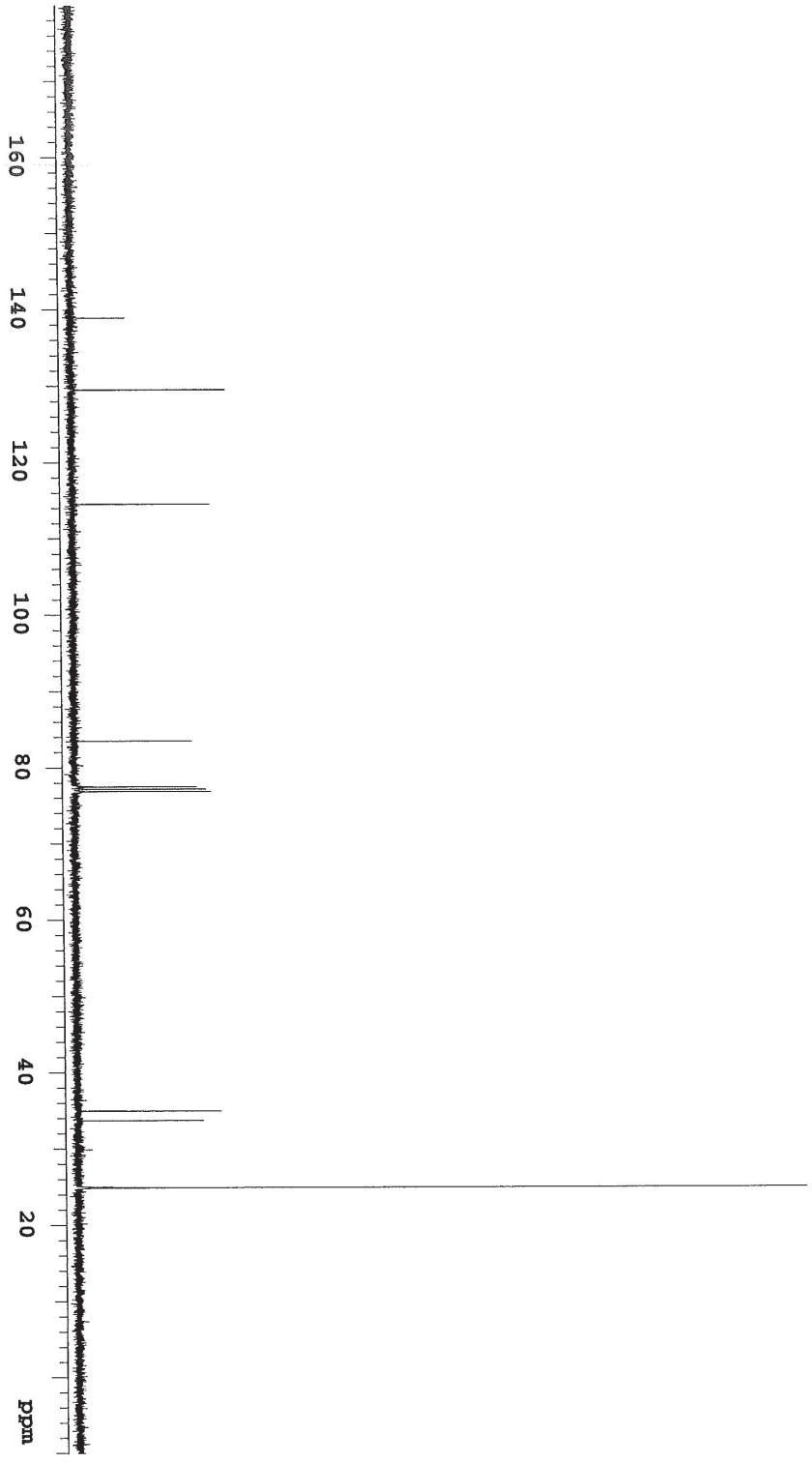
3
2
1
0
ppm


B(pin)
2.89
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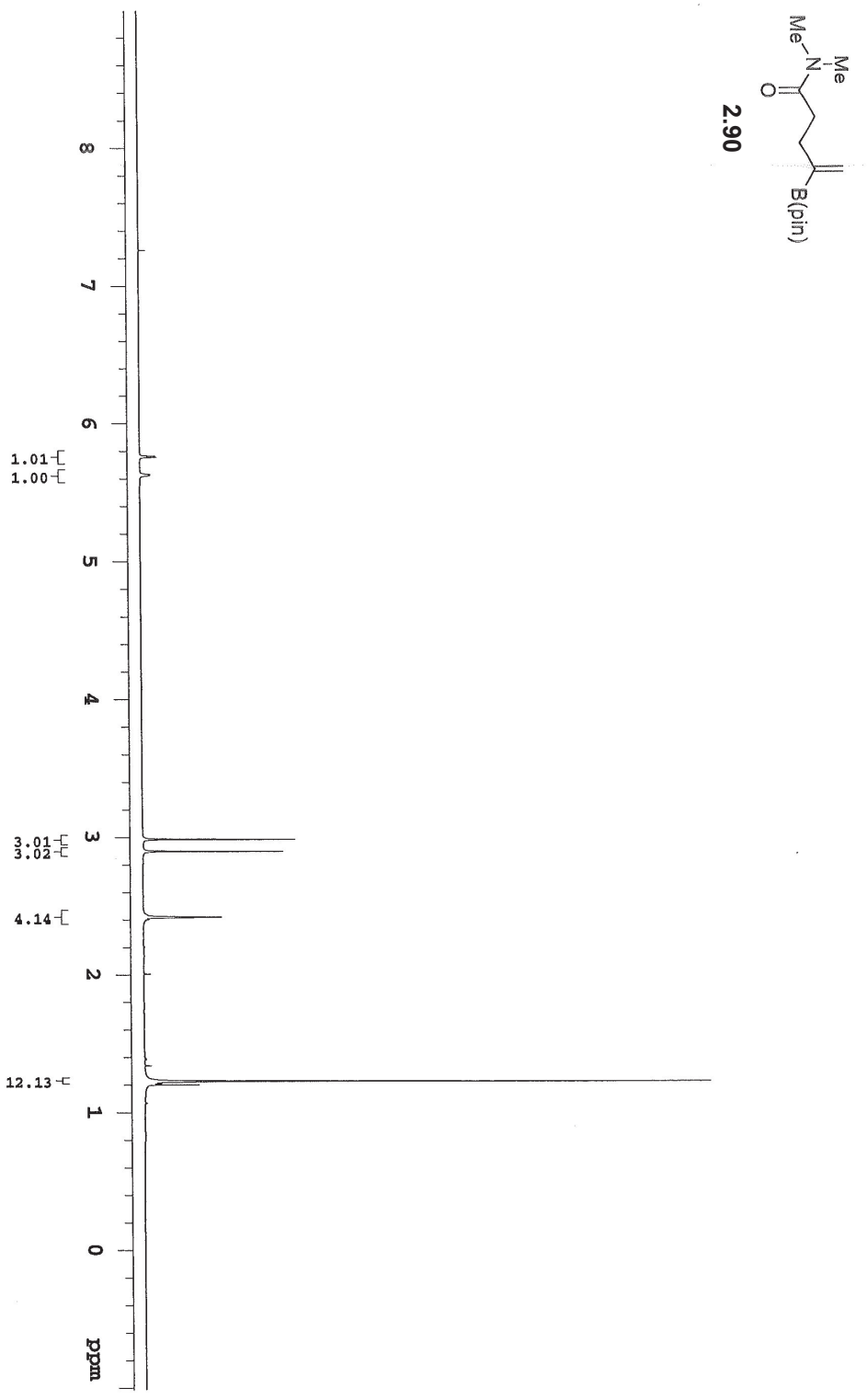
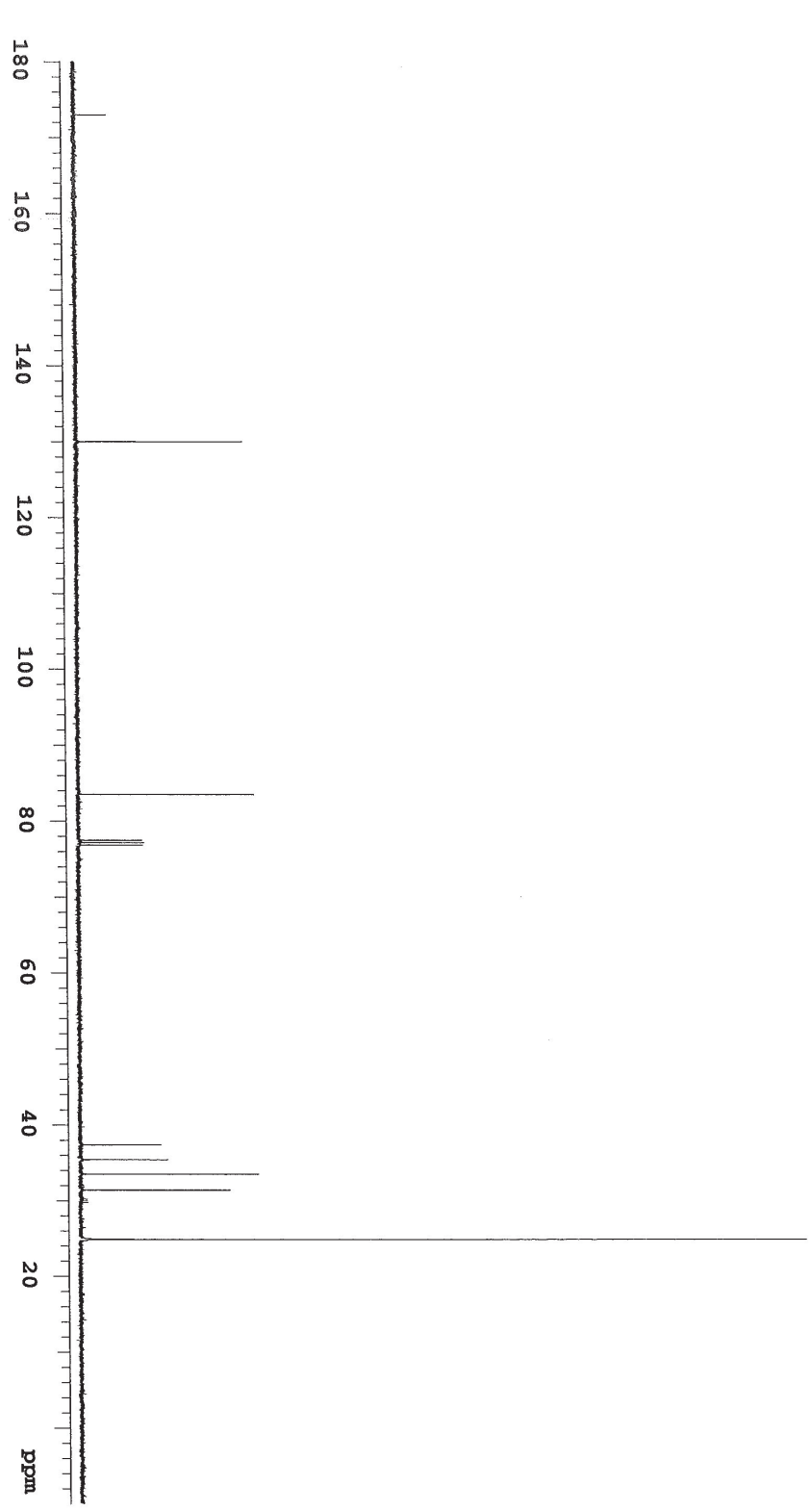
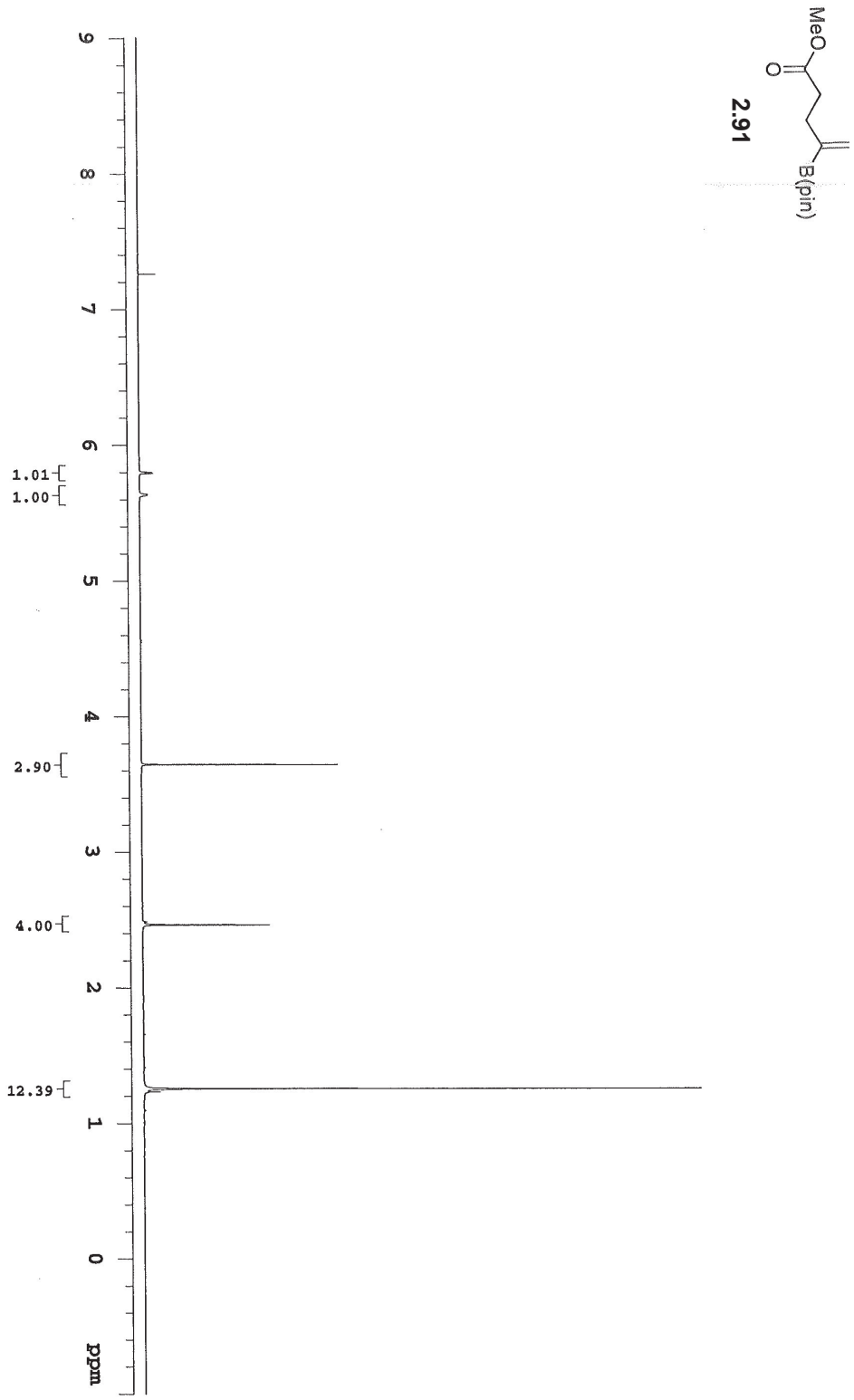
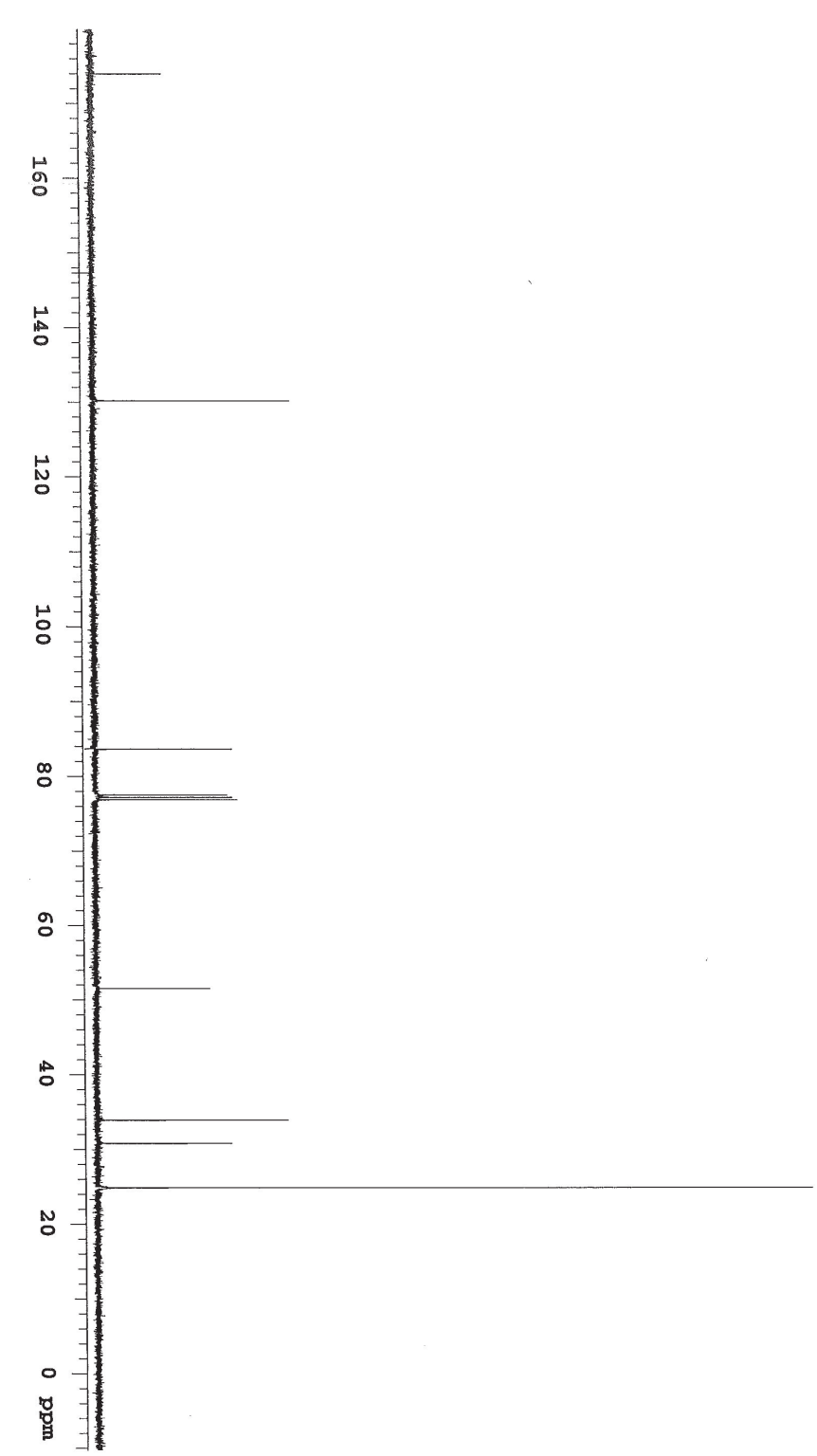
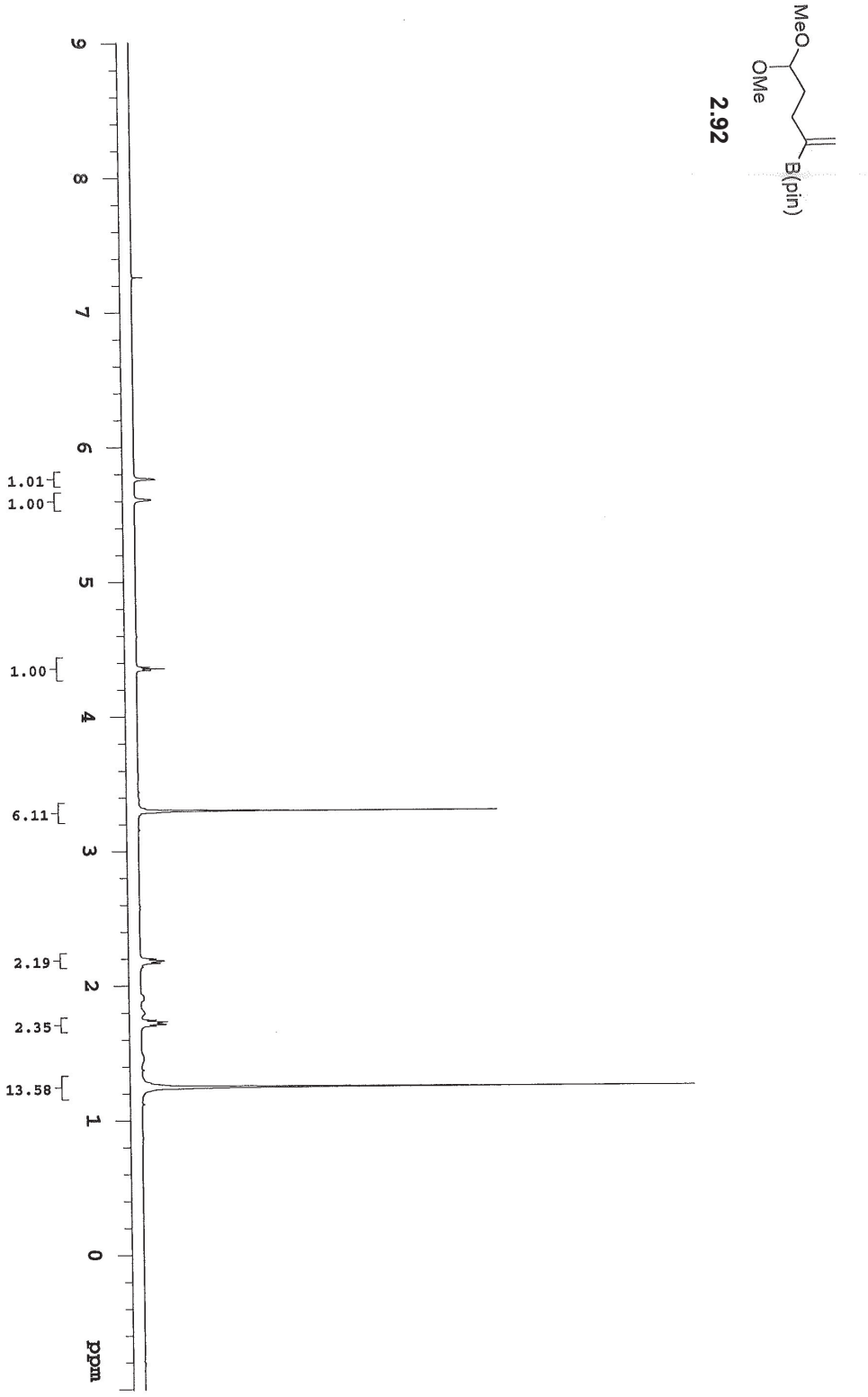
140
120
100
80
60
40
20
ppm

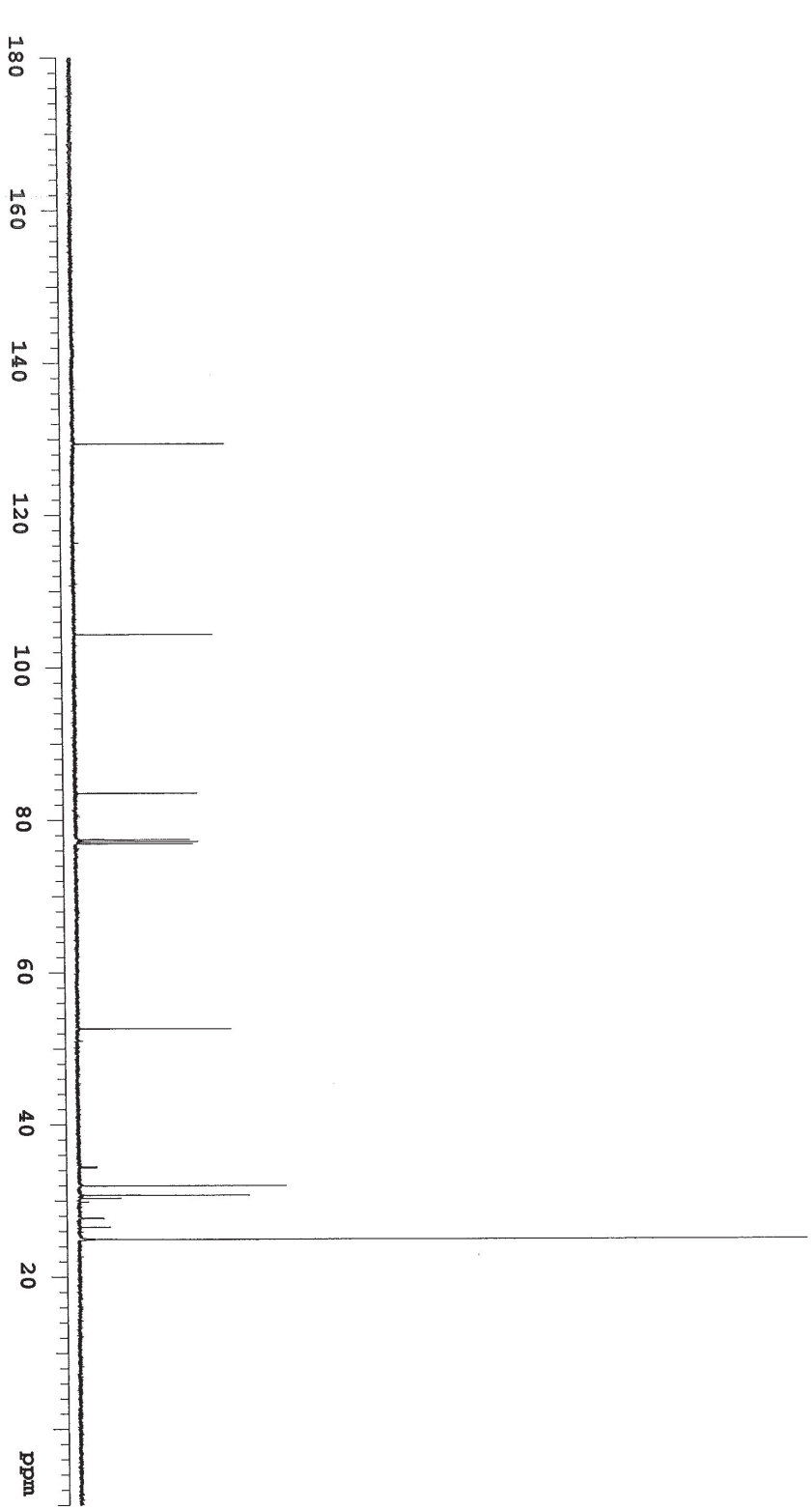

Me
Me
N
O
B(pin)
2.90
1.01
1.00
3.01
3.02
4.14
12.13
8
7
6
5
4
3
2
1
0
ppm

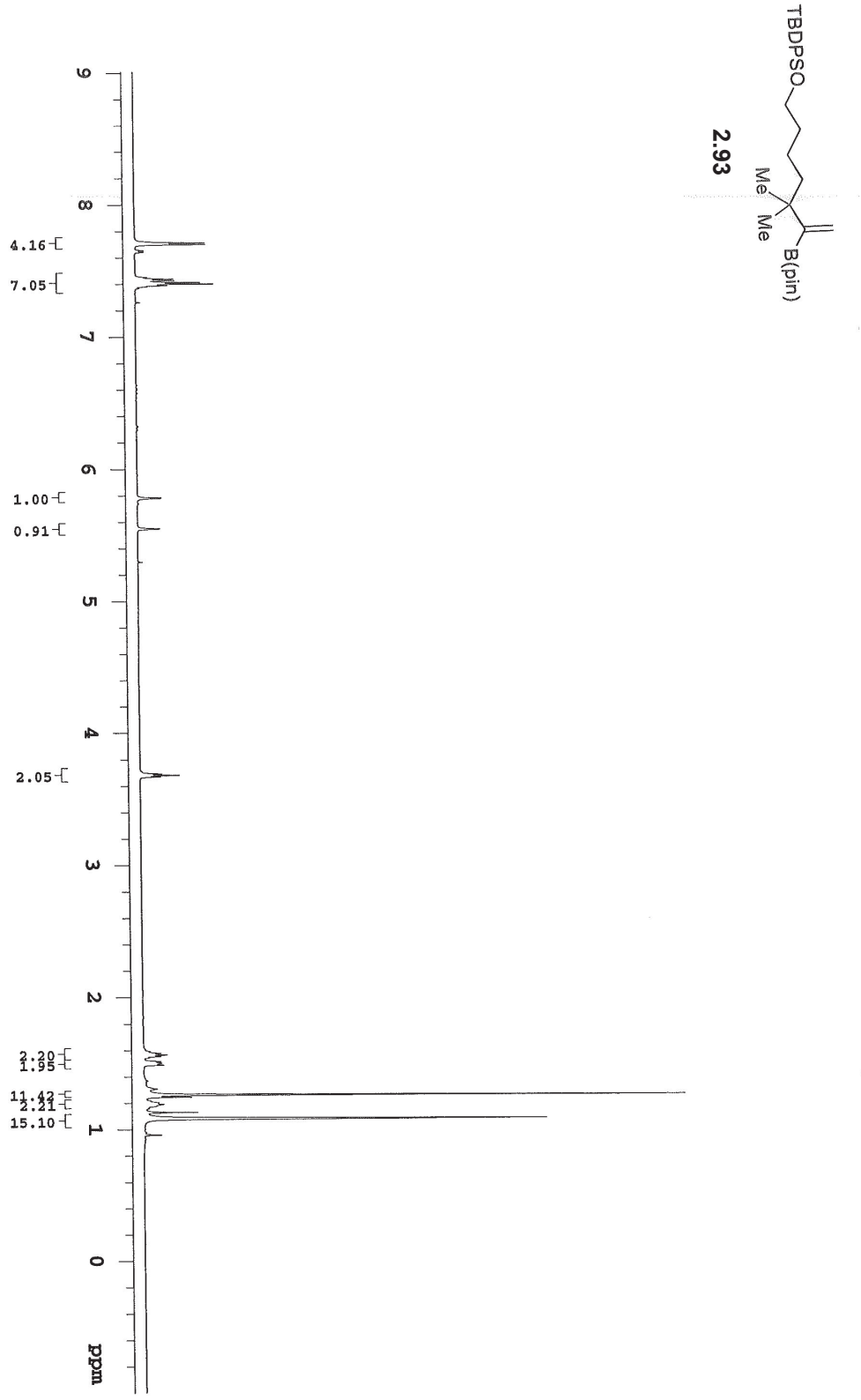

Me
Me
N
O
B(pin)
2.90
180
160
140
120
100
80
60
40
20
ppm

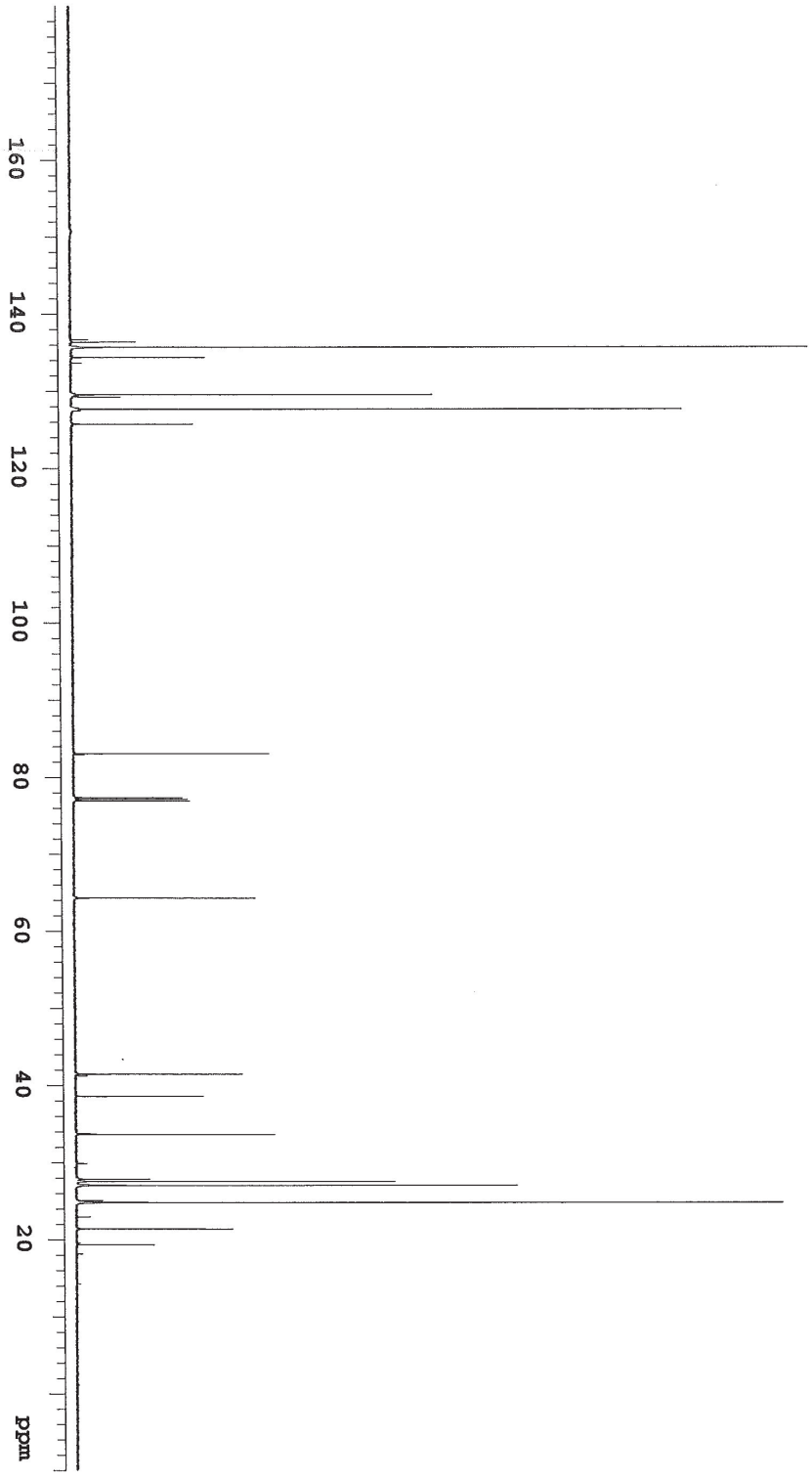

MeO
O
B(pin)
2.91
9
8
7
6
5
4
3
2
1
0
ppm
1.01
1.00
2.90
4.00
12.39

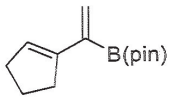

MeO
O
B(pin)
2.91
160
140
120
100
80
60
40
20
0 ppm


MeO
OMe
B(pin)
2.92
9
8
7
6
5
4
3
2
1
0
ppm
1.01
1.00
1.00
6.11
2.19
2.35
13.58


MeO
OMe
B(pin)
2.92
180
160
140
120
100
80
60
40
20
ppm

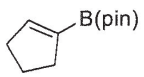

TBDPSO
Me
Me
B(pin)
2.93
4.16
7.05
1.00
0.91
2.05
2.20
1.95
11.42
2.21
15.10
9
8
7
6
5
4
3
2
1
0
ppm

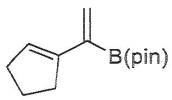

TBDPSO
Me
Me
B(pin)
2.93
160
140
120
100
80
60
40
20
ppm



2.94

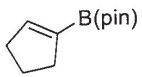
The peaks marked with an asterisk correspond to inseparable co-eluting starting material:

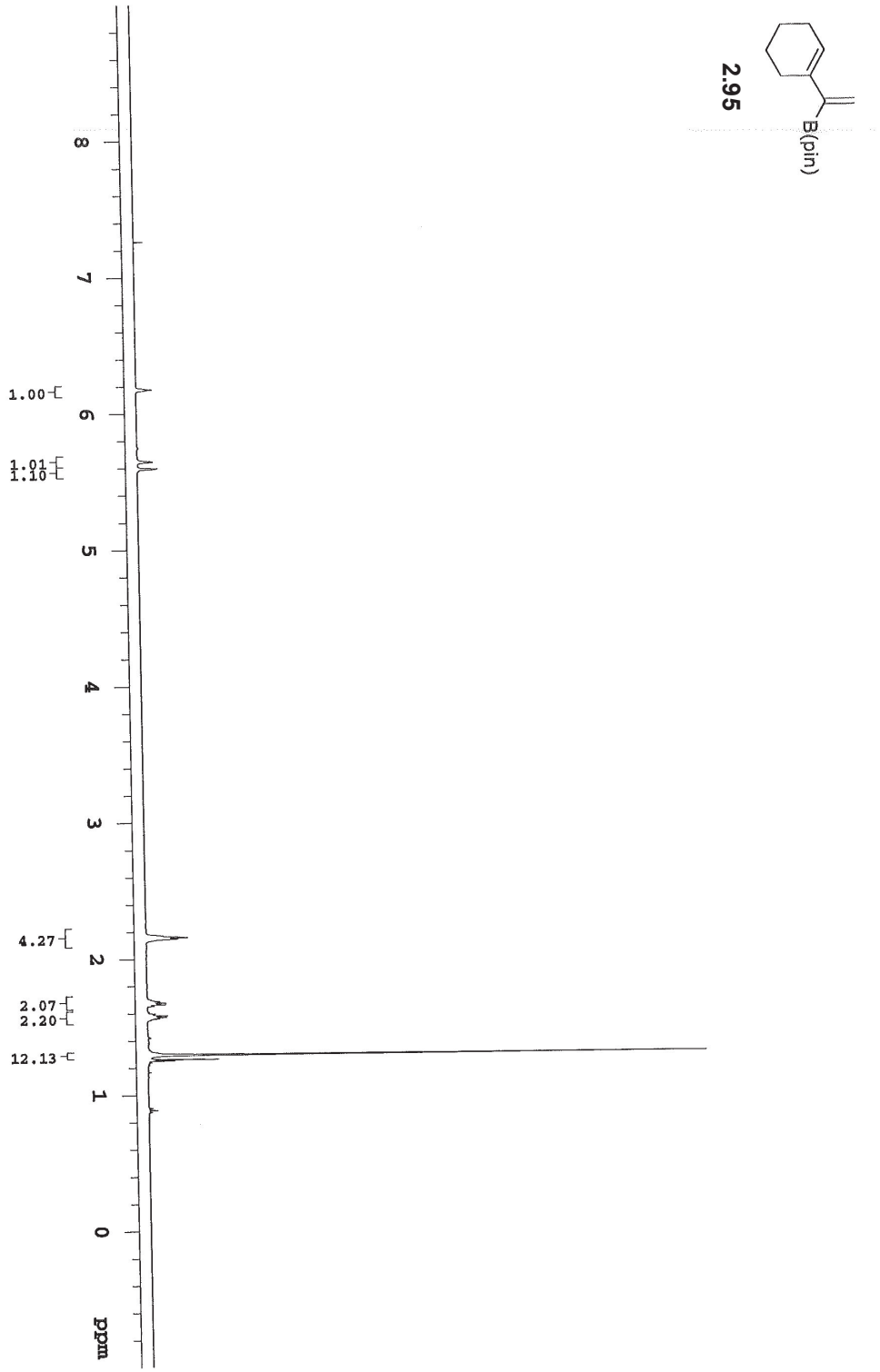


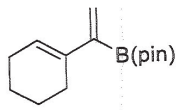


2.94

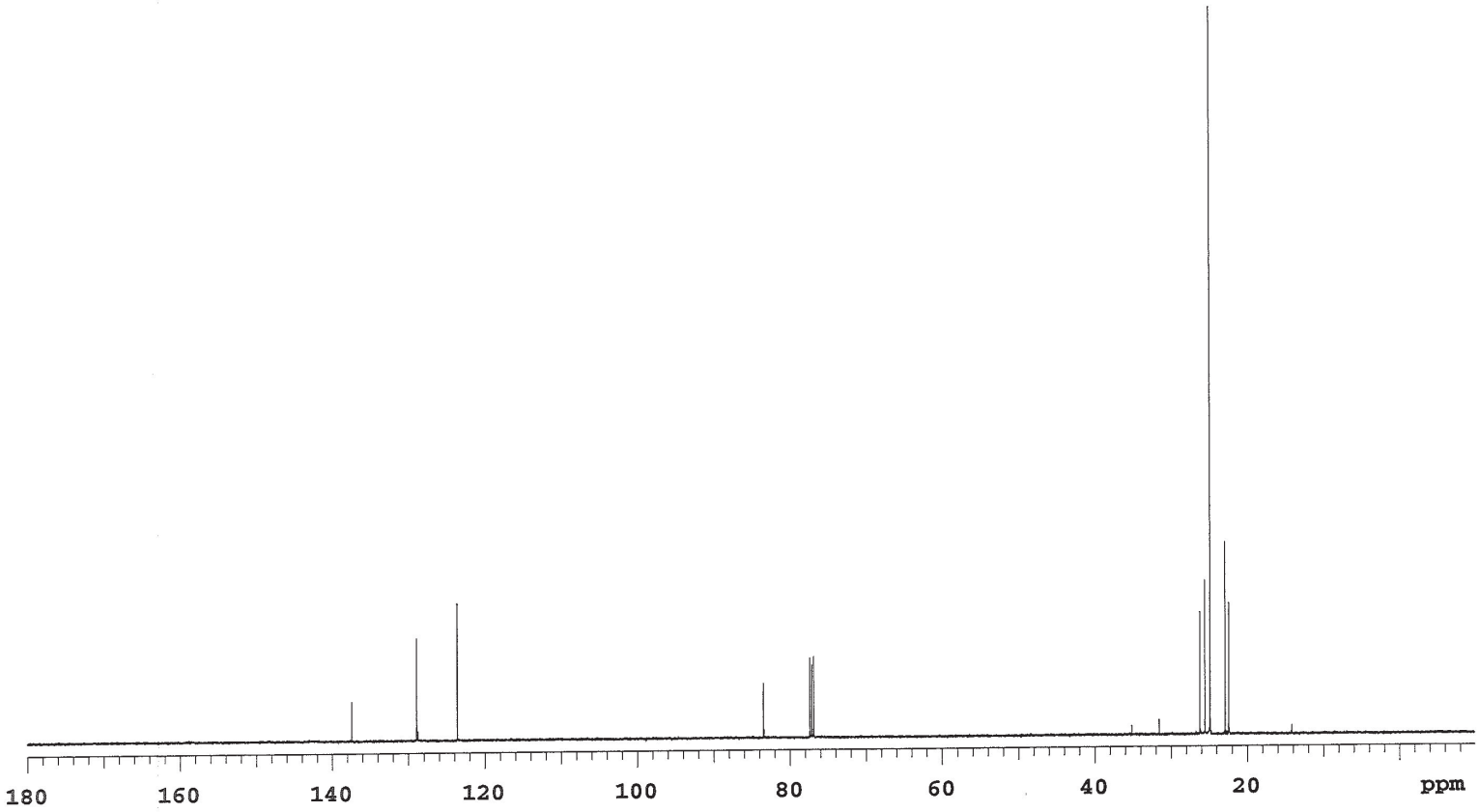
The peaks marked with an asterisk correspond to inseparable co-eluting starting material:

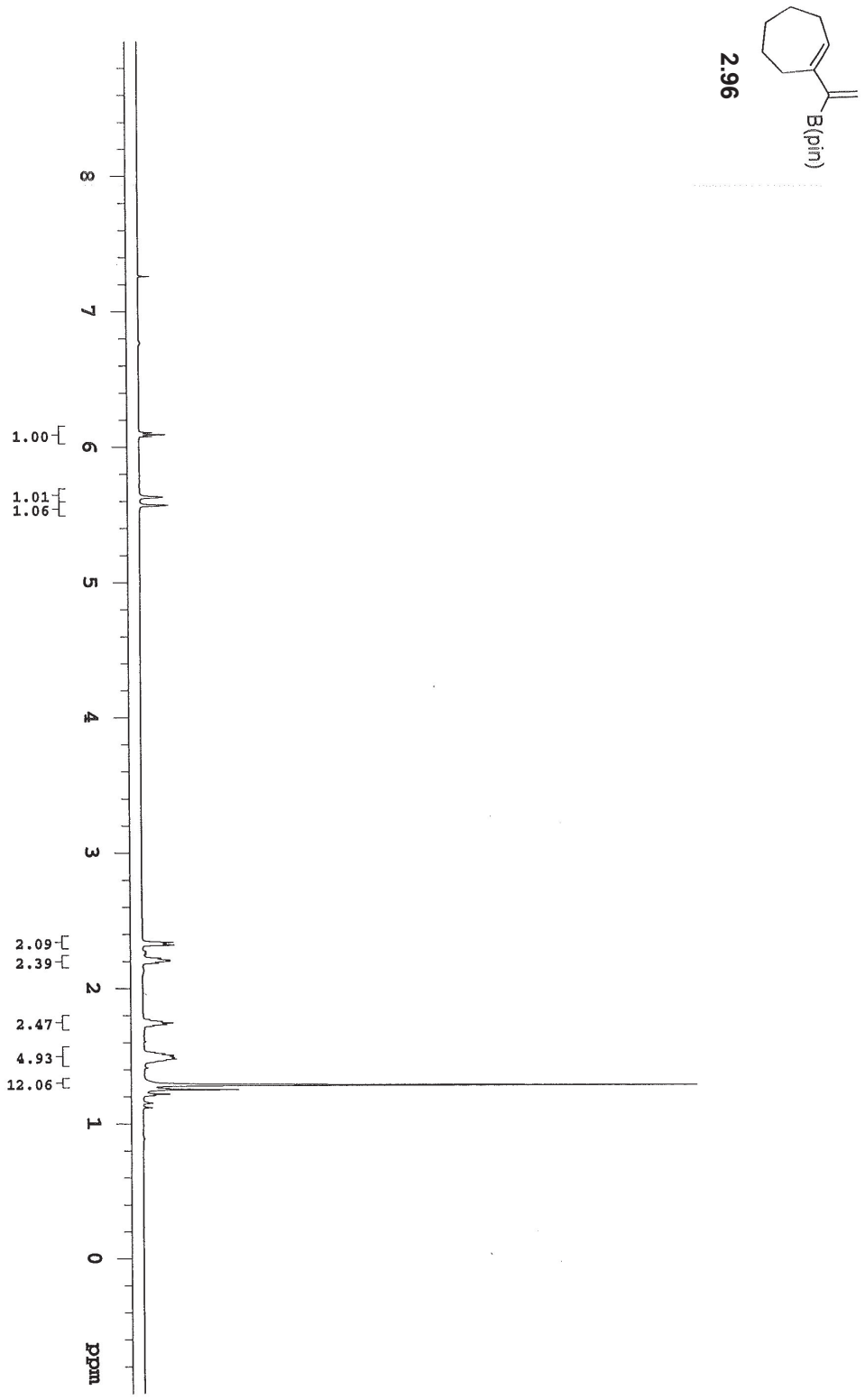


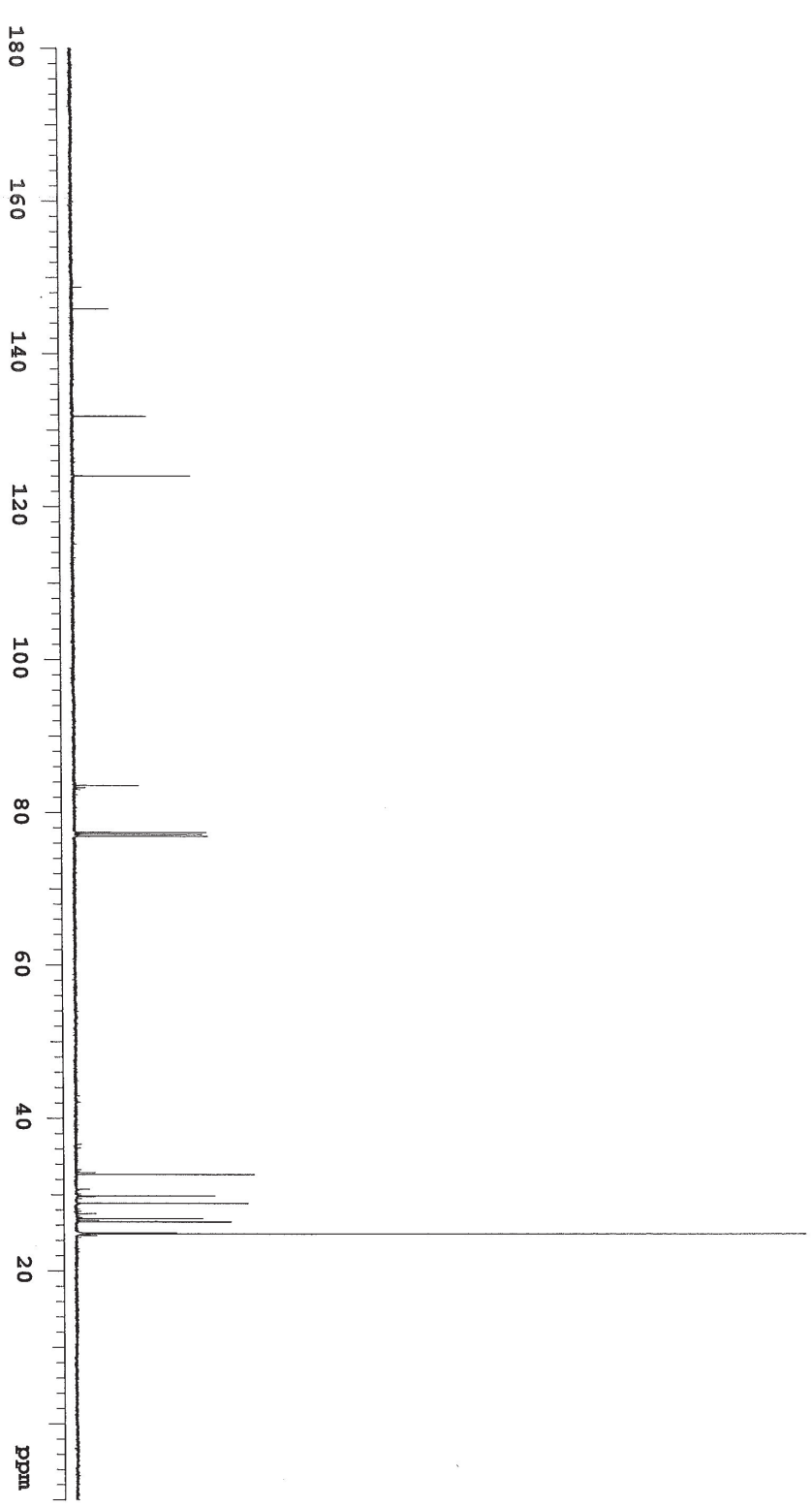

2.95
B(pin)
1.00
1.01
1.10
4.27
2.07
2.20
12.13
8
7
6
5
4
3
2
1
0
ppm

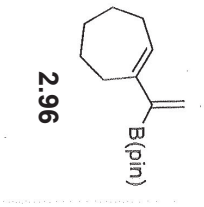


2.95

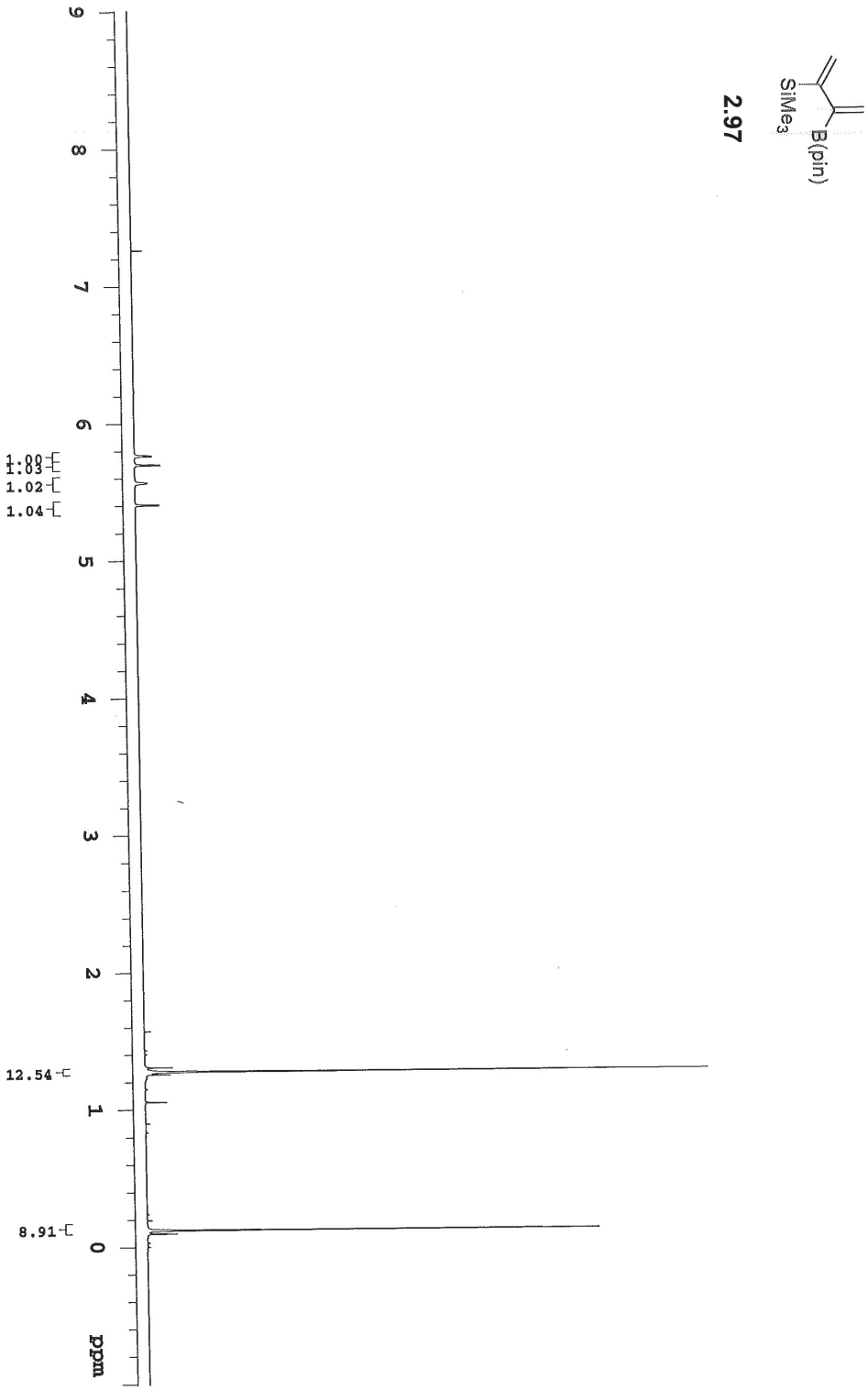



2.96
B(pin)
1.00
1.01
1.06
2.09
2.39
2.47
4.93
12.06
8
7
6
5
4
3
2
1
0
ppm





2.96


2.97
SiMe3
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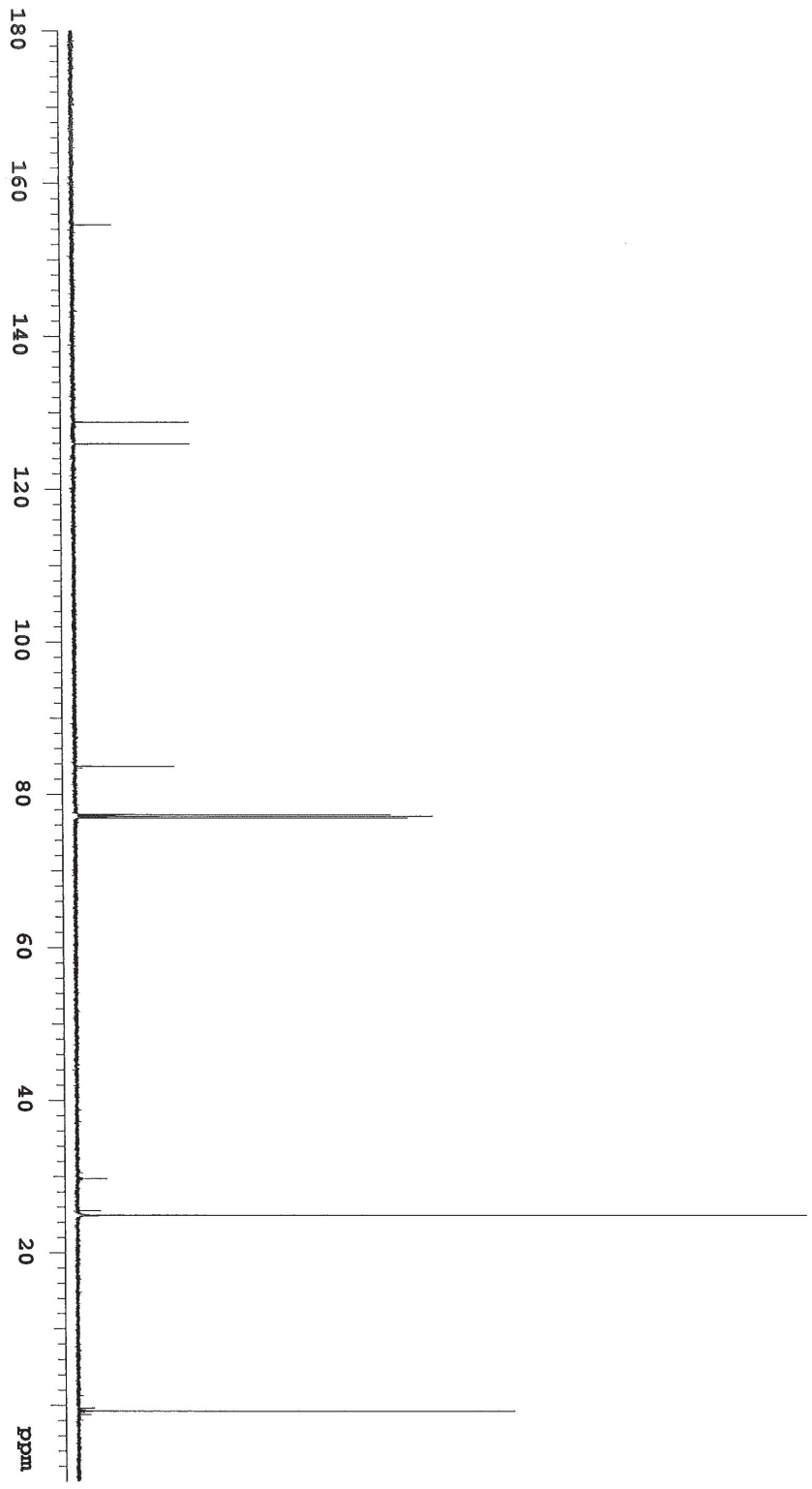
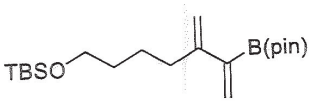
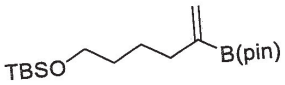
1.03
1.02
1.04
12.54
8.91
ppm


SiMe3
B(pin)
2.97
180
160
140
120
100
80
60
40
20
ppm

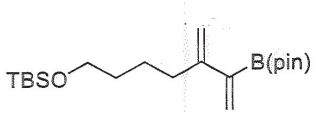


2.100

The peaks marked with an asterisk correspond to inseparable co-eluting starting material:

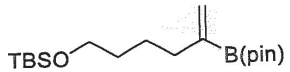


2.85

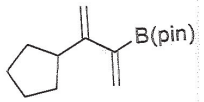


2.100

The peaks marked with an asterisk correspond to inseparable co-eluting starting material:

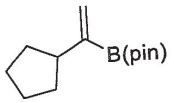


2.85

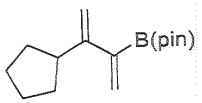


2.101

The peaks marked with an asterisk correspond to inseparable co-eluting starting material:

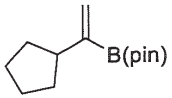


2.86

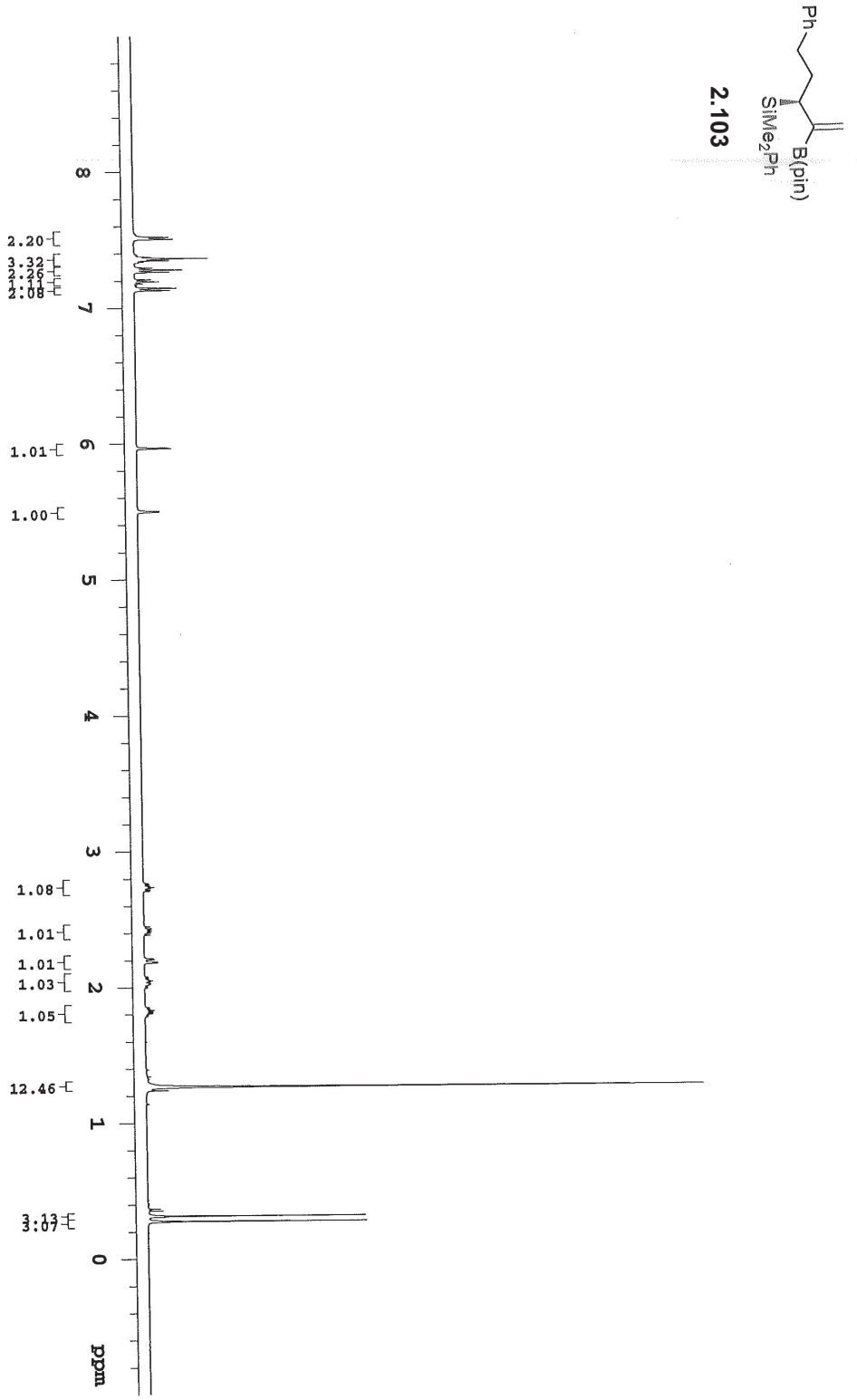


2.101

The peaks marked with an asterisk correspond to inseparable co-eluting starting material:



2.86


Ph
SiMe2Ph
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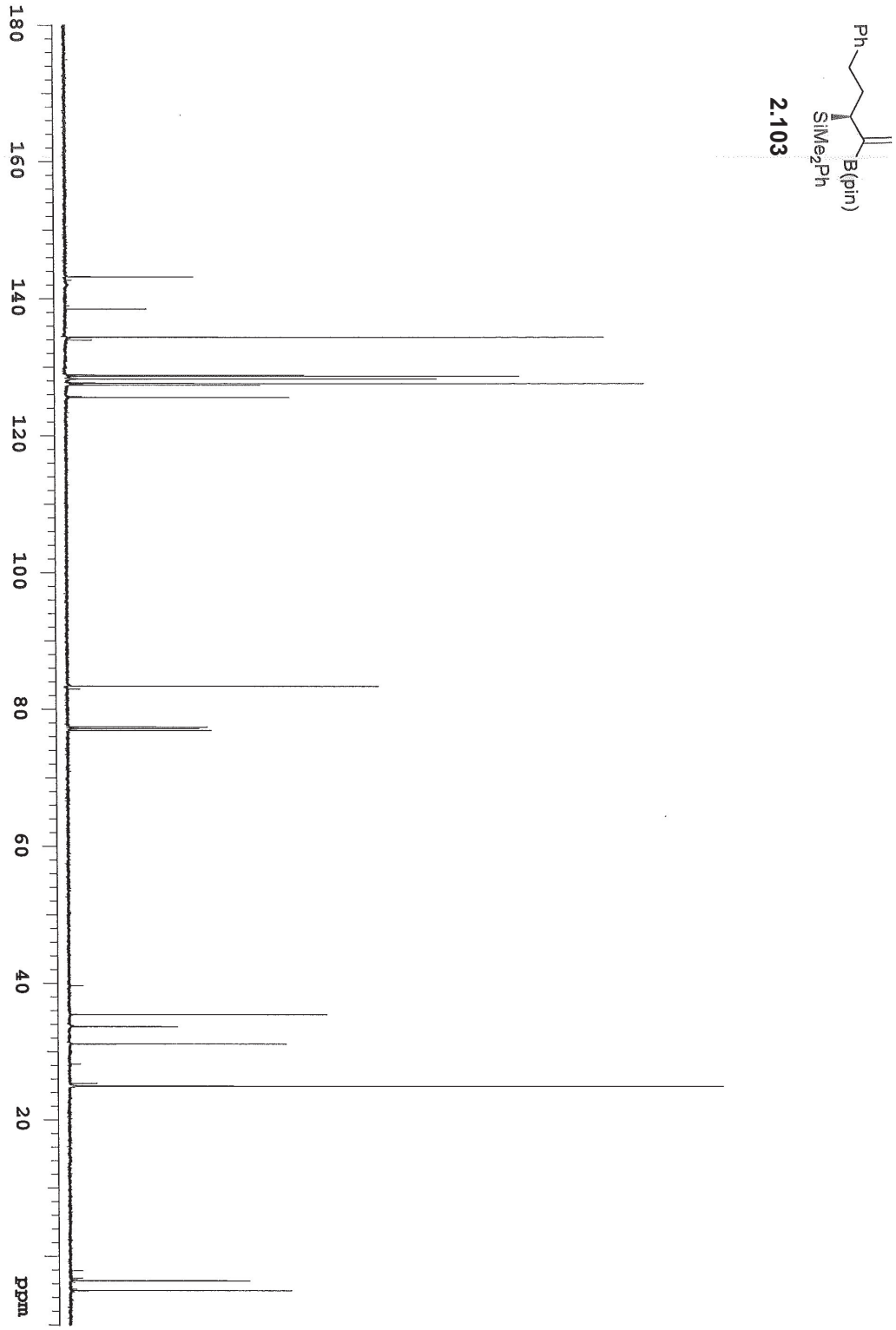
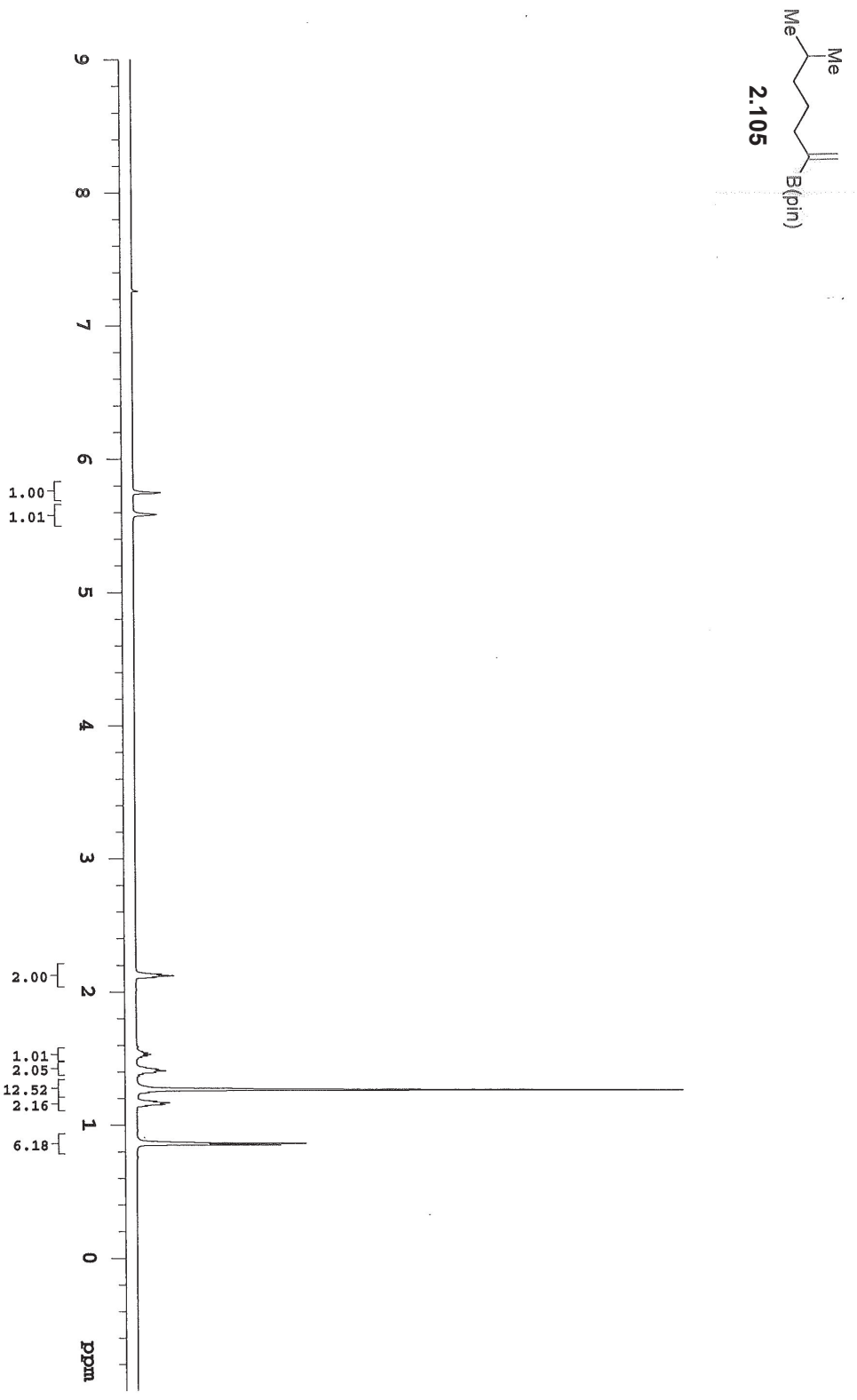
3.32
2.26
1.11
2.08
1.01
1.00
1.08
1.01
1.01
1.03
1.05
12.46
3.13
3.07
8
7
6
5
4
3
2
1
0
ppm


Ph
SiMe2Ph
B(pin)
2.103
180
160
140
120
100
80
60
40
20
ppm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8
7
6
5
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3
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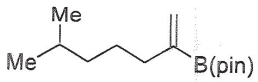
1.01
2.00
1.01
2.05
12.52
2.16
6.18



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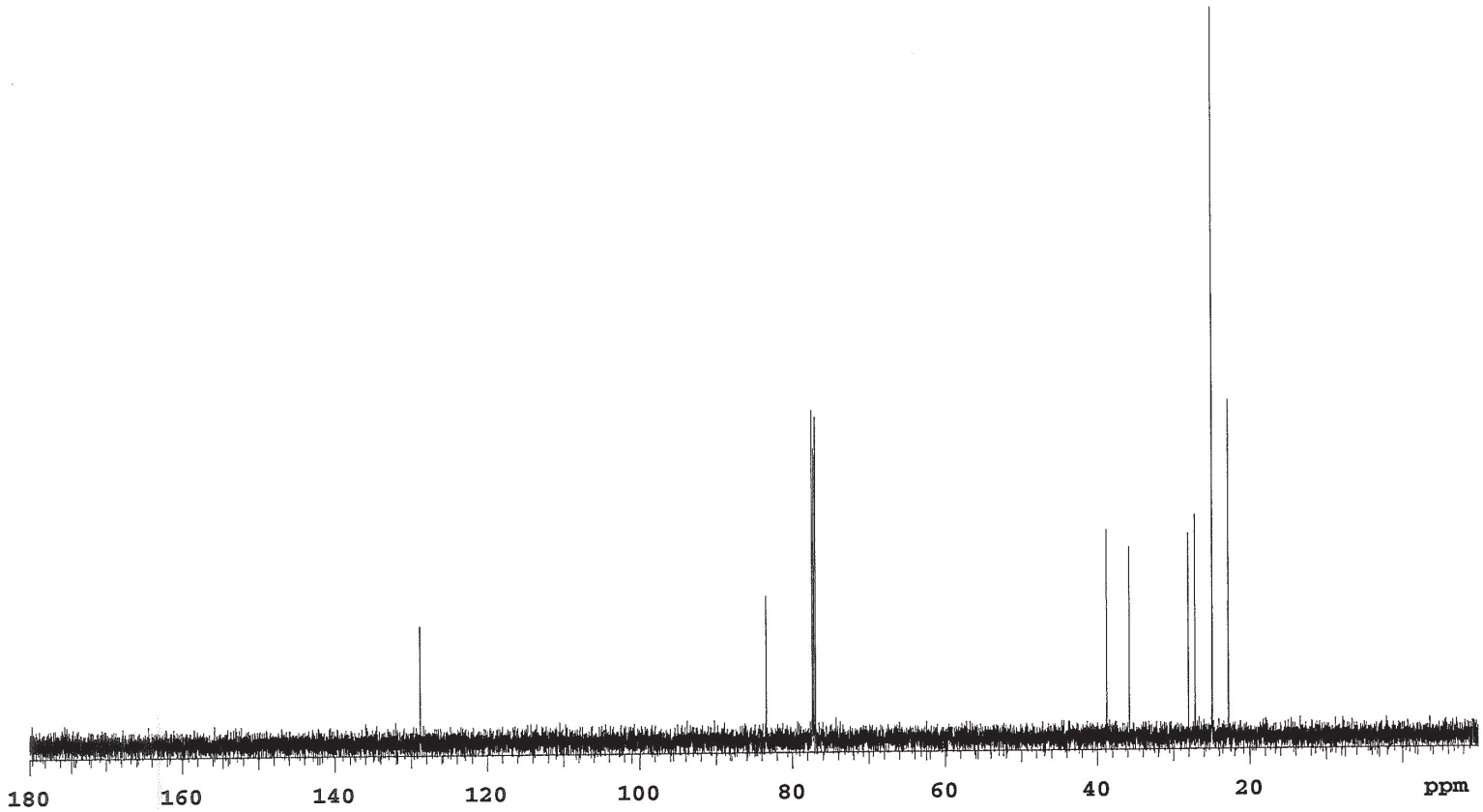
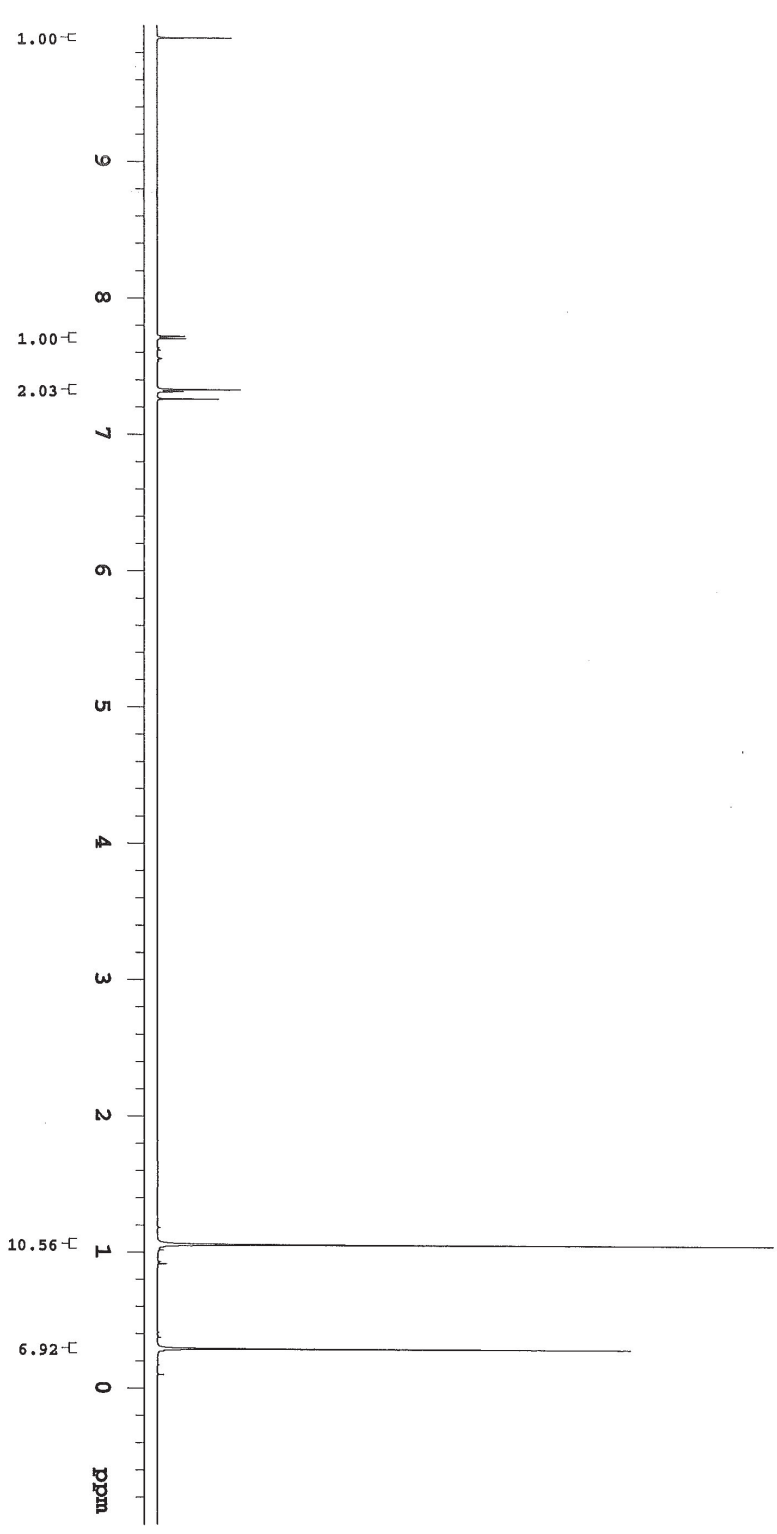
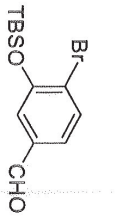
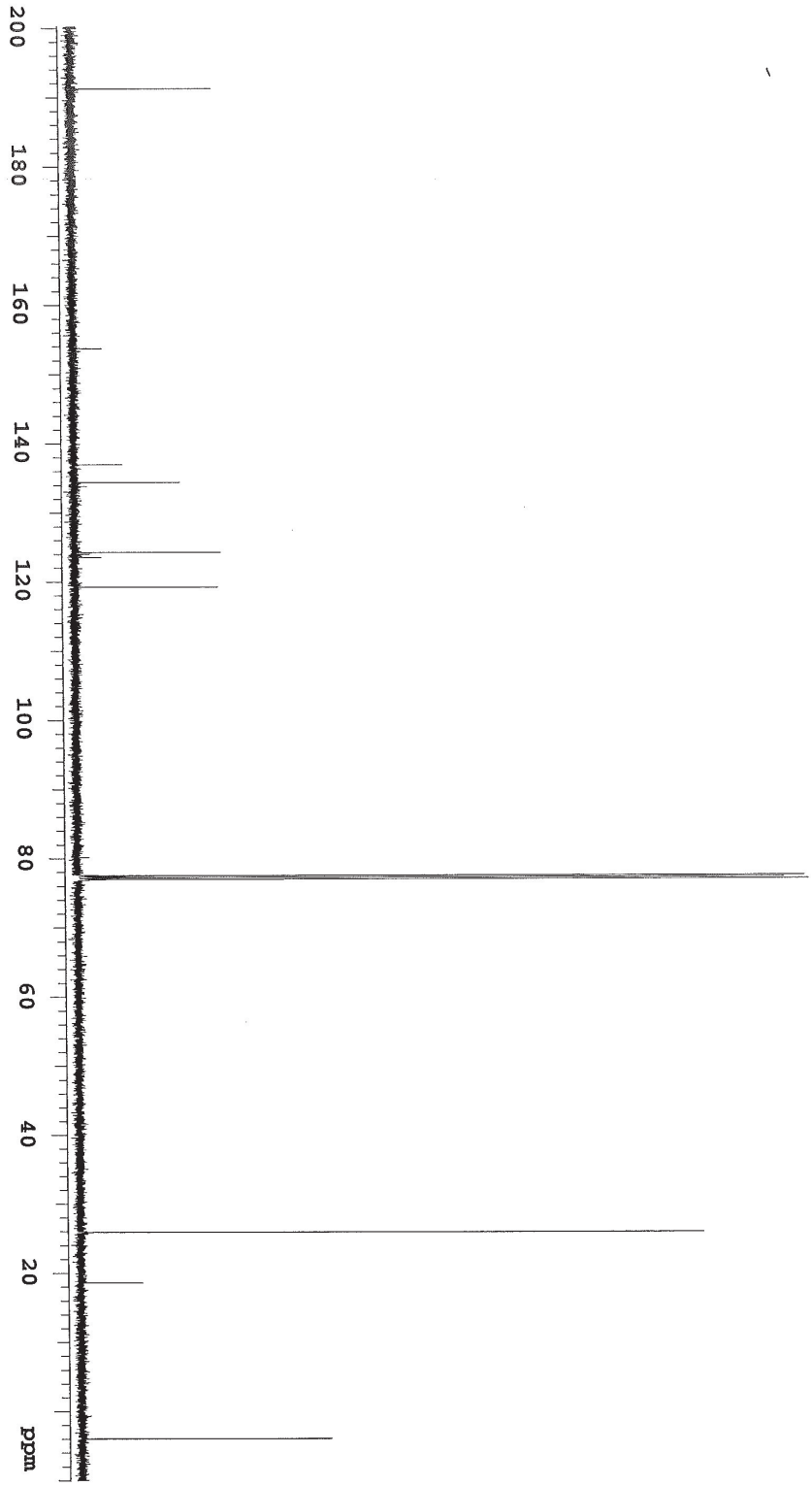
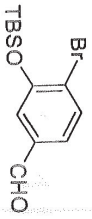




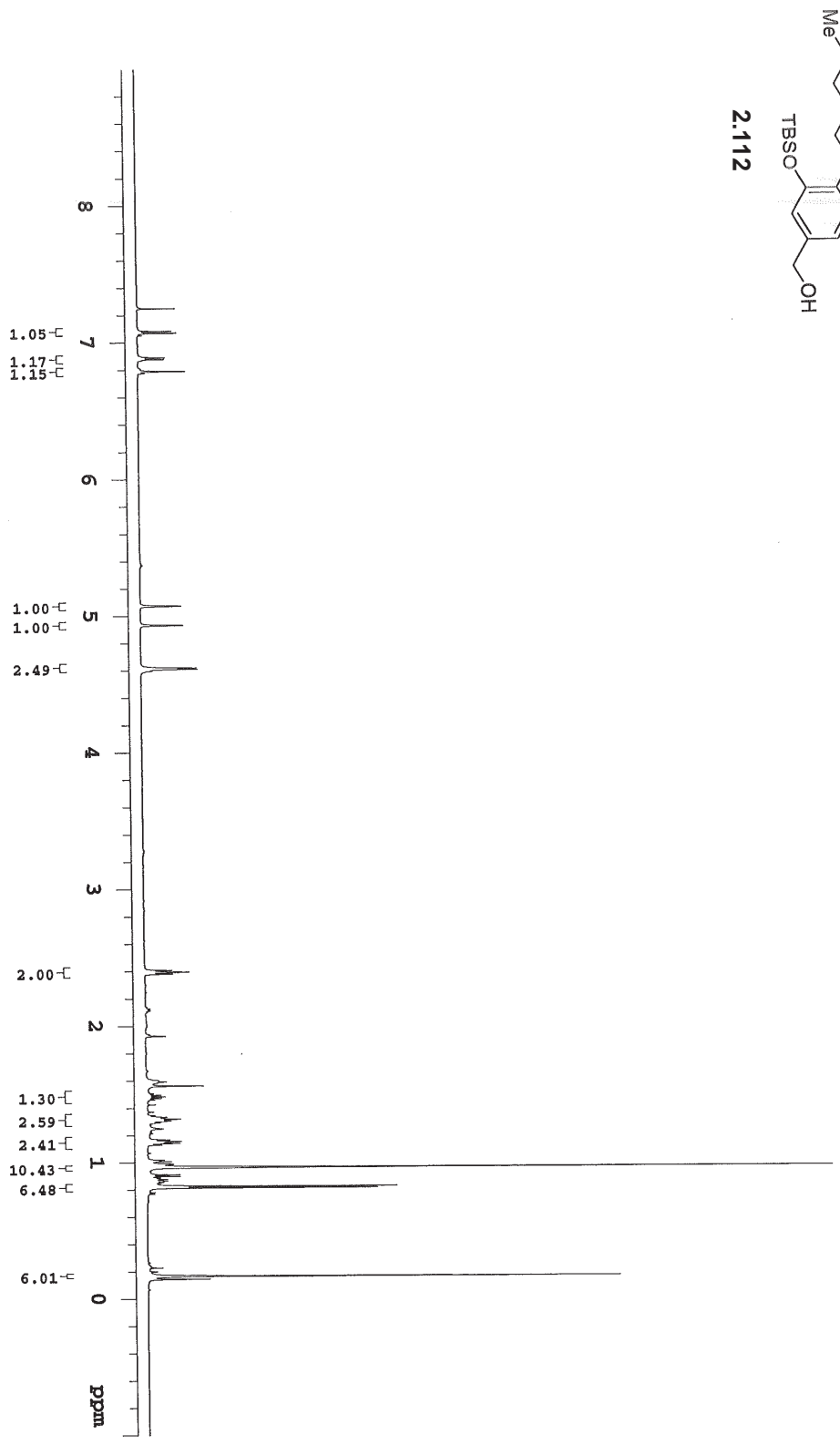


2.111





2.111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1.00
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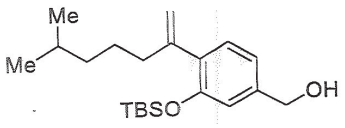
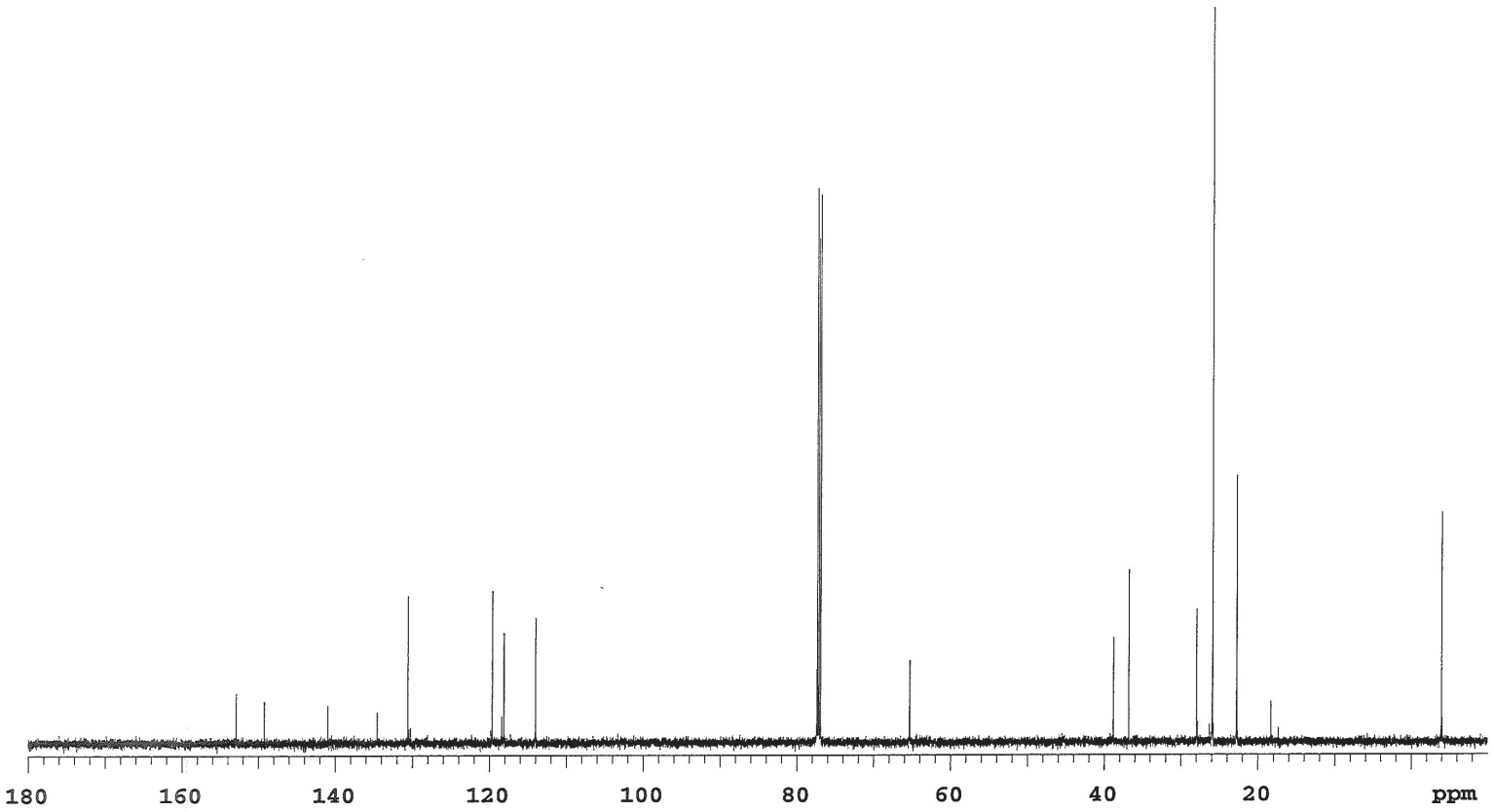
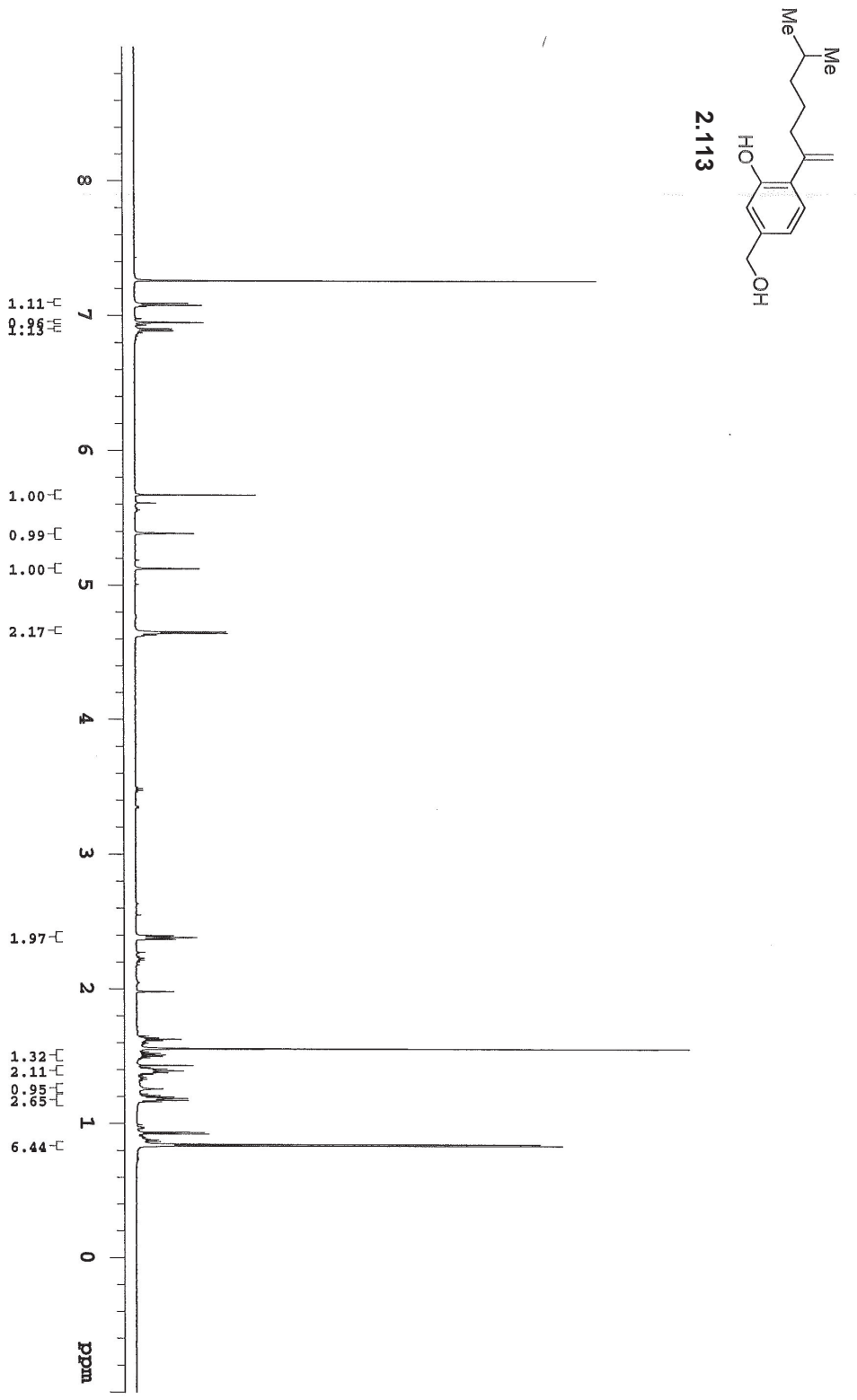
8
7
6
5
4
3
2
1
0
ppm



2.112

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Me
HO
OH
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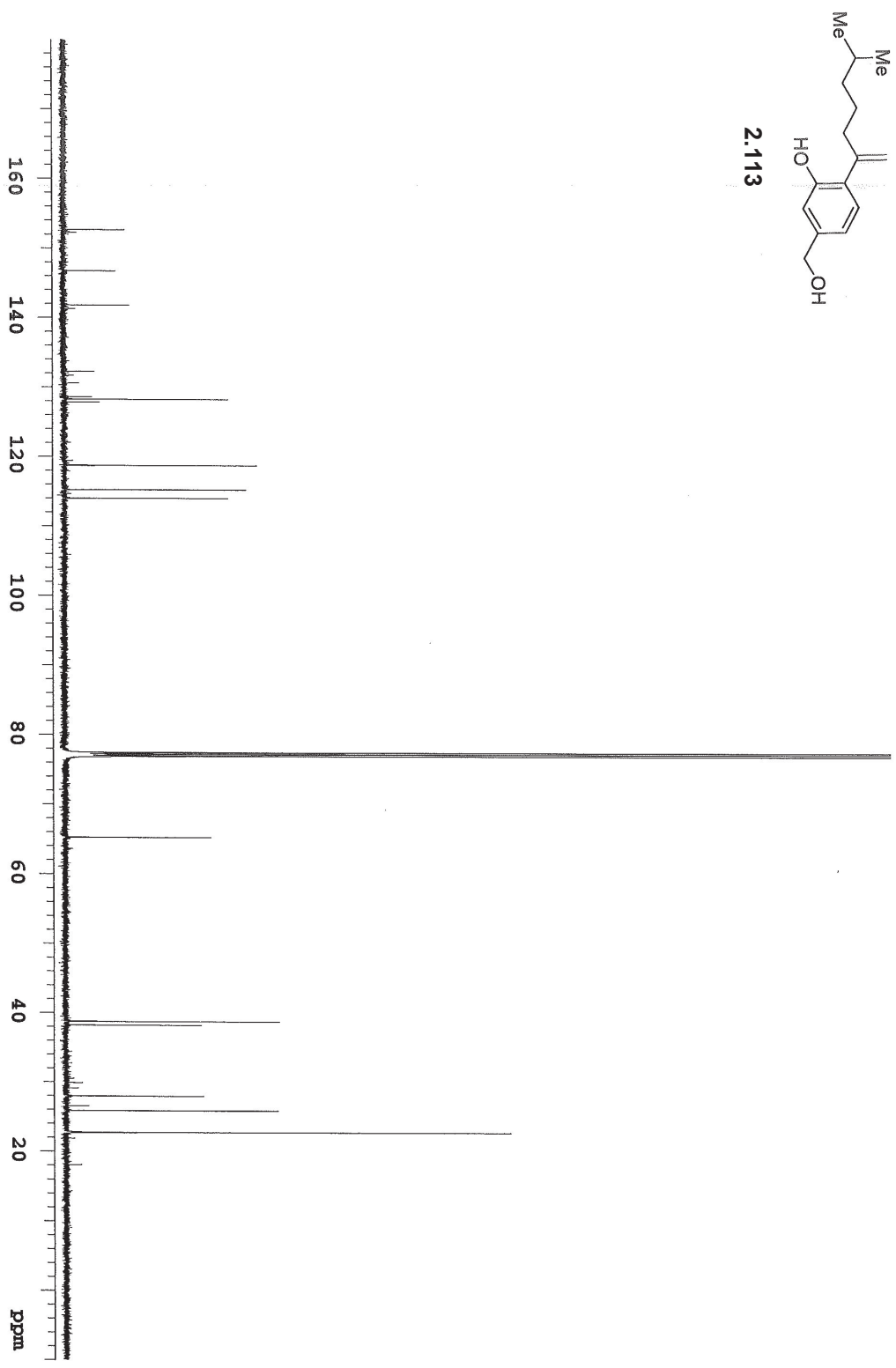
1.11
0.96
1.13
1.00
0.99
1.00
2.17
1.97
1.32
2.11
0.95
2.65
6.44
8
7
6
5
4
3
2
1
0
ppm


Me
Me
HO
OH
2.113
160
140
120
100
80
60
40
20
ppm

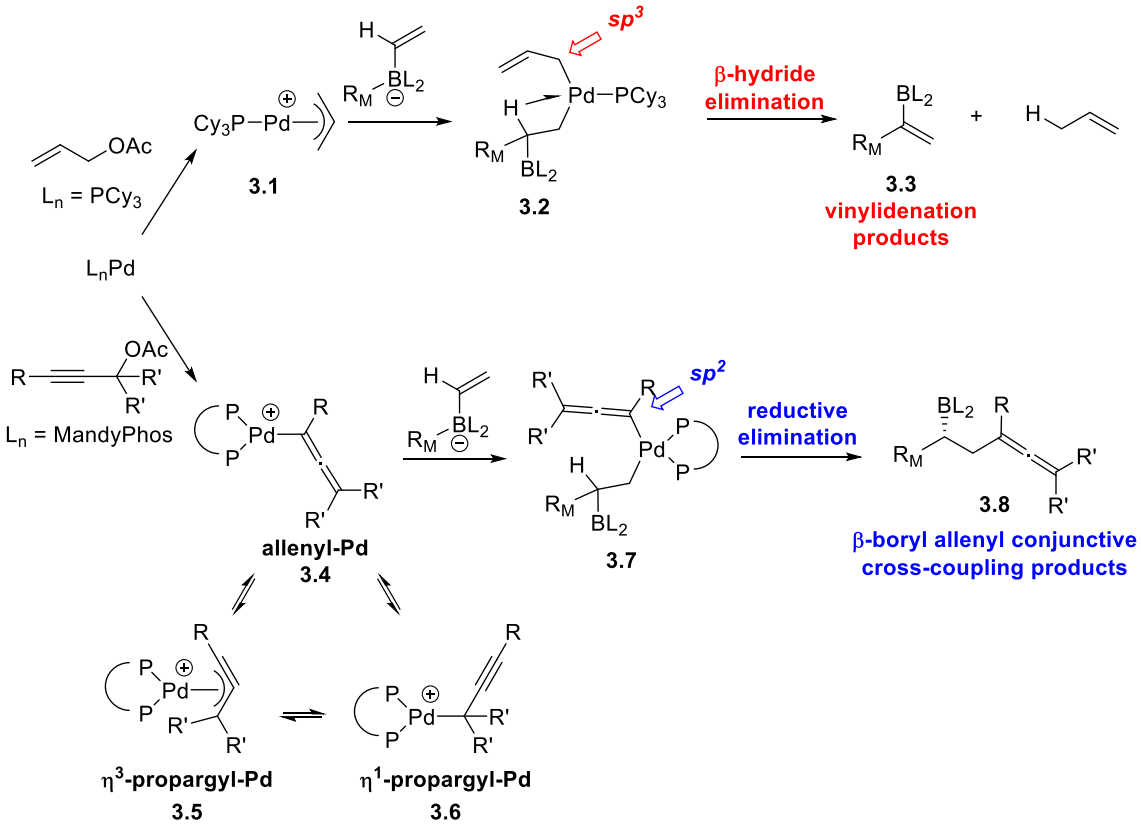
CHAPTER THREE

The Conjunctive Cross-Coupling Reaction with Propargyl Electrophiles and the Discovery of Alcohol Exchange on Boron "Ate" Complexes

3.1. Introduction

In the previous chapter, we showed that allyl electrophiles failed to give appreciable yields of the desired γ-boryl alkene conjunctive cross-coupling products, but instead, after switching from a bidentate MandyPhos ligand to a monodentate PCy_3 ligand, promoted β-hydride elimination to give vinylidenation products **3.3** (Scheme 3.1, top).[1] We reasoned

Scheme 3.1. Pd-induced 1,2-metallate shifts with allyl electrophiles vs. propargyl electrophiles

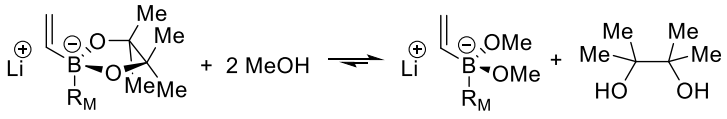


[1] Aparece, M. D.; Gao, C.; Lovinger, G. J.; Morken, J. P. *Angew. Chem. Int. Ed.* **2019**, *58*, 592.

that the sp^3-hybridized carbon atom of the η^1-allyl group bound to palladium in complex **3.2** is responsible for the failure of the conjunctive cross-coupling reaction with allyl electrophiles. Reductive elimination of alkyl groups is slow due to the increased orbital directionality associated with sp^3-hybridized centers leading to poorer orbital overlap between the coupling partners in the transition state,[2] in addition to the propensity for Pd(alkyl) species to undergo β-hydride elimination.

To explore whether related electrophiles could engage in conjunctive cross-coupling, we investigated the use of propargyl electrophiles. Palladium is known to undergo oxidative addition with these electrophiles in an S_N2' fashion, which would give a Pd(allenyl) complex **3.4** in equilibrium with its η^3-propargyl **3.5** and η^1-propargyl tautomers **3.6** (Scheme 3.1, bottom).[3] Following coordination of the boron "ate" followed by 1,2-metallate shift to give Pd(η^1-allenyl) complex **3.7**, we hypothesized that, as the carbon atom bound to palladium in this complex is sp^2-hybridized, this moiety would readily undergo reductive elimination similar to aryl and alkenyl groups in earlier reports

Scheme 3.2. Alcohol exchange on boron "ate" complexes



3.9 **3.10**

[2] Low, J. J.; Goddard, W. A. *J. Am. Chem. Soc.* **1984**, *106*, 8321–8322.

[3] (a) Baize, M. W.; Blosser, P. W.; Plantevin, V.; Schimpff, D. G.; Gallucci, J. C.; Wojcicki, A. *Organometallics* **1996**, *15*, 164. (b) Tsutsumi, K.; Ogoshi, S.; Kakiuchi, K.; Nishiguchi, S.; Kurosawa, H. *Inorganica Chim. Acta* **1999**, *296*, 37. (c) Canovese, L.; Visentin, F.; Biz, C.; Scattolin, T.; Santo, C.; Bertolasi, V. *J. Organomet. Chem.* **2015**, *786*, 21.

of the conjunctive cross-coupling reaction.[4] Indeed, we found that methyl propargyl carbonates derived from internal alkynes and tertiary propargyl alcohols gave β-boryl tetrasubstituted allenes **3.8** with generally high levels of enantioselectivity.[5] Furthermore, we discovered that the addition of methanol dramatically increases both the yields and enantioselectivities of this reaction. ^{1}H NMR studies revealed alkoxy ligand exchange on the pinacolatoboron "ate" complex **3.9** to give a bis(methanolato)boron "ate" complex **3.10**. To the best of our knowledge, this is a hitherto unrecognized phenomenon that might be attributed to the release of strain upon displacement of the bulky pinacolato ligand.

3.2. Background

3.2.1. Structure and Utility of Allenes

Allenes are the simplest of the cumulated polyenes in which the two π systems share an *sp*-hybridized atom yet are not in conjugation due to their orthogonality (Scheme 3.3). The first allene was first synthesized in 1887 by Burton and von Pechmann,[6] but due to the lack of more sophisticated analytical techniques at the time, its structure was not confirmed until 1954.[7] Some allenes possess axial chirality, the first example of which was synthesized in 1935.[8]

---

[4] (a) Zhang, L.; Lovinger, G. J.; Edelstein, E. K.; Szymaniak, A. A.; Chierchia, M. P.; Morken, J. P. *Science* **2016**, *351*, 70. (b) Lovinger, G. J.; Aparece, M. D.; Morken, J. P. *J. Am. Chem. Soc.* **2017**, *139*, 3153. (c) Edelstein, E. K.; Namirembe, S.; Morken, J. P. *J. Am. Chem. Soc.* **2017**, *139*, 5027. (d) Myhill, J. A.; Zhang, L.; Lovinger, G. J.; Morken, J. P. *Angew. Chem. Int. Ed.* **2018**, *57*, 12799. (e) Myhill, J. A.; Wilhelmsen, C. A.; Zhang, L.; Morken, J. P. *J. Am. Chem. Soc.* **2018**, *140*, 15181.

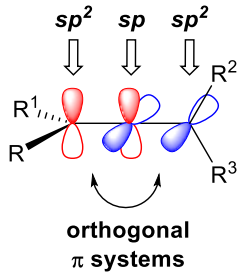
[5] Aparece, M. D.; Hu, W.; Morken, J. P. *ACS Catal.* **2019**, *9*, 11381.

[6] Burton, B. S.; von Pechmann, H. *Ber. Dtsch. Chem. Ges.* **1887**, *20*, 145.

[7] Jones, E. R. H.; Mansfield, G. H.; Whiting, M. C. *J. Chem. Soc.* **1954**, 3208.

[8] (a) Maitland, P.; Mills, W. H. *Nature* **1935**, *135*, 994. (b) Maitland, P.; Mills, W. H. *J. Chem. Soc.* **1936**, 987.

Scheme 3.3. Structure of allenes



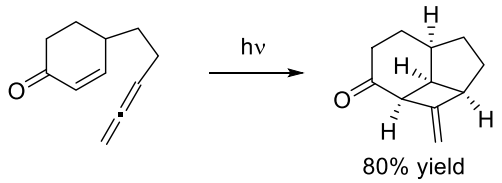
Due to their unique structure, allenes can undergo a diverse array of transformations.[9] They have been shown to participate in [2+2],[10] [4+2],[11] and [3+2][12] cycloadditions (Scheme 3.4). The PPh_3-catalyzed [3+2] cycloaddition with enantioenriched Michael acceptor **3.11** was applied to the total synthesis of (–)-hinesol **3.12** (Scheme 3.4d).[12a] A chiral ligand (*S*)-*t*Bu-Binaphane **3.13** has been used to effect an asymmetric [3+2] cycloaddition between achiral allenes and achiral Michael acceptors to give enantioenriched cyclopentane products (Scheme 3.4e).[12b]

Allenes can also undergo a variety of oxidation reactions. Treating 1,3-di-*t*-butyl allene **3.14** with *m*CPBA gives allene oxide **3.15**, which undergoes thermal isomerization to *trans*-di-*t*-butylcyclopropanone **3.16** (Scheme 3.5a).[13] Likewise, methoxyallene **3.17** can be converted to its corresponding oxide **3.18**, which has been used as an enolate equivalent in titanium-promoted aldol addition reactions: acetal electrophiles with Brønsted acid additives gave predominantly *syn* aldol products **3.19**, while aldehyde electrophiles with

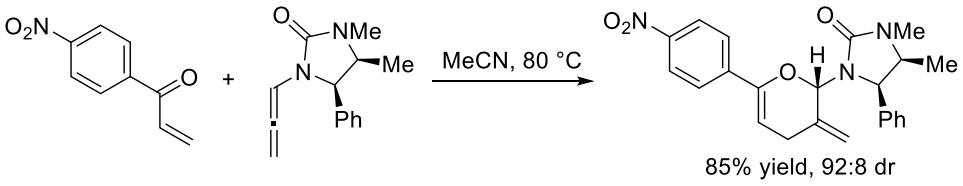
[9] (a) Ma, S. *Chem. Rev.* **2005**, *105*, 2829. (b) Yu, S.; Ma, S. *Angew. Chem. Int. Ed.* **2012**, *51*, 3074.
[10] Dauben, W. G.; Shapiro, G.; Luders, L. *Tetrahedron Lett*. **1985**, *26*, 1429.
[11] (a) Wei, L.-L.; Hsung, R. P.; Xiong, H.; Mulder, J. A.; Nkansah, N. T. *Org. Lett.* **1999**, *1*, 2145. (b) Zhu, X.-F.; Lan, J.; Kwon, O. *J. Am. Chem. Soc.* **2003**, *125*, 4716.
[12] (a) Du, Y.; Lu, X. *J. Org. Chem.* **2003**, *68*, 6463. (b) Schuler, M.; Voituriez, A.; Marinetti, A. *Tetrahedron Asymmetry* **2010**, *21*, 1569.
[13] Camp, R. L.; Greene, F. Davis. *J. Am. Chem. Soc.* **1968**, *90*, 7349.

Scheme 3.4. Cycloaddition reactions of allenes

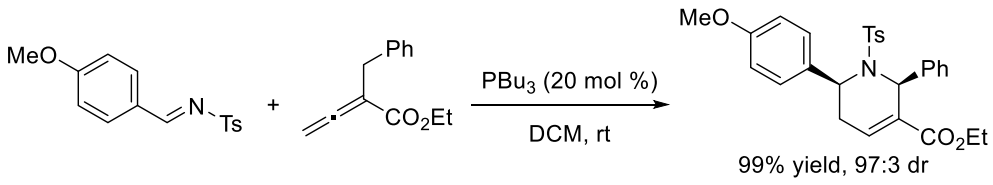
(a) Dauben's intramolecular [2+2] cycloaddition of allenes and olefins[10]



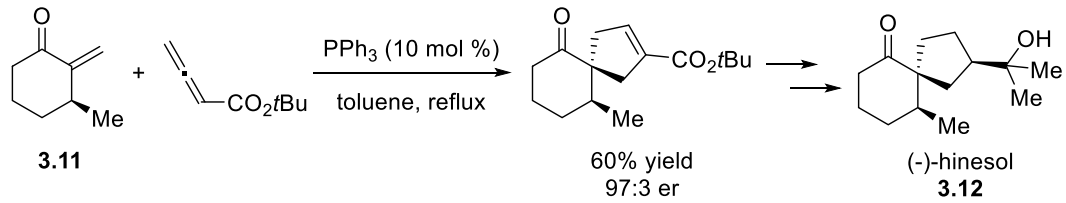
(b) Hsung's diastereoselective inverse electron-demand Diels-Alder of vinyl ketones and chiral allenes[11a]



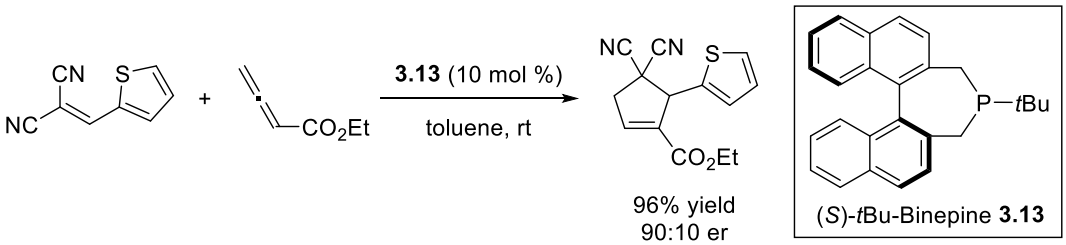
(c) Kwon's PBu_3-catalyzed [4+2] cycloaddition of allenes and imines[11b]



(d) Lu's PPh_3-catalyzed [3+2] cycloaddition en route to the total synthesis of (-)-hinesol[12a]

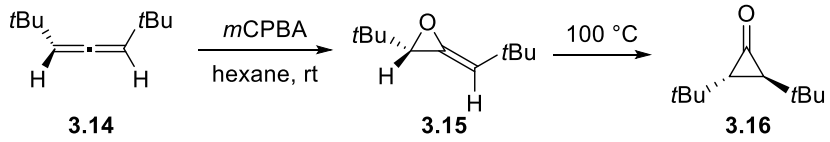


(e) Marinetti's enantioselective [3+2] cycloaddition with a chiral phosphine[12b]



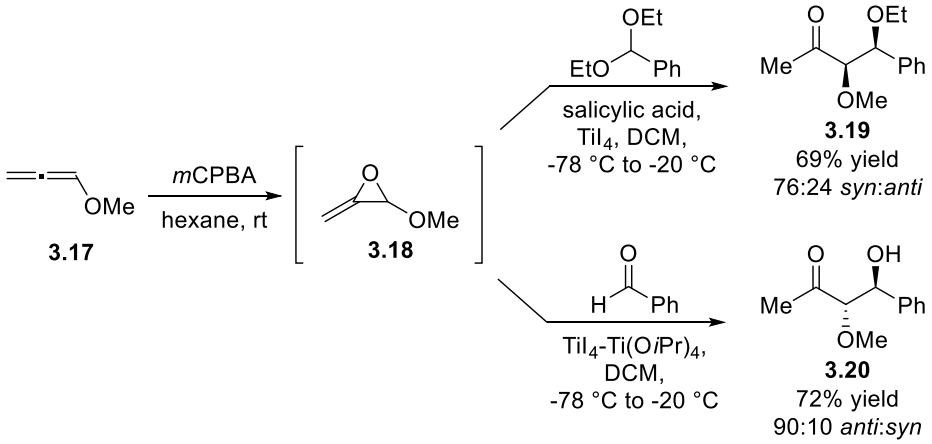
Scheme 3.5. Oxidation reactions of allenes

(a) Camp and Greene's epoxidation and isomerization of 1,3-di-*t*-butyl allene[13]



3.14 **3.15** **3.16**

(b) Shimizu's Ti-promoted aldol addition with methoxyallene[14]

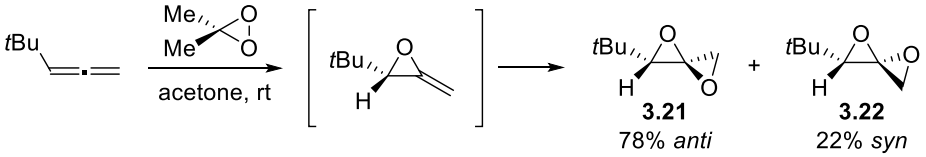


3.17 **3.18**

3.19
69% yield
76:24 *syn*:*anti*

3.20
72% yield
90:10 *anti*:*syn*

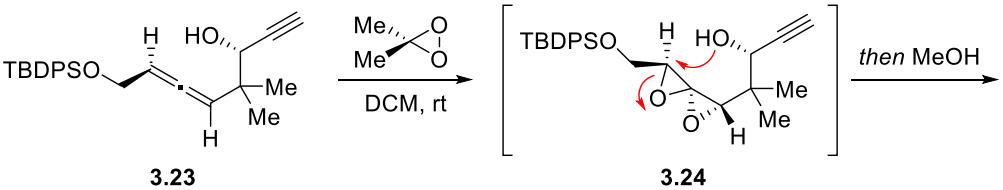
(c) Crandall's double epoxidation of monosubstituted allenes[15]



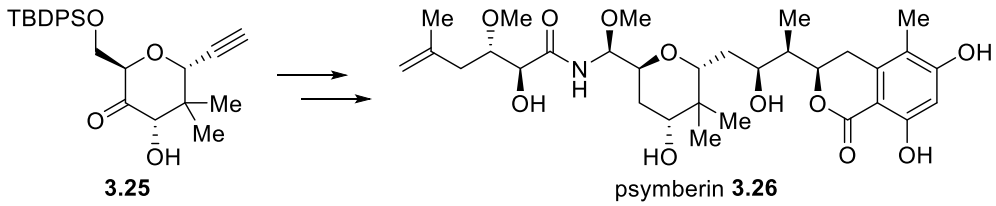
3.21
78% *anti*

3.22
22% *syn*

(d) Williams's oxidative cyclization of a β-hydroxy allene in the formal synthesis of psymberin[16]



3.23 **3.24**



3.25 psymberin **3.26**

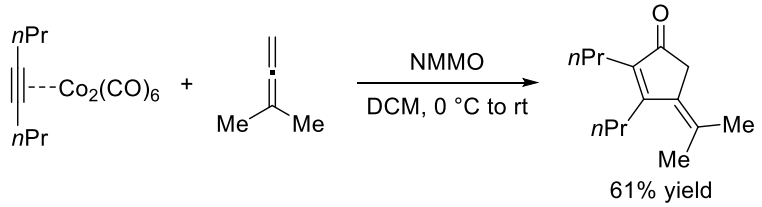
Lewis acid additives gave predominantly *anti* aldol products **3.20** (Scheme 3.5b).[14] Allenes are also known to undergo double epoxidation reactions with dimethyldioxirane (DMDO) to give l,4-dioxaspiro[2.2]pentanes such as **3.21** and **3.22** (Scheme 3.5c).[15] This strategy has been employed by Williams and coworkers in their formal synthesis of psymberin **3.26**: treating enantioenriched allene **3.23** with DMDO gives a l,4-dioxaspiro[2.2]pentane intermediate **3.24**, which undergoes nucleophilic attack by the pendant hydroxyl group to give stereodefined pyran **3.25** (Scheme 3.5d).[16]

Cyclometallation reactions of allenes have been used to rapidly build structural complexity. Allenes have been shown to react with alkynes in Pauson–Khand reactions (Scheme 3.6a)[17] and Ni-catalyzed [2+2+2] arene syntheses (Scheme 3.6b).[18] They have also been used in intramolecular cyclization reactions with alkynes (Scheme 3.6c),[19] alkenes (Scheme 3.6d),[20] and aldehydes (Scheme 3.6e)[21] to give a variety of densely functionalized ring systems.

[14] Hayakawa, R.; Shimizu, M. *Org. Lett.* **2000**, *2*, 4079.
[15] Crandall, J. K.; Batal, D. J.; Sebesta, D. P.; Lin, F. *J. Org. Chem.* **1991**, *56*, 1153.
[16] Shangguan, N.; Kiren, S.; Williams, L. J. *Org. Lett.* **2007**, *9*, 1093.
[17] Ahmar, M.; Antras, F.; Cazes, B. *Tetrahedron Lett.* **1995**, *36*, 4417.
[18] (a) Shanmugasundaram, M.; Wu, M.-S.; Cheng, C.-H. *Org. Lett.* **2001**, *3*, 4233. (b) Shanmugasundaram, M.; Wu, M.-S.; Jeganmohan, M.; Huang, C.-W.; Cheng, C.-H. *J. Org. Chem.* **2002**, *67*, 7724.
[19] Urabe, H.; Takeda, T.; Hideura, D.; Sato, F. *J. Am. Chem. Soc.* **1997**, *119*, 11295.
[20] Makino, T.; Itoh, K. *J. Org. Chem.* **2004**, *69*, 395.
[21] Montgomery, J.; Song, M. *Org. Lett.* **2002**, *4*, 4009.

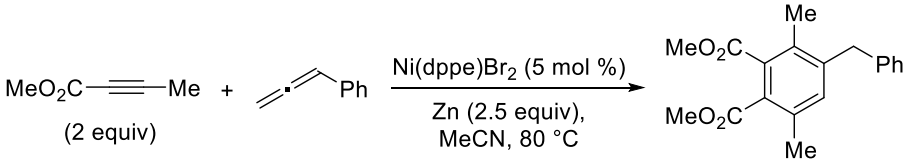
Scheme 3.6. Cyclometallation reactions of allenes

(a) Cazes's Pauson-Khand cyclization of allenes and alkynes[17]

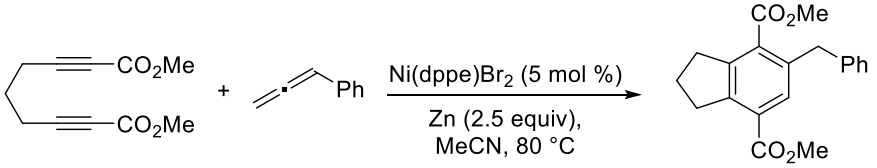


61% yield

(b) Cheng's Ni-catalyzed [2+2+2] arene synthesis[18]

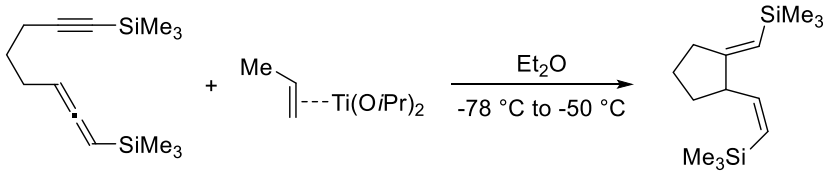


75% yield



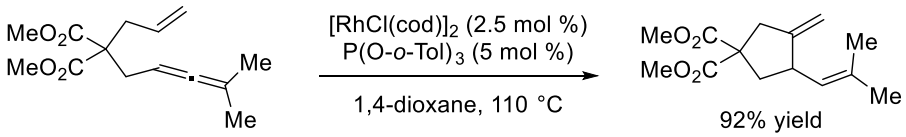
90% yield

(c) Sato's Ti-mediated cyclization of allenynes[19]



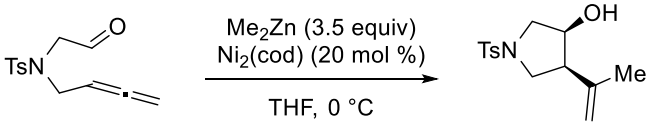
87% yield, *Z* only

(d) Itoh's Rh-catalyzed cyclization of allenenes[20]



92% yield

(e) Montgomery's Ni-catalyzed cyclization of allenyl aldehydes[21]



70% yield, >97:3 dr

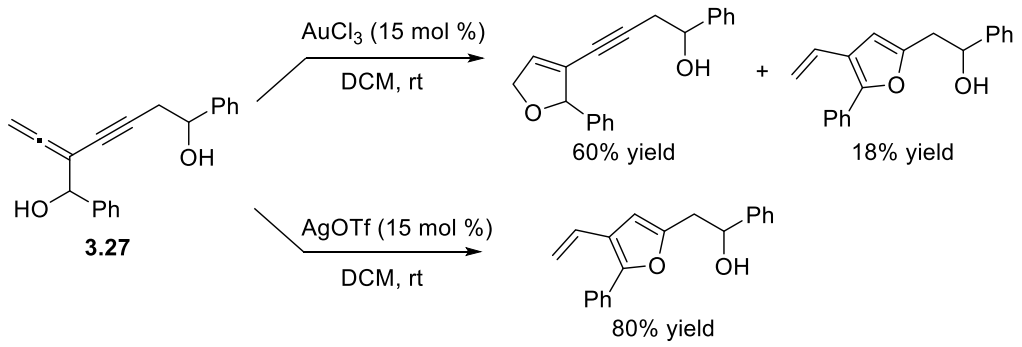
Like alkenes and alkynes, allenes are particularly effective substrates for silver, gold, and platinum catalysis due to the π-acidity of these transition metals.[22] Allenes have been shown to undergo silver- or gold-catalyzed heterocyclization reactions. Lee and coworkers reported the regiodivergent hydroalkoxylation of allenynyl 1,6-diols: a gold catalyst promotes a 5-*endo*-*trig* cyclization onto the allenyl moiety, whereas a silver catalyst promotes a 5-*endo*-*dig* cyclization onto the alkynyl moiety (Scheme 3.7a).[23] The Krause lab exploited this reactivity in their total synthesis of (–)-isocyclocapitelline **3.30**, a natural product isolated from the Rubiaceae plant *Hedyotis capitellata*, which is used in traditional Chinese and Vietnamese medicine: treating the enantioenriched allenyl alcohol **3.28** with low catalyst loadings of $AuCl_3$ formed dihydrofuran **3.29** with excellent levels of diastereoselectivity (Scheme 3.7b).[24]

Hydroamination reactions have also been developed. For example, the Toste group developed the enantioselective hydroamination of aminoallenes using a chiral gold catalyst to synthesize piperidines with high levels of enantioselectivity (Scheme 3.7c).[25] Bates and coworkers utilized the silver-catalyzed intramolecular hydroamination of an enantioenriched allenyl hydroxylamine derivative **3.31** to give oxazolidine **3.32**, which was converted several steps later to the *Sedum* alkaloid (–)-sedinine **3.33** (Scheme 3.7d).[26]

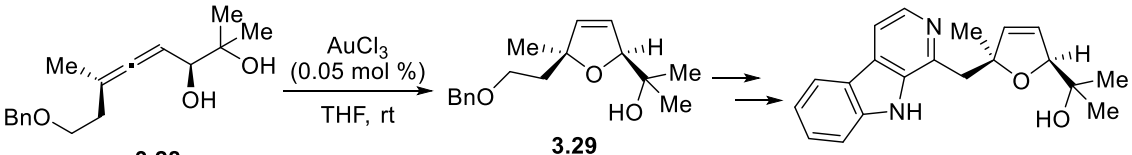
[22] Fürstner, A.; Davies, P. W. *Angew. Chem. Int. Ed.* **2007**, *46*, 3410.
[23] Kim, S.; Lee, P. H. *Adv. Synth. Catal.* **2008**, *350*, 547.
[24] Volz, F.; Krause, N. *Org. Biomol. Chem.* **2007**, *5*, 1519.
[25] LaLonde, R. L.; Sherry, B. D.; Kang, E. J.; Toste, F. D. *J. Am. Chem. Soc.* **2007**, *129*, 2452.
[26] Bates, R. W.; Lu, Y. *Org. Lett.* **2010**, *12*, 3938.

Scheme 3.7. Ag- and Au-catalyzed heterocyclization reactions of allenes

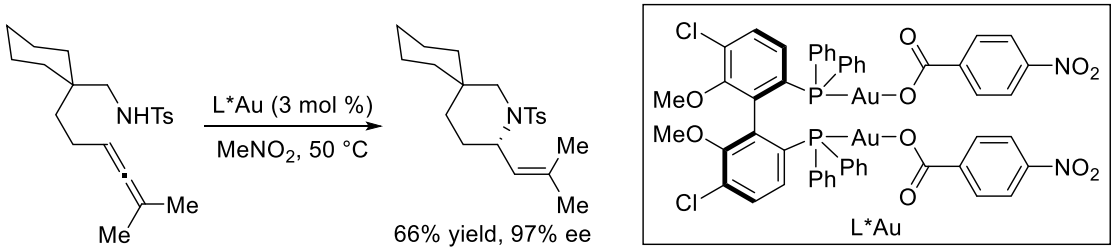
(a) Lee's regiodivergent hydroalkoxylation of allenynyl 1,6-diols with Ag and Au catalysts[23]



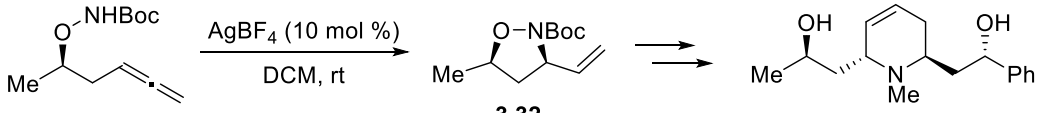
(b) Krause's Au-catalyzed hydroalkoxylation en route to the total synthesis of (-)-isocyclocapitelline[24]



(c) Toste's Au-catalyzed enantioselective hydroamination of aminoallenes[25]



(d) Bates's Ag-catalyzed hydroamination en route to the total synthesis of (-)-sedinine[26]

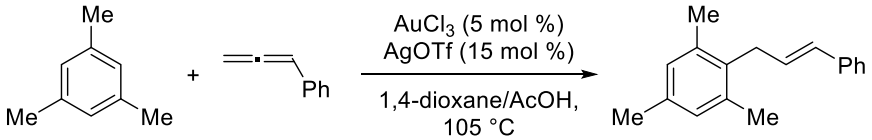


There are numerous examples of gold- and platinum-catalyzed hydroarylations of allenes which include intermolecular (Scheme 3.8a)[27] and intramolecular variants (Scheme 3.8b and c),[28] with the latter being more common. Hydroarylations with heterocycles are also known, such as Ma's Pt-catalyzed hydroarylation of indolylallenols to synthesize carbazoles (Scheme 3.8d)[29] and Widenhoefer's Au-catalyzed hydroarylation of indolylallenes with a chiral ligand to give cyclized products with good to high levels of enantioselectivities (Scheme 3.8e).[30] The Nelson lab reported the Au-catalyzed hydroarylation of enantioenriched pyrrolylallene **3.34** to give **3.35** with high diastereoselectivity, which was converted several steps later to (–)-rhazinilam **3.36**, an alkaloid isolated from the poisonous plant *Rhazya stricta* (Scheme 3.8f).[31]

[27] Skouta, R.; Li, C.-J. *Can. J. Chem.* **2008**, *86*, 616.
[28] (a) Watanabe, T.; Oishi, S.; Fujii, N.; Ohno, H. *Org. Lett.* **2007**, *9*, 4821. (b) Mo, J.; Lee, P. H. *Org. Lett.* **2010**, *12*, 2570.
[29] Kong, W.; Fu, C.; Ma, S. *Chem. Commun.* **2009**, *30*, 4572.
[30] Liu, C.; Widenhoefer, R. A. *Org. Lett.* **2007**, *9*, 1935.
[31] Liu, Z.; Wasmuth, A. S.; Nelson, S. G. *J. Am. Chem. Soc.* **2006**, *128*, 10352.

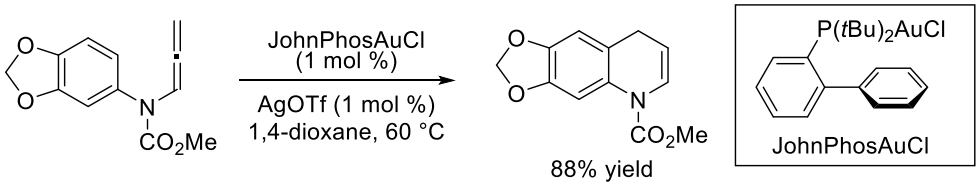
Scheme 3.8. Au- and Pt-catalyzed hydroarylation reactions of allenes

(a) Li's Au-catalyzed intermolecular hydroarylation of arylallenes[27]



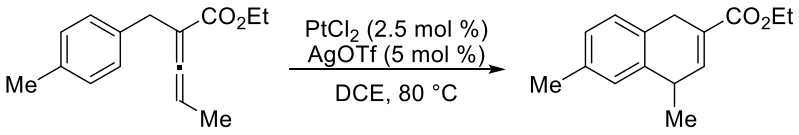
70% yield

(b) Fujii and Ohno's Au-catalyzed intramolecular hydroarylation of arylallenes[28a]



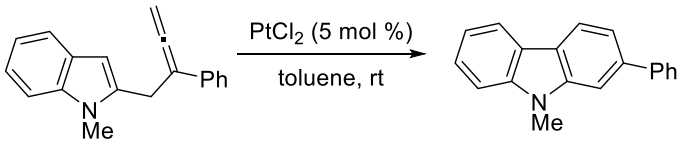
88% yield

(c) Lee's Pt-catalyzed intramolecular hydroarylation of arylallenes[28b]



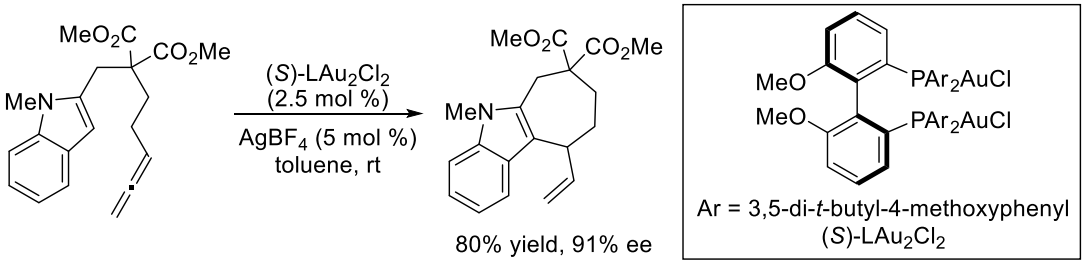
92% yield

(d) Ma's Pt-catalyzed intramolecular hydroarylation of indolylallenols to synthesize carbazoles[29]



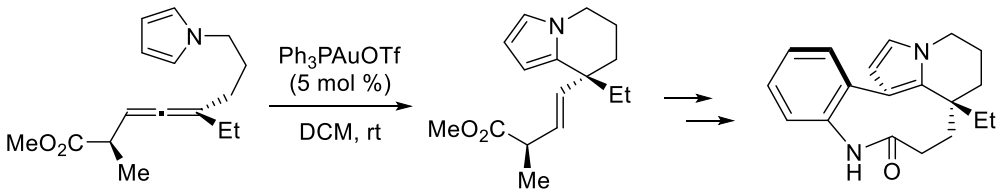
81% yield

(e) Widenhoefer's enantioselective Au-catalyzed intramolecular hydroarylation of indolylallenes[30]



80% yield, 91% ee

(f) Nelson's Au-catalyzed hydroarylation en route to the total synthesis of (-)-rhazinilam[31]



3.34

3.35

92% yield, 97:3 dr

(-)-rhazinilam **3.36**

3.2.2. Synthesis of Allenes

Allenes are most commonly synthesized from propargyl electrophiles. Hydroxyl-directed S_N2' reactions such as reductions (Scheme 3.9a and b)[32] and brominations (Scheme 3.9c)[33] have been reported. Carbon-based nucleophiles such as indoles (Scheme 3.9d)[34] and organometallics such as organozinc[35] and organoindium[36] reagents (Scheme 3.9e and f) have also been shown to engage with propargyl electrophiles.

The synthesis of allenes has been tremendously expanded and improved by the use of transition metal catalysis. Selected examples include Cu-catalyzed borylation[37] and alkylation[38] (Scheme 3.10a and b), Ni-catalyzed intramolecular allenylation of soft nucleophiles such as malonates (Scheme 3.10c),[39] and Rh-catalyzed arylation of propargyl epoxides (Scheme 3.10d).[40]

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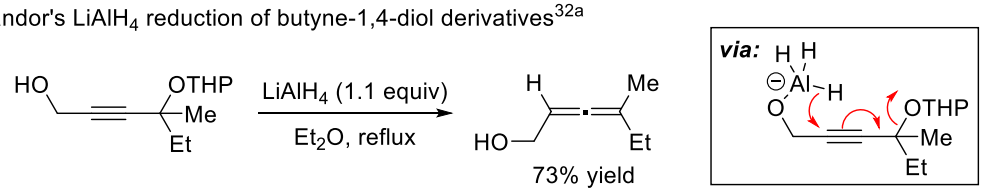
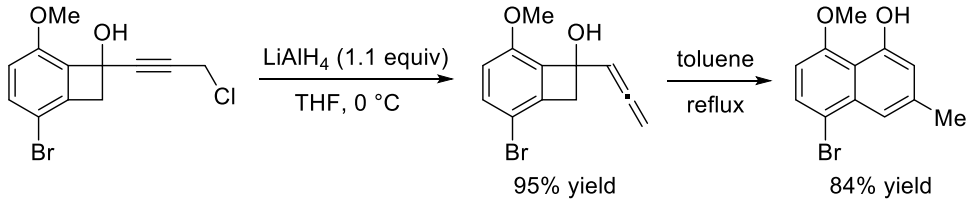
[32] (a) Cowie, J. S.; Landor, P. D.; Landor, S. R. *J. Chem. Soc. Perkin Trans. I* **1973**, 720. (b) Bungard, C. J.; Morris, J. C. *J. Org. Chem.* **2002**, *67*, 2361.
[33] Du, X.; Dai, Y.; He, R.; Lu, S.; Bao, M. *Synth. Commun.* **2009**, *39*, 3940.
[34] Sanz, R.; Gohain, M.; Miguel, D.; Martínez, A.; Rodríguez, F. *Synlett* **2009**, *2009*, 1985.
[35] Kobayashi, K.; Naka, H.; Wheatley, A. E. H.; Kondo, Y. *Org. Lett.* **2008**, *10*, 3375.
[36] Lee, K.; Lee, P. H. *Org. Lett.* **2008**, *10*, 2441.
[37] Ito, H.; Sasaki, Y.; Sawamura, M. *J. Am. Chem. Soc.* **2008**, *130*, 15774.
[38] Li, J.; Kong, W.; Fu, C.; Ma, S. *J. Org. Chem.* **2009**, *74*, 5104.
[39] Gou, F.-R.; Bi, H.-P.; Guo, L.-N.; Guan, Z.-H.; Liu, X.-Y.; Liang, Y.-M. *J. Org. Chem.* **2008**, *73*, 3837.
[40] Miura, T.; Shimada, M.; Ku, S.-Y.; Tamai, T.; Murakami, M. *Angew. Chem. Int. Ed.* **2007**, *46*, 7101.

Scheme 3.9. Non-transition metal-catalyzed allene syntheses from propargyl electrophiles

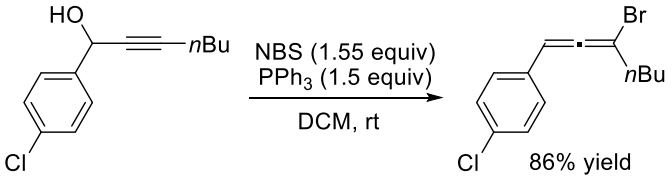
(a) Landor's $LiAlH_4$ reduction of butyne-1,4-diol derivatives[32a]



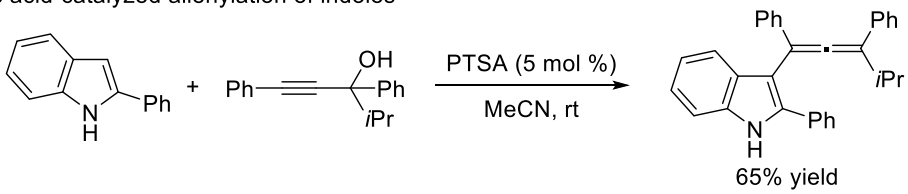
(b) Morris's $LiAlH_4$ reduction of propargyl chlorides en route to synthesize naphthols[32b]



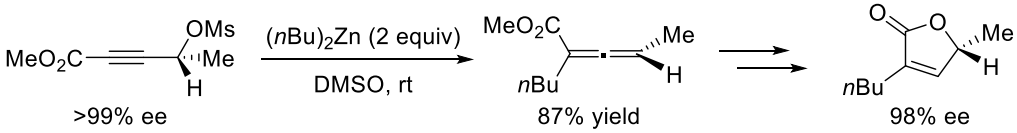
(c) Bao's conversion of propargyl alcohols to haloallenes[33]



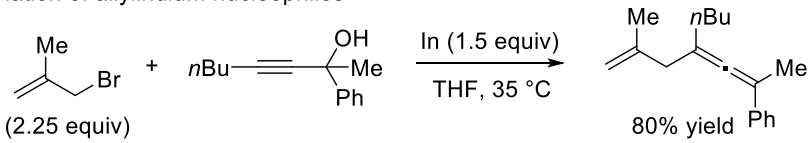
(d) Sanz's acid-catalyzed allenylation of indoles[34]



(e) Kondo's allenylation of organozinc nucleophiles[35]

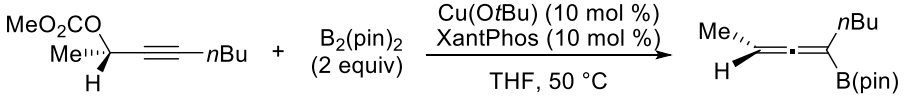


(f) Lee's allenylation of allylindium nucleophiles[36]



Scheme 3.10. Non-Pd transition metal-catalyzed allene syntheses from propargyl electrophiles

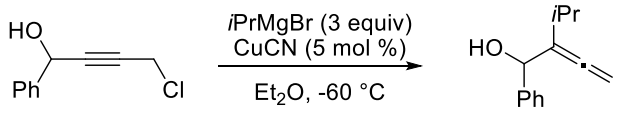
(a) Ito and Sawamura's Cu-catalyzed borylation of propargyl carbonates[37]



97% ee

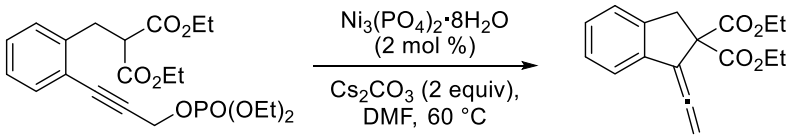
60% yield

(b) Ma's Cu-catalyzed allenylation of Grignard reagents[38]



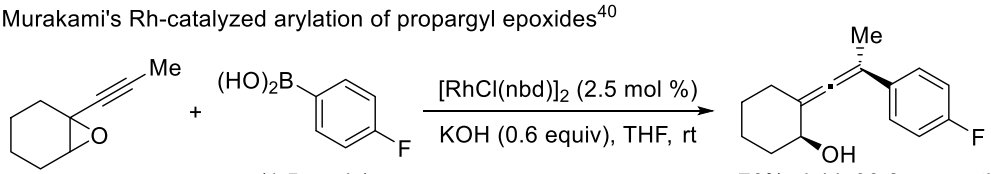
92% yield

(c) Liang's intramolecular allenylation of malonates to synthesize indanes[39]



81% yield

(d) Murakami's Rh-catalyzed arylation of propargyl epoxides[40]



(1.5 equiv)

76% yield, 98:2 *syn*:*anti*

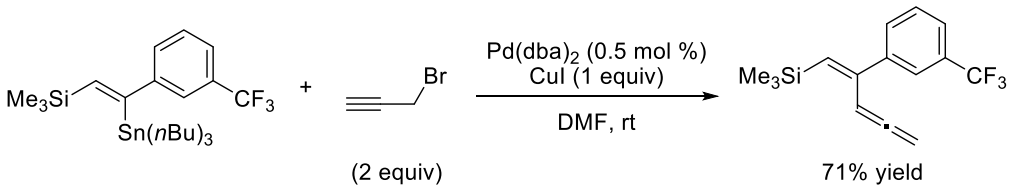
Of the transition metal-catalyzed methods to synthesize allenes, those utilizing palladium are the most extensively developed. Nakano and coworkers reported the Pd-catalyzed cross-coupling of alkenyl stannanes with propargyl bromide (Scheme 3.11a),[41] and the Liu group developed the Pd-catalyzed cross-coupling between aryl iodides and allenyl zirconium nucleophiles generated *in situ* from propargyl methyl ethers (Scheme 3.11b).[42] The Ma lab reported a ligand-dependent, regiodivergent allenylation of 2-

[41] Sasaki, F.; Endo, T.; Noguchi, M.; Kawai, K.; Nakano, T. *Appl. Organomet. Chem.* **2008**, *22*, 128.
[42] Zhang, H.; Fu, X.; Chen, J.; Wang, E.; Liu, Y.; Li, Y. *J. Org. Chem.* **2009**, *74*, 9351.

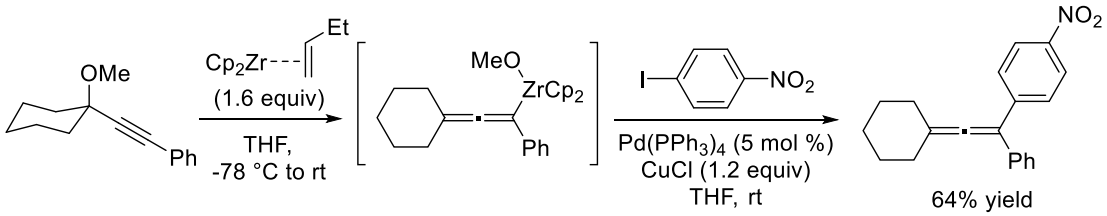
iodoalkenoates from organozinc reagents generated from alkyl aryl alkynes: using tri(2-furyl)phosphine **3.37** resulted in allenylation α to the alkyl group, while employing BINOL-derived ligand **3.38** resulting in allenylation α to the aryl group (Scheme 3.11c).[43]

Scheme 3.11. Pd-catalyzed allene syntheses from propargyl electrophiles

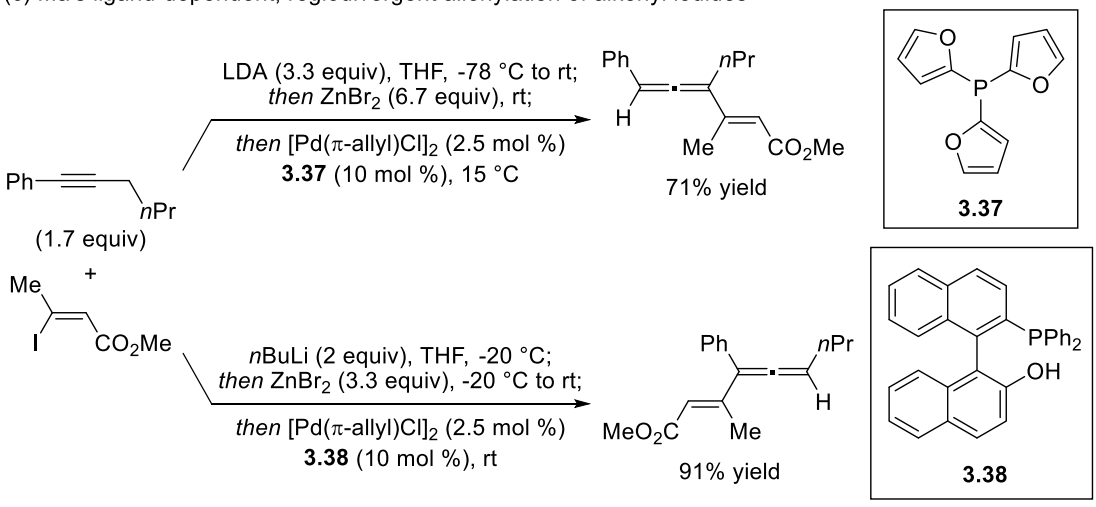
(a) Nakano's Pd-catalyzed allenylation of alkenyl stannanes[54]



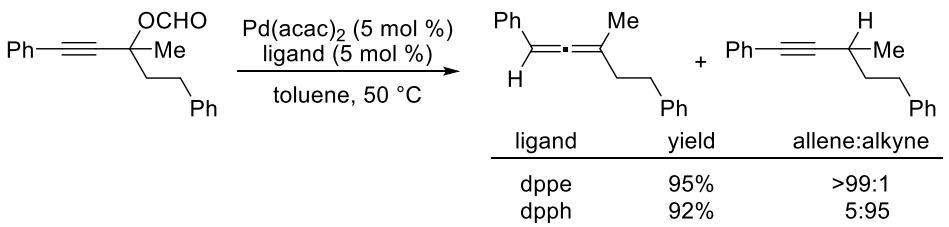
(b) Liu's Pd-catalyzed allenylation of aryl iodides[55]



(c) Ma's ligand-dependent, regiodivergent allenylation of alkenyl iodides[56]



(d) Sawamura's ligand-dependent, regiodivergent hydrogenolysis of propargyl formates[57]



ligand	yield	allene:alkyne
dppe	95%	>99:1
dpph	92%	5:95

[43] Zhao, J.; Yu, Y.; Ma, S. *Chem. Eur. J.* **2010**, *16*, 74.

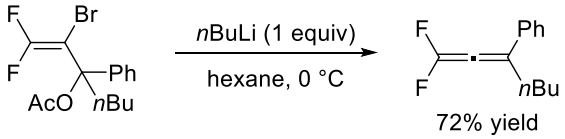
Sawamura reported a ligand-dependent, regiodivergent hydrogenolysis of propargyl formates: dppe was selective for allene formation, whereas dpph was selective for alkyne formation (Scheme 3.11d).[44]

Other methods to synthesize allenes include elimination reactions (Scheme 3.12a and b),[45] the Cu-promoted Crabbé homologation of terminal alkynes with iminium cations generated from paraformaldehyde and secondary amines (Scheme 3.12c),[46] [3,3]-sigmatropic rearrangements such as the Ireland–Claisen rearrangement (Scheme 3.12d),[47] and the enantioselective isomerization of alkynes catalyzed by a chiral guanidine base (Scheme 3.12e).[48]

[44] Ohmiya, H.; Yang, M.; Yamauchi, Y.; Ohtsuka, Y.; Sawamura, M. *Org. Lett.* **2010**, *12*, 1796.
[45] (a) Yokota, M.; Fuchibe, K.; Ueda, M.; Mayumi, Y.; Ichikawa, J. *Org. Lett.* **2009**, *11*, 3994. (b) Satoh, T.; Noguchi, T.; Miyagawa, T. *Tetrahedron Lett.* **2008**, *49*, 5689.
[46] (a) Searles, S.; Li, Y.; Nassim, B.; Lopes, M.-T. R.; Tran, P. T.; Crabbé, P. *J. Chem. Soc. Perkin Trans. I* **1984**, 747. (b) Kuang, J.; Ma, S. *J. Org. Chem.* **2009**, *74*, 1763.
[47] Baldwin, J. E.; Bennett, P. A. R.; Forrest, A. K. *J. Chem. Soc., Chem. Commun.* **1987**, *16*, 250.
[48] Liu, H.; Leow, D.; Huang, K.-W.; Tan, C.-H. *J. Am. Chem. Soc.* **2009**, *131*, 7212.

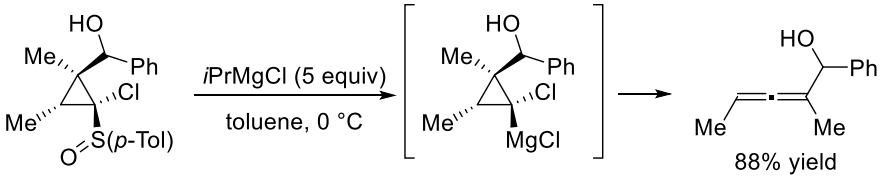
Scheme 3.12. Other methods to synthesize allenes

(a) Ichikawa's elimination of acetate promoted by lithium-halogen exchange[45a]



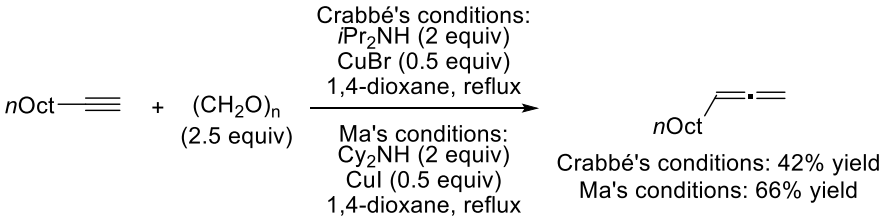
72% yield

(b) Satoh's cyclopropane-opening elimination of chloride promoted by lithium-sulfoxide exchange[45b]



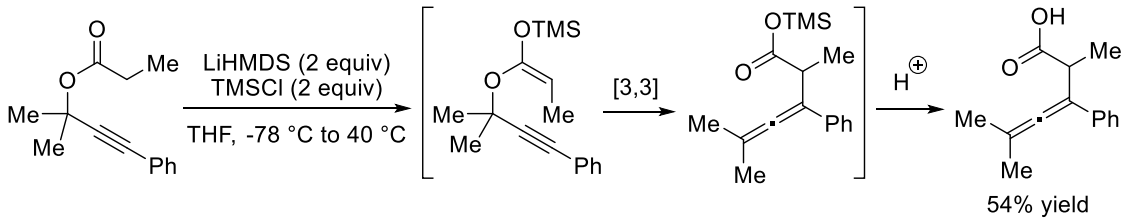
88% yield

(c) The Crabbé homologation of terminal alkynes[46a] and Ma's modifications[46b]



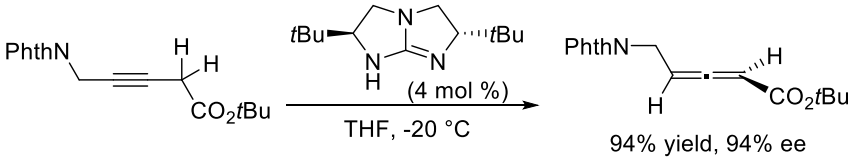
Crabbé's conditions: 42% yield
Ma's conditions: 66% yield

(d) Baldwin's synthesis of allenes by Ireland-Claisen rearrangement[47]



54% yield

(e) Tan's chiral guanidine-catalyzed isomerization of alkynes[48]



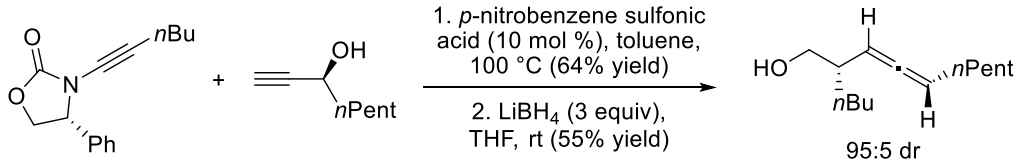
94% yield, 94% ee

Our proposed Pd-catalyzed conjunctive cross-coupling reaction between organoboron "ate" complexes and propargyl electrophiles would give β-hydroxy allenes following oxidation. Other groups have previously synthesized this motif in diastereoselective and/or enantioselective fashion. One type of transformation involves diastereoselective [3,3]-sigmatropic rearrangements, including Hsung's Saucy–Marbet rearrangement of chiral ynamides (Scheme 3.13a)[49] and Toste's Au-catalyzed propargyl Claisen rearrangement of alkenyl propargyl ethers (Scheme 3.13b).[50] The Guiry group reported an enantioselective Nozaki–Hiyama–Kishi reaction between 4-bromo-1,2-butadiene **3.39** and aldehydes with non-C_2-symmetric bisoxazoline ligand **3.40** to synthesize enantioenriched β-hydroxy allenes (Scheme 3.13c).[51] Liu and coworkers reported the conversion of conjugated enynes to zirconacyclopentenes **3.41**, which were trapped by aldehydes to give highly-substituted β-hydroxy allene products **3.42** bearing multiple contiguous stereocenters with high diastereoselectivity (Scheme 3.13d).[52] The Kimura lab developed a diastereoselective Ni-catalyzed three-component coupling of conjugated enynes, aldehydes, and dialkylzinc reagents (Scheme 3.13e).[53]

[49] Frederick, M. O.; Hsung, R. P.; Lambeth, R. H.; Mulder, J. A.; Tracey, M. R. *Org. Lett.* **2003**, *5*, 2663.
[50] Sherry, B. D.; Toste, F. D. *J. Am. Chem. Soc.* **2004**, *126*, 15978.
[51] Coeffard, V.; Aylward, M.; Guiry, P. *Angew. Chem. Int. Ed.* **2009**, *48*, 9152.
[52] Zhou, Y.; Chen, J.; Zhao, C.; Wang, E.; Liu, Y.; Li, Y. *J. Org. Chem.* **2009**, *74*, 5326.
[53] Mori, Y.; Onodera, G.; Kimura, M. *Chem. Lett.* **2014**, *43*, 97.

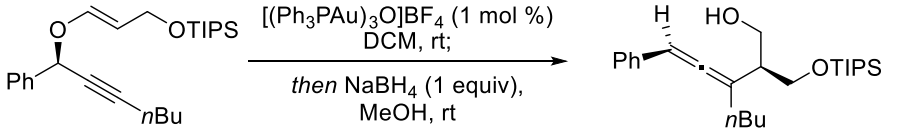
Scheme 3.13. Previous syntheses of β-hydroxy allenes

(a) Hsung's Saucy-Marbet rearrangement of chiral ynamides[49]



95:5 dr

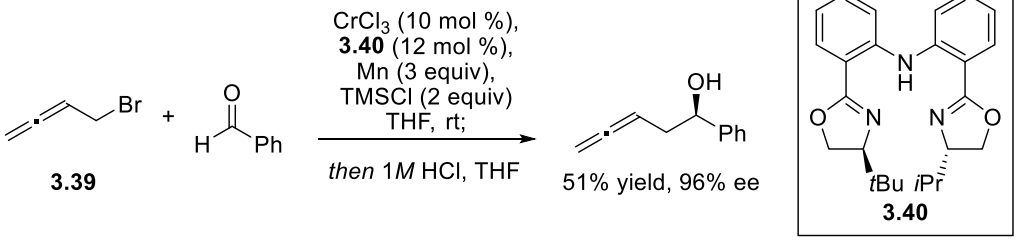
(b) Toste's Au-catalyzed propargyl Claisen rearrangement[50]



95% ee

81% yield, 94% ee, >20:1 dr

(c) Guiry's enantioselective Cr-catalyzed homoallenylation of aldehydes[51]

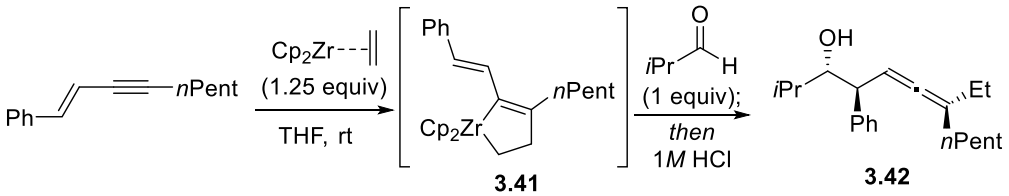


3.39

51% yield, 96% ee

3.40

(d) Liu's trapping of zirconacyclopentenes with aldehydes[52]

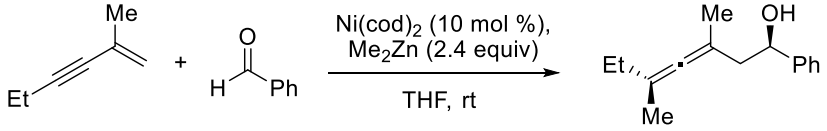


3.41

3.42

63% yield, 98:2 dr

(e) Kimura's Ni-catalyzed three-component coupling of enynes, aldehydes, and dialkylzinc reagents[53]



(2.4 equiv)

66% yield, 5:1 dr

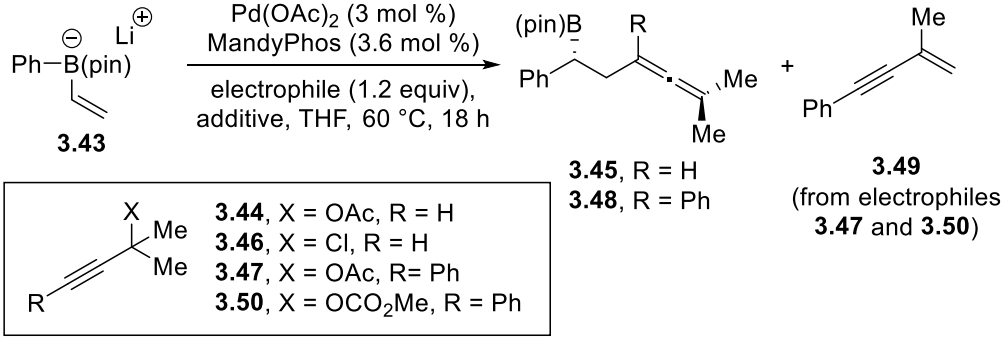
3.3. The Palladium-Catalyzed Conjunctive Cross-Coupling Reaction with Propargyl Electrophiles

3.3.1. Optimization and the Discovery of Alcohol Exchange on Boron "Ate" Complexes

We began our optimization studies using (phenyl)(vinyl)B(pin) "ate" complex **3.43** derived from phenylB(pin) and vinyllithium and 2-methyl-3-butynyl acetate **3.44** as the electrophile. Employing 3 mol % $Pd(OAc)_2$ and 3.6 mol % MandyPhos gave 17% yield of the desired trisubstituted β-boryl allene **3.45** with 88:12 er (Table 3.1, entry 1), confirming that this electrophile class could engage in the conjunctive cross-coupling reaction. Switching to a chloride leaving group (**3.46**) did not affect the reaction in a significant way (Table 3.1, entry 2). Using a propargyl acetate derived from an internal alkyne **3.47** gave the corresponding tetrasubstituted allene product **3.48** with a boost in yield to 40%, although we now observed an appreciable amount of enyne **3.49** derived from decomposition of the electrophile (Table 3.1 entry 3). Curiously, increasing the equivalents of propargyl acetate **3.47** from 1.2 to 2 resulted in a *decrease* in yield (Table 3.1, entry 4). We reasoned that acetic acid could be generated from the decomposition of the propargyl acetate—presumably via β-hydride elimination to form the enyne, followed by reductive elimination of acetic acid from palladium—which would destroy the "ate" complex.

To avoid the generation of acetic acid, we used $Pd_2(dba)_3$ and a propargylic methyl carbonate **3.50**, which not only gave modest yield of the conjunctive cross-coupling product **3.48** with slightly higher enantioselectivity but also lower amounts of enyne **3.49** (Table 3.1, entry 5). Increasing the equivalents of methyl propargyl carbonate electrophile

Table 3.1. The effect of propargyl electrophiles and additives on conjunctive cross-coupling



entry	electrophile (equiv)	additive (equiv)	yield of product (%)[b]	yield of enyne (%)[b]	e.r. of product[c]
1	**3.44** (1.2)	none	17	N/A	88:12
2	**3.46** (1.2)	NaOTf (2)	22	N/A	84:16
3	**3.47** (1.2)	none	40	66	90:10
4	**3.47** (2)	none	24	140	90:10
5[d]	**3.50** (1.2)	none	45	30	92:8
6[d]	**3.50** (2)	none	60	132	93:7
7[d]	**3.50** (3)	none	83	200	93:7
8[d]	**3.50** (4)	none	85	300	92:8
9[d]	**3.50** (2)	MeOH (2)	69	80	95:5
10[d]	**3.50** (2)	MeOH (4)	83[e]	45	96:4
11[d]	**3.50** (2)	MeOH (6)	86	28	97:3
12[d]	**3.50** (2)	EtOH (4)	77	72	95:5
13[d]	**3.50** (2)	CF_3CH_2OH (4)	69	55	98:2
14[d]	**3.50** (2)	*rac*-2-BuOH (4)	44	93	91:9
15[d]	**3.50** (2)	PhOH (4)	20	58	96:4

[a]Reactions conducted at 0.1 *M*. [b]Yields determined by ^{1}H NMR of the crude reaction mixture with respect to PhB(pin) as the limiting reagent with 1,1,2,2-tetrachloroethane as an internal standard. [c]Determined by chiral SFC chromatography of the derived alcohol compared to an authentic enantiomer mixture. [d]$Pd_2(dba)_3$ was used instead of $Pd(OAc)_2$ [e]Yield for this experiment is after oxidation to the corresponding alcohol and purification by silica gel chromatography.

3.50 resulted in attendant increases in yields of both the desired product and the enyne while maintaining high levels of enantioselectivity (Table 3.1, entries 6–8).

These results seem to imply that the methanol generated under these reaction conditions was not having an adverse effect on the reaction. To test this hypothesis, we added 2 equivalents of methanol to the reaction. To our surprise, we found a significant

boost in both the yield and the enantioselectivity (Table 3.1, entry 9). Increasing the amount of exogenous methanol not only led to further increases in yields and enantioselectivities but also suppression of the formation of enyne (Table 3.1, entries 10 and 11). As shown in Table 3.1, entries 12–15, the outcome of the reaction was dependent on the structure of the alcohol additive.

At this point, it was unclear whether the boosts in yield were due to methanol somehow retarding electrophile decomposition to the enyne or whether methanol was accelerating the conjunctive cross-coupling reaction in a different way. The increase in enantioselectivities seemed to suggest the latter, as methanol must be involved in the stereodetermining transition state. In order to ascertain the role of methanol in this reaction, we treated (phenyl)(vinyl)B(pin) "ate" complex **3.43** (Figure 3.1a) with four equivalents of methanol in THF-d_8 at 60 °C for 12 hours and then analyzed the reaction mixture by ^{1}H NMR. We observed the formation of a new "ate" complex (phenyl)(vinyl)B(OMe)$_2$ **3.51** in which the pinacol ligand on boron was exchanged with two methoxide ligands in approximately 68% conversion, in addition to peaks corresponding to free pinacol (Figure 3.1d). This new "ate" complex **3.51** was verified by independent synthesis from phenylB(OMe)$_2$ **3.55** and one equivalent of vinyllithium (Figure 3.1b). It should be noted that synthesizing "ate" **3.51** in this manner also gives another "ate" complex (phenyl)(vinyl)$_2$B(OMe) **3.52**; **3.52** was also independently synthesized by treating **3.55** with two equivalents of vinyllithium, although a ~1:1 mixture of **3.51** and **3.52** is formed under these conditions (Figure 3.1c). These experiments show that treating **3.43** with methanol is a reliable way to form **3.51** cleanly *in situ* as opposed to from **3.55** and vinyllithium, which is unsurprising given the lability of methoxide.

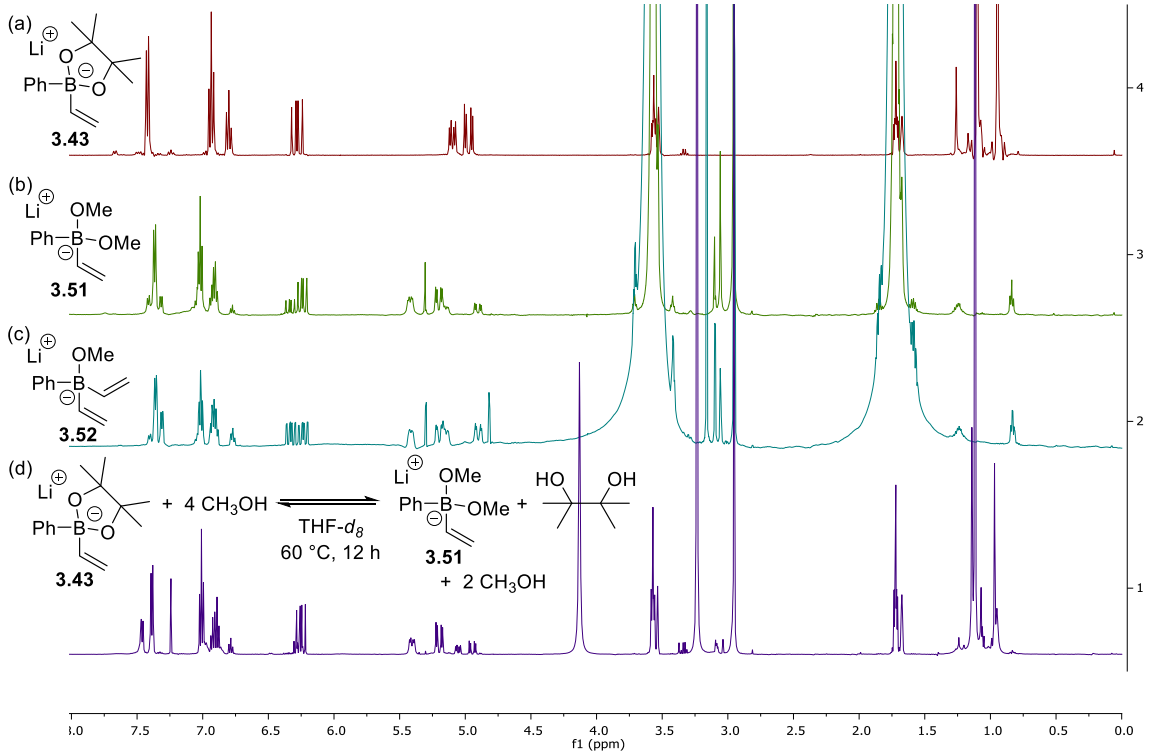


Figure 3.1. ^{1}H NMR studies of the methanol–pinacol exchange reaction on boron "ate" complexes. The solvent is anhydrous THF-d_8 in all cases. ^{1}H NMR spectra of (a) (phenyl)(vinyl)B(pin) "ate" **3.43**; (b) (phenyl)(vinyl)B(OMe)$_2$ "ate" **3.51** (mixture with (phenyl)(vinyl)$_2$B(OMe) "ate" **3.52** in ~3:1 ratio); (c) (phenyl)(vinyl)$_2$B(OMe) "ate" **3.52** (mixture with (phenyl)(vinyl)B(OMe)$_2$ "ate" **3.51** in ~1:1 ratio); (d) methanol–pinacol exchange experiment on **3.43** at 60 °C for 12 hours.

To probe the generality of this alcohol exchange phenomenon, we also investigated neopentyl glycol as an additive to see if it could exchange with pinacol to give (phenyl)(vinyl)B(neo) "ate" complex **3.53** *in situ*. **3.53** was independently synthesized from phenylB(neo) and vinyllithium (Figure 3.2b). After treating (phenyl)(vinyl)B(pin) "ate" **3.43** with 1 equivalent of neopentyl glycol in THF-d_8 at 60 °C for 12 hours, we observed the formation of **3.53** in approximately 69% conversion along with the liberation of pinacol (Figure 3.2c). We also treated (phenyl)(vinyl)B(neo) "ate" complex **3.53** with 1 equivalent of pinacol (Figure 3.2d) and observed approximately the same ratio of **3.43** to **3.53** in this experiment as in Figure 3.2c.

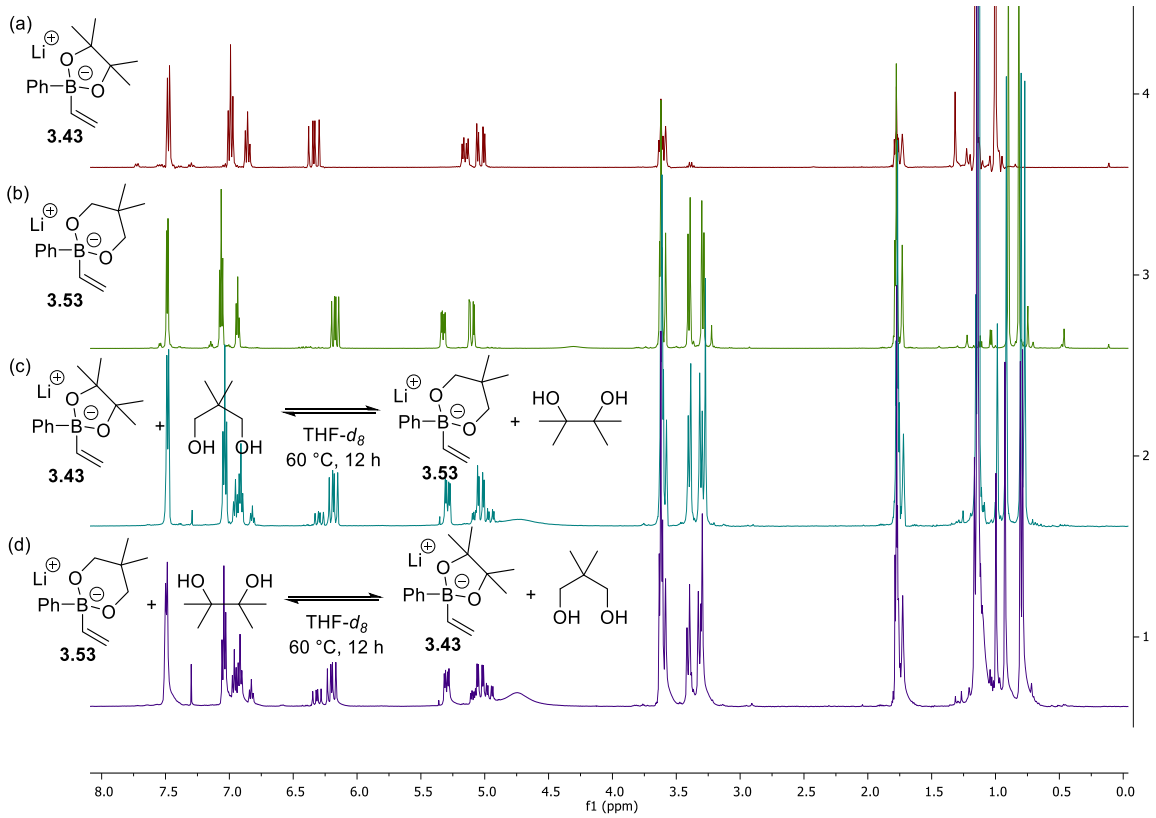


Figure 3.2. ^{1}H NMR studies of the neopentyl glycol–pinacol exchange reaction on boron "ate" complexes. The solvent is anhydrous THF-d_8 in all cases. ^{1}H NMR spectra of (a) (phenyl)(vinyl)B(pin) "ate" **3.43**; (b) (phenyl)(vinyl)B(neo) "ate" **3.53**; (c) neopentyl glycol–pinacol exchange experiment on **3.43** at 60 °C for 12 hours; (d) pinacol–neopentyl glycol exchange experiment on **3.53** at 60 °C for 12 hours;

We hypothesized that both the methanol–pinacol and neopentyl glycol–pinacol exchanges are driven by strain release, as having a pinacol ligand on a tetracoordinate boron "ate" would be more sterically congested than these other alkoxide ligands. Notably, this reactivity is opposite to what is known for neutral, tricoordinate boronates which favor chelating ligands like pinacol.[54] In fact, there are a few instances in the literature in which ligand exchange on tricoordinate boronic esters is a prominent feature of the reaction.[55]

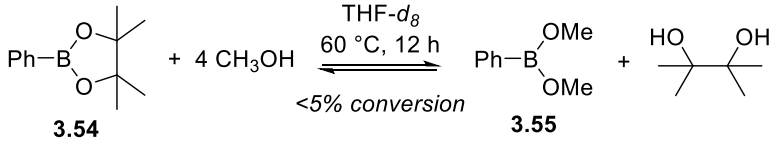
[54] Roy, C. D.; Brown, H. C. *J. Organomet. Chem.* **2007**, *692*, 784.

[55] (a) Pellegrinet, S. C.; Goodman, J. M. *J. Am. Chem. Soc.* **2006**, *128*, 3116. (b) Bishop, J. A.; Lou, S.; Schaus, S. E. *Angew. Chem. Int. Ed.* **2009**, *48*, 4337. (c) Taylor, M. S. *Acc. Chem. Res.* **2015**, *48*, 295. (d) Wu, H.; Garcia, J. M.; Haeffner, F.; Radomkit, S.; Zhugralin, A. R.; Hoveyda, A. H. *J. Am. Chem. Soc.*

Indeed, treating phenylB(pin) **3.54** with 4 equivalents of methanol THF-d_8 at 60 °C for 12 hours did not result in the formation of phenylB(OMe)$_2$ **3.55** (Scheme 3.14a), whereas treating phenylB(OMe)$_2$ **3.55** with one equivalent of pinacol resulted in compete conversion to phenylB(pin) **3.54** (Scheme 3.14b). However, in ^{1}H NMR spectra of crude reaction mixtures following conjunctive cross-coupling with methanol additive, free pinacol is almost never observed, as the conjunctive cross-coupling products we obtain prior to oxidation are the pinacol boronic esters. Furthermore, preliminary ^{1}H NMR time course studies of the reaction show the conversion of (phenyl)(vinyl)B(pin) "ate" **3.43** to (phenyl)(vinyl)B(OMe)$_2$ "ate" **3.51** with concomitant liberation of pinacol, but as the reaction progresses, the peaks corresponding to free pinacol gradually disappear.

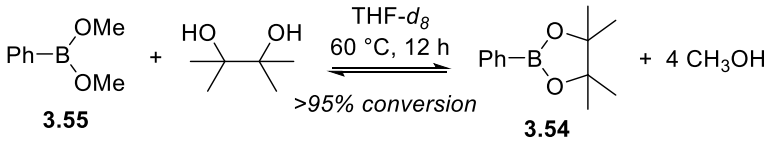
Scheme 3.14. Alcohol exchange experiments on neutral tricoordinate boronic esters

(a) Methanol-pinacol exchange experiment with phenylB(pin) and methanol



3.54 **3.55**

(b) Pinacol-methanol exchange experiment with phenylB(OMe)$_2$ and pinacol

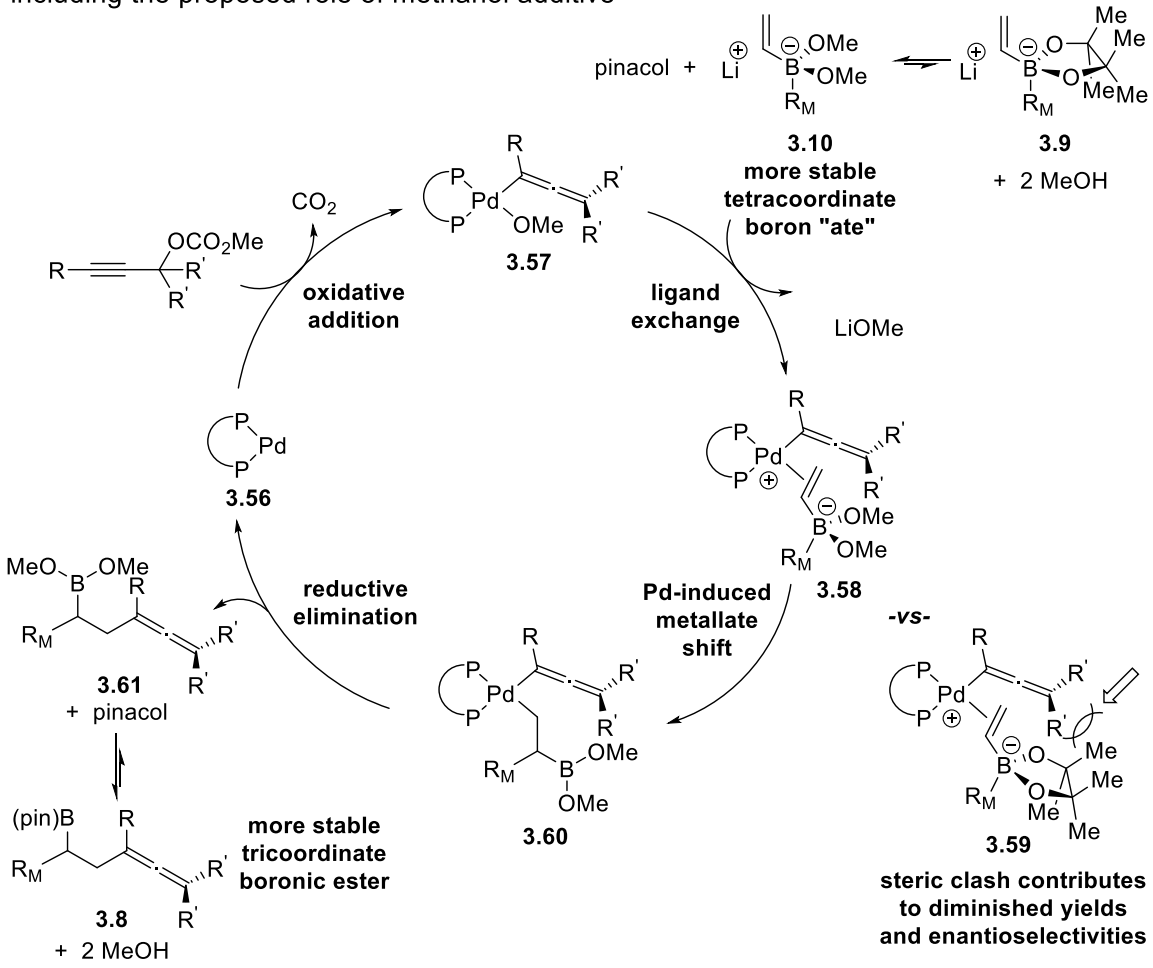


3.55 **3.54**

2015, *137*, 10585. (e) Yan, L.; Meng, Y.; Haeffner, F.; Leon, R. M.; Crockett, M. P.; Morken, J. P. *J. Am. Chem. Soc.* **2018**, *140*, 3663.

With these observations, we propose a modified conjunctive cross-coupling catalytic cycle that takes into account this boron "ate" alkoxide ligand exchange phenomenon as well as the formation of boronic pinacol ester products at the end of the reaction (Scheme 3.15). Palladium complex **3.56** undergoes oxidative addition with the propargyl electrophile in an S_N2' fashion to give L_nPd(allenyl)(OMe) species **3.57**. Meanwhile, pinacolatoboron "ate" **3.9** undergoes alkoxide ligand exchange with 2 equivalents of methanol to give bis(methanolato)boron "ate" **3.10**, which coordinates to palladium to give **3.58**. We propose that there is less of a steric clash between the smaller methoxy ligands on boron and the allenyl ligand on palladium compared to pinacolato complex **3.59**, which may account for the increased yields and enantioselectivities with methanol additive. This may also explain why larger alcohol additives such as ethanol and *rac*-2-butanol diminish both yields and enantioselectivities (Table 3.1, entries 12 and 14, *vide supra*). Following Pd-induced 1,2-metallate shift to give **3.60** and reductive elimination to close the catalytic cycle, the initial tricoordinate dimethoxy boronate **3.61** would undergo ligand exchange with the free pinacol in solution to give the more stable pinacolato product **3.8**, which is consistent with the experiments in Scheme 3.14.

Scheme 3.15. Modified conjunctive cross-coupling reaction with propargyl electrophiles including the proposed role of methanol additive

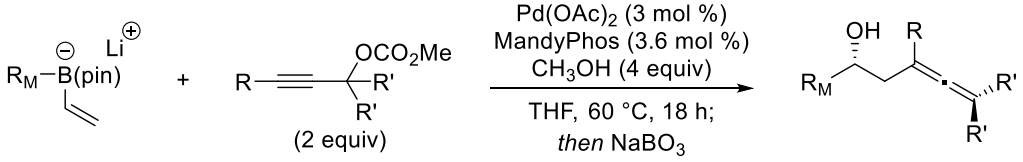


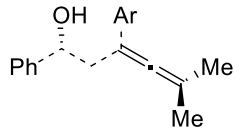
3.3.2. Substrate Scope and Demonstration of Synthetic Utility

Using the conditions in Table 3.1, entry 10, we examined the scope of the conjunctive cross-coupling reaction with other methyl propargyl carbonate electrophiles (Scheme 3.16). Various aryl alkynes were tolerated under the reaction conditions, including electron-rich (**3.63)** and electron-poor aryl groups (**3.64** and **3.65**), 2-naphtyl (**3.66**), and heterocycles (**3.67**–**3.69**). Alkenyl- (**3.70** and **3.71**) and alkynyl-substituted electrophiles (**3.72**) also performed well in the reaction. Although terminal (**3.73**) and *n*-alkyl-substituted (**3.74**) alkynes gave low yields of the desired products (<20% yield), methoxymethylene (**3.75**) and siloxymethylene groups (**3.76**) participated readily in the reaction with good yields and high levels of enantioselectivity. Methyl propargyl carbonates derived from cyclic tertiary alcohols were tolerated in the reaction as well (**3.77**–**3.79**).

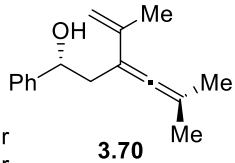
With respect to the scope of organoboronic esters, various C(sp^2) migrating groups were well-tolerated (**3.80**–**3.85**). A cyclopropyl migrating group was also tolerated under these reaction conditions (**3.86**), but other alkyl migrating groups required the use of 4 equivalents of 2,2,2-trifluoroethanol (TFE) instead of methanol to give high conversion (**3.87**–**3.89**). We attribute this to the electron-withdrawing fluorine atoms on TFE, which could stabilize alkyl-derived boron "ate" complexes following exchange with pinacol, although further study would have to be done to test this hypothesis.

Scheme 3.16. Enantioselective Pd-catalyzed conjunctive cross-coupling of organoboronic "ate" complexes with methyl propargyl carbonate electrophiles[a]

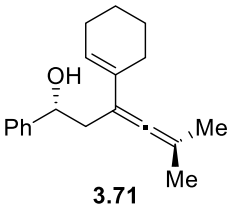




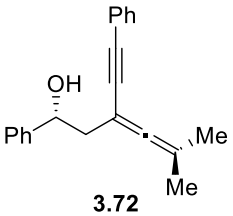
3.62, Ar = Ph: 82% yield, 96:4 er
3.63, Ar = *m*-xylyl: 79% yield, 96:4 er
3.64, Ar = *p*-CF_3Ph: 95% yield, 92:8 er
3.65, Ar = *p*-FPh: 57% yield, 94:6 er
3.66, Ar = 2-naphthyl: 81% yield, 96:4 er
3.67, Ar = 2-pyridyl: 69% yield, 98:2 er
3.68, Ar = 3-furyl: 74% yield, 97:3 er
3.69, Ar = 2-furyl: 47% yield, 96:4 er



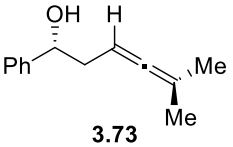
3.70
37% yield, 97:3 er



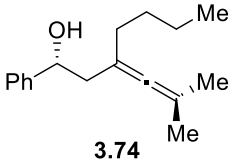
3.71
91% yield, 98:2 er



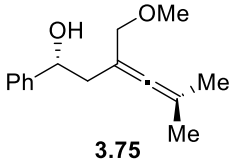
3.72
68% yield, 93:7 er



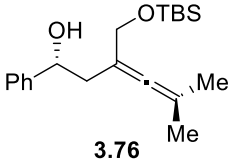
3.73
18% yield, 90:10 er



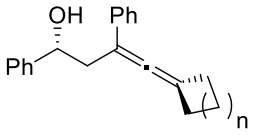
3.74
16% yield, 93:7 er



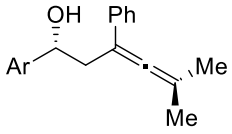
3.75
80% yield, 98:2 er



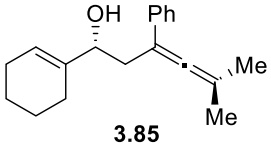
3.76
89% yield, 95:5 er



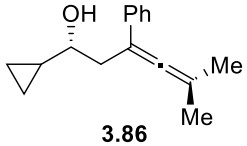
3.77, n = 1: 68% yield, 97:3 er
3.78, n = 2: 69% yield, 98:2 er
3.79, n = 3: 84% yield, 94:6 er



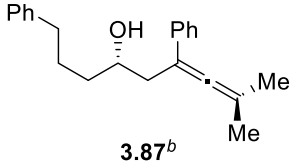
3.80, Ar = *p*-MeOPh: 88% yield, 95:5 er
3.81, Ar = *p*-CF_3Ph: 64% yield, 98:2 er
3.82, Ar = *p*-BrPh: 89% yield, 97:3 er
3.83, Ar = *o*-ClPh: 84% yield, 98:2 er
3.84, Ar = *p*-Ph_2NPh: 84% yield, 92:8 er



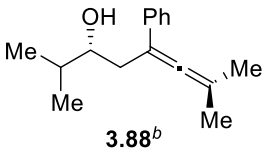
3.85
61% yield, 85:15 er



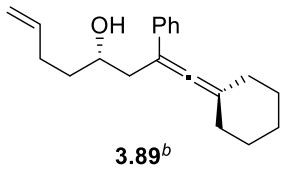
3.86
60% yield, 94:6 er



3.87[b]
61% yield, 92:8 er



3.88[b]
40% yield, 89:11 er



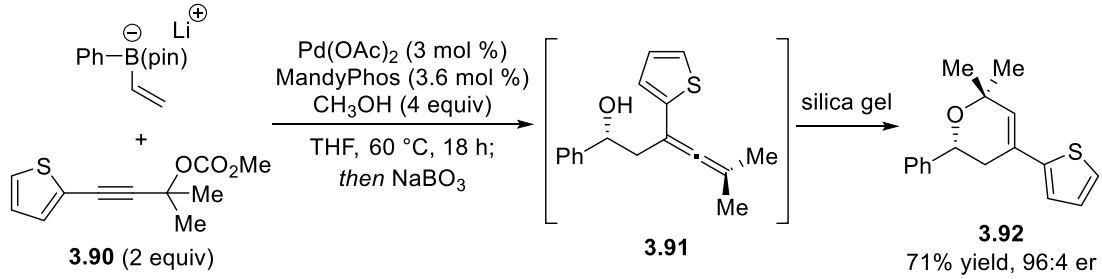
3.89[b]
52% yield, 93:7 er

[a]Reactions conducted at 0.1 *M*. Yields and enantioselectivities represent isolated yields and are the average of two trials. [b]2,2,2-trifluoroethanol was used instead of methanol.

Considering the aforementioned diversity of reactions allenes can undergo, we were interested in exploring potential transformations of our tetrasubstituted β-hydroxy allene products. Serendipitously, we observed that following conjunctive cross-coupling with 2-thiophenyl-substituted propargyl electrophile **3.90** and oxidative workup, the β-hydroxy allene **3.91** underwent a spontaneous 6-*endo-dig* cyclization during silica gel chromatography to give pyran **3.92** (Scheme 3.17a). Inspired by this finding, we found that β-hydroxy allenes **3.62** and **3.76** could undergo cyclization upon treatment with a gold catalyst to give pyrans **3.93** and **3.94**, respectively (Scheme 3.17b).[56]

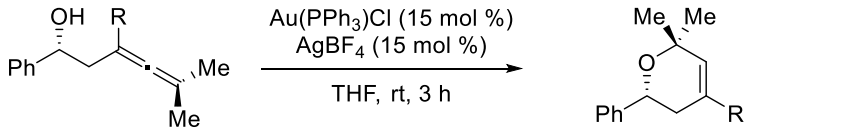
Scheme 3.17. 6-*endo-dig* cyclization reactions of β-hydroxy allenes

(a) Spontaneous cyclization of 2-thiophenyl-substituted β-hydroxy allene



3.90 (2 equiv) **3.91** **3.92** 71% yield, 96:4 er

(b) Au-catalyzed cyclization of β-hydroxy allenes



3.62, R = Ph
3.76, R = CH_2OTBS

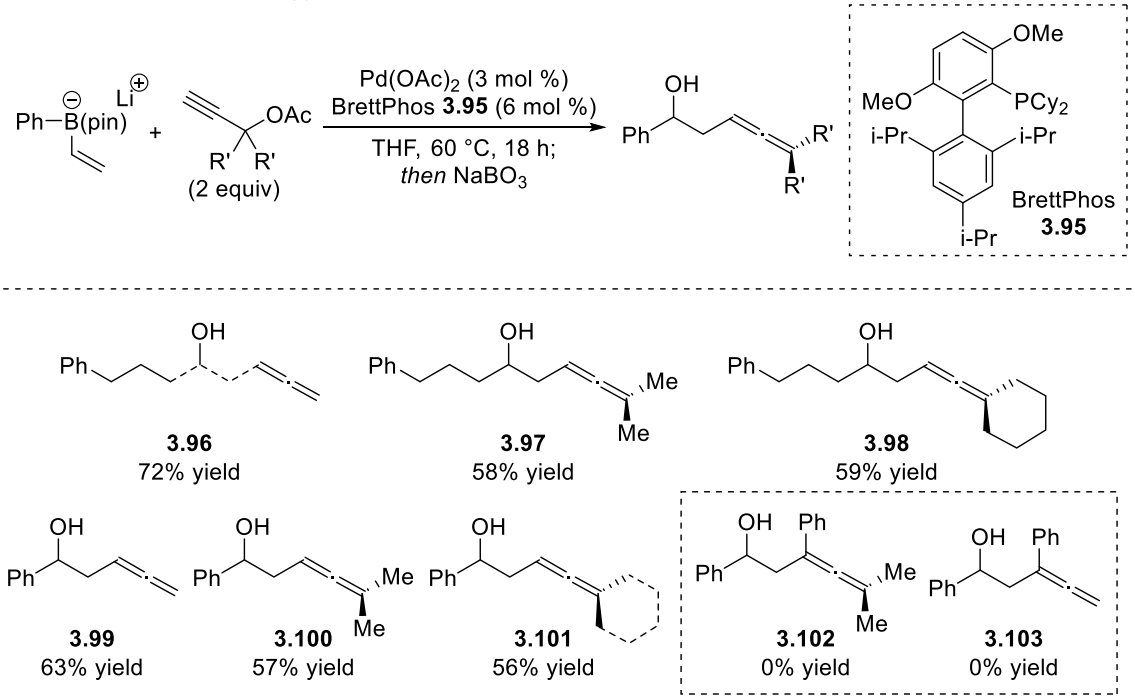
3.93, R = Ph: 81% yield
3.94, R = CH_2OTBS: 75% yield

[56] Gockel, B.; Krause, N. *Org. Lett.* **2006**, *8*, 4485.

3.3.3 Progress Toward Utilizing Electrophiles Derived from Terminal Alkynes and/or Primary Propargyl Alcohols: Outlook and Future Directions

As shown in Scheme 3.16, propargyl electrophiles derived from terminal alkynes (**3.73**) did not perform well in the reaction using the $Pd_2(dba)_3$/MandyPhos catalyst system. Furthermore, we discovered in the early stages of reaction optimization that electrophiles derived from primary propargyl alcohols did not give any of the desired conjunctive cross-coupling product at all with reversion to the starting organoboronic ester predominating. However, as shown in Scheme 3.18, these two classes of propargyl electrophiles could give conjunctive cross-coupling products using the achiral ligand BrettPhos **3.95** to give racemic monosubstituted or trisubstituted β-hydroxy allenes following oxidation, and were equally suitable with "ate" complexes derived from both aryl and aliphatic migrating groups (**3.96**–**3.101**). Interestingly, we found that the electrophiles derived from internal alkynes (**3.102** and **3.103**), which were generally successful with MandyPhos, failed to give conjunctive cross-coupling products using BrettPhos. These reactions did not benefit from the addition of alcohol additives, and in certain cases, a slight decrease in yield was observed.

Scheme 3.18. Racemic Pd-catalyzed conjunctive cross-coupling of organoboronic "ate" complexes with propargylic acetate electrophiles[a]



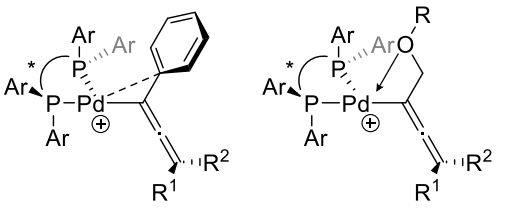
[a]Reactions conducted at 0.1 *M*. Yields and enantioselectivities represent isolated yields and are the average of two trials.

In light of the apparent complementarity of these two ligands, as well as the observation that only C(sp^2)- and C(sp)-substituted electrophiles and alkyl-substituted electrophiles bearing ethers gave high conversions using MandyPhos, we propose two possible rationales behind the observations we made for both systems. With respect to the MandyPhos-based protocol, it is possible that the sp^2/sp-hybridized carbon (**3.104**) or the ether oxygen (**3.105**) of the allenyl substituent on the (allenyl)Pd(MandyPhos)$^+$ complex coordinates to the electron-deficient palladium center to stabilize the complex (Scheme 3.19a). This phenomenon has been demonstrated for Buchwald-type ligands such as

BrettPhos in which the *ipso* carbon of the "lower" aryl ring coordinates to the metal center (Scheme 3.19b, **3.106**).[57] Further study is required to lend support to these claims.

Scheme 3.19. Possible rationales for observations in the conjunctive cross-coupling of propargyl electrophiles

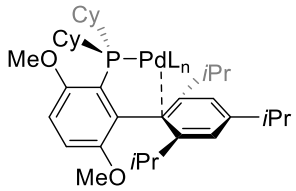
(a) Proposed explanation for substrate trends in the MandyPhos-based conjunctive cross-coupling reaction



3.104 **3.105**

possible coordination of *sp²* carbon or ether oxygen to increase electron density at cationic palladium

(b) Proposed explanation for the efficacy of BrettPhos in the racemic conjunctive cross-coupling reaction



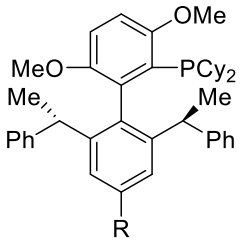
3.106

stabilizing effect of lower aryl ring of biaryl phosphine ligands

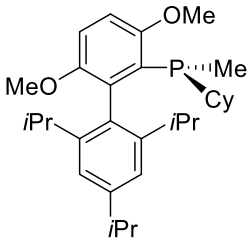
In order to render the conjunctive cross-coupling products **3.96**–**3.101** in Scheme 3.18 enantioenriched, we decided to synthesize enantioenriched chiral Buchwald-type ligands **3.107**[58] and **3.108**[59] possessing C- and P-chirality, respectively (Scheme 3.20). As of this writing, the syntheses of these ligands and their pending use in conjunctive cross-coupling reactions is still ongoing.

[57] Espinet, P.; Albéniz, A. C. Palladium–Carbon π-Bonded Complexes. In *Comprehensive Organometallic Chemistry III,* 3rd Ed.; Mingos, D. M. P., Crabtree, R. H., Eds.; Elsevier, Oxford, **2007**, *8*, 315.
[58] Spahn, E.; Albright, A.; Shevlin, M.; Pauli, L.; Pfaltz, A.; Gawley, R. E. *J. Org. Chem.* **2013**, *78*, 2731.
[59] Li, S.-G.; Yuan, M.; Topic, F.; Han, Z. S.; Senanayake, C. H.; Tsantrizos, Y. S. *J. Org. Chem.* **2019**, *84*, 7291.

Scheme 3.20. Chiral Buchwald-type ligands as a new ligand class for enantioselective conjunctive cross-coupling reactions



3.107



3.108

In conclusion, we have developed the enantioselective Pd-catalyzed conjunctive cross-coupling to access tetrasubstituted β-boryl allenes from organoboron "ate" complexes and methyl propargyl carbonate electrophiles derived from internal alkynes and tertiary alcohols with a Pd/MandyPhos catalyst system. During optimization studies, we discovered that the addition of methanol additive significantly increases both the yields and the enantioselectivities of the reaction. We attribute this to a novel methanol–pinacol exchange mechanism on the pinacolatoboron "ate" complex to generate bis(methanolato)boron "ate" complex *in situ*, a phenomenon that is opposite to what is known for neutral, tricoordinate boronic esters. ^{1}H NMR studies suggest that the liberation of pinacol from tetracoordinate boron "ate" complexes is driven by strain release. The smaller ligand set on the bis(methanolato)boron "ate" complex may have less of a steric clash with the ligands on palladium, which may account for the beneficial effects of methanol in terms of yield and enantioselectivities. The reaction tolerated a variety of propargyl electrophiles, and we demonstrated the utility of these products by conducting a Au-catalyzed 6-*endo-dig* cyclization on a few substrates to synthesize dihydropyran rings.

We have also observed that the Buchwald ligand BrettPhos was effective at promoting the conjunctive cross-coupling reaction with propargyl acetate electrophiles derived from terminal alkynes and/or primary alcohols, substrates which were ineffective in the MandyPhos-based process. Studies to ascertain the exact origin of the apparent complementarity of these two catalyst systems are underway, and efforts to synthesize chiral Buchwald-type ligands to render the conjunctive cross-coupling reaction with these less-substituted propargyl electrophiles are also ongoing.

3.4. Experimental

3.4.1. General Information

^{1}H NMR spectra were recorded on a Varian Gemini-400 (400 MHz), Varian Gemini-500 (500 MHz), or Varian Gemini-600 (600 MHz) spectrometer. Chemical shifts are reported in ppm with the solvent resonance as the internal standard ($CDCl_3$: 7.26 ppm). Data are reported as follows: chemical shift, multiplicity (s = singlet, d = doublet, t = triplet, q = quartet, p = pentet, m = multiplet, app = apparent), coupling constants (Hz), and integration. ^{13}C NMR spectra were recorded on a Varian Gemini-400 (100 MHz), Varian Gemini-500 (125 MHz), or Varian Gemini-600 (150 MHz) spectrometer with complete proton decoupling. Chemical shifts are reported in ppm with the solvent resonance as the internal standard ($CDCl_3$: 77.16 ppm). ^{19}F NMR spectra were recorded on a Varian Gemini-500 (470 MHz) spectrometer. Chemical shifts are reported in ppm using trifluoroacetic acid as the external standard (CF_3COOH: -76.55 ppm). Infrared (IR) spectra were recorded on a Bruker Alpha-P Spectrometer. Frequencies are reported in wavenumbers (cm^{-1}) as follows: strong (s), broad (br), medium (m), and weak (w). Optical rotations were measured on a Rudolph Analytical Research Autopol IV Polarimeter and the values reported are averages of seven measurements. Direct analysis in real time-high resolution mass spectrometry (DART-HRMS) was performed at the Mass Spectrometry Facility, Boston College, Chestnut Hill, MA. Flash column chromatography was performed using silica gel (SiO_2, 230 x 450 Mesh, purchased from Silicycle). Thin layer chromatography (TLC) was performed on 25 μm silica gel aluminum backed plates from Silicycle. Visualization was performed using ultraviolet

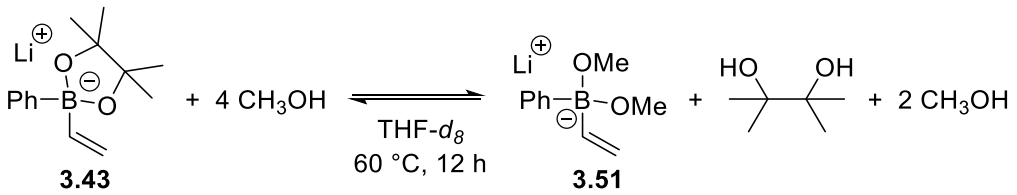
light (254 nm) and ceric ammonium molybdate (CAM) in ethanol or alkaline aqueous potassium permanganate ($KMnO_4$).

Analytical chiral supercritical fluid chromatography (SFC) was performed on a TharSFC Method Station II equipped with Waters 2998 Photodiode Array Detector with isopropanol as the modifier.

Anhydrous tetrahydrofuran (THF) and diethyl ether (Et_2O) were purified using a Pure Solv MD-4 solvent purification system, from Innovative Technology, Inc., by passing the solvent through two activated alumina columns after purging with argon. Anhydrous deuterated THF (THF-d_8) was purchased from Oakwood Chemicals and used without further purification. Tris(dibenzylideneacetone) dipalladium(0) ($Pd_2(dba)_3$), palladium(II) acetate ($Pd(OAc)_2$), bis(triphenylphosphine) palladium(II) dichloride ($PdCl_2(PPh_3)_2$), and (S_P,S_P)-MandyPhos were purchased from Strem Chemicals, Inc. and used without further purification. All pinacol and neopentyl glycol boronic esters not synthesized in-house according to literature procedures[1,4ab] were purchased from Combi Blocks, Oakwood Chemicals, or Frontier Scientific and used without further purification. Vinyllithium solution in THF was prepared from tetravinyltin and *n*-butyllithium according to the literature procedure.[4a] All other reagents were purchased from Aldrich, Alfa Aesar, or Acros and used without further purification.

3.4.2. Exchange Equilibria NMR Studies in Four-Coordinate Versus Three-Coordinate Organoboron Compounds

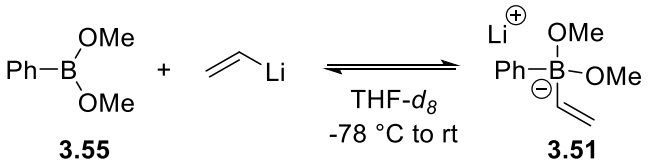
3.4.2.1. Pinacolato Boron "Ate"–Methanol Exchange



3.43 **3.51**

In a glovebox filled with argon, an oven-dried 2-dram vial equipped with a magnetic stir bar was charged with 4,4,5,5-tetramethyl-2-phenyl-1,3,2-dioxaborolane **(3.54)** (30.6 mg, 0.15 mmol, 1 equiv) and anhydrous Et_2O (0.3 mL), sealed with a septum cap, and removed from the glovebox. Outside the glovebox under positive nitrogen pressure, the vial was cooled to 0 ºC in an ice-water bath, and vinyllithium solution in THF (0.15 mmol, 1 equiv) was added dropwise with stirring to form the "ate" complex **3.43**. The reaction vial was allowed to warm to room temperature and stir for 30 minutes. The solvent was carefully removed from the "ate" complex under reduced pressure, and the "ate" residue was kept under vacuum for 30 minutes before being brought back into the glovebox. In the glovebox, the "ate" residue was re-dissolved in anhydrous deuterated THF (0.6 mL) and methanol (19.2 mg, 0.60 mmol, 4 equiv) was added. The vial was sealed with a polypropylene cap and electrical tape, brought out of the glovebox, and the reaction was stirred at 60 ºC for 12 hours. After cooling to room temperature, the contents of the vial were transferred to an NMR tube and analyzed using ^{1}H NMR spectroscopy (see Figure 3.1d).

3.4.2.2. Independent Synthesis of Bismethanolato Boron 'Ate'

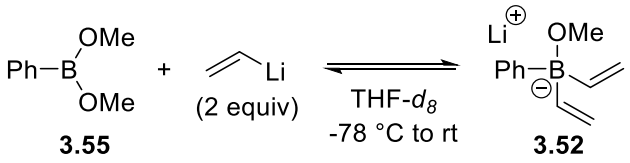


3.55 **3.51**

Dimethyl phenylboronate **(3.55)** was prepared following a literature procedure:[60] an oven-dried 2-dram vial equipped with a magnetic stir bar was charged with phenyl boronic acid (18.3 mg, 0.15 mmol, 1.2 equiv) and sealed with a septum cap. The atmosphere was exchanged with nitogen, trimethyl orthoformate (39.8 mg, 0.38 mmol, 3 equiv) and trifluoroacetic acid (2.2 mg, 0.019 mmol, 0.16 equiv) were added, and the reaction was allowed to stir for 15 minutes at room temperature. The volatiles were carefully removed under reduced pressure on the manifold vacuum, and the dimethyl phenylboronate residue was kept under vacuum for 30 minutes. This residue was then redissolved in anhydrous deuterated THF (0.6 mL), chilled to -78 °C in a dry ice-acetone bath, and vinyllithium solution in THF (0.13 mmol, 1 equiv) was added dropwise over ten minutes with stirring to form the "ate" complex. The solution was allowed to come to room temperature, and the contents of the vial were transferred to an NMR tube and analyzed using ^{1}H NMR spectroscopy (see Figure 3.1b). The bismethanolato boron "ate" **3.51** was detected along with the doubly-vinylated methanolato boron "ate" **3.52** (see below) in a ~3:1 **3.51**:**3.52** ratio.

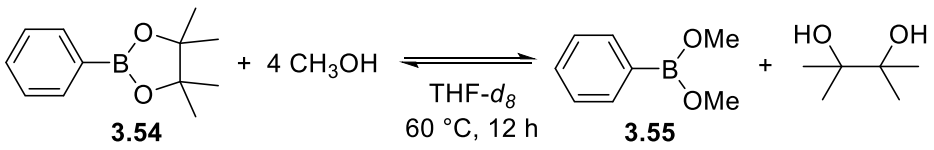
[60] Elkin, P. K.; Levin, V. V.; Dilman, A. D.; Struchkova, M. I.; Belyakov, P. A.; Arkhipov, D. E.; Korlyukov, A. A.; Tartakovsky, V. A. *Tetrahedron Lett.* **2011**, *52*, 5259.

3.4.2.3. Independent Synthesis of Doubly-Vinylated Methanolato Boron "Ate"



Dimethyl phenylboronate **(3.55)** was prepared following a literature procedure:[60] an oven-dried 2-dram vial equipped with a magnetic stir bar was charged with phenyl boronic acid (18.3 mg, 0.15 mmol, 1 equiv) and sealed with a septum cap. The atmosphere was exchanged with nitogen, trimethyl orthoformate (39.8 mg, 0.38 mmol, 2.5 equiv) and trifluoroacetic acid (2.2 mg, 0.019 mmol, 0.13 equiv) were added, and the reaction was allowed to stir for 15 minutes at room temperature. The volatiles were carefully removed under reduced pressure on the manifold vacuum, and the dimethyl phenylboronate residue was kept under vacuum for 30 minutes. This residue was then redissolved in anhydrous deuterated THF (0.6 mL), chilled to -78 °C in a dry ice-acetone bath, and vinyllithium solution in THF (0.30 mmol, 2 equiv) was added dropwise over ten minutes with stirring to form the "ate" complex. The solution was allowed to come to room temperature, and the contents of the vial were transferred to an NMR tube and analyzed using ^{1}H NMR spectroscopy (see Figure 3.1c). The doubly-vinylated methanolato boron "ate" **3.52** was detected along with bismethanolato boron "ate" **3.51** (see above) in a ~1:1 ratio.

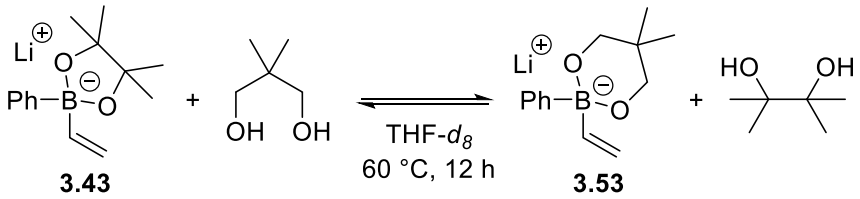
3.4.2.4. Phenyl Boronic Acid, Pinacol Ester–Methanol Exchange



An oven-dried 2-dram vial equipped with a magnetic stir bar was charged with 4,4,5,5-tetramethyl-2-phenyl-1,3,2-dioxaborolane **(3.54)** (30.6 mg, 0.15 mmol, 1 equiv)

and sealed with a septum cap. The atmosphere was exchanged with nitrogen, anhydrous deuterated THF (0.6 mL) and methanol (19.2 mg, 0.60 mmol, 4 equiv) were added, and the reaction was stirred at 60 ºC for 12 hours. After cooling to room temperature, the contents of the vial were transferred to an NMR tube and analyzed using ^{1}H NMR spectroscopy.

3.4.2.5. Pinacolato Boron "Ate"–Neopentyl Glycol Exchange

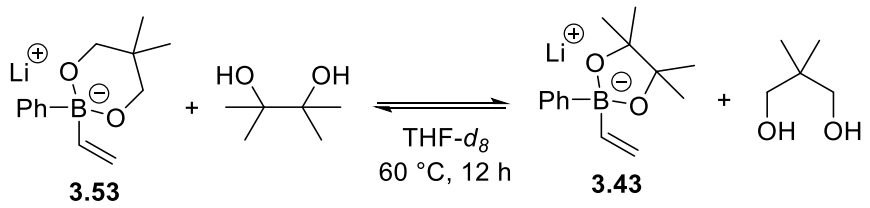


3.43 **3.53**

In a glovebox filled with argon, an oven-dried 2-dram vial equipped with a magnetic stir bar was charged with 4,4,5,5-tetramethyl-2-phenyl-1,3,2-dioxaborolane **(3.54)** (30.6 mg, 0.15 mmol, 1 equiv) and anhydrous Et_2O (0.3 mL), sealed with a septum cap, and removed from the glovebox. Outside the glovebox under positive nitrogen pressure, the vial was cooled to 0 ºC in an ice-water bath, and vinyllithium solution in THF (0.15 mmol, 1 equiv) was added dropwise with stirring to form the "ate" complex **3.43**. The reaction vial was allowed to warm to room temperature and stir for 30 minutes. The solvent was carefully removed from the "ate" complex under reduced pressure, and the "ate" residue was kept under vacuum for 30 minutes before being brought back into the glovebox. In the glovebox, the "ate" residue was re-dissolved in anhydrous deuterated THF (0.6 mL) and neopentyl glycol (15.6 mg, 0.15 mmol, 1 equiv) was added. The vial was sealed with a polypropylene cap and electrical tape, brought out of the glovebox, and the reaction was stirred at 60 ºC for 12 hours. After cooling to room temperature, the contents

of the vial were transferred to an NMR tube and analyzed using ^{1}H NMR spectroscopy (see Figure 3.2c).

3.4.2.6. Neopentyl Glycolato Boron "Ate"–Pinacol Exchange

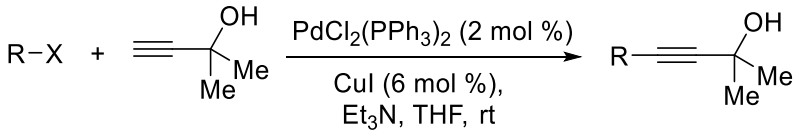


3.53 **3.43**

In a glovebox filled with argon, an oven-dried 2-dram vial equipped with a magnetic stir bar was charged with 5,5-dimethyl-2-phenyl-1,3,2-dioxaborinane (28.5 mg, 0.15 mmol, 1 equiv) and anhydrous Et_2O (0.3 mL), sealed with a septum cap, and removed from the glovebox. Outside the glovebox under positive nitrogen pressure, the vial was cooled to 0 ºC in an ice-water bath, and vinyllithium solution in THF (0.15 mmol, 1 equiv) was added dropwise with stirring to form the "ate" complex **3.53**. The reaction vial was allowed to warm to room temperature and stir for 30 minutes. The solvent was carefully removed from the "ate" complex under reduced pressure, and the "ate" residue was kept under vacuum for 30 minutes before being brought back into the glovebox. In the glovebox, the "ate" residue was re-dissolved in anhydrous deuterated THF (0.6 mL) and pinacol (17.7 mg, 0.15 mmol, 1 equiv) was added. The vial was sealed with a polypropylene cap and electrical tape, brought out of the glovebox, and the reaction was stirred at 60 ºC for 12 hours. After cooling to room temperature, the contents of the vial were transferred to an NMR tube and analyzed using ^{1}H NMR spectroscopy (see Figure 3.2d).

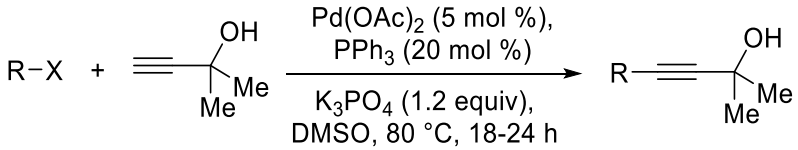
3.4.3. Sonogashira Cross-Coupling Procedures for the Preparation of Substituted Propargylic Alcohols

3.4.3.1. Method A: Procedure with Copper Co-Catalyst



Following a literature procedure:[61] An oven-dried vial equipped with a magnetic stir bar was charged with copper(I) iodide (6 mol %), bis(triphenylphosphine)palladium(II) dichloride (2 mol %), triethylamine (4.3 equiv), and arylhalide (1.05 equiv) in anhydrous THF (1 *M*) under nitrogen atmosphere. 2-methylbut-3-yn-2-ol (1 equiv) was added dropwise and the mixture was stirred at room temperature. Upon completion as checked by TLC, the reaction mixture was quenched with saturated aqueous NH_4Cl and extracted with Et_2O (3 x). The combined organic layers were washed with brine, dried over Na_2SO_4, filtered, concentrated under reduced pressure, and purified by silica gel column chromatography to afford pure substituted propargylic alcohol product.

3.4.3.2. Method B: Copper-Free Procedure



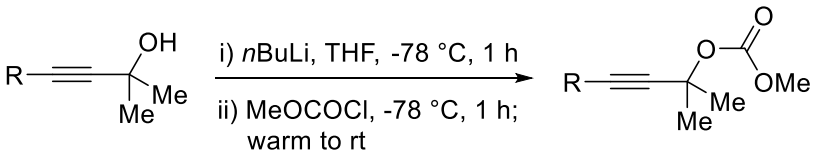
Following a literature procedure:[62] In a glovebox filled with argon, an oven-dried vial equipped with a magnetic stir bar was charged with aryl halide (1 equiv), 2-methyl-3-butyn-2-ol (1.5 equiv), palladium(II) acetate (5 mol %), triphenylphosphine (20 mol %),

[61] Peng, J.; Gao, Y.; Hu, W.; Gao, Y.; Hu, M.; Wu, W.; Ren, Y.; Jiang, H. Org. Lett. **2016**, *18*, 5924.
[62] Paegle, E.; Belyakov, S.; Petrova, M.; Liepinsh, E.; Arsenyan, P. *Eur. J. Org. Chem.* **2015**, *20*, 4389.

and anhydrous K_3PO_4 (1.2 equiv) in anhydrous DMSO (0.5 *M*). The vial was sealed, removed from the glovebox, and stirred at 80 °C for 12-24 h. After cooling to room temperature, the reaction mixture was quenched with EtOAc (15 × volume) and water (2 x volume) and stirred for an additional 30 min. The mixture was transferred to a separatory funnel and the aqueous phase was separated. The organic phase was washed with brine (4 x), dried over Na_2SO_4, filtered, concentrated under reduced pressure, and purified by silica gel column chromatography to afford pure substituted propargylic alcohol product.

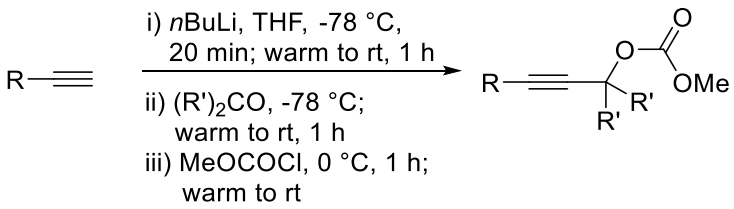
3.4.4. Procedures for the Preparation of Substituted Methyl Propargylic Carbonates

3.4.4.1. Method A: Propargylic Alcohols and Methyl Chloroformate

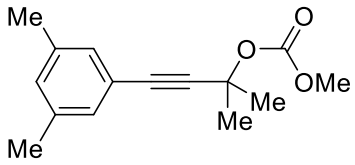


An oven-dried vial equipped with a magnetic stir bar was charged with propargylic alcohol (1 equiv) in anhydrous THF (0.25 *M*) under nitrogen atmosphere. The solution was chilled to -78 °C in a dry ice-acetone bath, and a hexane solution of *n*-butyllithium (1.1 equiv) was added dropwise. After 1 hour, methyl chloroformate (1.5 equiv) was added dropwise at -78 °C, and the solution was stirred for 1 hour before being warmed to room temperature. Upon completion as checked by TLC, the reaction mixture was quenched by addition of water. The reaction mixture was transferred to a separatory funnel, the organic layer was separated, and the aqueous layer was extracted twice with hexane. The combined organic phases were washed with brine, dried over Na_2SO_4, filtered, concentrated under reduced pressure, and purified by silica gel column chromatography to afford pure substituted methyl propargylic carbonate product.

3.4.4.2. Method B: Telescoped Acetylide Formation–Nucleophilic Addition to Ketone–Reaction with Methyl Chloroformate

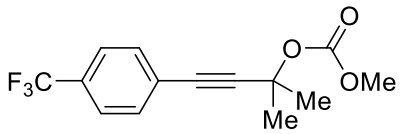


An oven-dried vial equipped with a magnetic stir bar was charged with alkyne (1 equiv) in anhydrous THF (0.25 *M*) under nitrogen atmosphere. The solution was chilled to -78 °C in a dry ice-acetone bath and a hexane solution of *n*-butyllithium (1.1 equiv) was added dropwise. After 20 minutes, the solution was warmed to room temperature and stirred for 1 hour. The solution was then chilled to -78 °C, ketone (1 or 1.25 equiv) was added dropwise, and the solution was warmed to room temperature and stirred for one hour. The solution was then cooled to 0 °C, methyl chloroformate (1.5 equiv) was added dropwise, and the solution was warmed to room temperature. Upon completion as checked by TLC, the reaction mixture was quenched by addition of water. The reaction mixture was transferred to a separatory funnel, the organic layer was separated, and the aqueous layer was extracted twice with hexane. The combined organic phases were washed with brine, dried over Na_2SO_4, filtered, concentrated under reduced pressure, and purified by silica gel column chromatography to afford pure substituted methyl propargylic carbonate product.

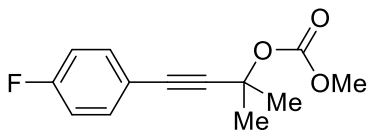


4-(3,5-dimethylphenyl)-2-methylbut-3-yn-2-yl methyl carbonate (3.109). Prepared according to the general procedure above (**Method A**) with 4-(3,5-dimethylphenyl)-2-methylbut-3-yn-2-ol (1.05 g, 5.58 mmol). The crude product was purified by silica gel column chromatography (30% EtOAc in hexanes, stained in $KMnO_4$) to afford a clear,

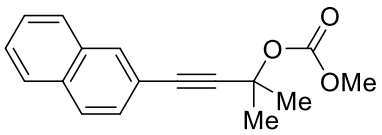
yellow oil (821.0 mg, 60% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.08 (s, 2H), 6.94 (s, 1H), 3.78 (s, 3H), 2.27 (s, 6H), 1.78 (s, 6H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 153.6, 137.9, 130.5, 129.7, 122.1, 88.8, 84.9, 74.9, 54.4, 29.1, 21.1.



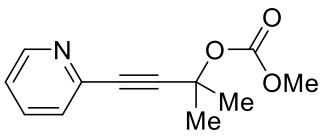
methyl {2-methyl-4-[4-(trifluoromethyl)phenyl]but-3-yn-2-yl} carbonate (3.110). Prepared according to the general procedure above (**Method A**) with 2-methyl-4-[4-(trifluoromethyl)phenyl]but-3-yn-2-ol (456.4 mg, 2.00 mmol). The crude product was purified by silica gel column chromatography (30% EtOAc in hexanes, stained in KMnO4) to afford a clear, yellow oil (446.5 mg, 78% yield). **^{1}H NMR** (500 MHz, CDCl3) δ 7.63 – 7.49 (m, 4H), 3.79 (s, 3H), 1.80 (s, 6H). **^{13}C NMR** (126 MHz, CDCl3) δ 153.6, 132.2, 130.4 (q, J = 32.7 Hz), 126.4, 125.3 (q, J = 3.8 Hz), 124.0 (q, J = 272.1 Hz), 92.0, 83.3, 74.6, 54.6, 28.9.



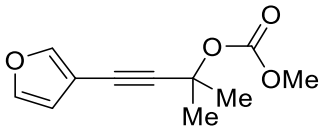
4-(4-fluorophenyl)-2-methylbut-3-yn-2-yl methyl carbonate (3.111). Prepared according to the general procedure above (**Method A**) with 4-(4-fluorophenyl)-2-methylbut-3-yn-2-ol (980.1 mg, 5.50 mmol). The crude product was purified by silica gel column chromatography (30% EtOAc in hexanes, stained in $KMnO_4$) to afford a clear, orange oil (1.25 g, 96% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) 7.45 – 7.39 (m, 2H), 7.03 – 6.96 (m, 2H), 3.78 (s, 3H), 1.78 (s, 6H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 162.7 (d, J = 249.8 Hz), 153.6, 133.9 (d, J = 8.4 Hz), 118.6 (d, J = 3.4 Hz), 115.5 (d, J = 22.1 Hz), 89.2 (d, J = 1.5 Hz), 83.5, 74.7, 54.4, 28.9. **^{19}F NMR** (470 MHz, $CDCl_3$) δ -110.73.



methyl [2-methyl-4-(naphthalen-2-yl)but-3-yn-2-yl] carbonate (3.112). Prepared according to the general procedure above (**Method A**) with 2-methyl-4-(naphthalen-2-yl)but-3-yn-2-ol (1.10 g, 5.23 mmol). The crude product was purified by silica gel column chromatography (30% EtOAc in hexanes, stained in $KMnO_4$) to afford a yellow solid (1.00 g, 71% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.97 (d, J = 1.5 Hz, 1H), 7.84 – 7.74 (m, 3H), 7.52 – 7.45 (m, 3H), 3.80 (s, 3H), 1.84 (s, 6H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 153.7, 133.03, 132.98, 132.0, 128.6, 128.0, 127.89, 127.85, 126.8, 126.6, 119.8, 89.8, 85.0, 75.0, 54.5, 29.1.

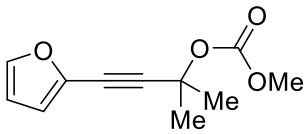


methyl [2-methyl-4-(pyridin-2-yl)but-3-yn-2-yl] carbonate (3.113). Prepared according to the general procedure above (**Method A**) with 2-methyl-4-(pyridin-2-yl)but-3-yn-2-ol (261.0 mg, 1.62 mmol). The crude product was purified by silica gel column chromatography (30% EtOAc in hexanes, stained in $KMnO_4$) to afford a brown oil (227.2 mg, 64% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 8.53 (d, J = 4.9 Hz, 1H), 7.60 (app t, J = 7.7 Hz, 1H), 7.41 (dd, J = 7.9, 1.2 Hz, 1H), 7.19 (dd, J = 7.6, 4.9 Hz, 1H), 3.74 (s, 3H), 1.78 (s, 6H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 153.6, 150.0, 142.7, 136.2, 127.5, 123.1, 89.3, 83.8, 74.3, 54.5, 28.8.

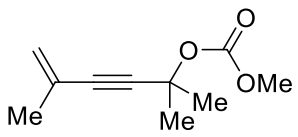


4-(furan-3-yl)-2-methylbut-3-yn-2-yl methyl carbonate (3.114). Prepared according to the general procedure above (**Method A**) with 4-(furan-3-yl)-2-methylbut-3-yn-2-ol (583.7 mg, 3.89 mmol). The crude product was purified by silica gel column chromatography (30% EtOAc in hexanes, stained in $KMnO_4$) to afford a clear, yellow oil (642.8 mg, 79% yield). **^{1}H NMR** (600 MHz,

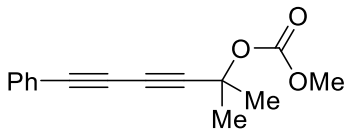
$CDCl_3$) δ 7.63 – 7.57 (m, 1H), 7.35 (t, J = 1.6 Hz, 1H), 6.44 (d, J = 1.9 Hz, 1H), 3.77 (s, 2H), 1.77 (s, 6H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 153.51, 146.08, 142.74, 112.61, 106.77, 91.24, 75.83, 74.68, 54.26, 28.85.



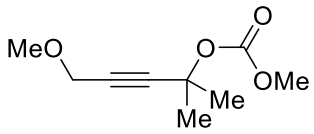
4-(furan-2-yl)-2-methylbut-3-yn-2-yl methyl carbonate (3.115). Prepared according to the general procedure above (**Method A**) with 4-(furan-3-yl)-2-methylbut-3-yn-2-ol (300.4 mg, 2.00 mmol). The crude product was purified by silica gel column chromatography (30% EtOAc in hexanes, stained in $KMnO_4$) to afford a clear, yellow oil (205.0 mg, 49% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.37 (dd, J = 1.8, 0.7 Hz, 1H), 6.61 (d, J = 3.4 Hz, 1H), 6.37 (dd, J = 3.4, 1.9 Hz, 1H), 3.77 (s, 3H), 1.78 (s, 6H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 153.6, 143.9, 136.5, 116.1, 111.0, 93.7, 75.1, 74.6, 54.6, 28.8.



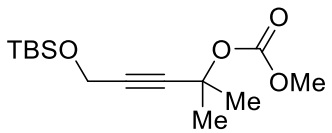
2,5-dimethylhex-5-en-3-yn-2-yl methyl carbonate (3.116). Prepared according to the general procedure above (**Method B**) with 2-methylbut-1-en-3-yne (363.6 mg, 5.50 mmol, 1.1 equiv) and acetone (290.4 mg, 5.00 mmol, 1 equiv). The crude product was purified by silica gel column chromatography (30% EtOAc in hexanes, stained in $KMnO_4$) to afford a clear, colorless oil (801.1 mg, 88% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 5.30 (dd, J = 2.0, 1.0 Hz, 1H), 5.23 (app p, J = 1.7 Hz, 1H), 3.76 (s, 3H), 1.88 (dd, J = 1.6, 1.0 Hz, 3H), 1.72 (s, 6H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 153.5, 126.2, 122.5, 88.5, 85.7, 74.7, 54.3, 28.9, 23.3.



methyl (2-methyl-6-phenylhexa-3,5-diyn-2-yl) carbonate (3.117). Prepared according to the general procedure above (**Method A**) with 2-methyl-6-phenylhexa-3,5-diyn-2-ol (650.0 mg, 3.53 mmol). The crude product was purified by silica gel column chromatography (30% EtOAc in hexanes, stained in $KMnO_4$) to afford a clear, colorless oil (650.2 mg, 76% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.48 (d, J = 6.8 Hz, 2H), 7.36 (t, J = 7.4 Hz, 1H), 7.31 (app t, J = 7.3 Hz, 2H), 3.79 (s, 3H), 1.75 (s, 6H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 153.6, 132.6, 129.4, 128.5, 121.5, 82.1, 79.6, 74.3, 73.2, 69.6, 54.6, 28.7.

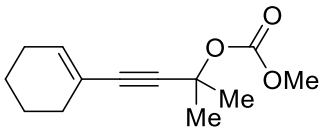


5-methoxy-2-methylpent-3-yn-2-yl methyl carbonate (3.118). Prepared according to the general procedure above (**Method B**) with 3-methoxyprop-1-yne (280.4 mg, 4.00 mmol, 1 equiv) and acetone (232.3 mg, 4.00 mmol, 1 equiv). The crude product was purified by silica gel column chromatography (30% EtOAc in hexanes, stained in $KMnO_4$) to afford a clear, colorless oil (501.5 mg, 67% yield). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 4.13 (s, 2H), 3.76 (s, 3H), 3.37 (s, 3H), 1.71 (s, 6H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 153.6, 87.0, 80.6, 74.2, 59.9, 57.6, 54.4, 28.9.

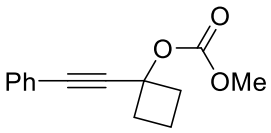


5-[(*tert*-butyldimethylsilyl)oxy]-2-methylpent-3-yn-2-yl methyl carbonate (3.119). Prepared according to the general procedure above (**Method B**) with *tert*-butyldimethyl(prop-2-yn-1-yloxy)silane (681.3 mg, 4.00 mmol, 1 equiv) and acetone (232.3 mg, 4.00 mmol, 1 equiv). The crude product was purified by silica gel column chromatography (30% EtOAc in hexanes, stained in

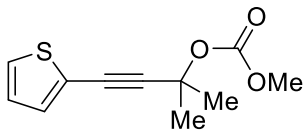
$KMnO_4$) to afford a clear, colorless oil (578.2 mg, 50% yield). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 4.35 (s, 2H), 3.75 (s, 3H), 1.69 (s, 6H), 0.91 (s, 9H), 0.12 (s, 6H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 153.6, 85.2, 83.5, 74.4, 54.4, 51.9, 28.9, 25.9, 18.4, -5.00.



4-(cyclohex-1-en-1-yl)-2-methylbut-3-yn-2-yl methyl carbonate (3.120). Prepared according to the general procedure above (**Method B**) with 1-ethynylcyclohex-1-ene (583.9 mg, 5.50 mmol) and acetone (290.4 mg, 5.00 mmol). The crude product was purified by silica gel column chromatography (30% EtOAc in hexanes, stained in $KMnO_4$) to afford a clear, colorless oil (800.0 mg, 72% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 6.11 (tt, J = 3.8, 1.7 Hz, 1H), 3.75 (s, 3H), 2.13 – 2.04 (m, 4H), 1.70 (s, 6H), 1.65 – 1.52 (m, 4H). **^{13}C NMR** δ 153.6, 135.8, 120.1, 86.9, 86.4, 75.1, 54.3, 29.20, 29.15, 25.7, 22.4, 21.6.

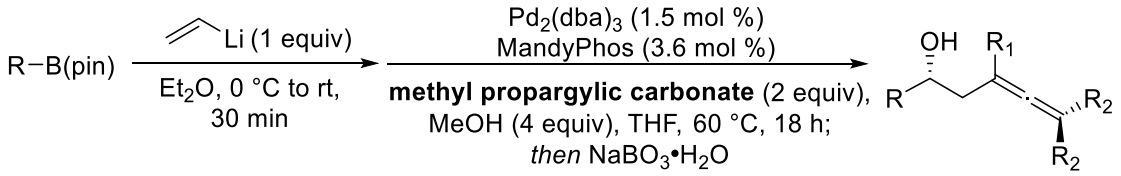


methyl [1-(phenylethynyl)cyclobutyl] carbonate (3.121). Prepared according to the general procedure above (**Method B**) with phenylacetylene (674.1 mg, 6.60 mmol) and cyclobutanone (498.9 mg, 6.00 mmol). The crude product was purified by silica gel column chromatography (30% EtOAc in hexanes, stained in $KMnO_4$) to afford a clear, colorless oil (1.32 g, 96% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.55 – 7.42 (m, 2H), 7.35 – 7.25 (m, 3H), 3.80 (s, 3H), 2.75 – 2.62 (m, 2H), 2.55 (qd, J = 9.7, 2.8 Hz, 2H), 2.10 – 1.89 (m, 2H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 153.7, 132.1, 128.6, 128.3, 122.6, 88.7, 84.9, 74.4, 54.7, 36.7, 14.3.



methyl [2-methyl-4-(thiophen-2-yl)but-3-yn-2-yl] carbonate (3.90). Prepared according to the general procedure above (**Method A**) with 2-methyl-4-(thiophen-2-yl)but-3-yn-2-ol (831.2 mg, 5.00 mmol). The crude product was purified by silica gel column chromatography (30% EtOAc in hexanes, stained in $KMnO_4$) to afford a clear, yellow oil (850.0 mg, 76% yield). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.27 – 7.24 (m, 1H), 7.22 (dd, J = 3.7, 1.2 Hz, 1H), 6.96 (dd, J = 5.2, 3.6 Hz, 1H), 3.78 (s, 3H), 1.79 (s, 6H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 153.6, 132.8, 127.6, 127.0, 122.4, 93.3, 78.0, 74.9, 54.5, 28.9.

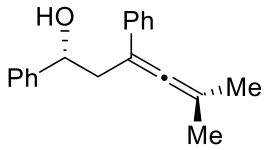
3.4.5. General Procedure for the Synthesis of β-Hydroxy Allenes by Conjunctive Cross-Coupling



In a glovebox filled with argon, an oven-dried 2-dram vial equipped with a magnetic stir bar was charged with $Pd_2(dba)_3$ (4.1 mg, 0.0045 mmol, 0.015 equiv), (S_P,S_P)-MandyPhos (11.4 mg, 0.0108 mmol, 0.036 equiv), and anhydrous THF (1 mL). The Pd/ligand solution was allowed to stir for at least one hour at room temperature inside the glovebox. Meanwhile, a second oven-dried 2-dram vial equipped with a magnetic stir bar was charged with 2-aryl(or alkenyl or alkyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (0.30 mmol, 1 equiv) and anhydrous Et_2O (1 mL). This second vial was sealed with a septum cap and removed from the glovebox. Outside the glovebox under positive nitrogen pressure, the reaction vial was cooled to 0 ºC in an ice-water bath, and vinyllithium solution in THF (0.30 mmol, 1 equiv) was added dropwise with stirring to form the 'ate' complex. The reaction vial was allowed to warm to room temperature and stir for 30 minutes. The

solvent was carefully removed from the 'ate' complex under reduced pressure, and the 'ate' residue was kept under vacuum for 30 minutes before being brought back into the glovebox. In the glovebox, the 'ate' residue was re-dissolved in anhydrous THF (1 mL), and the Pd/ligand solution was transferred into the reaction vial, followed by methyl propargylic carbonate (0.60 mmol, 2 equiv), ***either*** methanol (38.5 mg, 1.2 mmol, 4 equiv) ***or*** 2,2,2-trifluoroethanol (80.0 mg, 1.2 mmol, 4 equiv), and anhydrous THF (1 mL, used to rinse the Pd/ligand vial). The reaction vial was sealed with a polypropylene cap and electrical tape, brought out of the glovebox, and stirred at 60 ºC for 18 hours. After cooling to room temperature, the reaction solution was filtered through a silica gel plug with Et_2O washing and concentrated under reduced pressure. If desired, the residue was purified by silica gel column chromatography prior to oxidation. For oxidation to the corresponding β-hydroxy allene, the β-allenyl boronic ester was dissolved in a THF:H_2O mixture (1:1 ratio, 3 mL), and sodium perborate tetrahydrate (4 equiv) was added. The suspension was allowed to stir under air for 12-24 hours before being diluted with water (2 mL) and extracted with EtOAc (3 x 3 mL). The combined organic phases were dried over Na_2SO_4, filtered, concentrated under reduced pressure, and purified by silica gel column chromatography to afford pure product.

3.4.6. Characterization of β-Hydroxy Allene Products

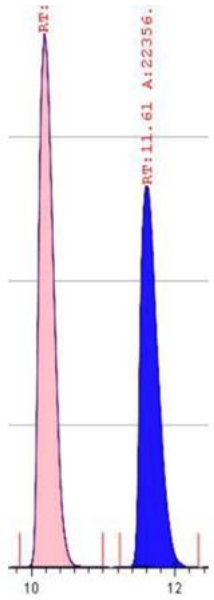


(*R*)-5-methyl-1,3-diphenylhexa-3,4-dien-1-ol (3.62). Prepared according to the general procedure above with 4,4,5,5-tetramethyl-2-phenyl-1,3,2-dioxaborolane **(3.54**, 61.2 mg, 0.30 mmol, 1 equiv), methyl (2-methyl-4-phenylbut-3-yn-2-yl) carbonate (131.0 mg, 0.60 mmol, 2 equiv), (147.8 mg, 0.60 mmol, 2 equiv), and methanol (38.5 mg, 1.2 mmol, 4 equiv). The crude product was purified by silica gel column chromatography (0% → 30% EtOAc in hexanes, stained in $KMnO_4$) to afford a clear, colorless oil (66.7 mg, 84% yield). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.44 – 7.34 (m, 6H), 7.32 (app t, J = 7.7 Hz, 2H), 7.28 (t, J = 7.3 Hz, 1H), 7.21 (t, J = 7.3 Hz, 1H), 4.91 (dd, J = 7.9, 5.3 Hz, 1H), 2.96 – 2.78 (m, 2H), 2.29 (d, J = 2.7 Hz, 1H), 1.77 (s, 3H), 1.73 (s, 3H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 202.4, 144.0, 137.6, 129.7, 128.53, 128.52, 127.6, 126.7, 126.2, 115.4, 100.4, 99.5, 72.8, 40.6, 20.6, 20.3. **IR** (neat) ν_{max} 3316.67 (br), 3028.99 (w), 2979.23 (w), 2904.31 (m), 1951.00 (w), 1595.96 (m), 1491.53 (s), 1442.43 (s), 1386.35 (m), 1361.01 (m), 1183.57 (m), 1058.33 (s), 1029.08 (s), 911.34 (m), 757.45 (s), 699.28 (s), 595.27 (m), 549.70 (m) cm^{-1}. **HRMS** (DART+) for $C_{19}H_{19}$ $[M+H–H_2O]^+$ calculated: 247.1481, found: 247.1476. **$[\alpha]_D^{20}$:** +33.915 (*c* = 3.20, CHCl3, *l* = 50 mm).

Analysis of Stereochemistry:

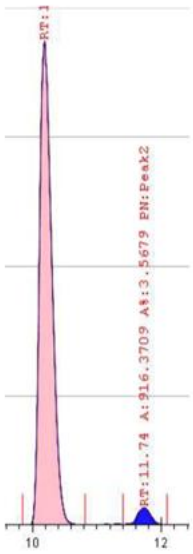
Chiral SFC (Chiracel OJ-H, 5% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of (*R*)-5-methyl-1,3-diphenylhexa-3,4-dien-1-ol **(3.62)**.

Enantiomer mixture

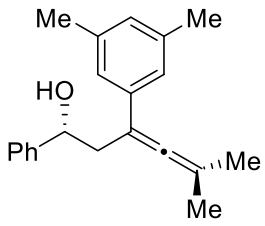


Peak No	% Area	Area	RT (min)
1	53.8992	26138.507	10.18
2	46.1008	22356.652	11.61
Total:	100	48495.159	

Standard conditions



Peak No	% Area	Area	RT (min)
1	96.4321	24767.4943	10.19
2	3.5679	916.3709	11.74
Total:	100	25683.8652	

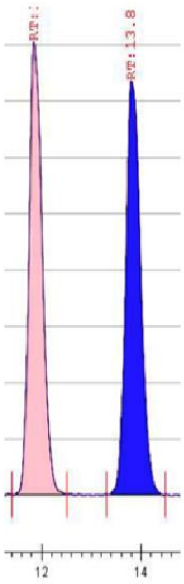


(*R*)-3-(3,5-dimethylphenyl)-5-methyl-1-phenylhexa-3,4-dien-1-ol (3.63). Prepared according to the general procedure above with 4,4,5,5-tetramethyl-2-phenyl-1,3,2-dioxaborolane **(3.54**, 61.2 mg, 0.30 mmol, 1 equiv), 4-(3,5-dimethylphenyl)-2-methylbut-3-yn-2-yl methyl carbonate (**3.109**, 147.8 mg, 0.60 mmol, 2 equiv), and methanol (38.5 mg, 1.2 mmol, 4 equiv). The crude product was purified by silica gel column chromatography (0% → 30% EtOAc in hexanes, stained in $KMnO_4$) to afford a clear, colorless oil (70.0 mg, 80% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.41 (d, J = 7.9 Hz, 2H), 7.36 (app t, J = 7.5 Hz, 2H), 7.29 (d, J = 7.8 Hz, 1H), 6.97 (s, 2H), 6.86 (s, 1H), 4.94 – 4.84 (m, 1H), 2.91 – 2.77 (m, 2H), 2.31 (s, 3H), 2.29 (d, J = 2.2 Hz, 1H), 1.77 (s, 3H), 1.73 (s, 3H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 202.3, 144.1, 138.0, 137.6, 128.52, 128.51, 127.6, 126.2, 124.1, 100.5, 99.2, 72.8, 40.9, 21.6, 20.7, 20.4. **IR** (neat) ν_{max} 3367.62 (br), 3029.13 (w), 2978.28 (w), 2910.77 (m), 2855.59 (w), 1953.60 (w), 1742.82 (w), 1597.18 (s), 1452.57 (s), 1376.37 (m), 1184.71 (m), 1057.22 (s), 1036.55 (s), 846.42 (s), 760.61 (s), 698.15 (s), 600.41 (m) cm^{-1}. **HRMS** (DART+) for $C_{21}H_{23}$ $[M+H–H_2O]^+$ calculated: 275.1794, found: 275.1792. **$[\alpha]_D^{20}$:** +32.277 (*c* = 1.13, CHCl3, *l* = 50 mm).

Analysis of Stereochemistry:

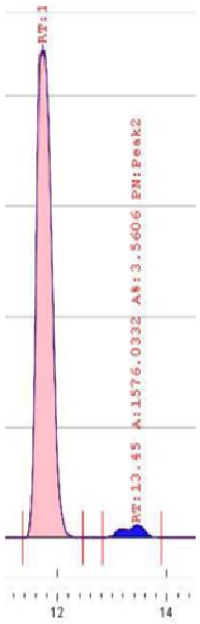
Chiral SFC (Chiracel OD-H, 5% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of (*R*)-3-(3,5-dimethylphenyl)-5-methyl-1-phenylhexa-3,4-dien-1-ol **(3.63)**.

Enantiomer mixture

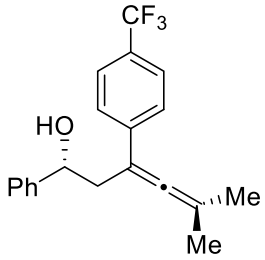


Peak No	% Area	Area	RT (min)
1	48.9453	14734.5235	11.85
2	51.0547	15369.5597	13.8
Total:	100	30104.0832	

Standard conditions



Peak No	% Area	Area	RT (min)
1	96.4394	42687.0169	11.73
2	3.5606	1576.0332	13.45
Total:	100	44263.0501	

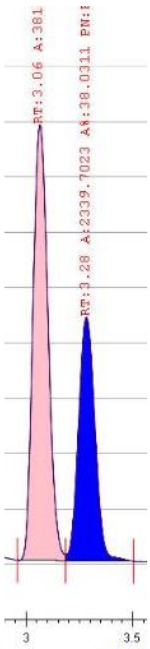


(*R*)-5-methyl-1-phenyl-3-[4-(trifluoromethyl)phenyl]hexa-3,4-dien-1-ol (3.64). Prepared according to the general procedure above with 4,4,5,5-tetramethyl-2-phenyl-1,3,2-dioxaborolane **(3.54**, 61.2 mg, 0.30 mmol, 1 equiv), methyl {2-methyl-4-[4-(trifluoromethyl)phenyl]but-3-yn-2-yl} carbonate (**3.110**, 171.8 mg, 0.60 mmol, 2 equiv), and methanol (38.5 mg, 1.2 mmol, 4 equiv). The crude product was purified by silica gel column chromatography (0% → 30% EtOAc in hexanes, stained in $KMnO_4$) to afford a clear, colorless oil (95.6 mg, 96% yield). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.55 (d, J = 8.1 Hz, 2H), 7.45 (d, J = 8.2 Hz, 2H), 7.42 – 7.34 (m, 4H), 7.29 (t, J = 6.9 Hz, 1H), 4.89 (dd, J = 7.6, 5.6 Hz, 1H), 2.99 – 2.81 (m, 2H), 2.23 (d, J = 7.5 Hz, 1H), 1.76 (s, 3H), 1.71 (s, 3H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 203.4, 143.8, 141.7, 129.8, 128.6, 128.5 (q, J = 32.4 Hz), 127.8, 126.3, 126.2, 125.4 (q, J = 3.6 Hz), 124.4 (q, J = 271.8 Hz), 115.4, 100.2, 99.7, 73.0, 40.2, 20.3, 20.1. **^{19}F NMR** (470 MHz, $CDCl_3$) δ -62.39. **IR** (neat) ν_{max} 3340.32 (br), 3028.34 (w), 2982.33 (w), 2910.11 (w), 2854.40 (w), 1613.91 (m), 1452.17 (w), 1382.43 (w), 1324.80 (s), 1163.28 (s), 1120.69 (s), 1066.65 (s), 1013.66 (m), 842.01 (m), 765.36 (w), 699.49 (m), 549.05 (w) 508.42 (w) cm^{-1}. **HRMS** (DART+) for $C_{20}H_{18}F_3$ $[M+H-H_2O]^+$ calculated: 315.1355, found: 315.1343. **$[\alpha]_D^{20}$:** +25.146 (*c* = 0.85, CHCl3, *l* = 50 mm).

Analysis of Stereochemistry:

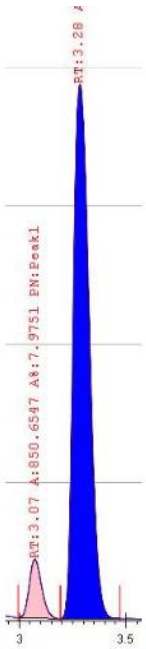
Chiral SFC (Chiracel OJ-H, 10% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of (*R*)-5-methyl-1-phenyl-3-[4-(trifluoromethyl)phenyl]hexa-3,4-dien-1-ol **(3.64)**.

Enantiomer mixture

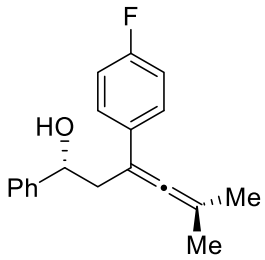


Peak No	% Area	Area	RT (min)
1	61.9689	3812.3716	3.06
2	38.0311	2339.7023	3.28
Total:	100	6152.0739	

Standard conditions



Peak No	% Area	Area	RT (min)
1	7.9751	850.6547	3.07
2	92.0249	9815.7572	3.28
Total:	100	10666.4119	

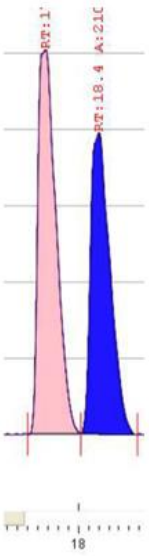


(*R*)-3-(4-fluorophenyl)-5-methyl-1-phenylhexa-3,4-dien-1-ol (3.65). Prepared according to the general procedure above with 4,4,5,5-tetramethyl-2-phenyl-1,3,2-dioxaborolane **(3.54**, 61.2 mg, 0.30 mmol, 1 equiv), 4-(4-fluorophenyl)-2-methylbut-3-yn-2-yl methyl carbonate (**3.111**, 94.5 mg, 0.60 mmol, 2 equiv), and methanol (38.5 mg, 1.2 mmol, 4 equiv). The crude product was purified by silica gel column chromatography (0% → 30% EtOAc in hexanes, stained in $KMnO_4$) to afford a clear, colorless oil (34.0 mg, 60% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.43 – 7.26 (m, 7H), 7.00 (app t, J = 8.7 Hz, 2H), 4.88 (app t, J = 6.6 Hz, 1H), 2.84 (d, J = 6.6 Hz, 2H), 2.28 (d, J = 3.7 Hz, 1H), 1.76 (s, 3H), 1.71 (s, 3H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 202.2, 161.8 (d, J = 245.6 Hz), 143.9, 133.6 (d, J = 3.0 Hz), 128.5, 127.7, 127.6, 126.2, 115.3 (d, J = 21.5 Hz), 99.7, 99.6, 72.9, 40.7, 20.6, 20.3. **^{19}F NMR** (470 MHz, $CDCl_3$) δ -116.37 (tt, J = 8.3, 5.4 Hz). **IR** (neat) ν_{max} 3377.99 (br), 3031.17 (w), 2978.92 (w), 2908.20 (m), 1954.09 (w), 1751.33 (m), 1701.51 (m), 1601.40 (m), 1506.70 (s), 1446.04 (m), 1362.70 (m), 1228.73 (s), 1158.42 (s), 1032.51 (s), 911.79 (m), 834.84 (s), 753.10 (m), 699.79 (s), 585.09 (w) cm^{-1}. **HRMS** (DART+) for $C_{19}H_{18}F$ $[M+H–H_2O]^+$ calculated: 265.1387, found: 265.1385. **$[\alpha]_D^{20}$:** +33.402 (*c* = 1.40, CHCl3, *l* = 50 mm).

Analysis of Stereochemistry:

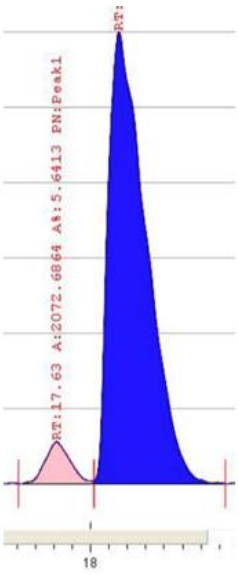
Chiral SFC (Chiracel OJ-H, 3% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of (*R*)-3-(4-fluorophenyl)-5-methyl-1-phenylhexa-3,4-dien-1-ol **(3.65)**.

Enantiomer mixture

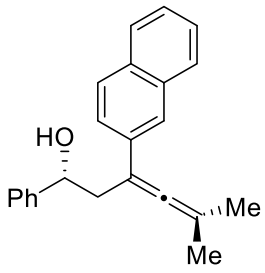


Peak No	% Area	Area	RT (min)
1	54.3168	25074.6615	17.37
2	45.6832	21089.0697	18.4
Total:	100	46163.7312	

Standard conditions



Peak No	% Area	Area	RT (min)
1	5.6413	2072.6864	17.63
2	94.3587	34668.852	18.31
Total:	100	36741.5384	

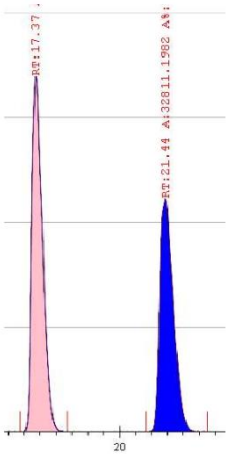


(*R*)-5-methyl-3-(naphthalen-2-yl)-1-phenylhexa-3,4-dien-1-ol (3.66). Prepared according to the general procedure above with 4,4,5,5-tetramethyl-2-phenyl-1,3,2-dioxaborolane **(3.54**, 61.2 mg, 0.30 mmol, 1 equiv), methyl [2-methyl-4-(naphthalen-2-yl)but-3-yn-2-yl] carbonate (**3.112**, 161.0 mg, 0.60 mmol, 2 equiv), and methanol (38.5 mg, 1.2 mmol, 4 equiv). The crude product was purified by silica gel column chromatography (0% → 30% EtOAc in hexanes, stained in $KMnO_4$) to afford a clear, yellow oil (79.0 mg, 84% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.83 – 7.72 (m, 4H), 7.54 (dd, J = 8.6, 1.9 Hz, 1H), 7.49 – 7.41 (m, 4H), 7.38 (app t, J = 7.5 Hz, 2H), 7.30 (t, J = 7.2 Hz, 1H), 4.99 (ddd, J = 6.6, 6.6, 2.5 Hz, 1H), 3.01 (app d, J = 6.5 Hz, 2H), 2.30 (d, J = 2.7 Hz, 1H), 1.81 (s, 3H), 1.76 (s, 3H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 203.1, 144.1, 135.0, 133.7, 132.5, 128.6, 128.1, 127.9, 127.69, 127.66, 126.26, 126.25, 125.8, 125.6, 123.6, 100.7, 99.9, 72.9, 40.6, 20.7, 20.4. **IR** (neat) ν_{max} 3363.50 (br), 3055.00 (w), 2978.55 (w), 2905.64 (m), 1951.38 (w), 1628.14 (w), 1597.29 (m), 1503.95 (m), 1448.56 (m), 1273.50 (m), 1192.11 (m), 1063.02 (s), 1019.88 (s), 888.82 (m), 855.40 (s), 817.91 (s), 699.12 (s) cm^{-1}. **HRMS** (DART+) for $C_{23}H_{23}O$ $[M+H]^+$ calculated: 315.1743, found: 315.1732. **$[\alpha]_D^{20}$:** +33.810 (*c* = 3.64, CHCl3, *l* = 50 mm).

Analysis of Stereochemistry:

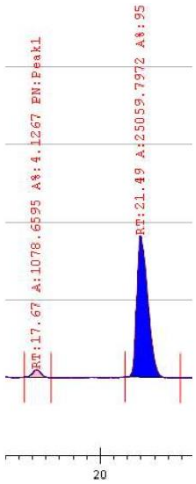
Chiral SFC (Chiracel OJ-H, 10% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of (*R*)-5-methyl-3-(naphthalen-2-yl)-1-phenylhexa-3,4-dien-1-ol **(3.66)**.

Enantiomer mixture

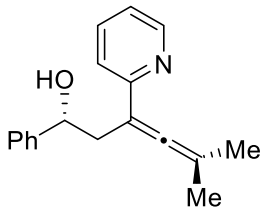


Peak No	% Area	Area	RT (min)
1	54.8158	39805.2637	17.37
2	45.1842	32811.1982	21.44
Total:	100	72616.4619	

Standard conditions



Peak No	% Area	Area	RT (min)
1	4.1267	1078.6595	17.67
2	95.8733	25059.7972	21.49
Total:	100	26138.4567	

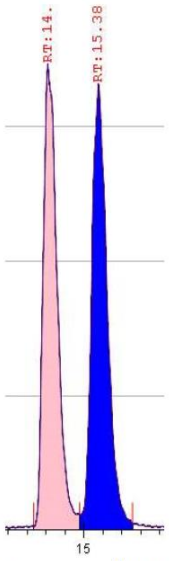


(*R*)-5-methyl-1-phenyl-3-(pyridin-2-yl)hexa-3,4-dien-1-ol (3.67). Prepared according to the general procedure above with 4,4,5,5-tetramethyl-2-phenyl-1,3,2-dioxaborolane **(3.54**, 61.2 mg, 0.30 mmol, 1 equiv), methyl [2-methyl-4-(pyridin-2-yl)but-3-yn-2-yl] carbonate (**3.113**, 131.5 mg, 0.60 mmol, 2 equiv), and methanol (38.5 mg, 1.2 mmol, 4 equiv). The crude product was purified by silica gel column chromatography (0% → 30% EtOAc in hexanes, stained in $KMnO_4$) to afford a red solid (57.1 mg, 72% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 8.51 (ddd, J = 4.9, 1.6, 0.9 Hz, 1H), 7.60 (ddd, J = 7.8, 7.8, 1.8 Hz, 1H), 7.46 – 7.36 (m, 2H), 7.36 – 7.28 (m, 3H), 7.19 (t, J = 7.3 Hz, 1H), 7.10 (ddd, J = 7.4, 5.0, 1.2 Hz, 1H), 5.05 (dd, J = 7.2, 2.9 Hz, 1H), 3.00 (dd, J = 14.2, 3.0 Hz, 1H), 2.89 (dd, J = 14.2, 7.2 Hz, 1H), 1.76 (s, 3H), 1.74 (s, 1H), 1.46 (s, 3H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 206.1, 157.7, 147.7, 145.6, 136.7, 128.1, 126.7, 126.0, 122.7, 121.0, 102.2, 98.6, 74.4, 41.5, 20.1, 19.7. **IR** (neat) ν_{max} 3200.40 (br), 3060.03 (w), 3026.75 (w), 2979.43 (w), 2906.69 (m), 2856.51 (m), 1953.09 (w), 1590.56 (s), 1562.44 (s), 1428.82 (s), 1388.34 (m), 1183.59 (m), 1150.68 (m), 1089.32 (m), 1061.29 (s), 784.91 (s), 744.08 (s), 698.47 (s), 597.17 (m) cm^{-1}. **HRMS** (DART+) for $C_{18}H_{20}NO$ $[M+H]^+$ calculated: 266.1539, found: 266.1538. **$[\alpha]_D^{20}$:** +2.086 (*c* = 2.37, CHCl3, *l* = 50 mm).

Analysis of Stereochemistry:

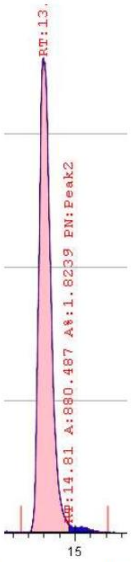
Chiral SFC (Chiracel ODR-H, 3% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of (*R*)-5-methyl-1-phenyl-3-(pyridin-2-yl)hexa-3,4-dien-1-ol **(3.67)**.

Enantiomer mixture

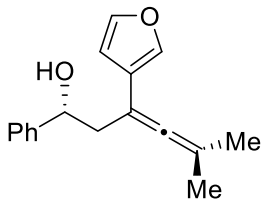


Peak No	% Area	Area	RT (min)
1	48.8869	45111.6645	14.04
2	51.1131	47166.0181	15.38
Total:	100	92277.6826	

Standard conditions



Peak No	% Area	Area	RT (min)
1	98.1761	47394.2007	13.99
2	1.8239	880.487	14.81
Total:	100	48274.6877	

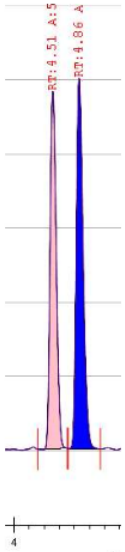


(*R*)-3-(furan-3-yl)-5-methyl-1-phenylhexa-3,4-dien-1-ol (3.68). Prepared according to the general procedure above with 4,4,5,5-tetramethyl-2-phenyl-1,3,2-dioxaborolane (**3.54**, 61.2 mg, 0.30 mmol, 1 equiv), 4-(furan-3-yl)-2-methylbut-3-yn-2-yl methyl carbonate (**3.114**, 124.9 mg, 0.60 mmol, 2 equiv), and methanol (38.5 mg, 1.2 mmol, 4 equiv). The crude product was purified by silica gel column chromatography (0% → 30% EtOAc in hexanes, stained in $KMnO_4$) to afford a clear, colorless oil (58.6 mg, 77% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.42 – 7.34 (m, 6H), 7.28 (t, J = 7.2 Hz, 1H), 6.34 (dd, J = 1.8, 1.0 Hz, 1H), 4.95 – 4.88 (m, 1H), 2.73 – 2.60 (m, 2H), 2.32 (s, 1H), 1.74 (s, 3H), 1.71 (s, 3H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 201.2, 143.9, 143.3, 138.1, 128.5, 127.7, 126.7, 126.2, 126.1, 124.3, 109.5, 99.2, 93.2, 72.8, 41.4, 20.7, 20.5. **IR** (neat) ν_{max} 3370.38 (br), 3059.85 (w), 3026.89 (w), 2977.30 (w), 2904.64 (m), 2854.55 (w), 1949.97 (w), 1595.60 (w), 1491.86 (m), 1445.66 (m), 1360.26 (m), 1156.37 (m), 1046.89 (s), 1026.25 (s), 1012.74 (s), 871.11 (s), 751.98 (s), 696.61 (s), 592.95 (s), 547.86 (m) cm^{-1}. **HRMS** (DART+) for $C_{17}H_{15}O$ $[M+H–H_2O]^+$ calculated: 235.1117, found: 235.1120. **$[\alpha]_D^{20}$:** +30.554 (*c* = 2.93, CHCl3, *l* = 50 mm).

Analysis of Stereochemistry:

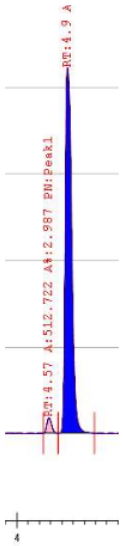
Chiral SFC (Chiracel OJ-H, 7% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of (*R*)-3-(furan-3-yl)-5-methyl-1-phenylhexa-3,4-dien-1-ol **(3.68)**.

Enantiomer mixture

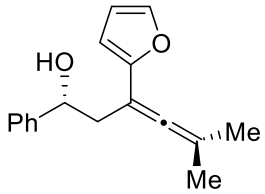


Peak No	% Area	Area	RT (min)
1	46.7033	5484.8617	4.51
2	53.2967	6259.2016	4.86
Total:	100	11744.0633	

Standard conditions



Peak No	% Area	Area	RT (min)
1	2.987	512.722	4.57
2	97.013	16652.3426	4.9
Total:	100	17165.0646	

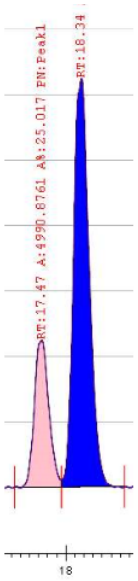


(*R*)-3-(furan-2-yl)-5-methyl-1-phenylhexa-3,4-dien-1-ol (3.69). Prepared according to the general procedure above with 4,4,5,5-tetramethyl-2-phenyl-1,3,2-dioxaborolane (**3.54**, 61.2 mg, 0.30 mmol, 1 equiv), 4-(furan-2-yl)-2-methylbut-3-yn-2-yl methyl carbonate (**3.115**, 124.9 mg, 0.60 mmol, 2 equiv), and methanol (38.5 mg, 1.2 mmol, 4 equiv). The crude product was purified by silica gel column chromatography (0% → 30% EtOAc in hexanes, stained in $KMnO_4$) to afford a clear, colorless oil (37.1 mg, 49% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.42 – 7.38 (m, 2H), 7.38 – 7.34 (m, 3H), 7.28 (t, J = 7.2 Hz, 1H), 6.39 (dd, J = 3.3, 1.8 Hz, 1H), 6.20 (dd, J = 3.3, 0.8 Hz, 1H), 4.91 (dd, J = 8.1, 5.1 Hz, 1H), 2.80 – 2.66 (m, 2H), 2.27 (s, 1H), 1.77 (s, 3H), 1.72 (s, 3H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 201.0, 151.5, 143.8, 141.9, 128.5, 127.7, 126.7, 126.20, 126.15, 111.4, 106.0, 100.6, 93.1, 73.0, 40.3, 20.9, 20.6. **IR** (neat) ν_{max} 3425.64 (br), 3029.20 (w), 2973.05 (m), 2929.10 (m), 2911.42 (m), 1951.60 (w), 1664.66 (m), 1602.89 (m), 1492.25 (m), 1450.84 (m), 1361.07 (m), 1154.51 (m), 1056.04 (s), 1024.49 (s), 755.89 (s), 699.51 (s), 595.33 (w) cm^{-1}. **HRMS** (DART+) for $C_{17}H_{15}O$ $[M+H-H_2O]^+$ calculated: 235.1117, found: 235.1118. **$[\alpha]_D^{20}$:** +19.318 (*c* = 1.67, CHCl3, *l* = 50 mm).

Analysis of Stereochemistry:

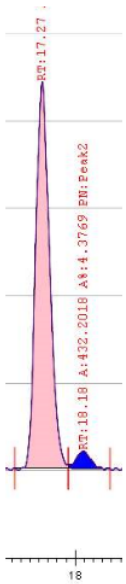
Chiral SFC (Chiracel OD-H, 3% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of (*R*)-3-(furan-2-yl)-5-methyl-1-phenylhexa-3,4-dien-1-ol **(3.69)**.

Enantiomer mixture

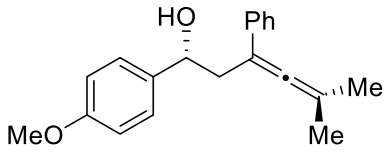


Peak No	% Area	Area	RT (min)
1	25.017	4990.8761	17.47
2	74.983	14959.0611	18.34
Total:	100	19949.9372	

Standard conditions



Peak No	% Area	Area	RT (min)
1	95.6231	9442.4882	17.27
2	4.3769	432.2018	18.18
Total:	100	9874.69	

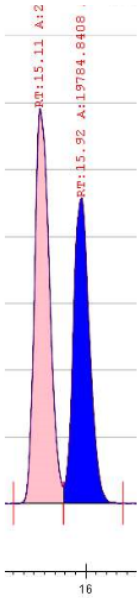


(*R*)-1-(4-methoxyphenyl)-5-methyl-3-phenylhexa-3,4-dien-1-ol (3.80). Prepared according to the general procedure above with 2-(4-methoxyphenyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (70.2 mg, 0.30 mmol), methyl (2-methyl-4-phenylbut-3-yn-2-yl) carbonate (131.0 mg, 0.60 mmol, 2 equiv), and methanol (38.5 mg, 1.2 mmol, 4 equiv). The crude product was purified by silica gel column chromatography (0% → 30% EtOAc in hexanes, stained in $KMnO_4$) to afford a clear, colorless oil (78.4 mg, 89% yield). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.39 (d, J = 7.2 Hz, 2H), 7.36 – 7.30 (m, 5H), 6.91 (d, J = 8.6 Hz, 2H), 4.87 (app t, J = 6.5 Hz, 1H), 3.82 (s, 3H), 2.88 (m, 2H), 2.38 (br s, 1H), 1.77 (s, 3H), 1.74 (s, 3H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 202.5, 159.1, 137.6, 136.2, 131.7, 128.5, 128.3, 127.4, 126.6, 126.1, 113.8, 100.4, 99.3, 72.4, 55.4, 40.4, 20.5, 20.2. **IR** (neat) ν_{max} 3370.85 (br), 2906.07 (w), 2832.59 (w), 2004.68 (w), 1610.75 (m), 1510.42 (s), 1442.17 (m), 1246.09 (s), 1175.41 (m), 1034.87 (m), 829.06 (m), 759.38 (w), 693.94 (w) cm^{-1}. **HRMS** (DART+) for $C_{20}H_{21}O$ $[M+H–H_2O]^+$ calculated: 277.1587, found: 277.1584. **$[\alpha]_D^{20}$:** +24.280 (*c* = 0.58, CHCl3, *l* = 50 mm).

Analysis of Stereochemistry:

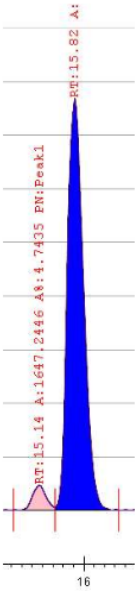
Chiral SFC (Chiracel OD-H, 6% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of (*R*)-1-(4-methoxyphenyl)-5-methyl-3-phenylhexa-3,4-dien-1-ol **(3.80)**.

Enantiomer mixture

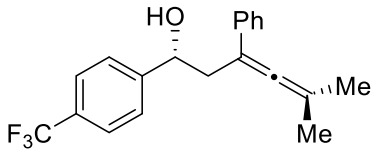


Peak No	% Area	Area	RT (min)
1	54.4678	23667.5303	15.11
2	45.5322	19784.8408	15.92
Total:	100	43452.3711	

Standard conditions



Peak No	% Area	Area	RT (min)
1	4.7435	1647.2446	15.14
2	95.2565	33078.7472	15.82
Total:	100	34725.9918	

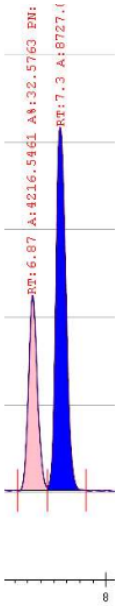


(*R*)-5-methyl-3-phenyl-1-[4-(trifluoromethyl)phenyl] hexa-3,4-dien-1-ol (3.81). Prepared according to the general procedure above with 4,4,5,5-tetramethyl-2-[4-(trifluoromethyl)phenyl]-1,3,2-dioxaborolane (81.6 mg, 0.3 mmol), methyl (2-methyl-4-phenylbut-3-yn-2-yl) carbonate (131.0 mg, 0.60 mmol, 2 equiv), and methanol (38.5 mg, 1.2 mmol, 4 equiv). The crude product was purified by silica gel column chromatography (0% → 30% EtOAc in hexanes, stained in $KMnO_4$) to afford a clear, colorless oil (67.6 mg, 68% yield). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.62 (d, J = 8.1 Hz, 2H), 7.52 (d, J = 8.1 Hz, 2H), 7.37 (d, J = 8.1 Hz, 2H), 7.34 (app t, J = 7.7 Hz, 2H), 7.23 (t, J = 7.1 Hz, 1H), 4.97 (dd, J = 7.9, 5.3 Hz, 1H), 2.94 – 2.76 (m, 2H), 2.42 (d, J = 8.5 Hz, 1H), 1.79 (s, 3H), 1.72 (s, 3H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 202.4, 147.9, 137.3, 129.8 (q, J = 32.3 Hz), 128.6, 126.9, 126.5, 126.2, 125.4 (q, J = 3.7 Hz), 124.3 (q, J = 273.3 Hz), 100.1, 99.8, 72.3, 40.8, 20.6, 20.2. **^{19}F NMR** (470 MHz, $CDCl_3$) δ -62.51. **IR** (neat) ν_{max} 3397.78 (br), 3059.62 (w), 2977.96 (w), 2931.10 (w), 1688.90 (m), 1617.52 (m), 1447.60 (m), 1411.95 (m), 1321.00 (s), 1161.87 (s), 1120.08 (s), 1064.33 (s), 1015.07 (m), 906.92 (m), 839.05 (m), 757.22 (m), 730.14 (s), 692.02 (m), 600.82 (m) cm^{-1}. **HRMS** (DART+) for $C_{20}H_{18}F_3$ $[M+H-H_2O]^+$ calculated: 315.1355, found: 315.1356. **$[\alpha]_D^{20}$:** +18.777 (*c* = 2.93, CHCl3, *l* = 50 mm).

Analysis of Stereochemistry:

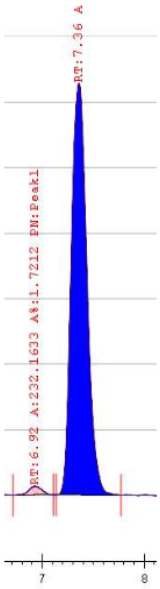
Chiral SFC (Chiracel OD-H, 6% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of (R)-5-methyl-3-phenyl-1-(4-(trifluoromethyl)phenyl)hexa-3,4-dien-1-ol **(3.81)**.

Enantiomer mixture

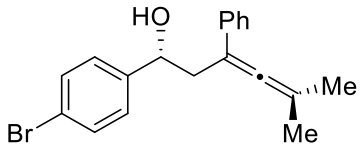


Peak No	% Area	Area	RT (min)
1	32.5763	4216.5461	6.87
2	67.4237	8727.035	7.3
Total:	100	12943.5811	

Standard conditions



Peak No	% Area	Area	RT (min)
1	1.7212	232.1633	6.92
2	98.2788	13256.122	7.36
Total:	100	13488.2853	

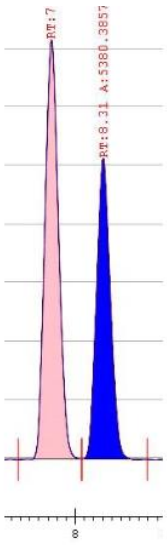


(*R*)-1-(4-bromophenyl)-5-methyl-3-phenylhexa-3,4-dien-1-ol (3.82). Prepared according to the general procedure above with 2-(4-bromophenyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (84.9 mg, 0.30 mmol, 1 equiv), methyl (2-methyl-4-phenylbut-3-yn-2-yl) carbonate (131.0 mg, 0.60 mmol, 2 equiv), and methanol (38.5 mg, 1.2 mmol, 4 equiv). The crude product was purified by silica gel column chromatography (0% → 30% EtOAc in hexanes, stained in $KMnO_4$) to afford a clear, colorless oil (93.6 mg, 91% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.49 (d, J = 8.4 Hz, 2H), 7.37 (d, J = 7.0 Hz, 2H), 7.33 (app t, J = 7.7 Hz, 2H), 7.28 (d, J = 8.3 Hz, 2H), 7.22 (t, J = 7.1 Hz, 1H), 4.87 (app t, J = 6.2 Hz, 1H), 2.83 (app d, J = 7.1 Hz, 2H), 2.39 (s, 1H), 1.79 (s, 3H), 1.74 (s, 3H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 202.4, 143.0, 137.4, 131.5, 128.6, 127.9, 126.8, 126.1, 121.3, 100.1, 99.6, 72.2, 40.6, 20.6, 20.3. **IR** (neat) ν_{max} 3279.08 (br), 3025.20 (w), 2978.58 (w), 2904.52 (m), 2358.91 (w), 2159.61 (w), 1952.99 (w), 1646.21 (w), 1616.53 (w), 1588.54 (m), 1489.34 (s), 1443.71 (m), 1267.93 (m), 1182.14 (m), 1068.80 (s), 1009.41 (s), 759.69 (s), 694.14 (s) cm^{-1}. **HRMS** (DART+) for $C_{19}H_{18}Br$ $[M+H-H_2O]^+$ calculated: 325.0586, found: 325.0577. **$[\alpha]_D^{20}$:** +17.883 (*c* = 4.47, CHCl3, *l* = 50 mm).

Analysis of Stereochemistry:

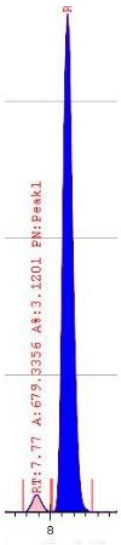
Chiral SFC (Chiracel OD-H, 10% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of (*R*)-1-(4-bromophenyl)-5-methyl-3-phenylhexa-3,4-dien-1-ol **(3.82)**.

Enantiomer mixture

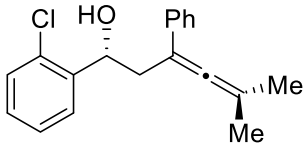


Peak No	% Area	Area	RT (min)
1	57.9445	7413.1497	7.74
2	42.0555	5380.3857	8.31
Total:	100	12793.5354	

Standard conditions



Peak No	% Area	Area	RT (min)
1	3.1201	679.3356	7.77
2	96.8799	21093.8102	8.29
Total:	100	21773.1458	

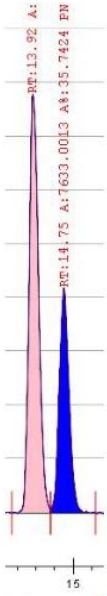


(*R*)-1-(2-chlorophenyl)-5-methyl-3-phenylhexa-3,4-dien-1-ol (3.83). Prepared according to the general procedure above with 2-(2-chlorophenyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (71.6 mg, 0.30 mmol, 1 equiv), methyl (2-methyl-4-phenylbut-3-yn-2-yl) carbonate (131.0 mg, 0.60 mmol, 2 equiv), and methanol (38.5 mg, 1.2 mmol, 4 equiv). The crude product was purified by silica gel column chromatography (0% → 30% EtOAc in hexanes, stained in $KMnO_4$) to afford a clear, colorless oil (78.0 mg, 87% yield). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.65 (dd, J = 7.7, 1.7 Hz, 1H), 7.43 (dd, J = 8.4, 1.2 Hz, 2H), 7.38 – 7.27 (m, 4H), 7.25 – 7.17 (m, 2H), 5.32 (ddd, J = 8.8, 3.3, 3.3 Hz, 1H), 3.04 (dd, J = 15.2, 3.9 Hz, 1H), 2.65 (dd, J = 15.2, 8.9 Hz, 1H), 2.40 (d, J = 2.9 Hz, 1H), 1.82 (s, 3H), 1.78 (s, 3H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 202.5, 141.4, 137.3, 132.2, 129.5, 129.1, 128.6, 127.4, 127.2, 126.8, 126.3, 100.4, 99.8, 69.2, 39.0, 20.6, 20.4. **IR** (neat) ν_{max} 3381.51 (br), 3060.26 (w), 2904.44 (w), 1954.13 (w), 1596.02 (m), 1492.05 (m), 1473.44 (m), 1442.16 (s), 1182.42 (m), 1126.86 (m), 1031.93 (s), 693.73 (s) cm^{-1}. **HRMS** (DART+) for $C_{19}H_{18}Cl$ $[M+H-H_2O]^+$ calculated: 281.1092, found: 281.1088. **$[\alpha]_D^{20}$:** +49.872 (*c* = 3.90, CHCl3, *l* = 50 mm).

Analysis of Stereochemistry:

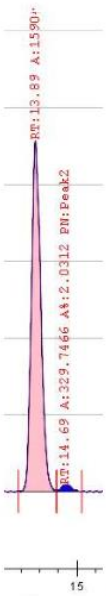
Chiral SFC (Chiracel OD-H, 5% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of (*R*)-1-(2-chlorophenyl)-5-methyl-3-phenylhexa-3,4-dien-1-ol **(3.83)**.

Enantiomer mixture

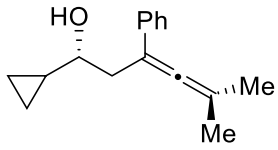


Peak No	% Area	Area	RT (min)
1	64.2576	13722.6187	13.92
2	35.7424	7633.0013	14.75
Total:	100	21355.62	

Standard conditions



Peak No	% Area	Area	RT (min)
1	97.9688	15904.2645	13.89
2	2.0312	329.7466	14.69
Total:	100	16234.0111	

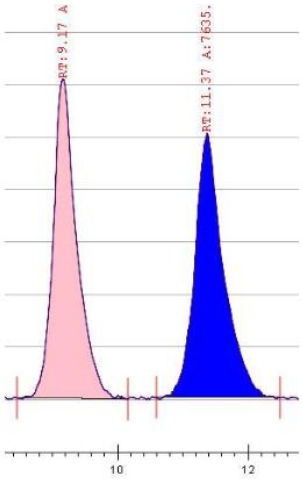


(*R*)-1-cyclopropyl-5-methyl-3-phenylhexa-3,4-dien-1-ol (3.86). Prepared according to the general procedure above with 2-cyclopropyl-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (60.0 mg, 0.30 mmol, 1 equiv), methyl (2-methyl-4-phenylbut-3-yn-2-yl) carbonate (131.0 mg, 0.60 mmol, 2 equiv), and methanol (38.5 mg, 1.2 mmol, 4 equiv). The crude product was purified by silica gel column chromatography (0% → 30% EtOAc in hexanes, stained in $KMnO_4$) to afford a clear, colorless oil (44.1 mg, 64% yield). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.37 (dd, J = 8.3, 1.3 Hz, 2H), 7.31 (dd, J = 8.4, 7.1 Hz, 2H), 7.19 (app t, J = 7.3 Hz, 1H), 3.15 (dddd, J = 8.4, 3.7, 2.0, 2.0 Hz, 1H), 2.80 (dd, J = 15.0, 3.7 Hz, 1H), 2.65 (dd, J = 15.0, 8.6 Hz, 1H), 1.98 (d, J = 2.4 Hz, 1H), 1.839 (s, 3H), 1.835 (s, 3H), 1.01 (dddd, J = 9.8, 8.1, 8.1, 4.9 Hz, 1H), 0.58 – 0.48 (m, 2H), 0.41 – 0.34 (m, 1H), 0.29 – 0.22 (m, 1H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 202.2, 137.8, 128.5, 126.6, 126.2, 100.6, 99.0, 74.8, 38.7, 20.7, 20.5, 17.4, 2.9, 2.5. **IR** (neat) ν_{max} 3408.90 (br), 3081.64 (w), 3007.34 (w), 2978.12 (w), 2930.37 (w), 2096.11 (w), 1716.14 (m), 1597.93 (w), 1447.30 (w), 1272.84 (w), 1214.54 (m), 1175.87 (m), 1025.30 (m), 961.49 (m), 747.95 (s), 696.99 (s), 665.45 (m) cm^{-1}. **HRMS** (DART+) for $C_{16}H_{19}$ $[M+H–H_2O]^+$ calculated: 211.1481, found: 211.1485. **$[\alpha]_D^{20}$:** +10.506 (*c* = 2.21, CHCl3, *l* = 50 mm).

Analysis of Stereochemistry:

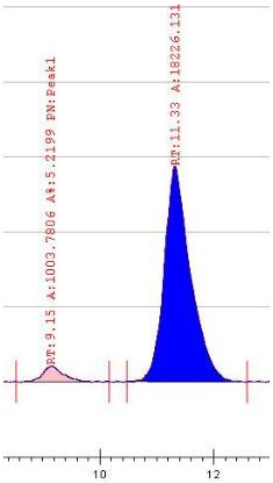
Chiral SFC (Chiracel AD-H, 6% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of (*R*)-1-cyclopropyl-5-methyl-3-phenylhexa-3,4-dien-1-ol **(3.86)**.

Enantiomer mixture

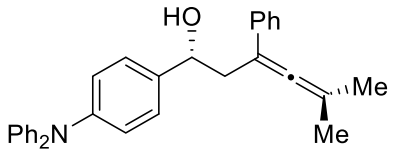


Peak No	% Area	Area	RT (min)
1	50.034	7646.0945	9.17
2	49.966	7635.7026	11.37
Total:	100	15281.7971	

Standard conditions



Peak No	% Area	Area	RT (min)
1	5.2199	1003.7806	9.15
2	94.7801	18226.1312	11.33
Total:	100	19229.9118	

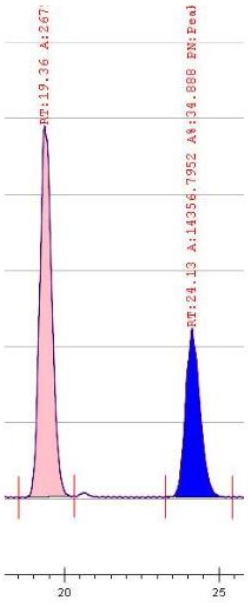


(*R*)-1-[4-(*N*,*N*-diphenylamino)phenyl]-5-methyl-3-phenylhexa-3,4-dien-1-ol (3.84). Prepared according to the general procedure above with *N*,*N*-diphenyl-4-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)aniline (111.4 mg, 0.30 mmol, 1 equiv), methyl (2-methyl-4-phenylbut-3-yn-2-yl) carbonate (131.0 mg, 0.60 mmol, 2 equiv), and methanol (38.5 mg, 1.2 mmol, 4 equiv). The crude product was purified by silica gel column chromatography (0% → 30% EtOAc in hexanes, stained in $KMnO_4$) to afford a dark yellow oil (111.2 mg, 86% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.68 (d, J = 8.8 Hz, 1H), 7.40 – 7.29 (m, 4H), 7.28 – 7.15 (m, 10H), 7.09 – 7.05 (m, 2H), 7.03 – 6.96 (m, 2H), 4.85 (app t, J = 6.6 Hz, 1H), 2.95 – 2.83 (m, 2H), 2.23 (s, 1H), 1.78 (s, 3H), 1.76 (s, 3H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 190.6, 153.5, 148.0, 147.3, 146.3, 143.5, 138.2, 137.6, 131.5, 130.7, 129.9, 129.3, 129.2, 129.1, 128.5, 127.2, 126.7, 126.5, 126.2, 125.3, 124.3, 124.2, 123.0, 122.8, 119.5, 100.4, 99.4, 72.6, 40.4, 20.6, 20.4. **IR** (neat) ν_{max} 3423.95 (br), 3055.47 (w), 3031.38 (w), 2920.00 (m), 2849.39 (w), 1948.23 (w), 1689.22 (m), 1581.42 (s), 1505.72 (m), 1486.66 (s), 1447.84 (m), 1313.19 (m), 1270.78 (s), 1161.24 (m), 908.04 (m), 826.35 (m), 752.93 (s), 693.34 (s), 621.75 (m) cm^{-1}. **HRMS** (DART+) for $C_{31}H_{28}N$ $[M+H–H_2O]^+$ calculated: 414.2216, found: 414.2208. **$[\alpha]_D^{20}$:** +14.524 (*c* = 5.56, CHCl3, *l* = 50 mm).

Analysis of Stereochemistry:

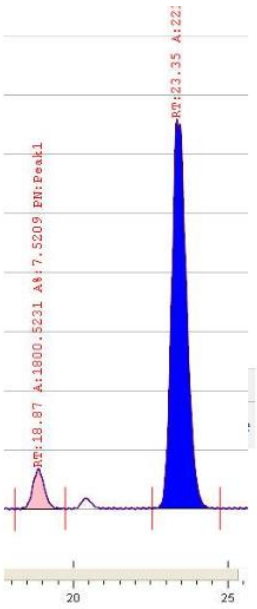
Chiral SFC (Chiracel OD-H, 10% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of (*R*)-1-[4-(*N*,*N*-diphenylamino)phenyl]-5-methyl-3-phenylhexa-3,4-dien-1-ol **(3.84)**.

Enantiomer mixture

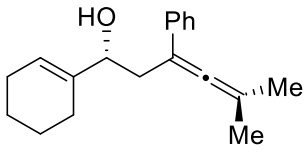


Peak No	% Area	Area	RT (min)
1	65.112	26794.267	19.36
2	34.888	14356.7952	24.13
Total:	100	41151.0622	

Standard conditions



Peak No	% Area	Area	RT (min)
1	7.5209	1800.5231	18.87
2	92.4791	22139.7678	23.35
Total:	100	23940.2909	

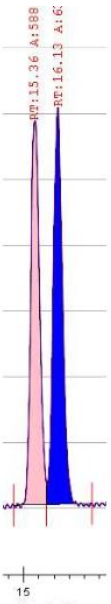


(*R*)-1-(cyclohex-1-en-1-yl)-5-methyl-3-phenylhexa-3,4-dien-1-ol (3.85). Prepared according to the general procedure above with 2-(cyclohexen-1-yl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (62.4 mg, 0.30 mmol, 1 equiv), methyl (2-methyl-4-phenylbut-3-yn-2-yl) carbonate (131.0 mg, 0.60 mmol, 2 equiv), and methanol (38.5 mg, 1.2 mmol, 4 equiv). The crude product was purified by silica gel column chromatography (0% → 30% EtOAc in hexanes, stained in $KMnO_4$) to afford a clear, colorless oil (50.8 mg, 63% yield). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.38 – 7.35 (m, 2H), 7.31 (app t, J = 8.0 Hz, 2H), 7.19 (t, J = 8.0 Hz, 1H), 5.70 (s, 1H), 4.18 (app t, J = 6.4 Hz, 1H), 2.71 (dd, J = 14.9, 5.1 Hz, 1H), 2.61 (dd, J = 14.9, 7.9 Hz, 1H), 2.20 – 2.09 (m, 1H), 2.07 – 1.91 (m, 3H), 1.91 – 1.82 (m, 1H), 1.82 (s, 6H), 1.72 – 1.49 (m, 4H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 202.3, 139.2, 137.9, 128.5, 126.6, 126.2, 123.6, 100.5, 99.0, 74.8, 36.6, 25.2, 24.0, 22.8, 22.7, 20.8, 20.5. **IR** (neat) ν_{max} 3351.78 (br), 3057.43 (w), 2926.66 (s), 2857.01 (m), 2360.23 (w), 1597.17 (m), 1492.26 (m), 1445.73 (s), 1359.37 (w), 1236.71 (w), 1182.95 (m), 1086.06 (s), 1057.76 (s), 1013.18 (s), 919.41 (m), 758.64 (s), 692.99 (s), 623.10 (m) cm^{-1}. **HRMS** (DART+) for $C_{19}H_{23}$ $[M+H-H_2O]^+$ calculated: 251.1794, found: 251.1794. **$[\alpha]_D^{20}$:** +10.886 (*c* = 2.32, CHCl3, *l* = 50 mm).

Analysis of Stereochemistry:

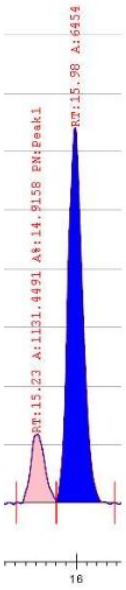
Chiral SFC (Chiracel OD-H, 3% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of (*R*)-1-(cyclohex-1-en-1-yl)-5-methyl-3-phenylhexa-3,4-dien-1-ol **(3.85)**.

Enantiomer mixture

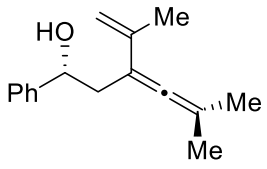


Peak No	% Area	Area	RT (min)
1	48.2825	5883.7822	15.36
2	51.7175	6302.372	16.13
Total:	100	12186.1542	

Standard conditions



Peak No	% Area	Area	RT (min)
1	14.9158	1131.4491	15.23
2	85.0842	6454.1309	15.98
Total:	100	7585.58	

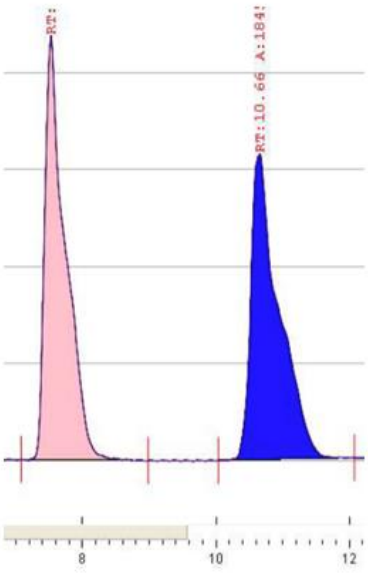


(*R*)-5-methyl-1-phenyl-3-(prop-1-en-2-yl)hexa-3,4-dien-1-ol (3.70). Prepared according to the general procedure above with 4,4,5,5-tetramethyl-2-phenyl-1,3,2-dioxaborolane (**3.54**, 61.2 mg, 0.30 mmol, 1 equiv), 2,5-dimethylhex-5-en-3-yn-2-yl methyl carbonate (**3.116**, 109.3 mg, 0.60 mmol, 2 equiv), and methanol (38.5 mg, 1.2 mmol, 4 equiv). The crude product was purified by silica gel column chromatography (0% → 30% EtOAc in hexanes, stained in $KMnO_4$) to afford a clear, colorless oil (29.1 mg, 42% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.42 – 7.31 (m, 4H), 7.30 – 7.24 (m, 1H), 4.96 (s, 1H), 4.91 (s, 1H), 4.86 (dd, J = 8.2, 5.0 Hz, 1H), 2.69 – 2.55 (m, 2H), 2.23 (s, 1H), 1.80 (s, 3H), 1.70 (s, 3H), 1.66 (s, 3H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 203.3, 144.2, 141.3, 128.5, 127.5, 126.1, 110.4, 102.3, 98.5, 72.9, 40.0, 22.1, 20.7, 20.4. **IR** (neat) ν_{max} 3368.30 (br), 3087.61 (w), 3062.64 (w), 3029.31 (w), 2975.01 (m), 2916.79 (s), 2856.66 (m), 2358.97 (w), 1952.87 (w), 1617.43 (m), 1450.14 (s), 1374.37 (m), 1184.91 (m), 1058.61 (m), 1034.90 (m), 878.77 (m), 699.15 (s) cm^{-1}. **HRMS** (DART+) for $C_{16}H_{21}O$ $[M+H]^+$ calculated: 229.1587, found: 229.1579. **$[\alpha]_D^{20}$:** +38.660 (*c* = 0.47, CHCl3, *l* = 50 mm).

Analysis of Stereochemistry:

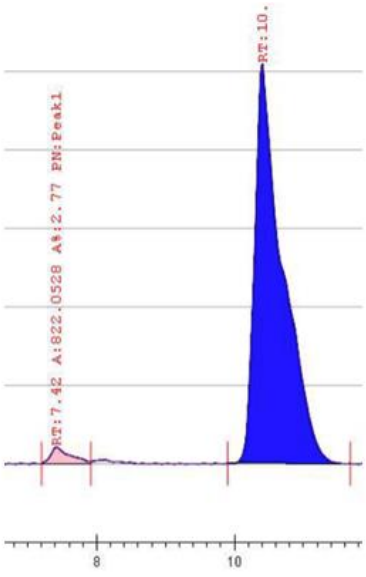
Chiral SFC (Chiracel AD-H, 5% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of (*R*)-5-methyl-1-phenyl-3-(prop-1-en-2-yl)hexa-3,4-dien-1-ol **(3.70)**.

Enantiomer mixture

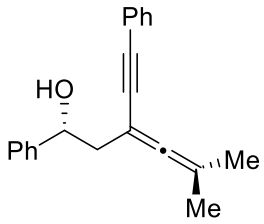


Peak No	% Area	Area	RT (min)
1	50.2758	18660.3216	7.53
2	49.7242	18455.6011	10.66
Total:	100	37115.9227	

Standard conditions



Peak No	% Area	Area	RT (min)
1	2.77	822.0528	7.42
2	97.23	28855.0809	10.41
Total:	100	29677.1337	

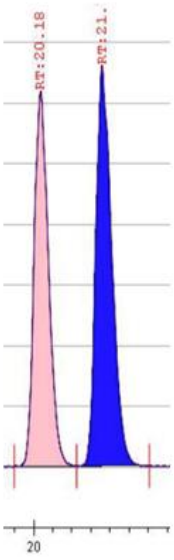


(*R*)-5-methyl-1-phenyl-3-(phenylethynyl)hexa-3,4-dien-1-ol (3.72). Prepared according to the general procedure above with 4,4,5,5-tetramethyl-2-phenyl-1,3,2-dioxaborolane (**3.54**, 61.2 mg, 0.30 mmol, 1 equiv), methyl (2-methyl-6-phenylhexa-3,5-diyn-2-yl) carbonate (**3.117**, 145.4 mg, 0.60 mmol, 2 equiv), and methanol (38.5 mg, 1.2 mmol, 4 equiv). The crude product was purified by silica gel column chromatography (0% → 30% EtOAc in hexanes, stained in $KMnO_4$) to afford a yellow solid (61.8 mg, 71% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.46 – 7.40 (m, 4H), 7.39 – 7.34 (m, 2H), 7.33 – 7.27 (m, 4H), 5.00 (app t, J = 6.7 Hz, 1H), 2.68 – 2.55 (m, 2H), 2.28 (s, 1H), 1.72 (s, 3H), 1.62 (s, 3H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 208.2, 143.6, 131.6, 128.5, 128.4, 128.2, 127.7, 126.2, 123.6, 97.9, 90.1, 85.8, 84.4, 73.0, 44.7, 20.5, 20.2. **IR** (neat) ν_{max} 3351.30 (br), 3030.37 (w), 2981.47 (w), 2905.88 (m), 2206.29 (w), 1952.35 (w), 1596.80 (m), 1490.50 (s), 1441.63 (s), 1273.40 (m), 1182.94 (m), 1057.22 (s), 1026.11 (s), 911.91 (m), 690.49 (s), 580.24 (m), 550.04 (m) cm^{-1}. **HRMS** (DART+) for $C_{21}H_{19}$ $[M+H–H_2O]^+$ calculated: 271.1481, found: 271.1485. **$[\alpha]_D^{20}$:** –14.544 (*c* = 2.09, CHCl3, *l* = 50 mm).

Analysis of Stereochemistry:

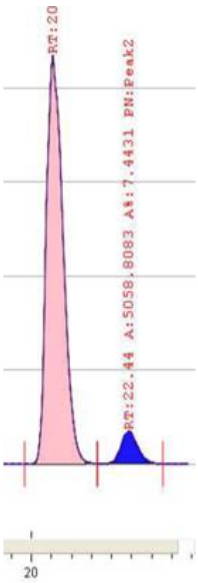
Chiral SFC (Chiracel OD-H, 5% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of (*R*)-5-methyl-1-phenyl-3-(phenylethynyl)hexa-3,4-dien-1-ol **(3.72)**.

Enantiomer mixture

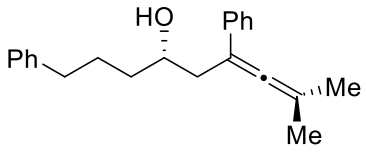


Peak No	% Area	Area	RT (min)
1	45.7521	32300.9941	20.18
2	54.2479	38298.9663	21.79
Total:	100	70599.9604	

Standard conditions



Peak No	% Area	Area	RT (min)
1	92.5569	62907.6657	20.53
2	7.4431	5058.8083	22.44
Total:	100	67966.474	

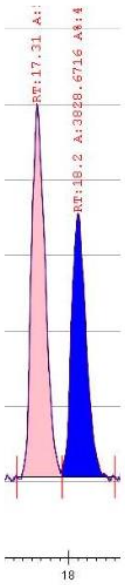


(*S*)-8-methyl-1,6-diphenylnona-6,7-dien-4-ol (3.87). Prepared according to the general procedure above with 4,4,5,5-tetramethyl-2-(3-phenylpropyl)-1,3,2-dioxaborolane (73.9 mg, 0.3 mmol, 1 equiv), methyl (2-methyl-4-phenylbut-3-yn-2-yl) carbonate (131.0 mg, 0.60 mmol, 2 equiv), and 2,2,2-trifluoroethanol (120.1 mg, 1.2 mmol, 4 equiv). The crude product was purified by silica gel column chromatography (0% → 30% EtOAc in hexanes, stained in $KMnO_4$) to afford a clear, colorless oil (59.2 mg, 64% yield). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.38 (d, J = 7.5 Hz, 2H), 7.35 – 7.28 (m, 4H), 7.24 – 7.18 (m, 4H), 3.86 (dddd, J = 8.3, 8.3, 4.3, 4.3 Hz, 1H), 2.68 (app t, J = 7.7 Hz, 2H), 2.64 (dd, J = 15.0, 3.9 Hz, 1H), 2.50 (dd, J = 15.0, 8.5 Hz, 1H), 1.97 (s, 1H), 1.93 – 1.87 (m, 1H), 1.85 (s, 6H), 1.80 – 1.70 (m, 1H), 1.69 – 1.58 (m, 2H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 202.0, 142.5, 137.7, 128.6, 128.5, 128.4, 126.7, 126.2, 125.8, 100.7, 99.1, 70.2, 38.8, 36.6, 36.1, 27.7, 20.7, 20.5. **IR** (neat) ν_{max} 3446.68 (br), 3056.68 (w), 3024.16 (w), 2974.02 (w), 2932.82 (m), 2864.76 (w), 2021.99 (w), 1717.95 (s), 1597.95 (m), 1493.08 (s), 1449.31 (s), 1362.12 (m), 1272.85 (m), 1173.02 (s), 754.85 (s), 698.67 (s) cm^{-1}. **HRMS** (DART+) for $C_{22}H_{25}$ $[M+H-H_2O]^+$ calculated: 289.1951, found: 289.1944. **$[\alpha]_D^{20}$:** +5.816 (*c* = 1.11, CHCl3, *l* = 50 mm).

Analysis of Stereochemistry:

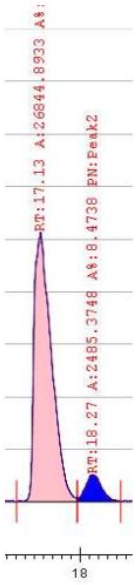
Chiral SFC (Chiracel OJ-H, 5% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of (*S*)-8-methyl-1,6-diphenylnona-6,7-dien-4-ol **(3.87)**.

Enantiomer mixture

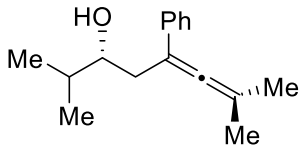


Peak No	% Area	Area	RT (min)
1	57.0975	5095.4566	17.31
2	42.9025	3828.6716	18.2
Total:	100	8924.1282	

Standard conditions



Peak No	% Area	Area	RT (min)
1	91.5262	26844.8933	17.13
2	8.4738	2485.3748	18.27
Total:	100	29330.2681	

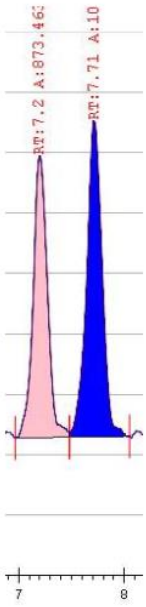


(*R*)-2,7-dimethyl-5-phenylocta-5,6-dien-3-ol (3.88). Prepared according to the general procedure above with 2-isopropyl-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (51.0 mg, 0.3 mmol), methyl (2-methyl-4-phenylbut-3-yn-2-yl) carbonate (131.0 mg, 0.60 mmol, 2 equiv), and 2,2,2-trifluoroethanol (120.1 mg, 1.2 mmol, 4 equiv). The crude product was purified by silica gel column chromatography (0% → 30% EtOAc in hexanes, stained in $KMnO_4$) to afford a clear, colorless oil (30.8 mg, 45% yield). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.37 (d, J = 7.3 Hz, 2H), 7.32 (app t, J = 7.6 Hz, 2H), 7.20 (t, J = 7.3 Hz, 1H), 3.60 (ddd, J = 9.0, 5.0, 3.0 Hz, 1H), 2.70 (dd, J = 15.0, 3.1 Hz, 1H), 2.42 (dd, J = 15.0, 9.3 Hz, 1H), 1.90 (s, 1H), 1.85 (s, 3H), 1.84 (s, 3H), 1.81 (m, 1H), 1.01 (d, J = 6.8 Hz, 6H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 202.1, 137.8, 128.5, 126.7, 126.2, 101.0, 99.1, 74.7, 35.8, 33.3, 20.8, 20.5, 19.1, 17.6. **IR** (neat) ν_{max} 3459.49 (br), 3056.26 (w), 3022.03 (w), 2955.56 (s), 2928.96 (s), 2904.91 (s), 2869.80 (s), 1944.99 (w), 1650.42 (w), 1619.12 (m), 1491.51 (m), 1445.32 (m), 1361.61 (m), 1182.23 (m), 1051.43 (m), 997.64 (m), 908.01 (w), 759.89 (s), 693.01 (s) cm^{-1}. **HRMS** (DART+) for $C_{16}H_{21}$ $[M+H-H_2O]^+$ calculated: 213.1638, found: 213.1641. **$[\alpha]_D^{20}$:** +18.130 (*c* = 1.44, CHCl3, *l* = 50 mm).

Analysis of Stereochemistry:

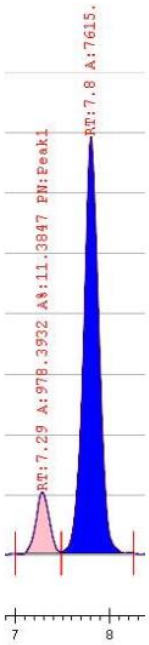
Chiral SFC (Chiracel AD-H, 6% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of (*R*)-2,7-dimethyl-5-phenylocta-5,6-dien-3-ol **(3.88)**.

Enantiomer mixture

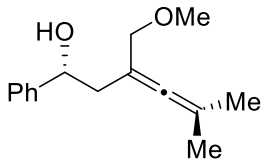


Peak No	% Area	Area	RT (min)
1	45.2149	873.4634	7.2
2	54.7851	1058.341	7.71
Total:	100	1931.8044	

Standard conditions



Peak No	% Area	Area	RT (min)
1	11.3847	978.3932	7.29
2	88.6153	7615.5013	7.8
Total:	100	8593.8945	

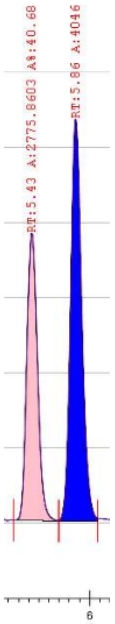


(*R*)-3-(methoxymethyl)-5-methyl-1-phenylhexa-3,4-dien-1-ol (3.75). Prepared according to the general procedure above with 4,4,5,5-tetramethyl-2-phenyl-1,3,2-dioxaborolane (**3.54**, 61.2 mg, 0.30 mmol, 1 equiv), 5-methoxy-2-methylpent-3-yn-2-yl methyl carbonate (**3.118**, 111.7 mg, 0.60 mmol, 2 equiv), and methanol (38.5 mg, 1.2 mmol, 4 equiv). The crude product was purified by silica gel column chromatography (0% → 30% EtOAc in hexanes, stained in $KMnO_4$) to afford a clear, colorless oil (57.4 mg, 82% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.38 (d, J = 7.5 Hz, 2H), 7.32 (app t, J = 7.6 Hz, 2H), 7.24 (t, J = 7.2 Hz, 1H), 4.80 (dd, J = 8.3, 4.2 Hz, 1H), 3.87 (s, 2H), 3.39 (s, 1H), 3.31 (s, 3H), 2.51 (dd, J = 14.7, 4.2 Hz, 1H), 2.42 (dd, J = 14.7, 8.2 Hz, 1H), 1.67 (s, 3H), 1.60 (s, 3H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 202.1, 144.2, 128.3, 127.2, 126.0, 96.1, 95.3, 75.0, 73.3, 57.6, 41.4, 20.63, 20.61. **IR** (neat) ν_{max} 3410.38 (br), 3058.75 (w), 3026.95 (w), 2976.18 (m), 2904.52 (m), 2852.26 (m), 2815.93 (m), 1492.14 (w), 1448.67 (m), 1401.99 (w), 1360.64 (w), 1186.57 (m), 1145.15 (w), 1081.72 (s), 1067.50 (s), 943.26 (w), 905.95 (w), 756.09 (m), 699.05 (s), 582.43 (w), 547.41 (w) cm^{-1}. **HRMS** (DART+) for $C_{14}H_{17}O$ $[M+H–H_2O]^+$ calculated: 201.1274, found: 201.1268. **$[\alpha]_D^{20}$:** +0.334 (*c* = 2.65, CHCl3, *l* = 50 mm).

Analysis of Stereochemistry:

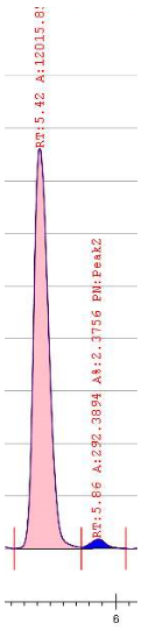
Chiral SFC (Chiracel OD-H, 6% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of (*R*)-3-(methoxymethyl)-5-methyl-1-phenylhexa-3,4-dien-1-ol **(3.75)**.

Enantiomer mixture

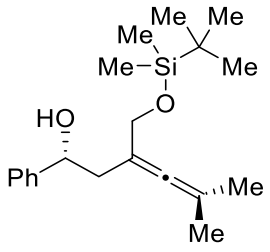


Peak No	% Area	Area	RT (min)
1	40.6883	2775.8603	5.43
2	59.3117	4046.3898	5.86
Total:	100	6822.2501	

Standard conditions



Peak No	% Area	Area	RT (min)
1	97.6244	12015.8529	5.42
2	2.3756	292.3894	5.86
Total:	100	12308.2423	

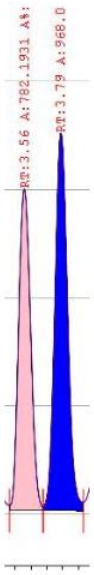


(*R*)-3-{[(*tert*-butyldimethylsilyl)oxy]methyl}-5-methyl-1-phenylhexa-3,4-dien-1-ol (3.76). Prepared according to the general procedure above with 4,4,5,5-tetramethyl-2-phenyl-1,3,2-dioxaborolane (**3.54**, 61.2 mg, 0.30 mmol, 1 equiv), 5-[(*tert*-butyldimethylsilyl)oxy]-2-methylpent-3-yn-2-yl methyl carbonate (**3.119**, 171.9 mg, 0.60 mmol, 2 equiv), and methanol (38.5 mg, 1.2 mmol, 4 equiv). The crude product was purified by silica gel column chromatography (0% → 30% EtOAc in hexanes, stained in $KMnO_4$) to afford a clear, colorless oil (91.8 mg, 92% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.40 (d, J = 7.1 Hz, 2H), 7.33 (app t, J = 7.6 Hz, 2H), 7.24 (t, J = 7.3 Hz, 1H), 4.82 (d, J = 8.6 Hz, 1H), 4.13 (s, 2H), 3.64 (s, 1H), 2.54 (dd, J = 14.6, 3.7 Hz, 1H), 2.39 (dd, J = 14.6, 8.7 Hz, 1H), 1.68 (s, 3H), 1.62 (s, 3H), 0.94 (s, 9H), 0.12 (s, 6H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 200.7, 144.5, 128.3, 127.2, 126.0, 98.5, 96.5, 73.4, 65.9, 41.5, 26.0, 20.7, 20.6, 18.5, -5.2. **IR** (neat) ν_{max} 3417.36 (br), 3059.53 (w), 3027.38 (w), 2950.33 (m), 2926.42 (m), 2902.99 (m), 2853.60 (m), 1754.39 (w), 1460.86 (m), 1360.35 (m), 1253.17 (s), 1140.77 (w), 1055.66 (s), 835.62 (s), 776.21 (s), 698.59 (s) cm^{-1}. **HRMS** (DART+) for $C_{20}H_{31}OSi$ $[M+H-H_2O]^+$ calculated: 315.2139, found: 315.2135. **$[\alpha]_D^{20}$:** +5.007 (*c* = 0.85, CHCl3, *l* = 50 mm).

Analysis of Stereochemistry:

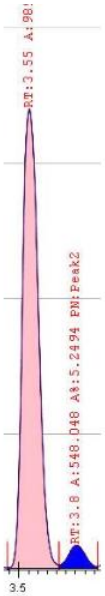
Chiral SFC (Chiracel OD-H, 8% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of (*R*)-3-{[(*tert*-butyldimethylsilyl)oxy]methyl}-5-methyl-1-phenylhexa-3,4-dien-1-ol **(3.76)**.

Enantiomer mixture

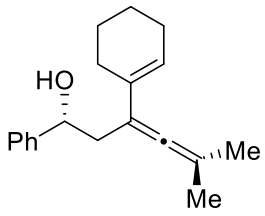


Peak No	% Area	Area	RT (min)
1	44.6897	782.1931	3.56
2	55.3103	968.084	3.79
Total:	100	1750.2771	

Standard conditions



Peak No	% Area	Area	RT (min)
1	94.7506	9892.0854	3.55
2	5.2494	548.048	3.8
Total:	100	10440.1334	

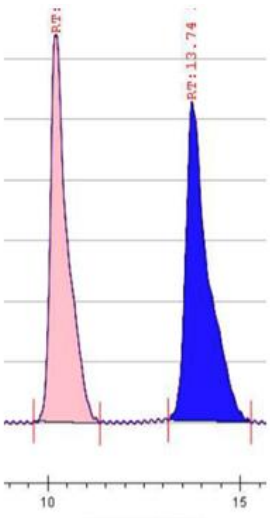


(*R*)-3-(cyclohex-1-en-1-yl)-5-methyl-1-phenylhexa-3,4-dien-1-ol (3.71). Prepared according to the general procedure above with 4,4,5,5-tetramethyl-2-phenyl-1,3,2-dioxaborolane (**3.54**, 61.2 mg, 0.30 mmol, 1 equiv), 4-(cyclohex-1-en-1-yl)-2-methylbut-3-yn-2-yl methyl carbonate (**3.120**, 133.4 mg, 0.60 mmol, 2 equiv), and methanol (38.5 mg, 1.2 mmol, 4 equiv). The crude product was purified by silica gel column chromatography (0% → 30% EtOAc in hexanes, stained in $KMnO_4$) to afford a white solid (73.7 mg, 92% yield). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.39 (d, J = 7.1 Hz, 2H), 7.34 (app t, J = 7.5 Hz, 2H), 7.28 – 7.24 (m, 1H), 5.74 (app t, J = 4.1 Hz, 1H), 4.84 (ddd, J = 8.6, 2.9, 2.5 Hz, 1H), 2.62 (dd, J = 15.1, 4.1 Hz, 1H), 2.54 (dd, J = 15.1, 8.9 Hz, 1H), 2.30 (d, J = 2.6 Hz, 1H), 2.15 – 2.10 (m, 2H), 2.06 – 2.01 (m, 2H), 1.70 (s, 3H), 1.67 (s, 3H), 1.66 – 1.62 (m, 2H), 1.61 – 1.55 (m, 2H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 201.7, 144.3, 133.7, 128.4, 127.4, 126.1, 122.5, 102.5, 98.8, 72.8, 39.9, 27.4, 26.1, 23.1, 22.6, 21.0, 20.7. **IR** (neat) ν_{max} 3353.31 (br), 3030.25 (w), 2977.52 (w), 2924.55 (s), 2855.97 (m), 2832.86 (m), 1948.31 (w), 1446.46 (m), 1360.45 (w), 1184.23 (w), 1060.09 (m), 1016.94 (m), 914.70 (w), 754.04 (m), 698.65 (s), 599.10 (w) cm^{-1}. **HRMS** (DART+) for $C_{19}H_{23}$ $[M+H-H_2O]^+$ calculated: 251.1794, found: 251.1793. **$[\alpha]_D^{20}$:** +49.833 (*c* = 3.69, CHCl3, *l* = 50 mm).

Analysis of Stereochemistry:

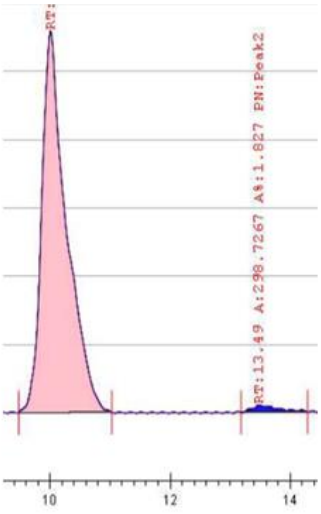
Chiral SFC (Chiracel AD-H, 7% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of (*R*)-3-(cyclohex-1-en-1-yl)-5-methyl-1-phenylhexa-3,4-dien-1-ol **(3.71)**.

Enantiomer mixture

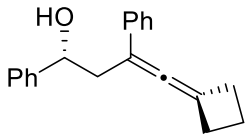


Peak No	% Area	Area	RT (min)
1	47.9539	9903.8983	10.21
2	52.0461	10749.0413	13.74
Total:	100	20652.9396	

Standard conditions



Peak No	% Area	Area	RT (min)
1	98.173	16051.7429	10.01
2	1.827	298.7267	13.49
Total:	100	16350.4696	

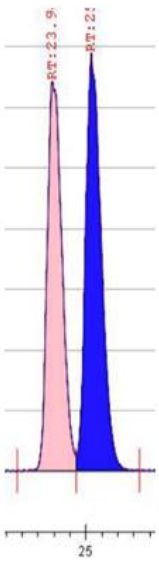


(*R*)-4-cyclobutylidene-1,3-diphenylbut-3-en-1-ol (3.77). Prepared according to the general procedure above with 4,4,5,5-tetramethyl-2-phenyl-1,3,2-dioxaborolane (**3.54**, 61.2 mg, 0.30 mmol, 1 equiv), methyl [1-(phenylethynyl) cyclobutyl] carbonate (**3.121**, 138.2 mg, 0.60 mmol, 2 equiv), and methanol (38.5 mg, 1.2 mmol, 4 equiv). The crude product was purified by silica gel column chromatography (0% → 30% EtOAc in hexanes, stained in $KMnO_4$) to afford a white solid (60.0 mg, 72% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.46 – 7.41 (m, 4H), 7.37 (app t, J = 7.5 Hz, 2H), 7.33 (app t, J = 7.6 Hz, 2H), 7.29 (t, J = 7.3 Hz, 1H), 7.22 (t, J = 7.3 Hz, 1H), 4.95 (ddd, J = 7.8, 3.4, 3.4 Hz, 1H), 3.06 – 2.95 (m, 2H), 2.95 – 2.82 (m, 4H), 2.38 (d, J = 2.6 Hz, 1H), 2.09 – 1.96 (m, 2H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 195.7, 144.0, 137.4, 128.6, 128.5, 127.6, 127.0, 126.3, 126.1, 105.2, 104.9, 72.7, 40.9, 30.2, 30.0, 17.6. **IR** (neat) ν_{max} 3358.98 (br), 3060.04 (w), 3029.09 (w), 2952.12 (w), 2921.01 (m), 1946.97 (w), 1596.21 (w), 1493.50 (m), 1451.94 (m), 1415.79 (w), 1021.56 (m), 909.79 (m), 761.50 (s), 693.23 (s), 594.58 (m) cm^{-1}. **HRMS** (DART+) for $C_{20}H_{19}$ $[M+H-H_2O]^+$ calculated: 259.1481, found: 259.1475. **$[\alpha]_D^{20}$:** –37.540 (*c* = 1.85, CHCl3, *l* = 50 mm).

Analysis of Stereochemistry:

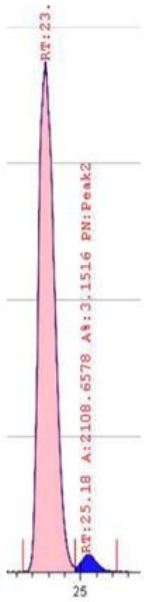
Chiral SFC (Chiracel OD-H, 5% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of (*R*)-4-cyclobutylidene-1,3-diphenylbut-3-en-1-ol **(3.77)**.

Enantiomer mixture

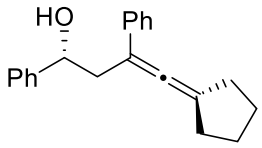


Peak No	% Area	Area	RT (min)
1	46.8363	41374.9214	23.94
2	53.1637	46964.5851	25.16
Total:	100	88339.5065	

Standard conditions



Peak No	% Area	Area	RT (min)
1	96.8484	64799.836	23.9
2	3.1516	2108.6578	25.18
Total:	100	66908.4938	

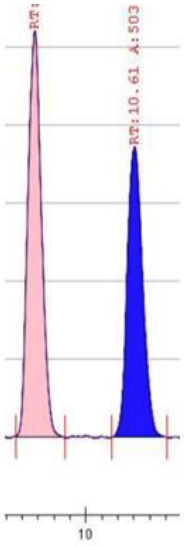


(*R*)-4-cyclopentylidene-1,3-diphenylbut-3-en-1-ol (3.78). Prepared according to the general procedure above with 4,4,5,5-tetramethyl-2-phenyl-1,3,2-dioxaborolane (**3.54**, 61.2 mg, 0.30 mmol, 1 equiv), methyl (1-(phenylethynyl)cyclopentyl) carbonate (146.6 mg, 0.60 mmol, 2 equiv), and methanol (38.5 mg, 1.2 mmol, 4 equiv). The crude product was purified by silica gel column chromatography (0% → 30% EtOAc in hexanes, stained in $KMnO_4$) to afford a white solid (60.3 mg, 69% yield). **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.42 (d, J = 7.1 Hz, 2H), 7.40 – 7.34 (m, 4H), 7.32 (app t, J = 7.7 Hz, 2H), 7.29 (t, J = 7.3 Hz, 1H), 7.20 (t, J = 7.3 Hz, 1H), 4.92 (ddd, J = 7.9, 4.5, 2.7 Hz, 1H), 2.92 (dd, J = 15.2, 4.6 Hz, 1H), 2.85 (dd, J = 15.2, 8.4 Hz, 1H), 2.53 – 2.41 (m, 2H), 2.40 – 2.28 (m, 3H), 1.81 – 1.69 (m, 4H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 197.9, 144.0, 137.7, 128.6, 128.52, 128.49, 127.6, 126.7, 126.2, 108.3, 102.9, 72.8, 40.7, 31.4, 31.1, 27.31, 27.27. **IR** (neat) ν_{max} 3380.51 (br), 3029.03 (w), 2952.51 (m), 2866.65 (w), 1946.38 (w), 1597.36 (w), 1492.49 (m), 1450.98 (m), 1390.39 (w), 1309.55 (w), 1197.36 (w), 1022.01 (m), 944.97 (w), 909.70 (w), 755.81 (s), 693.27 (s) cm^{-1}. **HRMS** (DART+) for $C_{21}H_{21}$ $[M+H-H_2O]^+$ calculated: 273.1638, found: 273.1637. **$[\alpha]_D^{20}$:** +37.470 (*c* = 1.51, CHCl3, *l* = 50 mm).

Analysis of Stereochemistry:

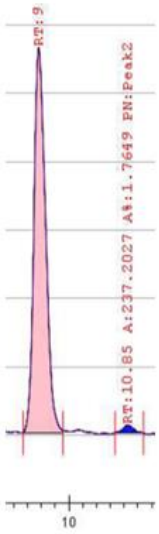
Chiral SFC (Chiracel OJ-H, 8% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of (*R*)-4-cyclopentylidene-1,3-diphenylbut-3-en-1-ol **(3.78)**.

Enantiomer mixture

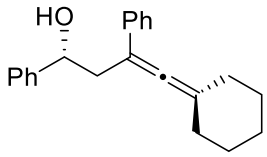


Peak No	% Area	Area	RT (min)
1	54.9069	6125.3499	9.36
2	45.0931	5030.5387	10.61
Total:	100	11155.8886	

Standard conditions



Peak No	% Area	Area	RT (min)
1	98.2351	13202.5213	9.56
2	1.7649	237.2027	10.85
Total:	100	13439.724	

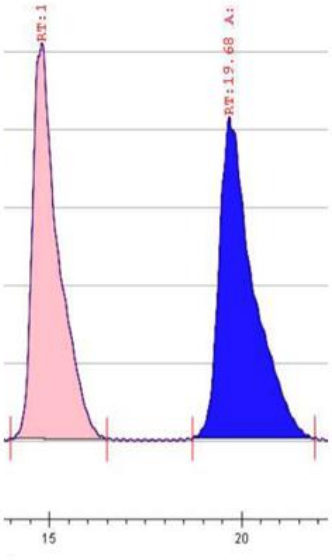


(*R*)-4-cyclohexylidene-1,3-diphenylbut-3-en-1-ol (3.79). Prepared according to the general procedure above with 4,4,5,5-tetramethyl-2-phenyl-1,3,2-dioxaborolane (**3.54**, 61.2 mg, 0.30 mmol, 1 equiv), methyl (1-(phenylethynyl)cyclohexyl) carbonate (155.0 mg, 0.60 mmol, 2 equiv), and methanol (38.5 mg, 1.2 mmol, 4 equiv). The crude product was purified by silica gel column chromatography (0% → 30% EtOAc in hexanes, stained in $KMnO_4$) to afford a white solid (78.3 mg, 86% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.41 (app t, J = 7.2 Hz, 4H), 7.39 – 7.25 (m, 5H), 7.20 (t, J = 7.3 Hz, 1H), 4.93 (app t, J = 6.6 Hz, 1H), 2.95 – 2.79 (m, 2H), 2.36 (d, J = 2.6 Hz, 1H), 2.28 – 2.14 (m, 3H), 2.14 – 2.06 (m, 1H), 1.74 – 1.48 (m, 6H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 198.6, 144.0, 137.7, 128.6, 128.5, 127.6, 126.6, 126.2, 126.1, 107.0, 100.3, 72.8, 40.9, 31.7, 31.5, 27.8, 26.2. **IR** (neat) ν_{max} 3363.21 (br), 3029.35 (w), 2924.69 (s), 2851.29 (m), 1949.82 (w), 1596.36 (w), 1492.15 (m), 1446.21 (m), 1341.51 (w), 1262.38 (w), 1200.70 (w), 1021.95 (m), 908.97 (w), 759.96 (s), 694.14 (s), 584.18 (w) cm^{-1}. **HRMS** (DART+) for $C_{22}H_{23}$ $[M+H–H_2O]^+$ calculated: 287.1794, found: 287.1791. **$[\alpha]_D^{20}$:** +29.864 (*c* = 3.9, CHCl3, *l* = 50 mm).

Analysis of Stereochemistry:

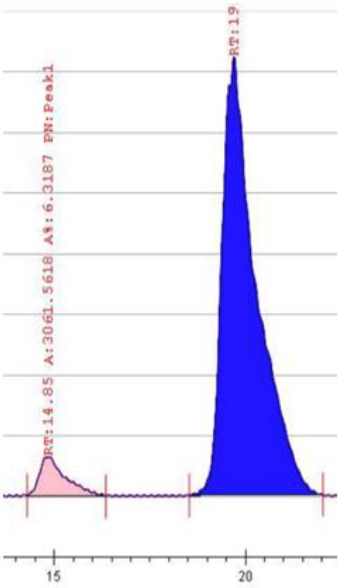
Chiral SFC (Chiracel AD-H, 10% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of (*R*)-4-cyclohexylidene-1,3-diphenylbut-3-en-1-ol **(3.79)**.

Enantiomer mixture

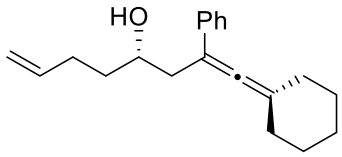


Peak No	% Area	Area	RT (min)
1	48.1874	23743.1266	14.8
2	51.8126	25529.3467	19.68
Total:	100	49272.4733	

Standard conditions



Peak No	% Area	Area	RT (min)
1	6.3187	3061.5618	14.85
2	93.6813	45391.1492	19.71
Total:	100	48452.711	

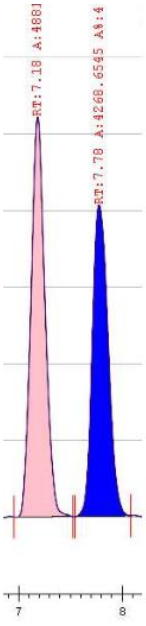


(*S*)-1-cyclohexylidene-2-phenylocta-1,7-dien-4-ol (3.89). Prepared according to the general procedure above with 2-but-3-enyl-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (54.6 mg, 0.3 mmol), methyl (1-(phenylethynyl)cyclohexyl) carbonate (155.0 mg, 0.60 mmol, 2 equiv), and 2,2,2-trifluoroethanol (120.1 mg, 1.2 mmol, 4 equiv). The crude product was purified by silica gel column chromatography (0% → 30% EtOAc in hexanes, stained in $KMnO_4$) to afford a clear, colorless oil (32.6 mg, 38% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.39 (d, J = 7.2 Hz, 2H), 7.31 (app t, J = 7.8 Hz, 2H), 7.19 (t, J = 7.3 Hz, 1H), 5.87 (dddd, J = 16.9, 10.1, 6.6, 6.6, 1H), 5.06 (dddd, J = 17.1, 1.7, 1.7, 1.7 Hz, 1H), 4.98 (dddd, J = 10.2, 2.2, 1.3, 1.3 Hz, 1H), 3.93 – 3.82 (m, 1H), 2.64 (dd, J = 15.1, 4.0 Hz, 1H), 2.51 (dd, J = 15.1, 8.3 Hz, 1H), 2.34 – 2.12 (m, 6H), 1.99 (s, 1H), 1.73 – 1.64 (m, 6H), 1.60 (m, 2H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 198.3, 138.8, 137.9, 128.5, 126.6, 126.1, 114.8, 106.7, 100.4, 69.9, 38.8, 36.1, 31.8, 31.6, 30.3, 27.87, 27.86, 26.2. **IR** (neat) ν_{max} 3384.87 (br), 2924.43 (s), 2849.95 (m), 1639.02 (w), 1595.76 (w), 1503.86 (w), 1444.76 (m), 1054.09 (w), 906.84 (m), 758.26 (s), 692.73 (s) cm^{-1}. **HRMS** (DART+) for $C_{20}H_{25}$ $[M+H–H_2O]^+$ calculated: 265.1951, found: 265.1956. **$[\alpha]_D^{20}$:** +7.193 (*c* = 0.83, CHCl3, *l* = 50 mm).

Analysis of Stereochemistry:

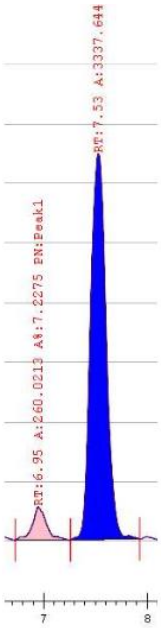
Chiral SFC (Chiracel OJ-H, 3% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of (*S*)-1-cyclohexylidene-2-phenylocta-1,7-dien-4-ol **(3.89)**.

Enantiomer mixture

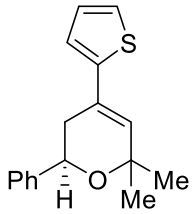


Peak No	% Area	Area	RT (min)
1	53.351	4881.9225	7.18
2	46.649	4268.6545	7.78
Total:	100	9150.577	

Standard conditions



Peak No	% Area	Area	RT (min)
1	7.2275	260.0213	6.95
2	92.7725	3337.644	7.53
Total:	100	3597.6653	

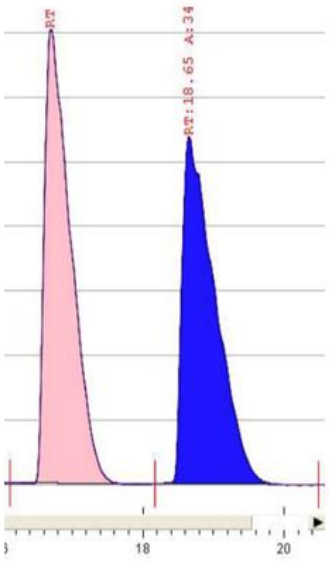


(*R*)-6,6-dimethyl-2-phenyl-4-(thiophen-2-yl)-3,6-dihydro-2*H*-pyran (3.92). Prepared according to the general procedure above with 4,4,5,5-tetramethyl-2-phenyl-1,3,2-dioxaborolane (**3.54**, 61.2 mg, 0.30 mmol, 1 equiv), methyl (2-methyl-4-(thiophen-2-yl)but-3-yn-2-yl) carbonate (**3.90**, 134.6 mg, 0.60 mmol, 2 equiv), and methanol (38.5 mg, 1.2 mmol, 4 equiv). The crude product was purified by silica gel column chromatography (0% → 30% EtOAc in hexanes, stained in $KMnO_4$) to afford a clear, yellow oil (57.6 mg, 71% yield), which spontaneously cyclized to the 3,6-dihydro-2*H*-pyran. **^{1}H NMR** (600 MHz, $CDCl_3$) δ 7.47 (d, J = 7.4 Hz, 2H), 7.39 (app t, J = 7.6 Hz, 2H), 7.31 (t, J = 7.4 Hz, 1H), 7.17 (dd, J = 4.5, 1.7 Hz, 1H), 7.00 – 6.96 (m, 2H), 6.11 (d, J = 2.1 Hz, 1H), 4.84 (dd, J = 10.2, 3.6 Hz, 1H), 2.67 – 2.52 (m, 2H), 1.44 (s, 3H), 1.43 (s, 3H). **^{13}C NMR** (151 MHz, $CDCl_3$) δ 145.0, 142.8, 129.9, 128.6, 127.7, 127.6, 127.5, 126.4, 123.7, 122.3, 74.0, 71.1, 35.3, 29.9, 26.1. **IR** (neat) ν_{max} 3029.31 (w), 2972.43 (s), 2926.86 (m), 2029.07 (w), 1643.09 (w), 1604.31 (w), 1494.83 (m), 1452.51 (m), 1379.22 (m), 1359.59 (m), 1239.14 (s), 1177.62 (m), 1150.63 (s), 1068.24 (s), 1025.19 (m), 975.53 (m), 913.94 (w), 849.61 (m), 820.38 (m), 750.85 (s), 558.14 (m) cm^{-1}. **HRMS** (DART+) for $C_{17}H_{19}OS$ $[M+H]^+$ calculated: 271.1151, found: 271.1141. **$[\alpha]_D^{20}$:** +37.694 (*c* = 2.81, CHCl3, *l* = 50 mm).

Analysis of Stereochemistry:

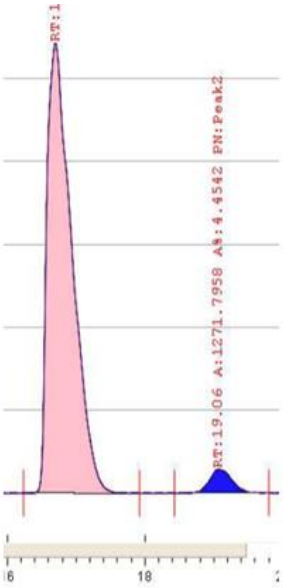
Chiral SFC (Chiracel OJ-H, 5% IPA, 3 mL/min, 100 bar, 35 °C, 210-270 nm) analysis of (*R*)-6,6-dimethyl-2-phenyl-4-(thiophen-2-yl)-3,6-dihydro-2H-pyran **(3.92)**.

Enantiomer mixture



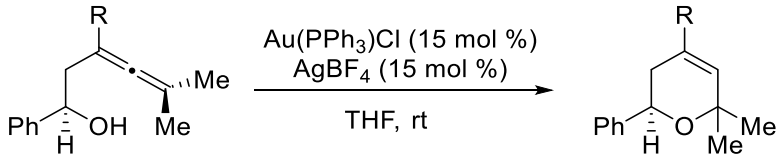
Peak No	% Area	Area	RT (min)
1	50.8503	36056.7765	16.7
2	49.1497	34850.9108	18.65
Total:	100	70907.6873	

Standard conditions

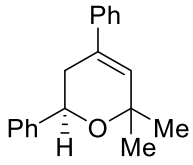


Peak No	% Area	Area	RT (min)
1	95.5458	27281.2136	16.7
2	4.4542	1271.7958	19.06
Total:	100	28553.0094	

3.4.7. General Procedure for the Gold-Catalyzed Cyclization of β-Hydroxy Allenes to 3,6-Dihydro-2H-pyran Derivatives

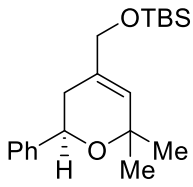


Following a modified literature procedure:[75] A vial equipped with a magnetic stir bar was charged with triphenylphosphinegold(I) chloride (0.15 equiv), silver tetrafluoroborate (0.15 equiv), and THF (0.015 *M*) and stirred for five minutes. A solution of β-hydroxy allene (1 equiv) in THF (0.1 *M*) was added, and the resulting solution was stirred at room temperature. Upon completion as checked by TLC, the reaction solution was filtered through a silica gel plug with Et_2O washing, concentrated under reduced pressure, and purified by silica gel column chromatography to afford pure product.



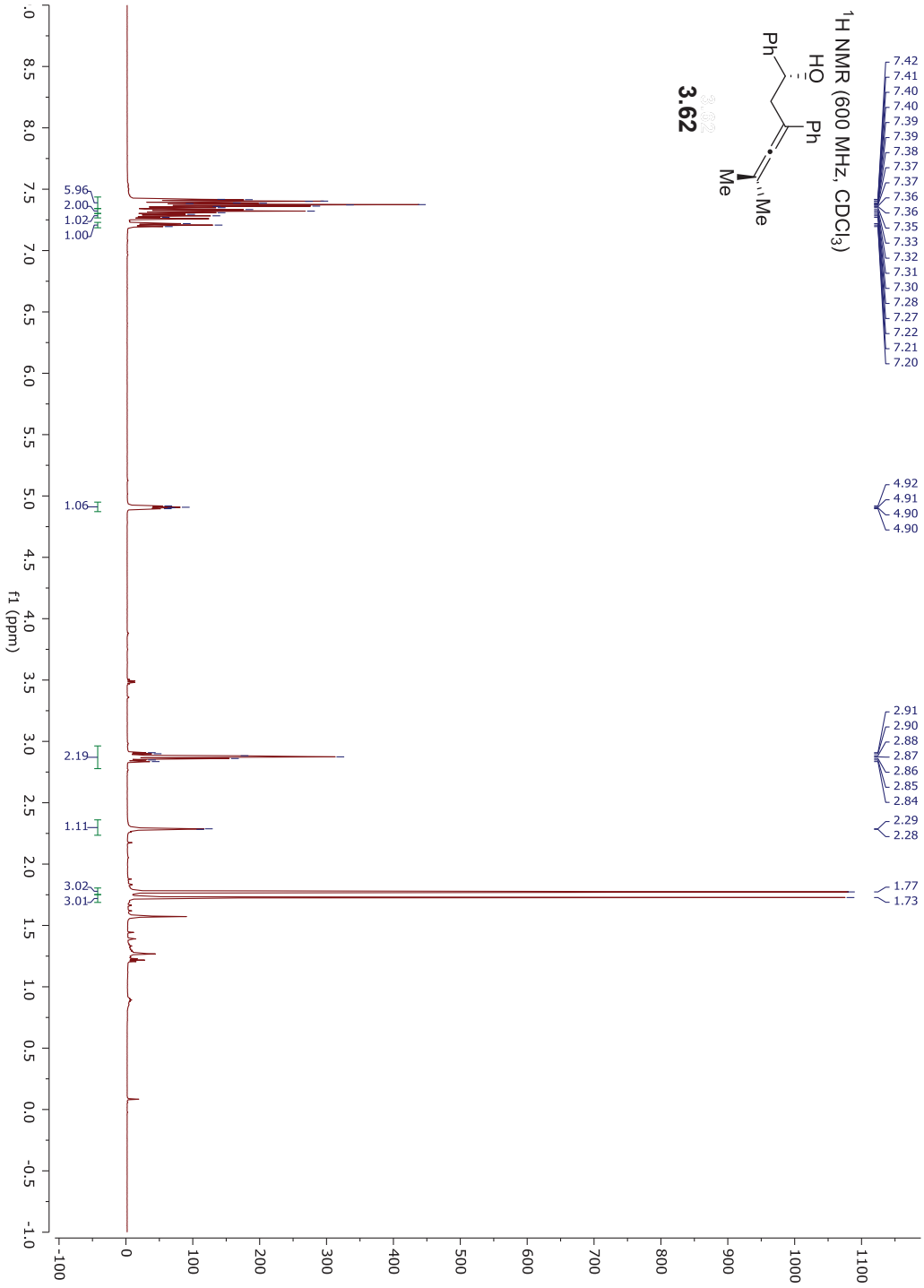
(*R*)-6,6-dimethyl-2,4-diphenyl-3,6-dihydro-2*H*-pyran (3.93). Prepared according to the general procedure above with (*R*)-5-methyl-1,3-diphenylhexa-3,4-dien-1-ol (**3.62**, 63.8 mg, 0.24 mmol, 1 equiv) in THF (2.4 mL), and triphenylphosphinegold(I) chloride (17.9 mg, 0.036 mmol, 0.15 equiv) and silver tetrafluoroborate (7.0 mg, 0.036 mmol, 0.15 equiv) in THF (2.4 mL). The crude product was purified by silica gel column chromatography (15% EtOAc in hexanes, stained in $KMnO_4$) to afford a white solid (51.7 mg, 81% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.50 (d, J = 7.1 Hz, 2H), 7.43 (dd, J = 8.4, 1.3 Hz, 2H), 7.40 (app t, J = 7.6 Hz, 2H), 7.35 (app t, J = 7.6 Hz, 2H), 7.32 (t, J = 7.4 Hz, 1H), 7.28 (t, J = 7.3 Hz, 1H), 6.13 (dd, J = 2.2, 1.0 Hz, 1H), 4.85 (dd, J = 9.4, 4.3 Hz, 1H), 2.69 – 2.55 (m, 2H), 1.47 (s, 3H), 1.46 (s, 3H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 143.1, 140.4, 132.8, 131.2, 128.59, 128.56, 127.6, 127.4,

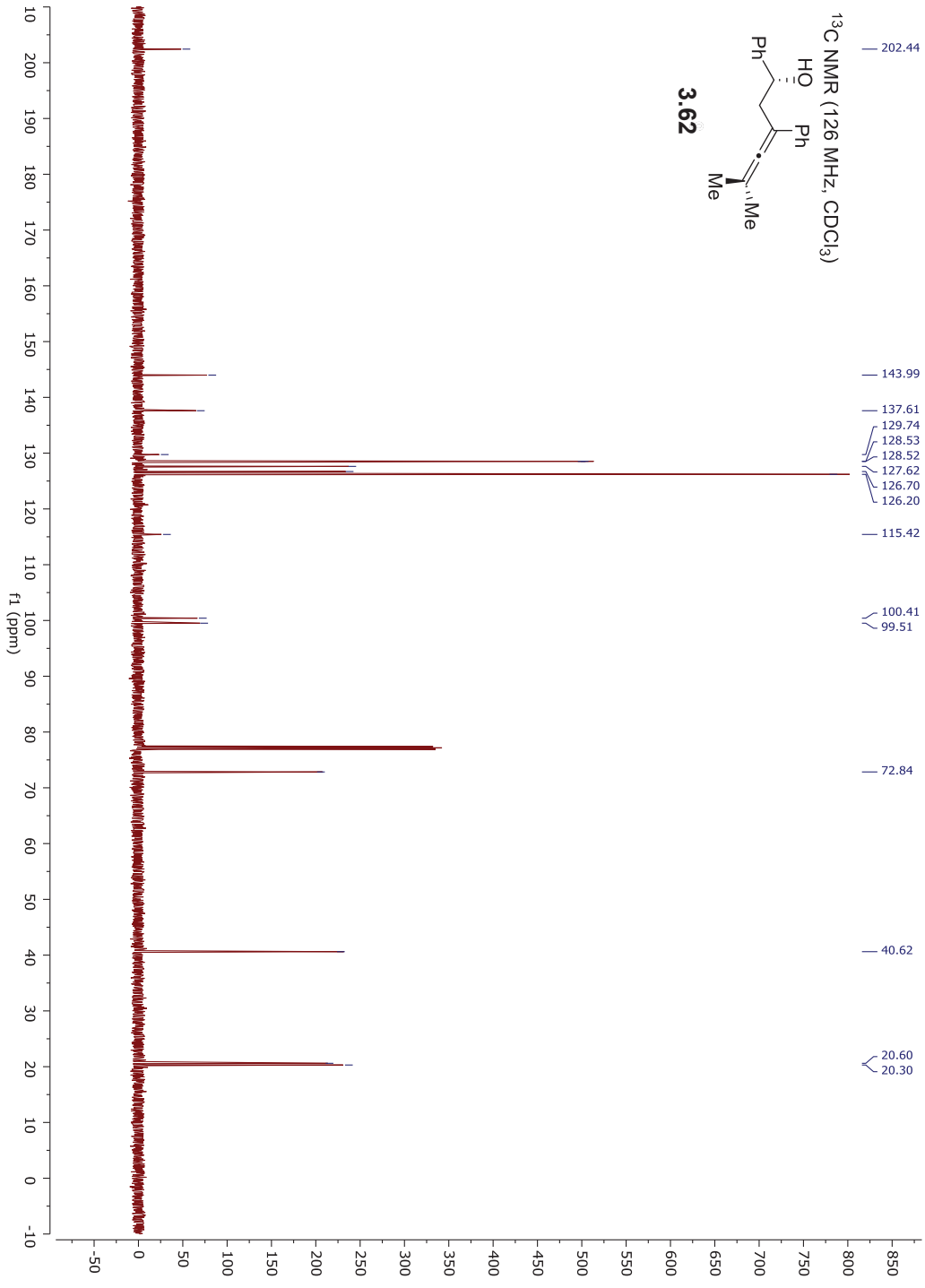
126.4, 125.1, 74.1, 71.4, 35.1, 30.0, 26.2. **IR** (neat) ν_{max} 3082.92 (w), 3056.58 (w), 3025.26 (w), 2969.36 (m), 2923.97 (w), 2893.73 (w), 2861.82 (w), 1598.69 (w), 1493.71 (m), 1445.25 (m), 1375.83 (m), 1357.91 (m), 1237.60 (m), 1180.36 (m), 1160.13 (m), 1090.77 (m), 1067.26 (m), 1027.11 (m), 966.69 (w), 934.61 (w), 878.46 (w), 858.92 (w), 750.27 (s), 694.99 (s), 562.23 (w), 546.48 (w) cm^{-1}. **HRMS** (DART+) for $C_{19}H_{19}$ $[M+H-H_2O]^+$ calculated: 247.1481, found: 247.1478. **$[\alpha]_D^{20}$:** +76.464 (*c* = 2.59, $CHCl_3$, *l* = 50 mm).

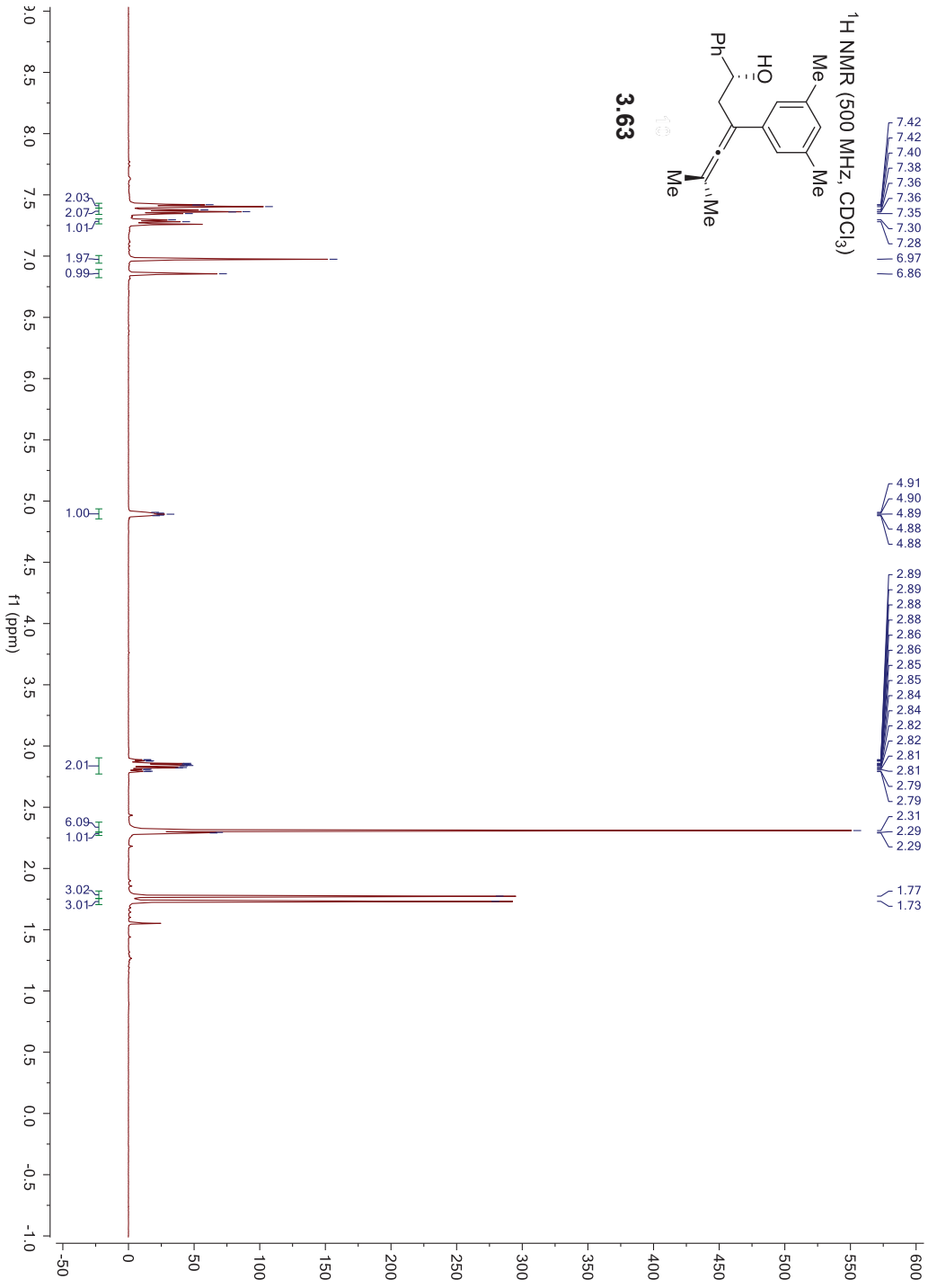


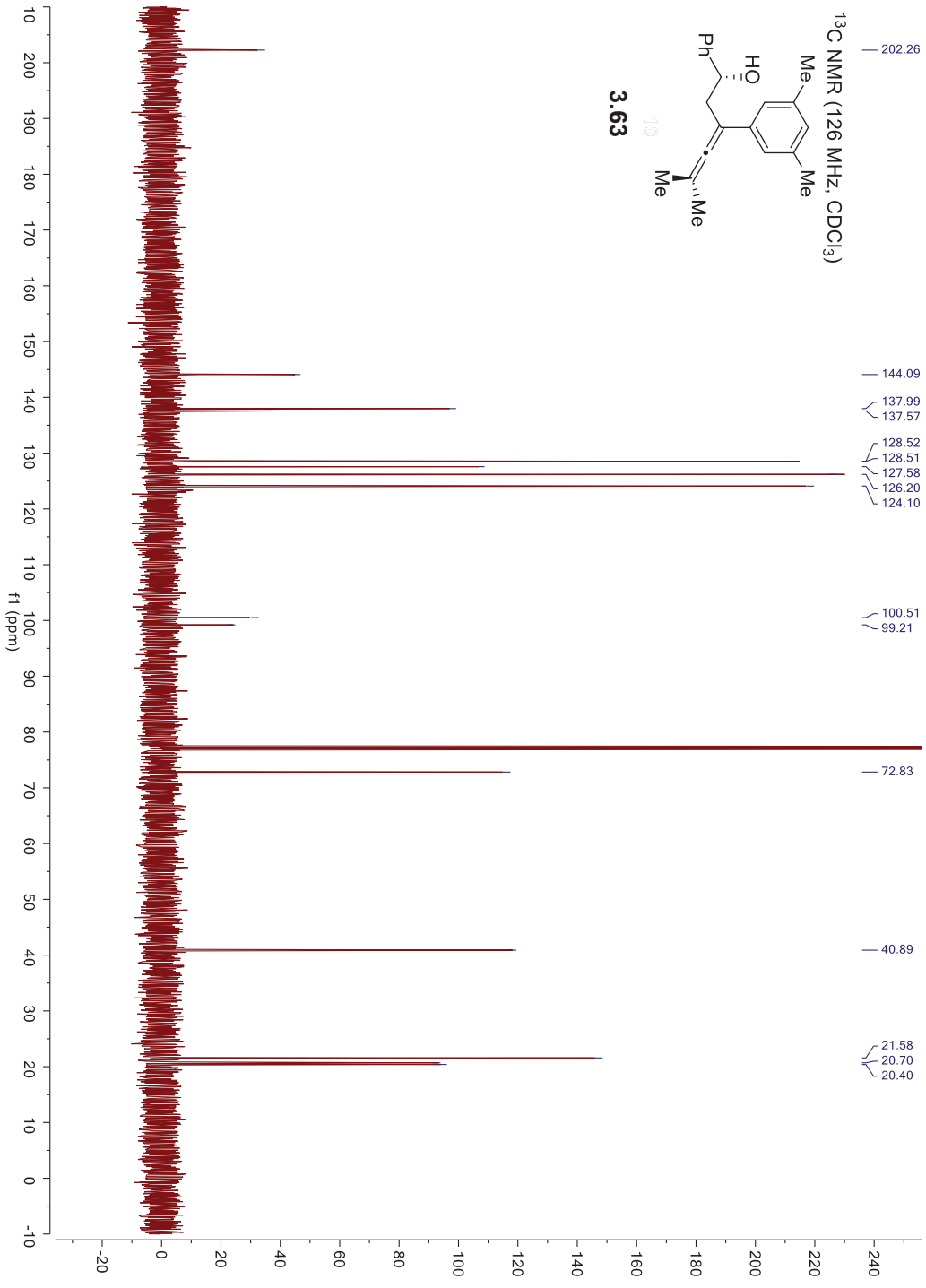
(*R*)-*tert*-butyl[(6,6-dimethyl-2-phenyl-3,6-dihydro-2*H*-pyran-4-yl)methoxy] dimethylsilane (3.94). Prepared according to the general procedure above with (*R*)-3-{[(*tert*-butyldimethylsilyl)oxy]methyl}-5-methyl-1-phenylhexa-3,4-dien-1-ol (**3.76**, 133.0 mg, 0.40 mmol, 1 equiv) in THF (4 mL), and triphenylphosphinegold(I) chloride (29.7 mg, 0.060 mmol, 0.15 equiv) and silver tetrafluoroborate (11.7 mg, 0.060 mmol, 0.15 equiv) in THF (4 mL). The crude product was purified by silica gel column chromatography (15% EtOAc in hexanes, stained in $KMnO_4$) to afford a clear, colorless oil (100.0 mg, 75% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.42 (d, J = 7.0 Hz, 2H), 7.35 (app t, J = 7.6 Hz, 2H), 7.27 (t, J = 7.3 Hz, 1H), 5.64 (m, 1H), 4.70 (dd, J = 9.2, 4.7 Hz, 1H), 4.08 (s, 2H), 2.21 – 2.06 (m, 2H), 1.35 (s, 3H), 1.34 (s, 3H), 0.92 (s, 9H), 0.09 (s, 6H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 143.2, 133.7, 128.6, 128.5, 127.5, 126.3, 73.6, 71.0, 66.3, 33.1, 29.8, 26.12, 26.10, 18.6, -5.0, -5.1. **IR** (neat) ν_{max} 3060.87 (w), 3027.00 (w), 2952.96 (m), 2925.73 (m), 2891.60 (w), 2853.66 (m), 1756.84 (w), 1603.41 (w), 1493.67 (w), 1469.99 (m), 1461.30 (m), 1373.49 (m), 1359.29 (m), 1251.17 (s), 1199.07 (m), 1176.98 (m), 1127.77 (s), 1065.48 (s), 1004.98 (m), 835.07 (s),

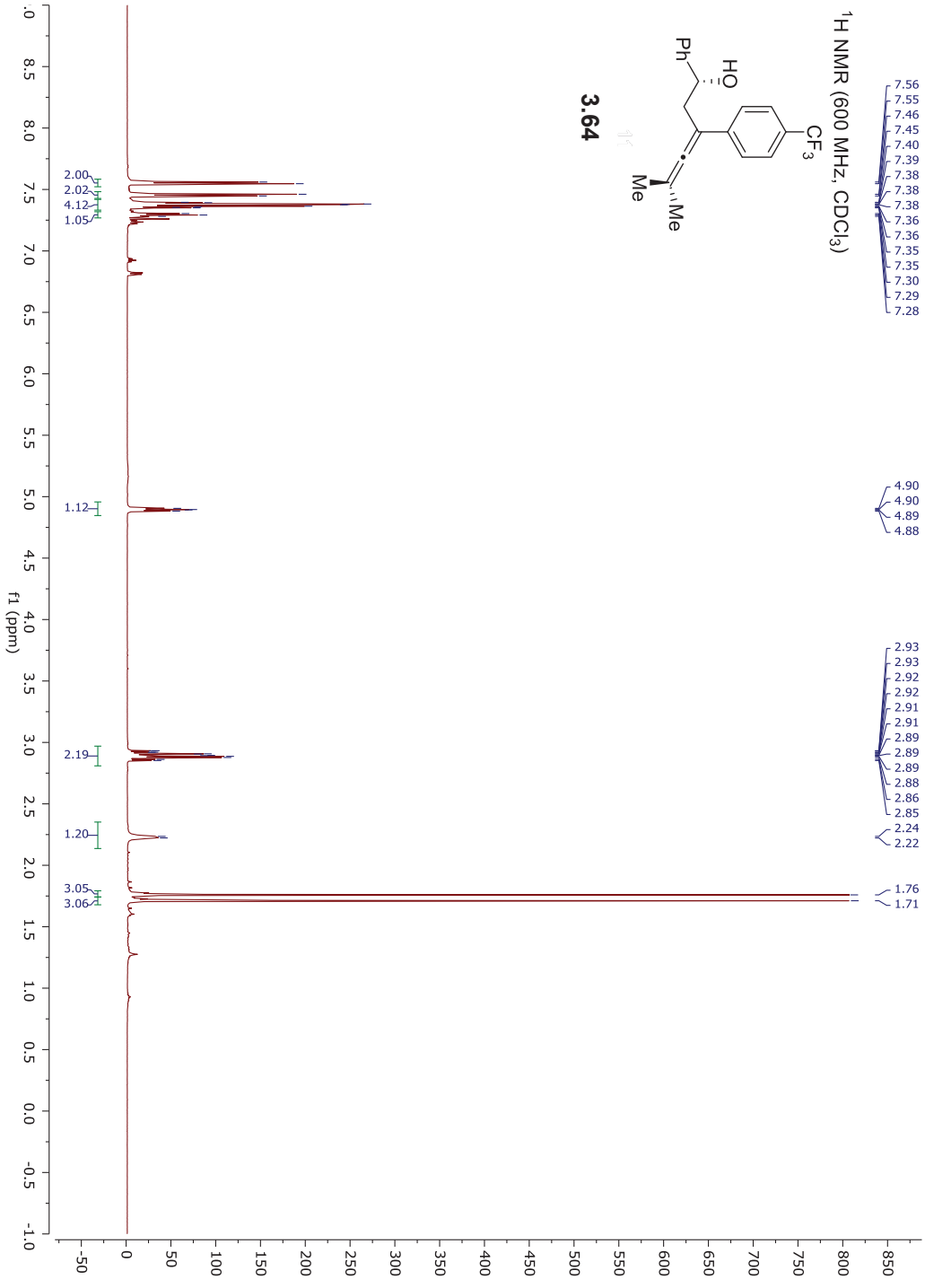
775.37 (s), 750.44 (m), 697.12 (m) cm^{-1}. **HRMS** (DART+) for $C_{20}H_{31}OSi$ $[M+H-H_2O]^+$ calculated: 315.2139, found: 315.2138. **$[\alpha]_D^{20}$:** +67.255 (*c* = 2.02, CHCl3, *l* = 50 mm).

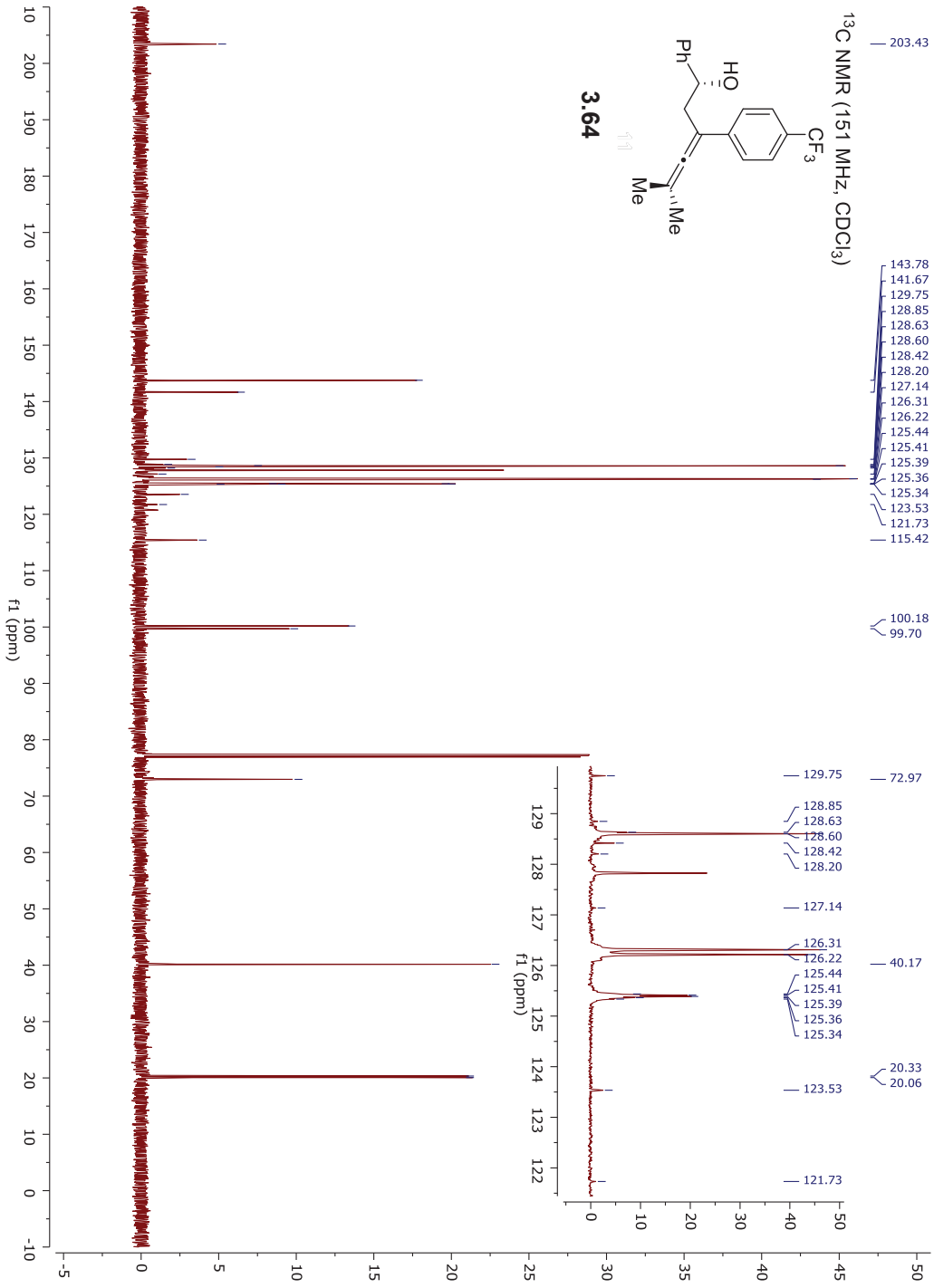

3.62
^{1}H NMR (600 MHz, CDCl$_3$)
HO
Ph
Ph
Me
Me
7.42
7.41
7.40
7.40
7.39
7.39
7.38
7.37
7.37
7.36
7.36
7.35
7.33
7.32
7.31
7.30
7.28
7.27
7.22
7.21
7.20
4.92
4.91
4.90
4.90
2.91
2.90
2.88
2.87
2.86
2.85
2.84
2.29
2.28
1.77
1.73
5.96
2.00
1.02
1.00
1.06
2.19
1.11
3.02
3.01
f1 (ppm)

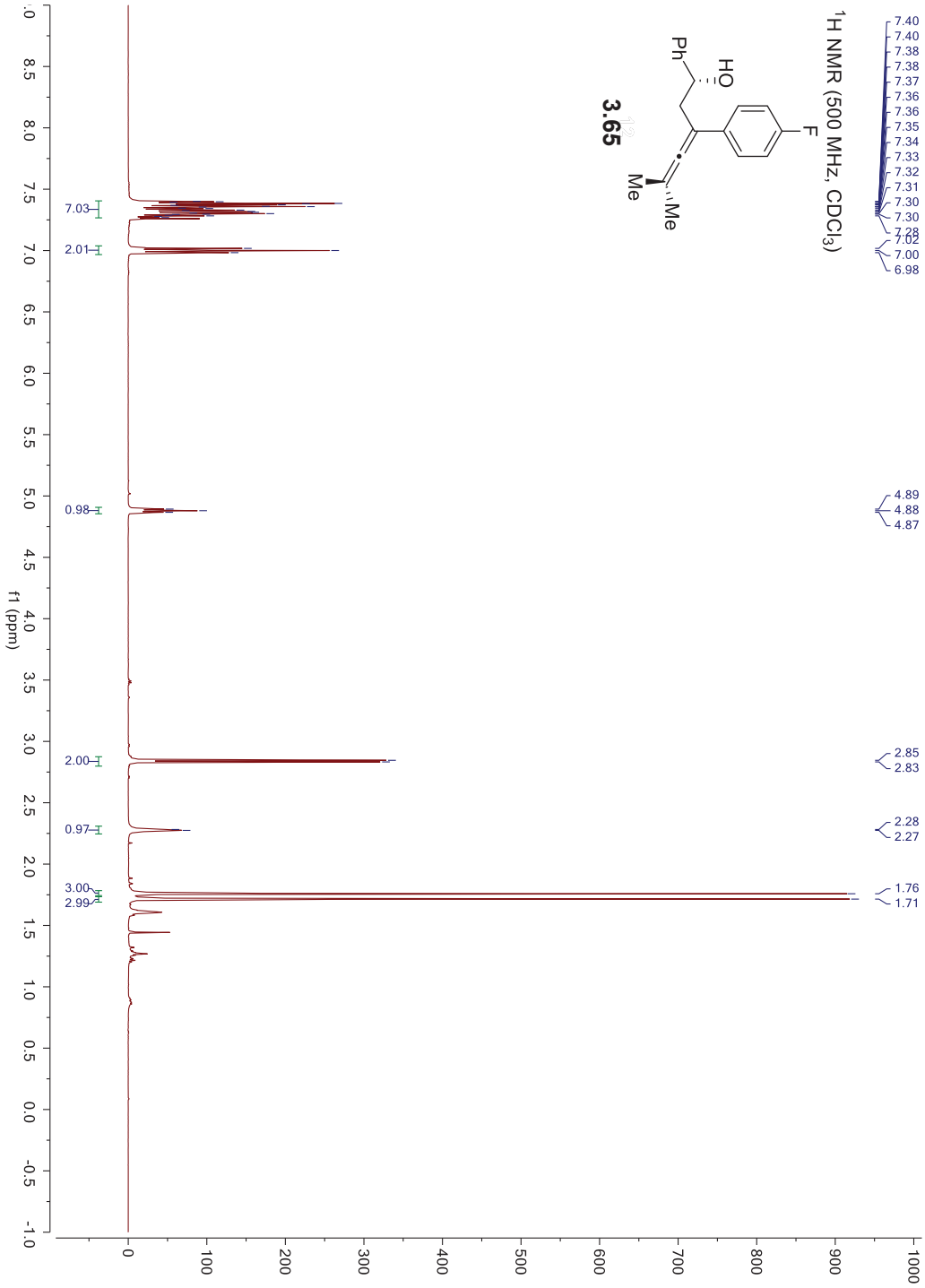

^{13}C NMR (126 MHz, CDCl$_3$)
3.62
Ph
HO
Ph
Me
Me
202.44
143.99
137.61
129.74
128.53
128.52
127.62
126.70
126.20
115.42
100.41
99.51
72.84
40.62
20.60
20.30
f1 (ppm)

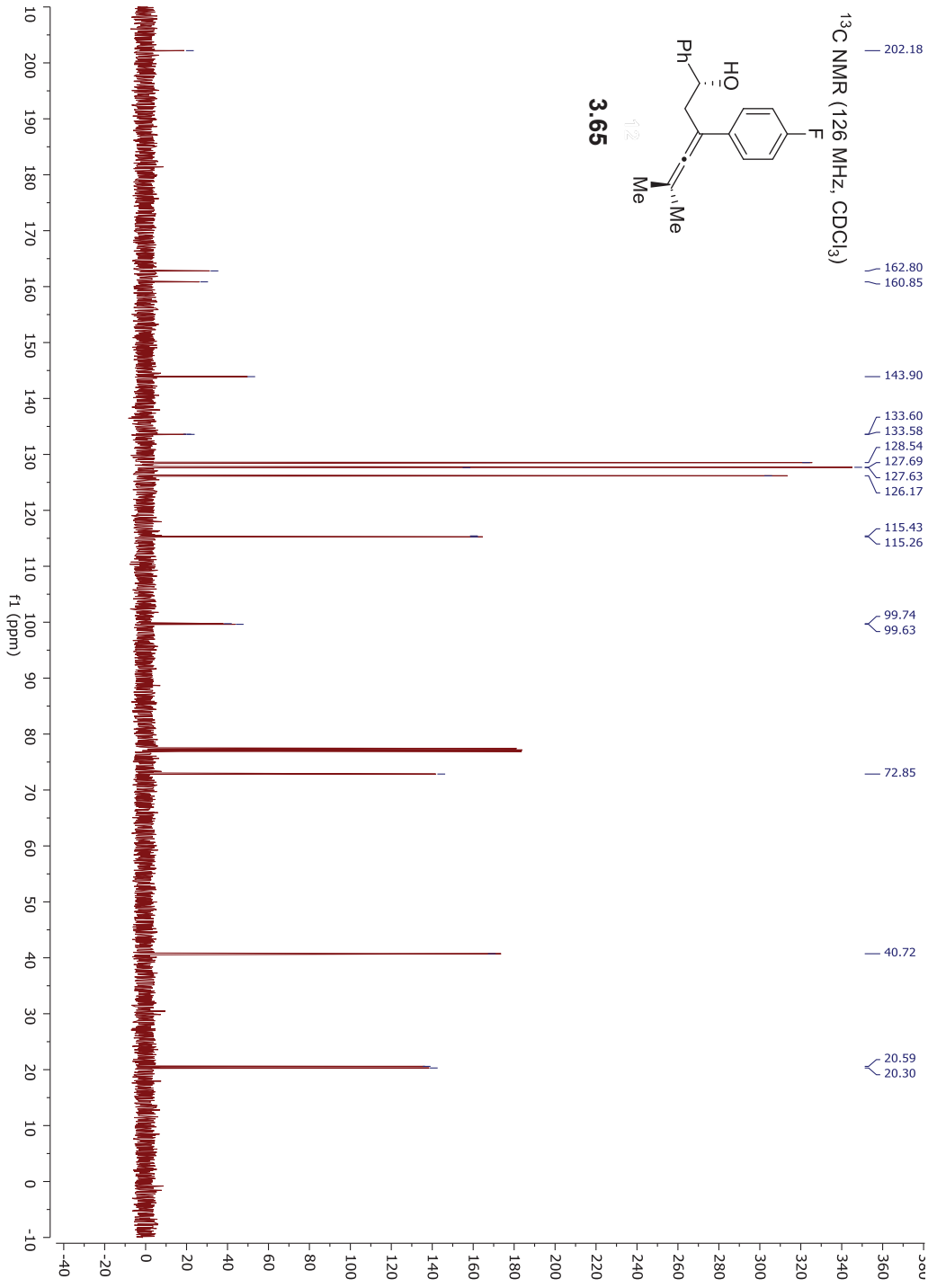

3.63
Ph
HO
Me
Me
Me
Me
^{1}H NMR (500 MHz, CDCl$_3$)
7.42
7.42
7.40
7.38
7.36
7.36
7.35
7.30
7.28
6.97
6.86
4.91
4.90
4.89
4.88
4.88
2.89
2.89
2.88
2.88
2.86
2.86
2.85
2.85
2.84
2.84
2.82
2.82
2.81
2.81
2.79
2.79
2.31
2.29
2.29
1.77
1.73
2.03
2.07
1.01
1.97
0.99
1.00
2.01
6.09
1.01
3.02
3.01
f1 (ppm)

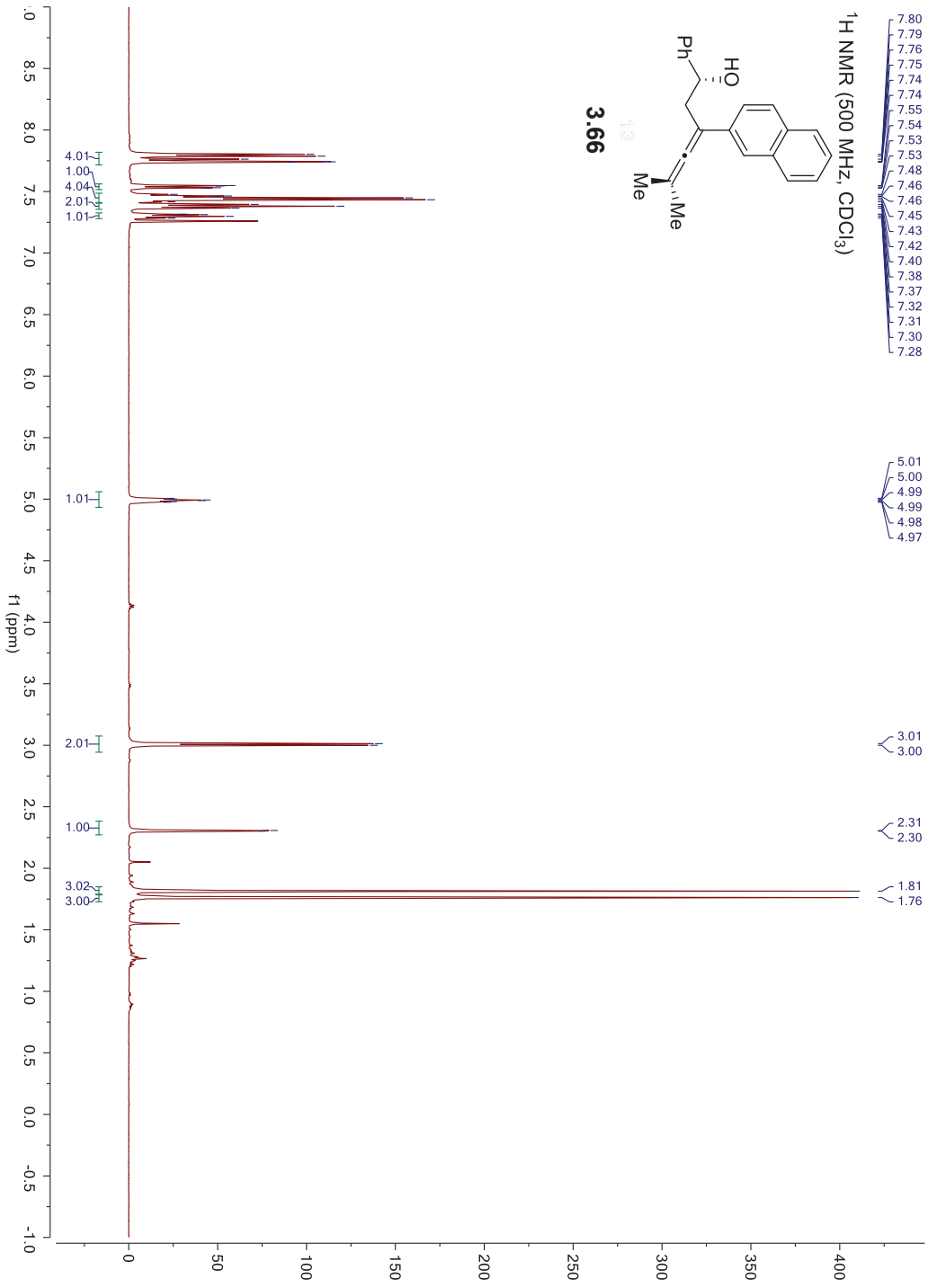

^{13}C NMR (126 MHz, CDCl$_3$)
3.63
Ph
HO
Me
Me
Me
Me
202.26
144.09
137.99
137.57
128.52
128.51
127.58
126.20
124.10
100.51
99.21
72.83
40.89
21.58
20.70
20.40
f1 (ppm)

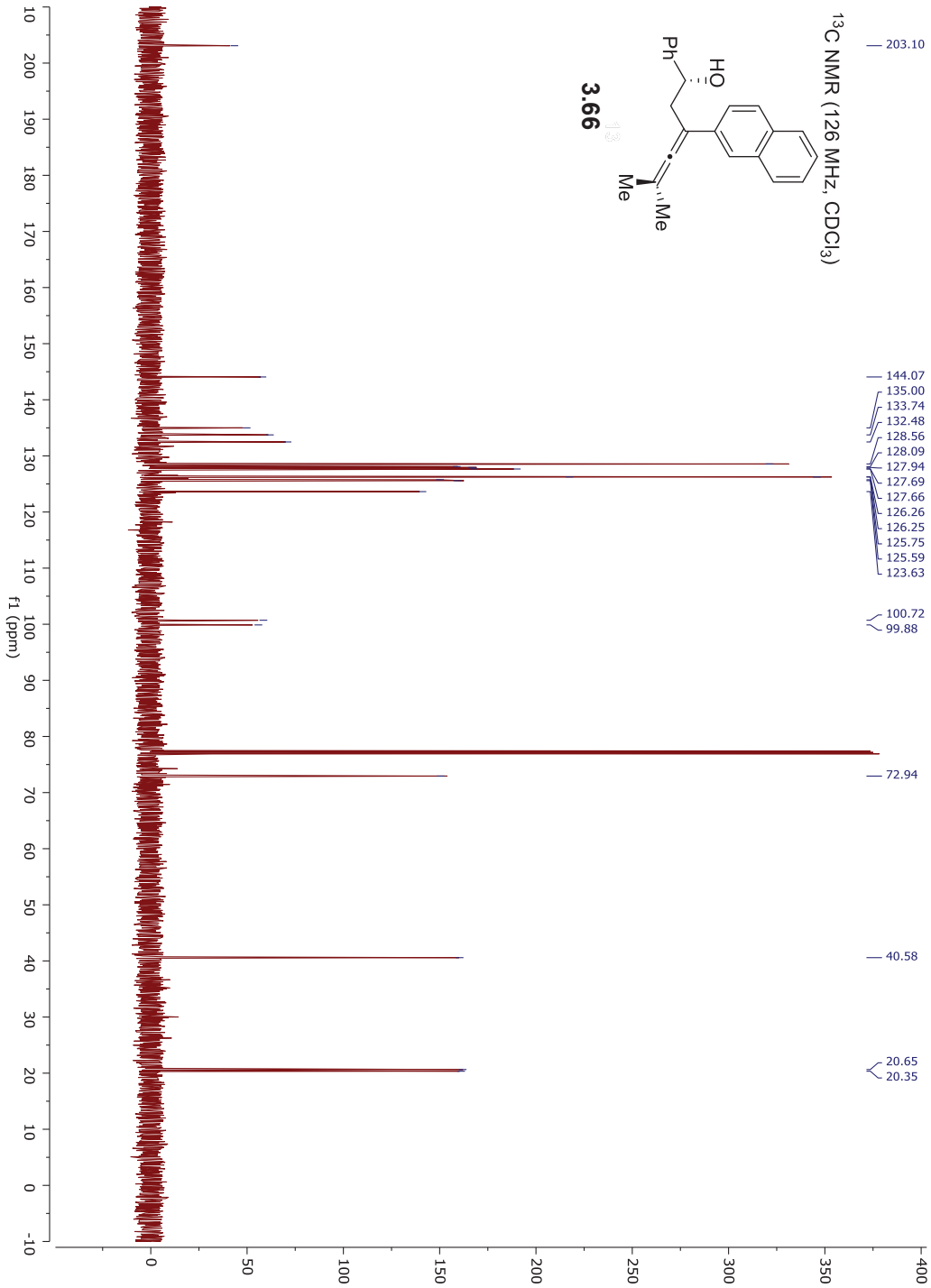

3.64
Ph
HO
CF3
Me
Me
1H NMR (600 MHz, CDCl3)
7.56
7.55
7.46
7.45
7.40
7.39
7.38
7.38
7.38
7.36
7.36
7.35
7.35
7.30
7.29
7.28
4.90
4.90
4.89
4.88
2.93
2.93
2.92
2.92
2.91
2.91
2.89
2.89
2.89
2.89
2.88
2.86
2.85
2.24
2.22
1.76
1.71
2.00
2.02
4.12
1.05
1.12
2.19
1.20
3.05
3.06
f1 (ppm)

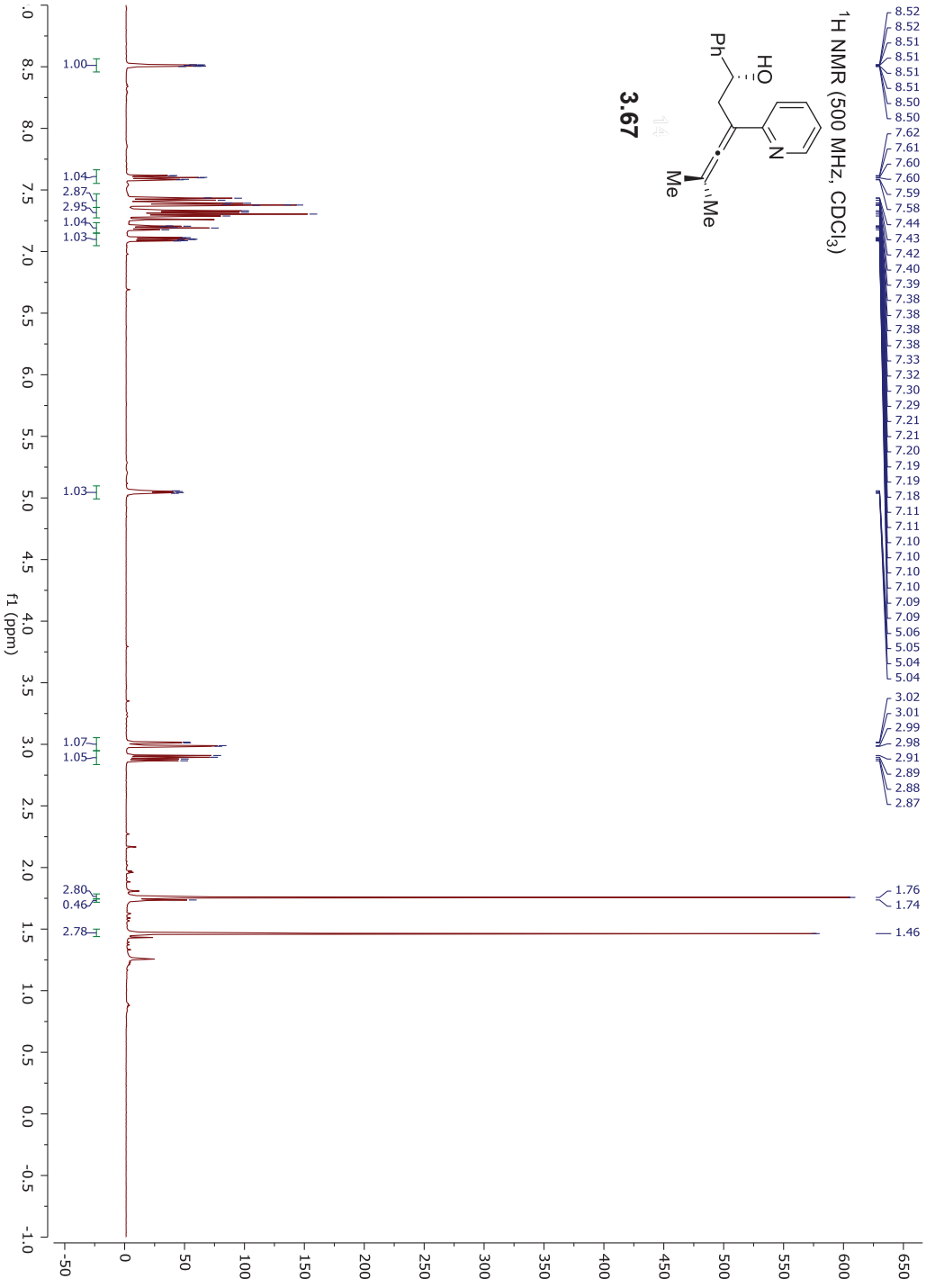

^{13}C NMR (151 MHz, CDCl$_3$)
3.64
Ph
HO
CF$_3$
Me
Me
203.43
143.78
141.67
129.75
128.85
128.63
128.60
128.42
128.20
127.14
126.31
126.22
125.44
125.41
125.39
125.36
125.34
123.53
121.73
115.42
100.18
99.70
72.97
40.17
20.33
20.06
f1 (ppm)

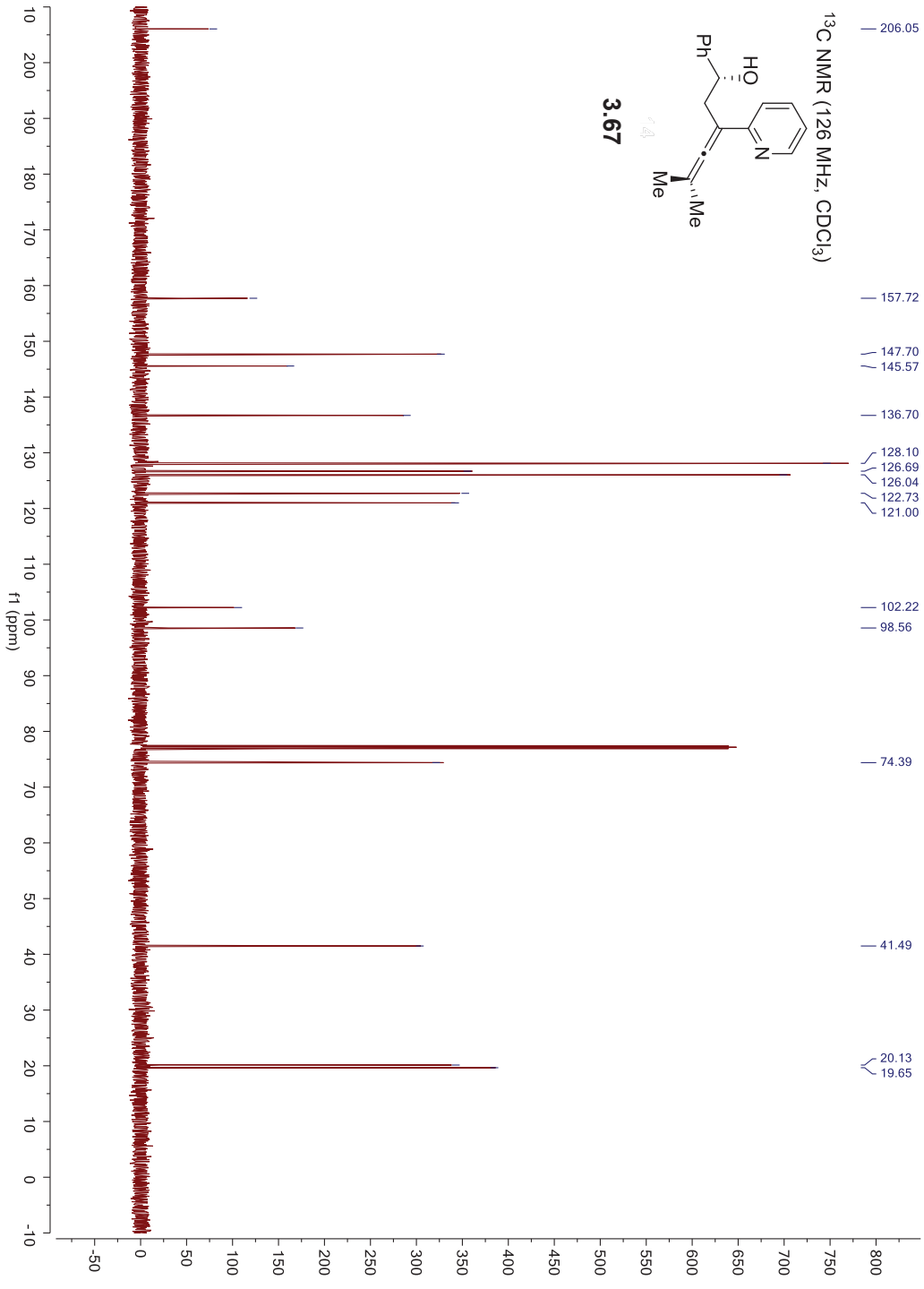

3.65
Ph
HO
F
Me
Me
^{1}H NMR (500 MHz, CDCl$_3$)
7.40
7.40
7.38
7.38
7.37
7.36
7.36
7.35
7.34
7.33
7.32
7.31
7.30
7.30
7.28
7.02
7.00
6.98
4.89
4.88
4.87
2.85
2.83
2.28
2.27
1.76
1.71
7.03
2.01
0.98
2.00
0.97
3.00
2.99
f1 (ppm)

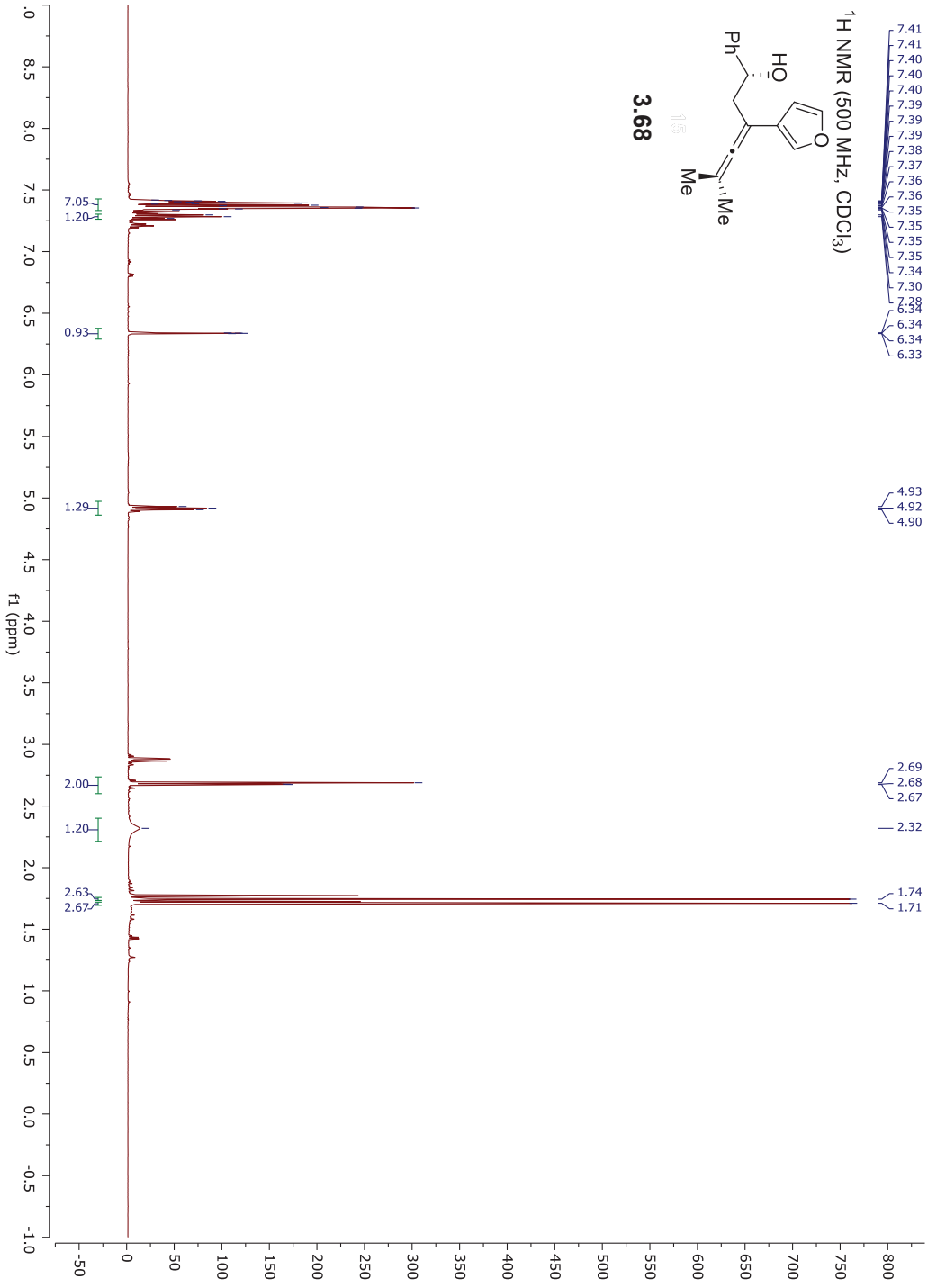

^{13}C NMR (126 MHz, CDCl$_3$)
3.65
Ph
HO
F
Me
Me
202.18
162.80
160.85
143.90
133.60
133.58
128.54
127.69
127.63
126.17
115.43
115.26
99.74
99.63
72.85
40.72
20.59
20.30
f1 (ppm)

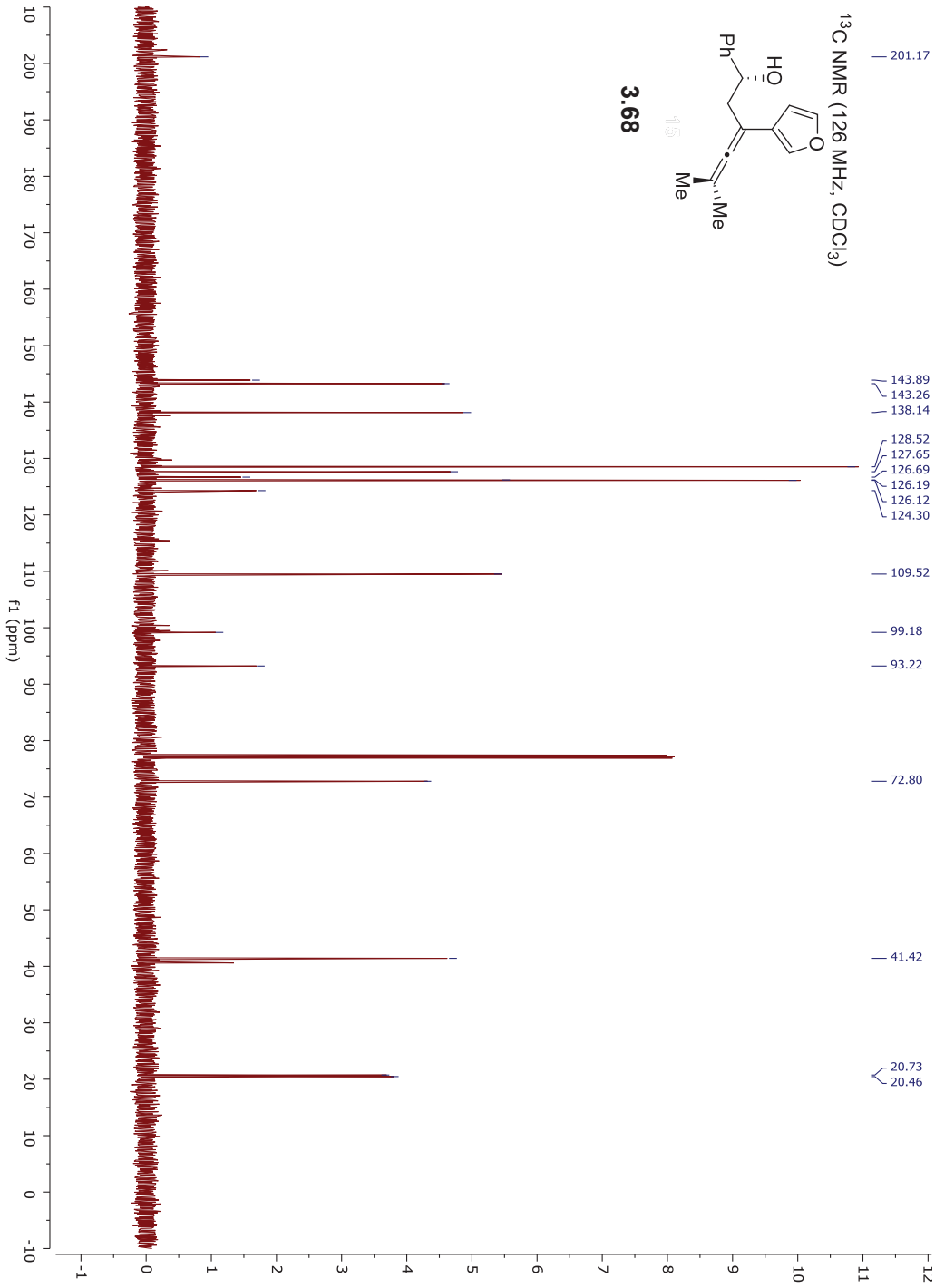

3.66
Ph
HO
Me
Me
1H NMR (500 MHz, CDCl3)
7.80
7.79
7.76
7.75
7.74
7.74
7.55
7.54
7.53
7.53
7.48
7.46
7.46
7.45
7.43
7.42
7.40
7.38
7.37
7.32
7.31
7.30
7.28
5.01
5.00
4.99
4.99
4.98
4.97
3.01
3.00
2.31
2.30
1.81
1.76
4.01
1.00
4.04
2.01
1.01
1.01
2.01
1.00
3.02
3.00
f1 (ppm)

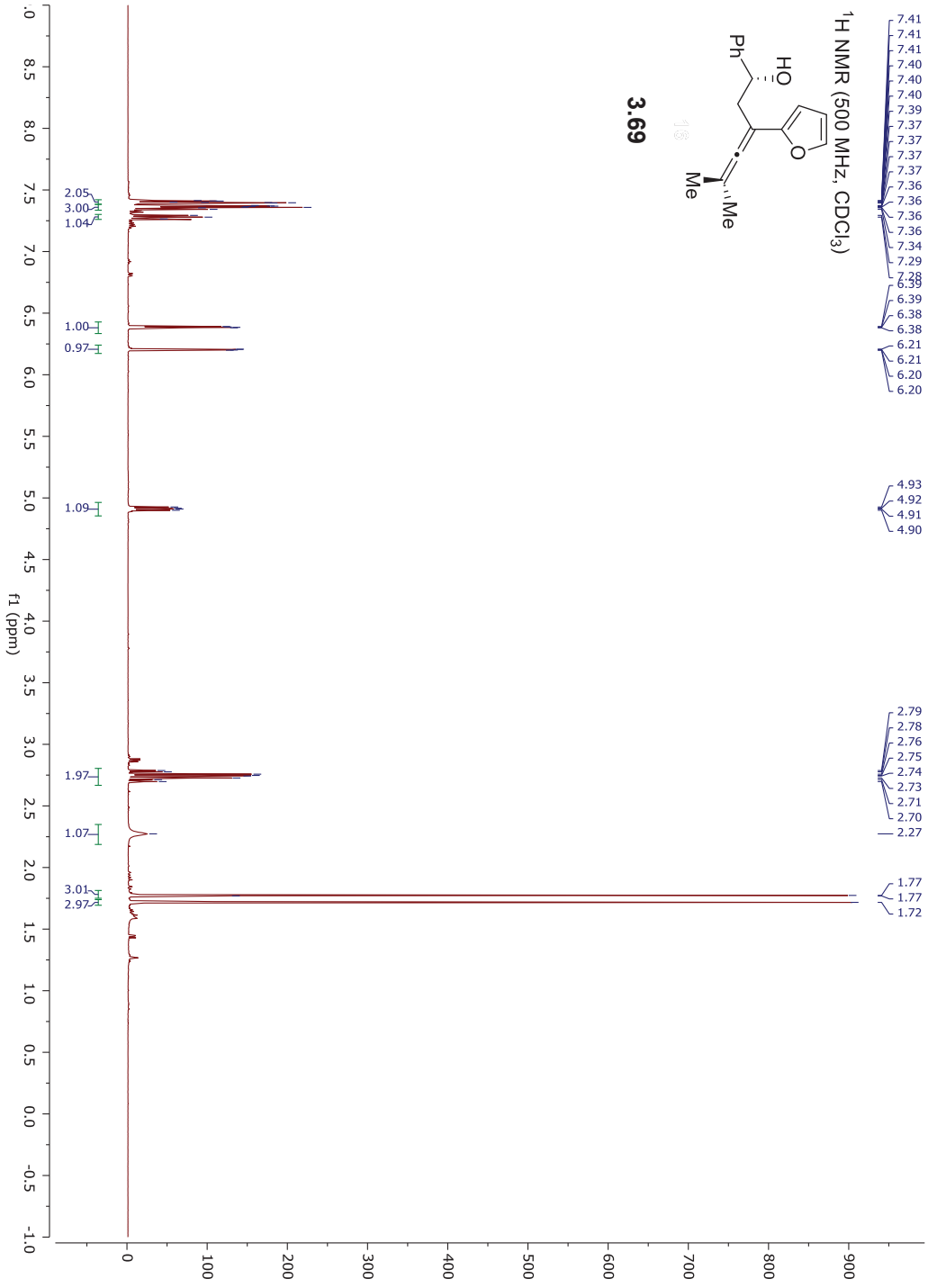

^{13}C NMR (126 MHz, CDCl$_3$)
3.66
Ph
HO
Me
Me
203.10
144.07
135.00
133.74
132.48
128.56
128.09
127.94
127.69
127.66
126.26
126.25
125.75
125.59
123.63
100.72
99.88
72.94
40.58
20.65
20.35
f1 (ppm)

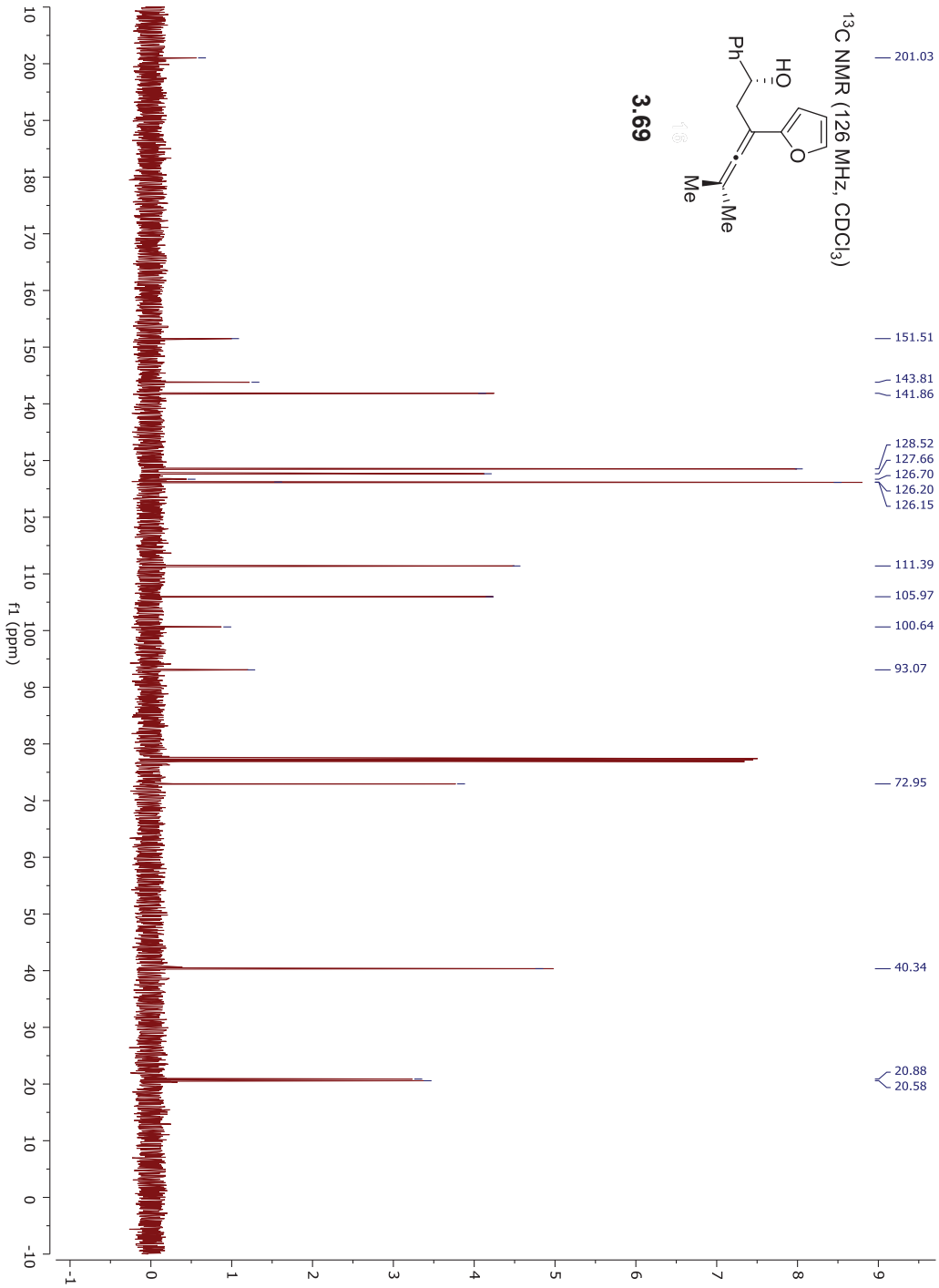

3.67
Ph
HO
N
Me
Me
^{1}H NMR (500 MHz, CDCl$_3$)
f1 (ppm)

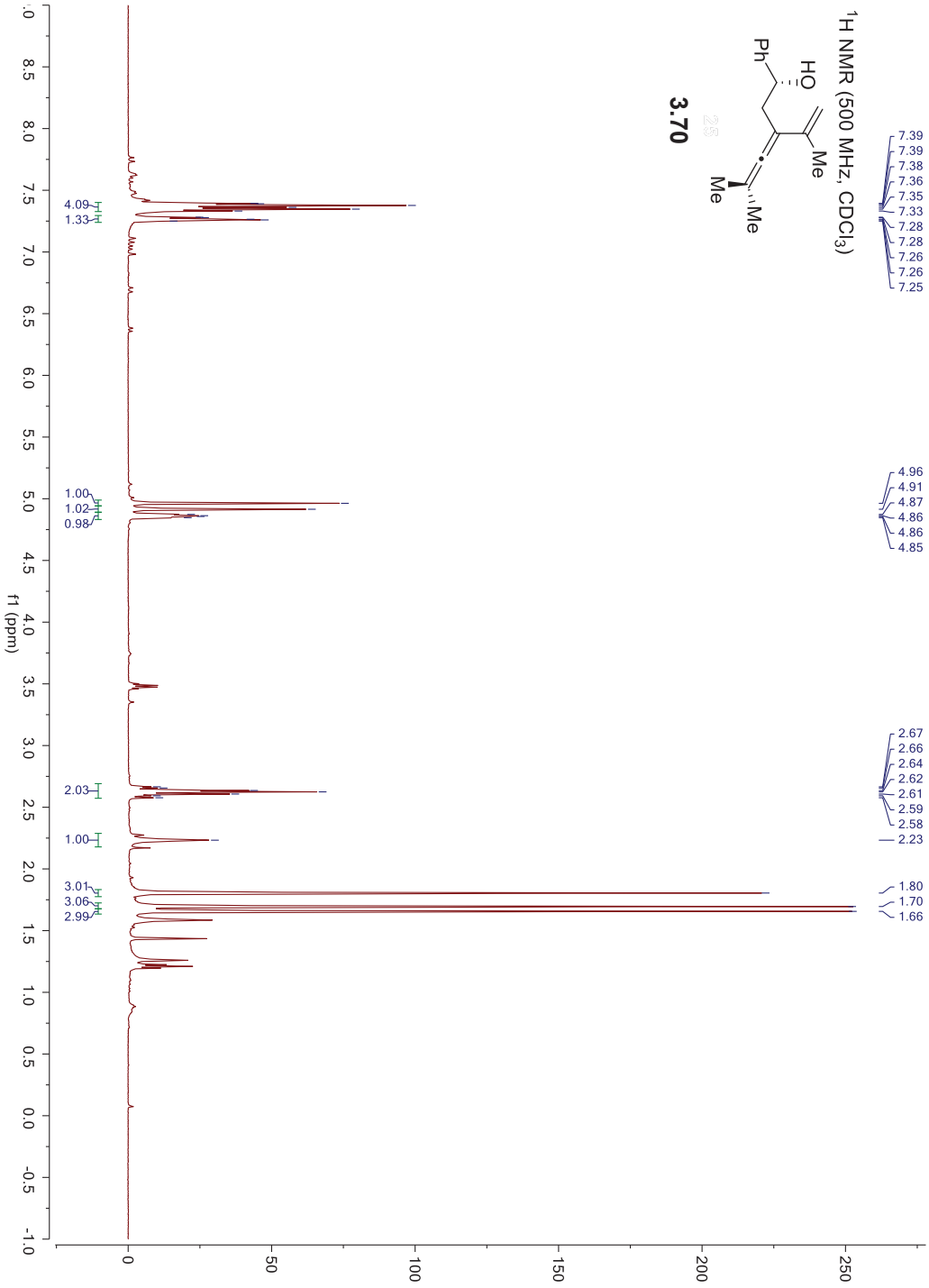

^{13}C NMR (126 MHz, CDCl$_3$)
3.67
Ph
HO
N
Me
Me
206.05
157.72
147.70
145.57
136.70
128.10
126.69
126.04
122.73
121.00
102.22
98.56
74.39
41.49
20.13
19.65
f1 (ppm)

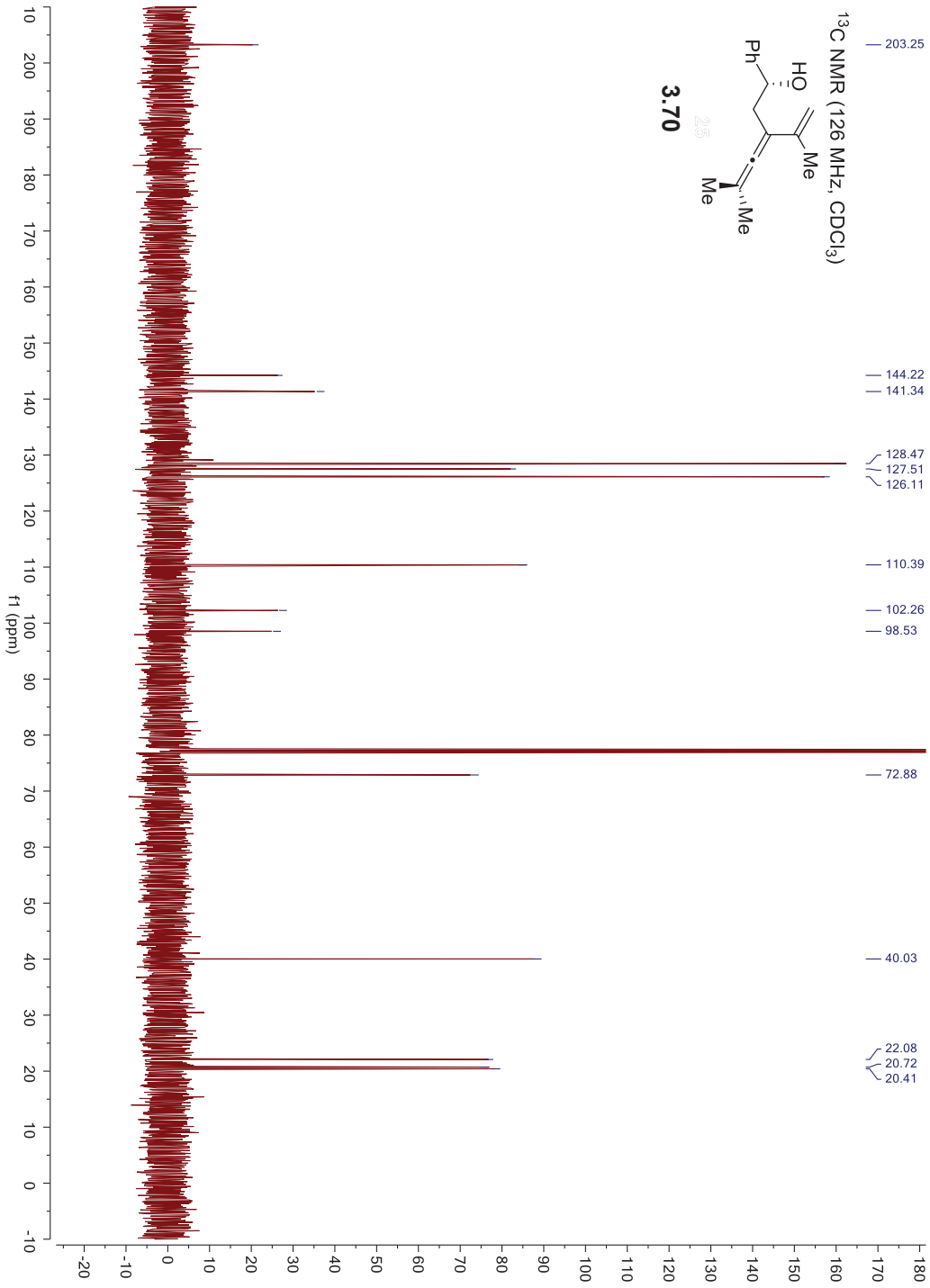

3.68
Ph
HO
O
Me
Me
^{1}H NMR (500 MHz, CDCl$_3$)
7.41
7.41
7.40
7.40
7.40
7.39
7.39
7.39
7.38
7.37
7.36
7.36
7.35
7.35
7.35
7.35
7.34
7.30
7.28
6.34
6.34
6.34
6.34
6.33
4.93
4.92
4.90
2.69
2.68
2.67
2.32
1.74
1.71
7.05
1.20
0.93
1.29
2.00
1.20
2.63
2.67
f1 (ppm)

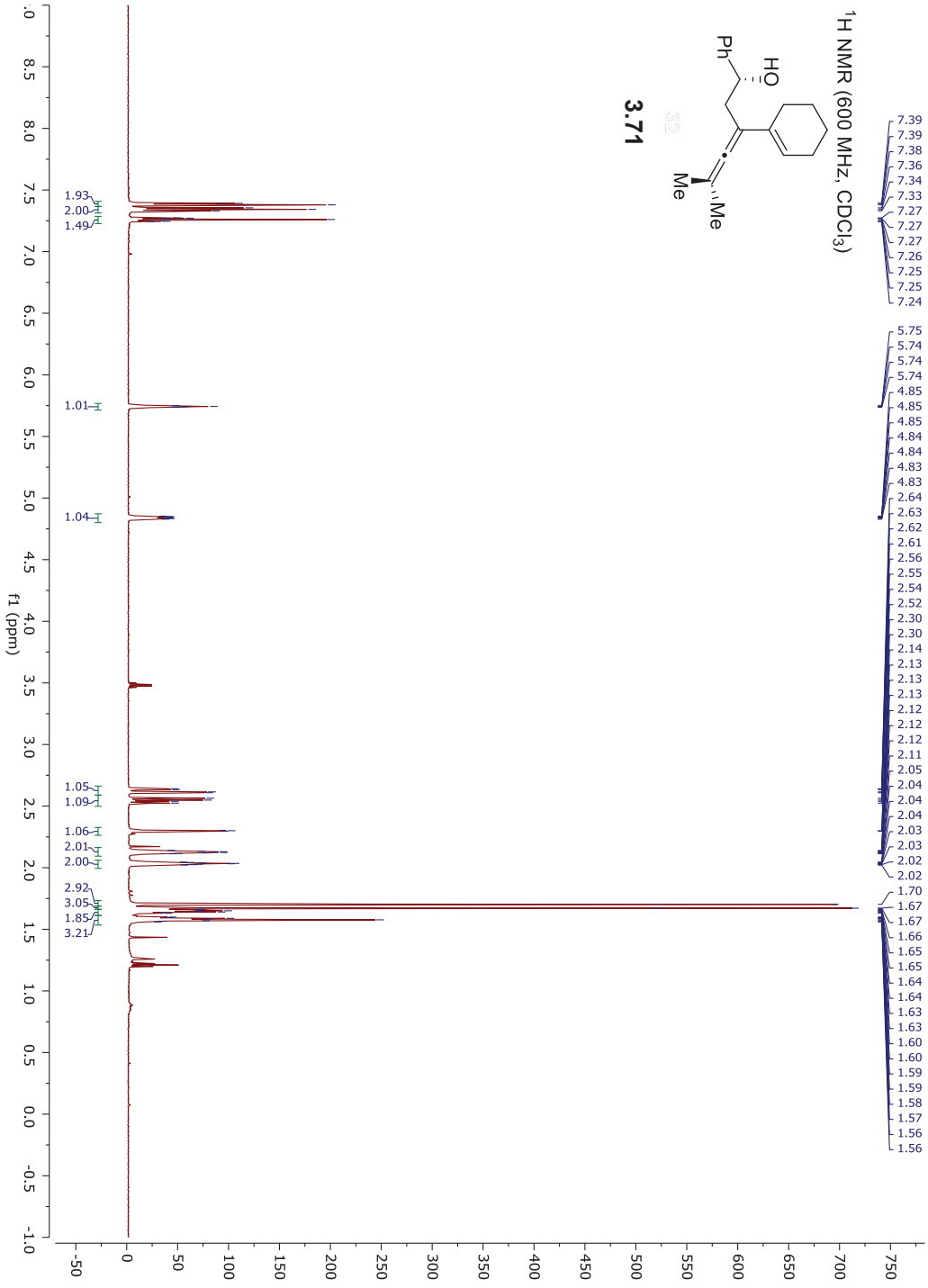

^{13}C NMR (126 MHz, CDCl$_3$)
3.68
Ph
HO
O
Me
Me
201.17
143.89
143.26
138.14
128.52
127.65
126.69
126.19
126.12
124.30
109.52
99.18
93.22
72.80
41.42
20.73
20.46
f1 (ppm)

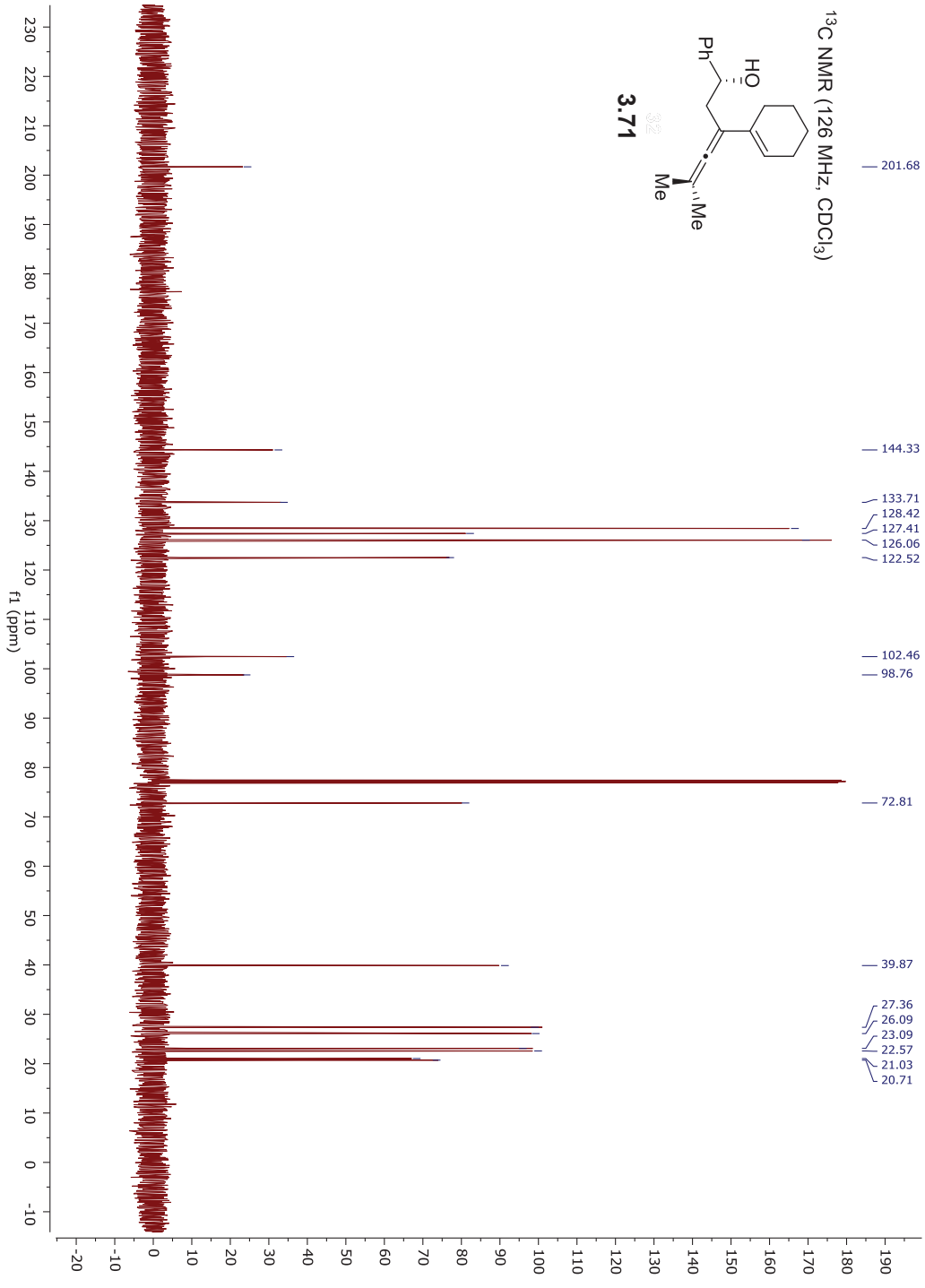

3.69
Ph
HO
O
Me
Me
^{1}H NMR (500 MHz, CDCl$_3$)
7.41
7.41
7.41
7.40
7.40
7.40
7.39
7.37
7.37
7.37
7.37
7.36
7.36
7.36
7.36
7.34
7.29
7.28
6.39
6.39
6.38
6.38
6.21
6.21
6.20
6.20
4.93
4.92
4.91
4.90
2.79
2.78
2.76
2.75
2.74
2.73
2.71
2.70
2.27
1.77
1.77
1.72
2.05
3.00
1.04
1.00
0.97
1.09
1.97
1.07
3.01
2.97
f1 (ppm)

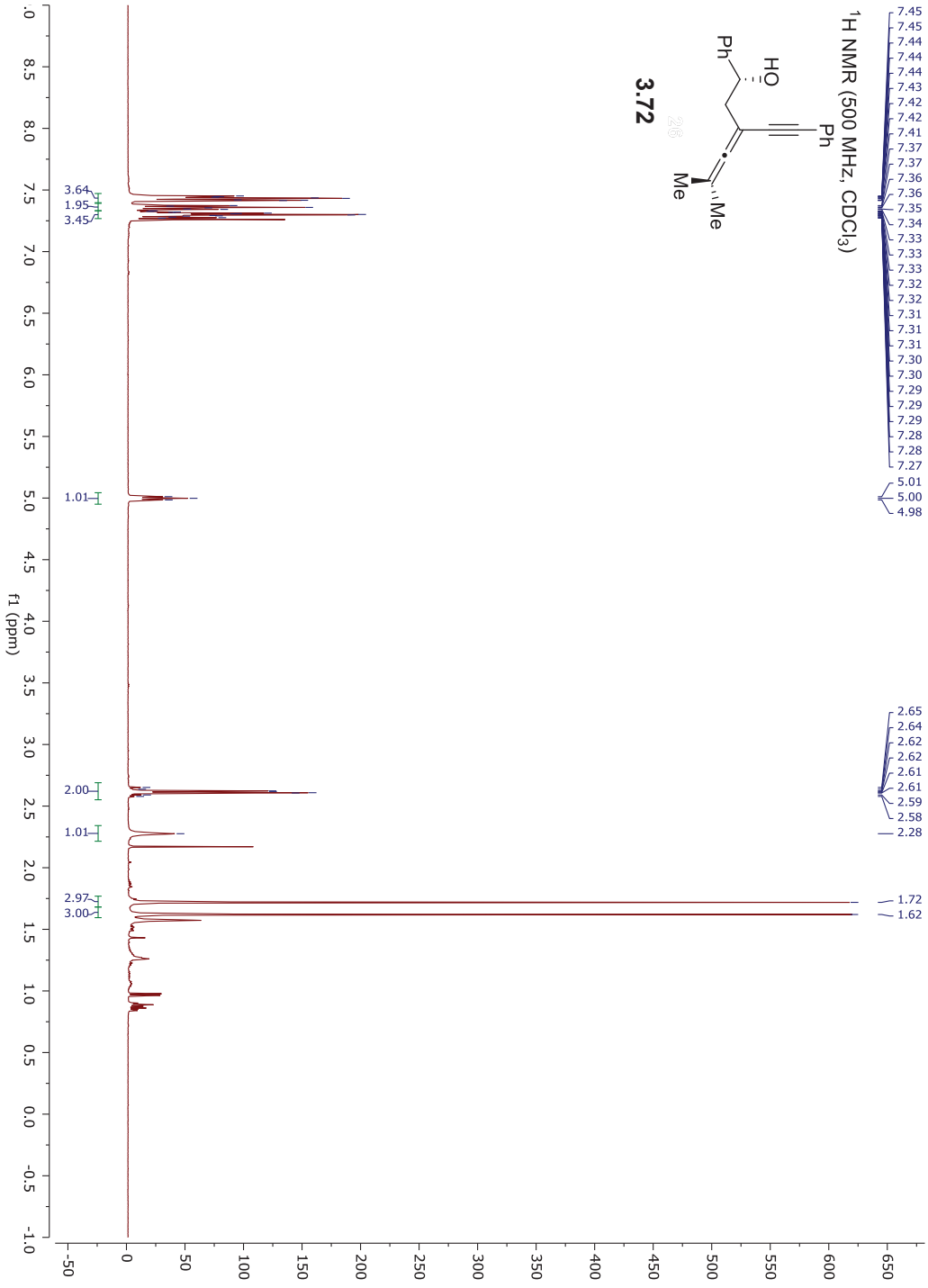

^{13}C NMR (126 MHz, CDCl$_3$)
3.69
HO
Ph
O
Me
Me
201.03
151.51
143.81
141.86
128.52
127.66
126.70
126.20
126.15
111.39
105.97
100.64
93.07
72.95
40.34
20.88
20.58
f1 (ppm)

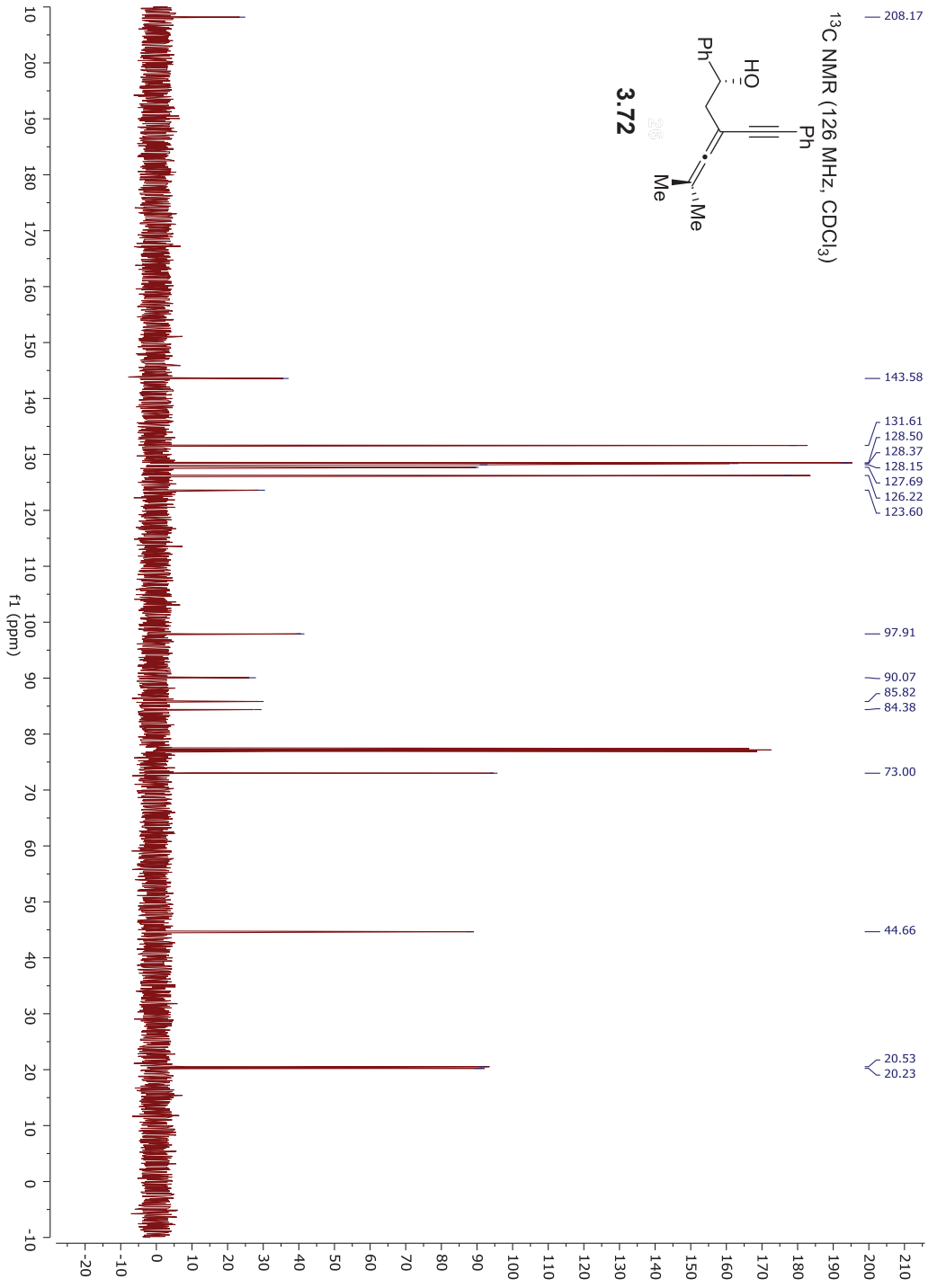

^{1}H NMR (500 MHz, CDCl$_3$)
3.70
Ph
HO
Me
Me
Me
7.39
7.39
7.38
7.36
7.35
7.33
7.28
7.28
7.26
7.26
7.25
4.96
4.91
4.87
4.86
4.86
4.85
2.67
2.66
2.64
2.62
2.61
2.59
2.58
2.23
1.80
1.70
1.66
4.09
1.33
1.00
1.02
0.98
2.03
1.00
3.01
3.06
2.99
f1 (ppm)

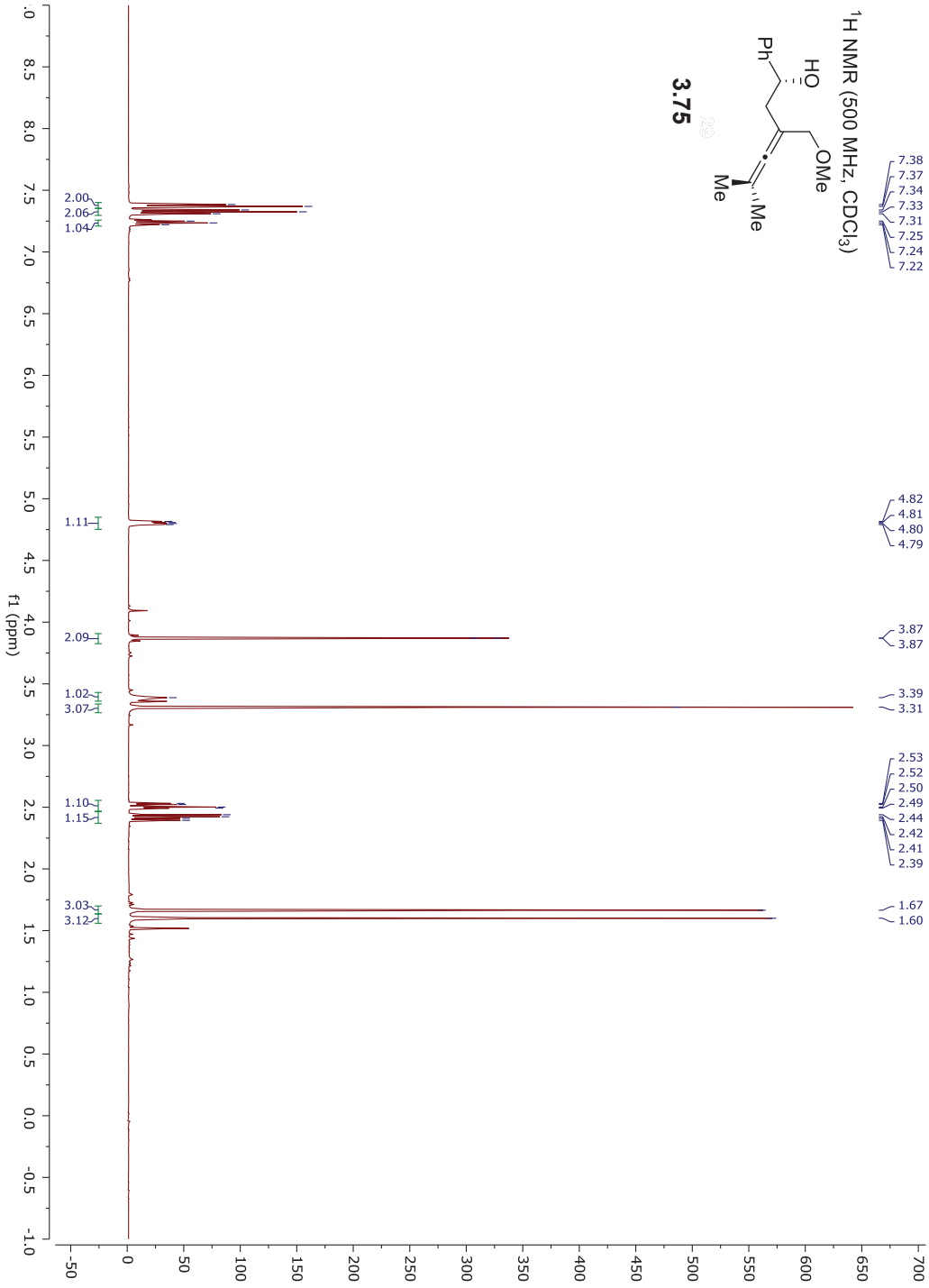

^{13}C NMR (126 MHz, CDCl$_3$)
3.70
Ph
HO
Me
Me
Me
203.25
144.22
141.34
128.47
127.51
126.11
110.39
102.26
98.53
72.88
40.03
22.08
20.72
20.41
f1 (ppm)

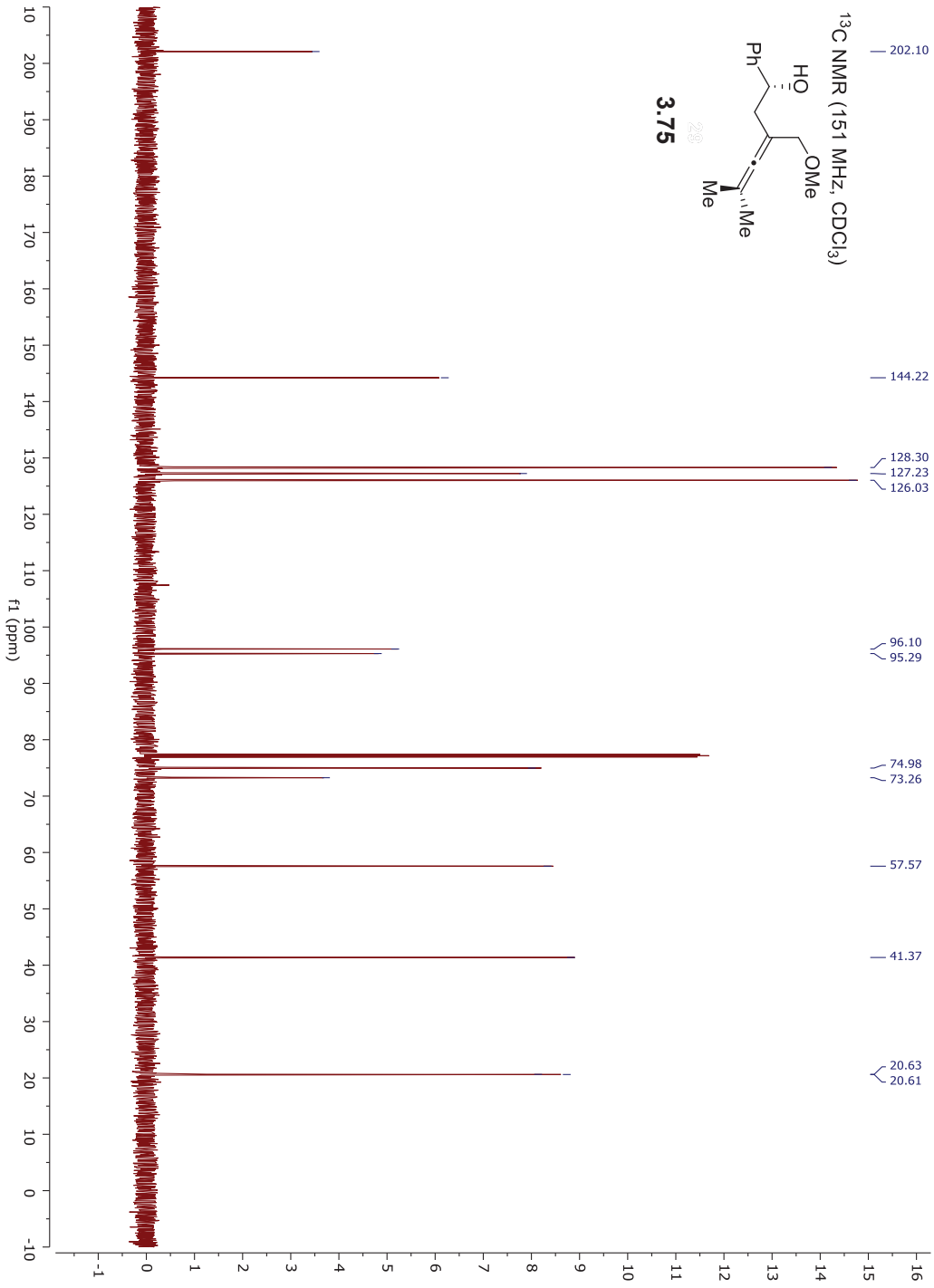

3.71
Ph
HO
Me
Me
^{1}H NMR (600 MHz, CDCl$_3$)
f1 (ppm)

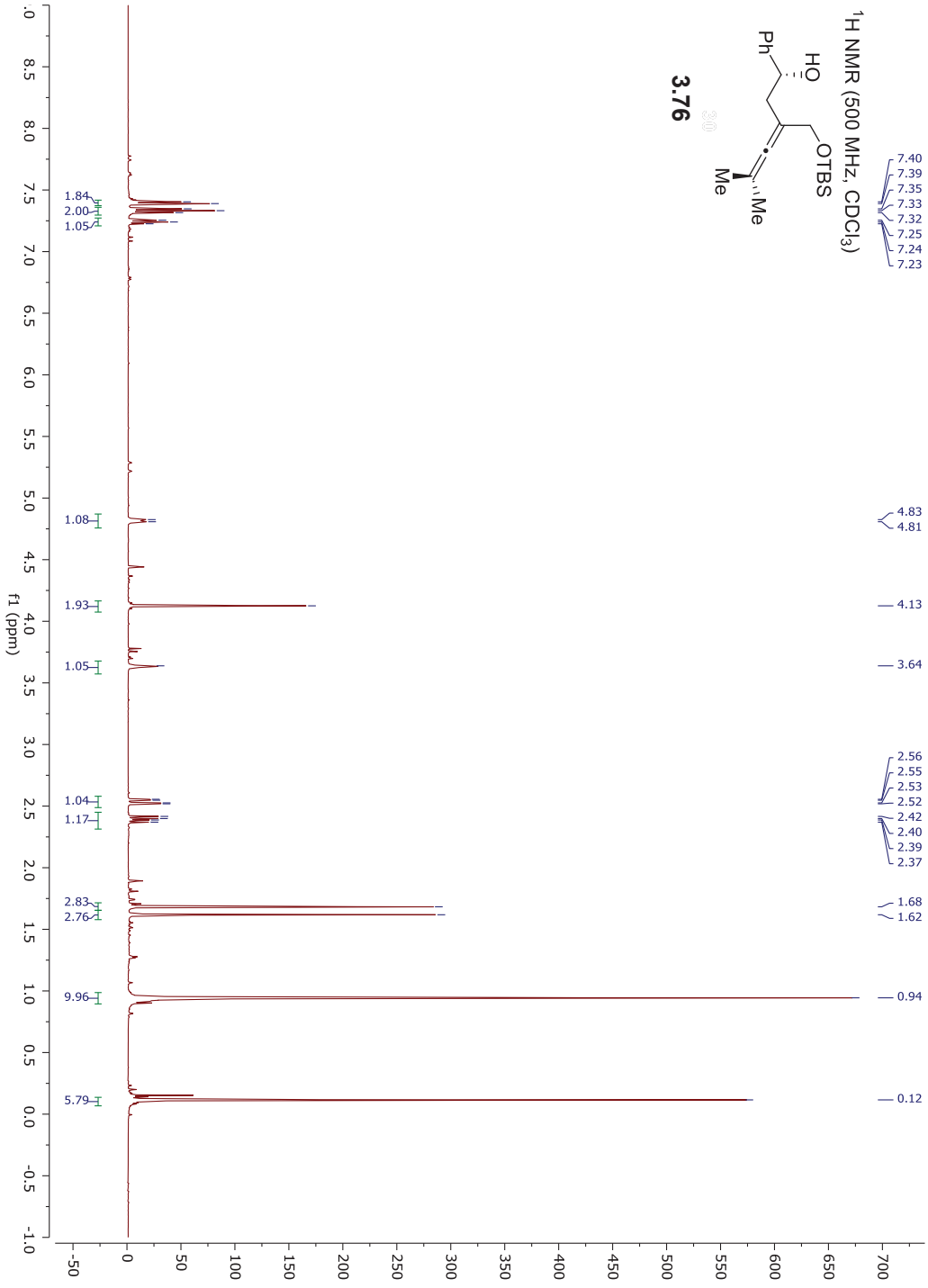

^{13}C NMR (126 MHz, CDCl$_3$)
3.71
Ph
HO
Me
Me
201.68
144.33
133.71
128.42
127.41
126.06
122.52
102.46
98.76
72.81
39.87
27.36
26.09
23.09
22.57
21.03
20.71
f1 (ppm)

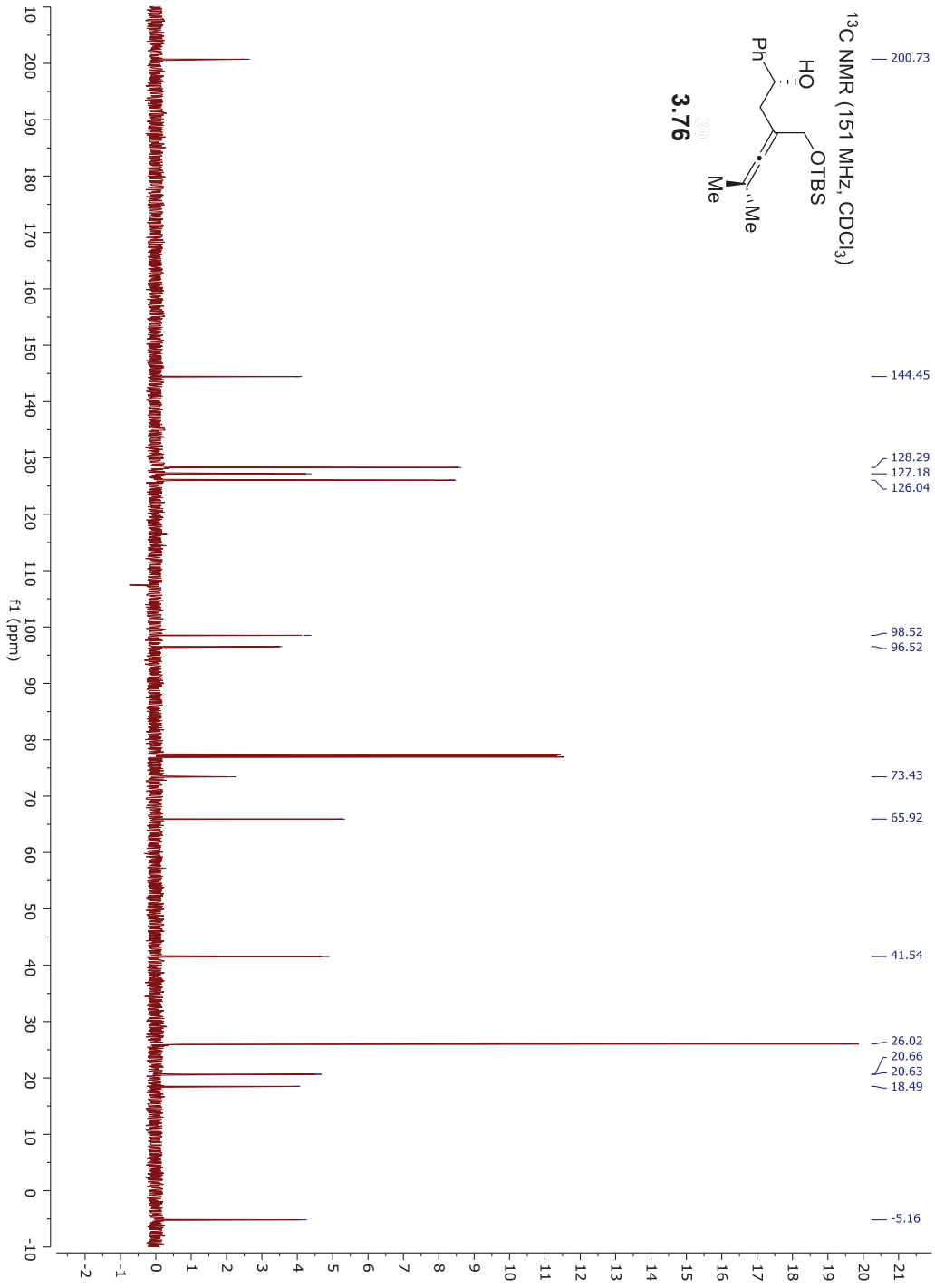

3.72
Ph
HO
Ph
Me
Me
^{1}H NMR (500 MHz, CDCl$_3$)
7.45
7.45
7.44
7.44
7.44
7.43
7.42
7.42
7.41
7.37
7.37
7.36
7.36
7.35
7.34
7.33
7.33
7.33
7.32
7.32
7.31
7.31
7.31
7.30
7.30
7.29
7.29
7.29
7.28
7.28
7.27
5.01
5.00
4.98
2.65
2.64
2.62
2.62
2.61
2.61
2.59
2.58
2.28
1.72
1.62
3.64
1.95
3.45
1.01
2.00
1.01
2.97
3.00
f1 (ppm)

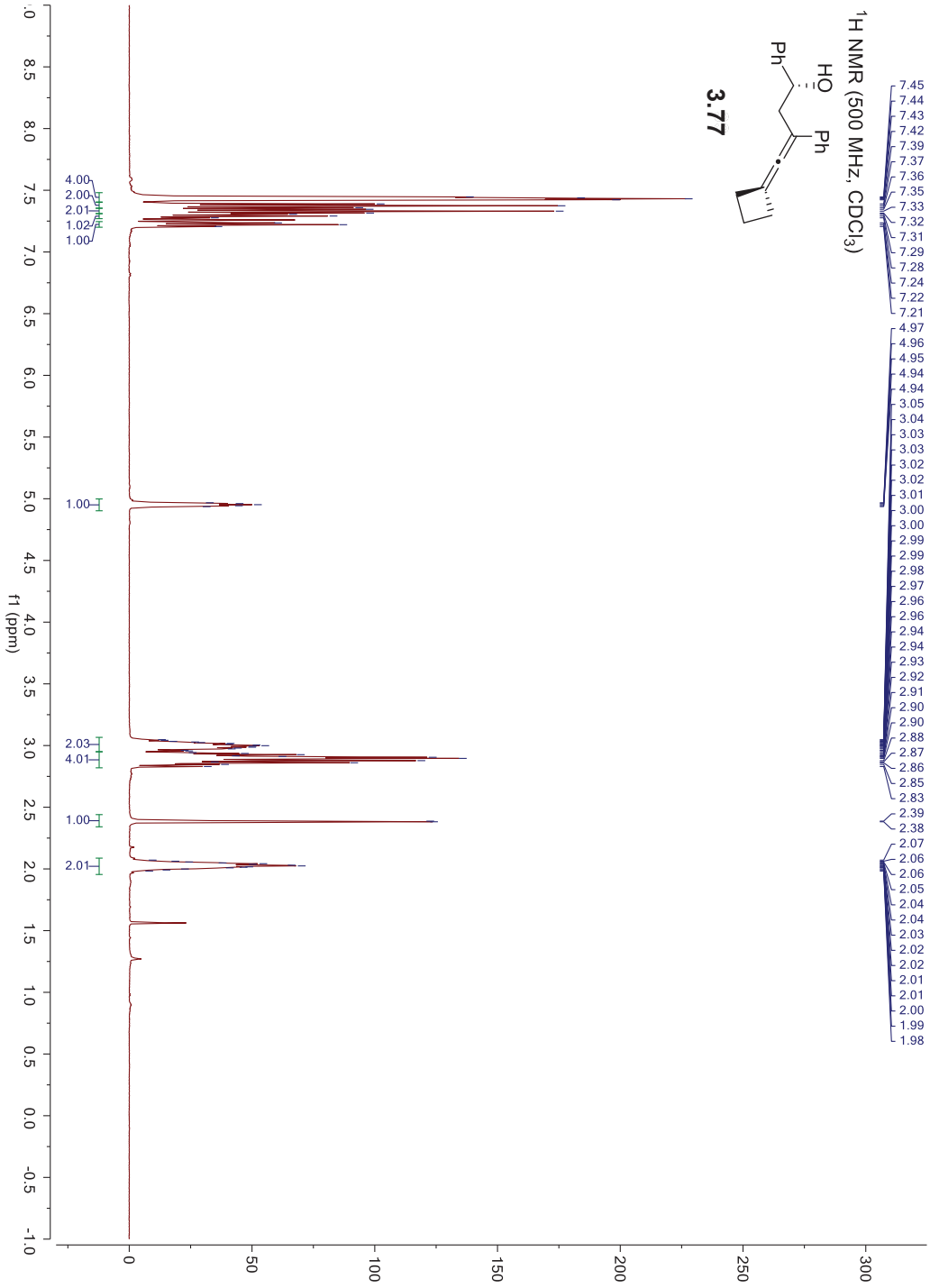

^{13}C NMR (126 MHz, CDCl$_3$)
3.72
Ph
HO
Ph
Me
Me
208.17
143.58
131.61
128.50
128.37
128.15
127.69
126.22
123.60
97.91
90.07
85.82
84.38
73.00
44.66
20.53
20.23
f1 (ppm)

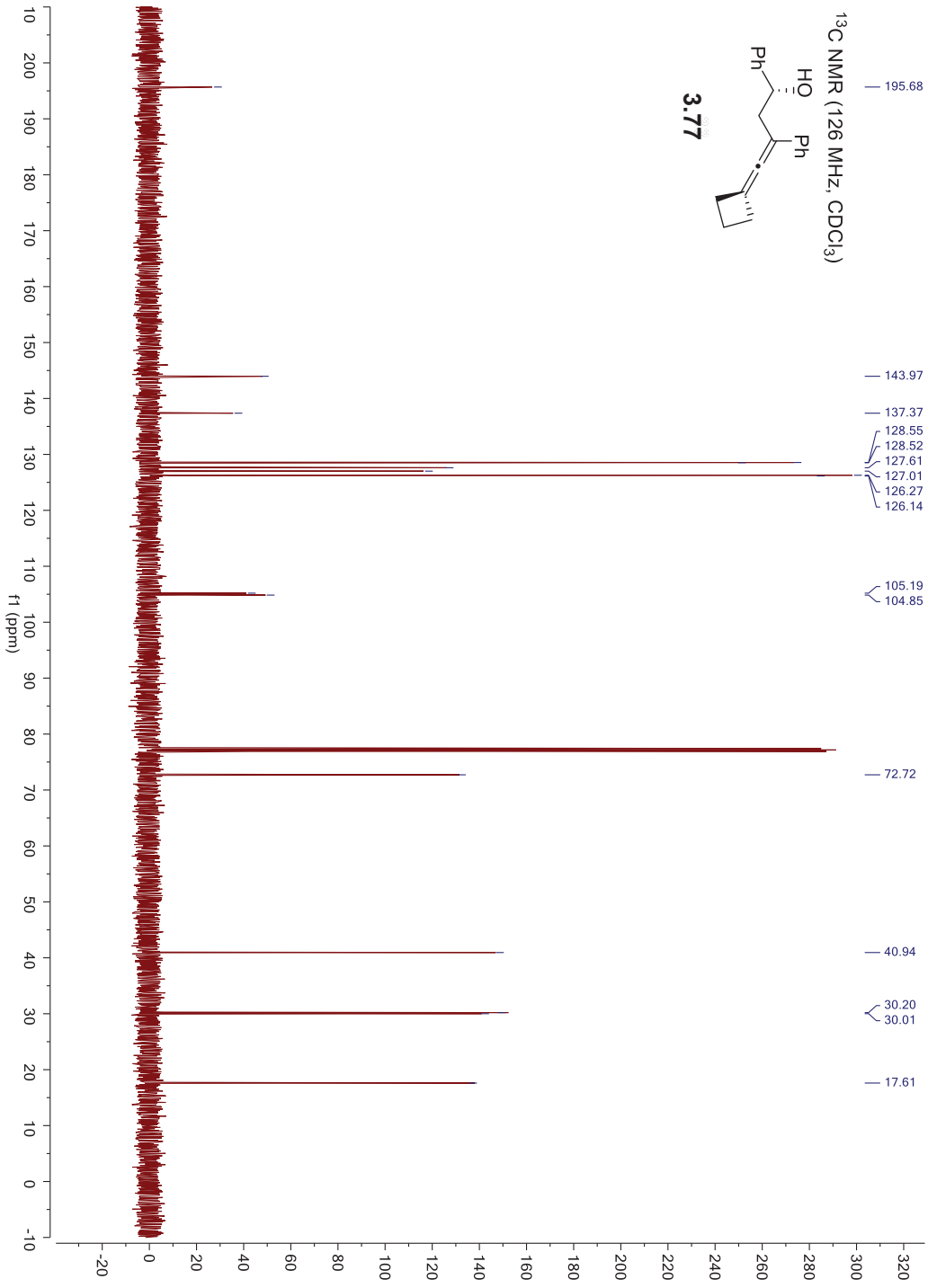

3.75
Ph
HO
OMe
Me
Me
^{1}H NMR (500 MHz, CDCl$_3$)
7.38
7.37
7.34
7.33
7.31
7.25
7.24
7.22
4.82
4.81
4.80
4.79
3.87
3.87
3.39
3.31
2.53
2.52
2.50
2.49
2.44
2.42
2.41
2.39
1.67
1.60
2.00
2.06
1.04
1.11
2.09
1.02
3.07
1.10
1.15
3.03
3.12
f1 (ppm)

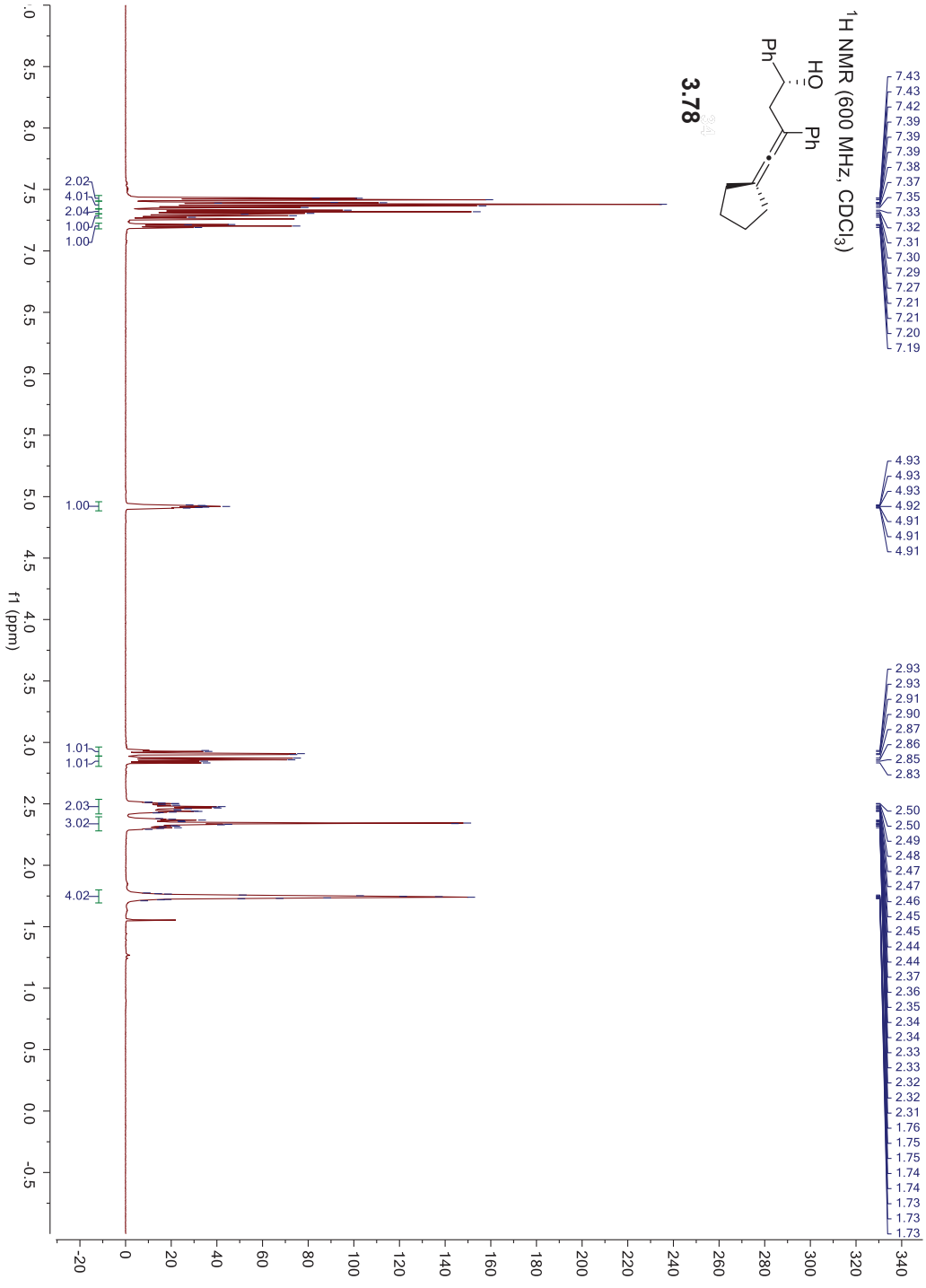

^{13}C NMR (151 MHz, CDCl$_3$)
3.75
HO
Ph
OMe
Me
Me
202.10
144.22
128.30
127.23
126.03
96.10
95.29
74.98
73.26
57.57
41.37
20.63
20.61
f1 (ppm)

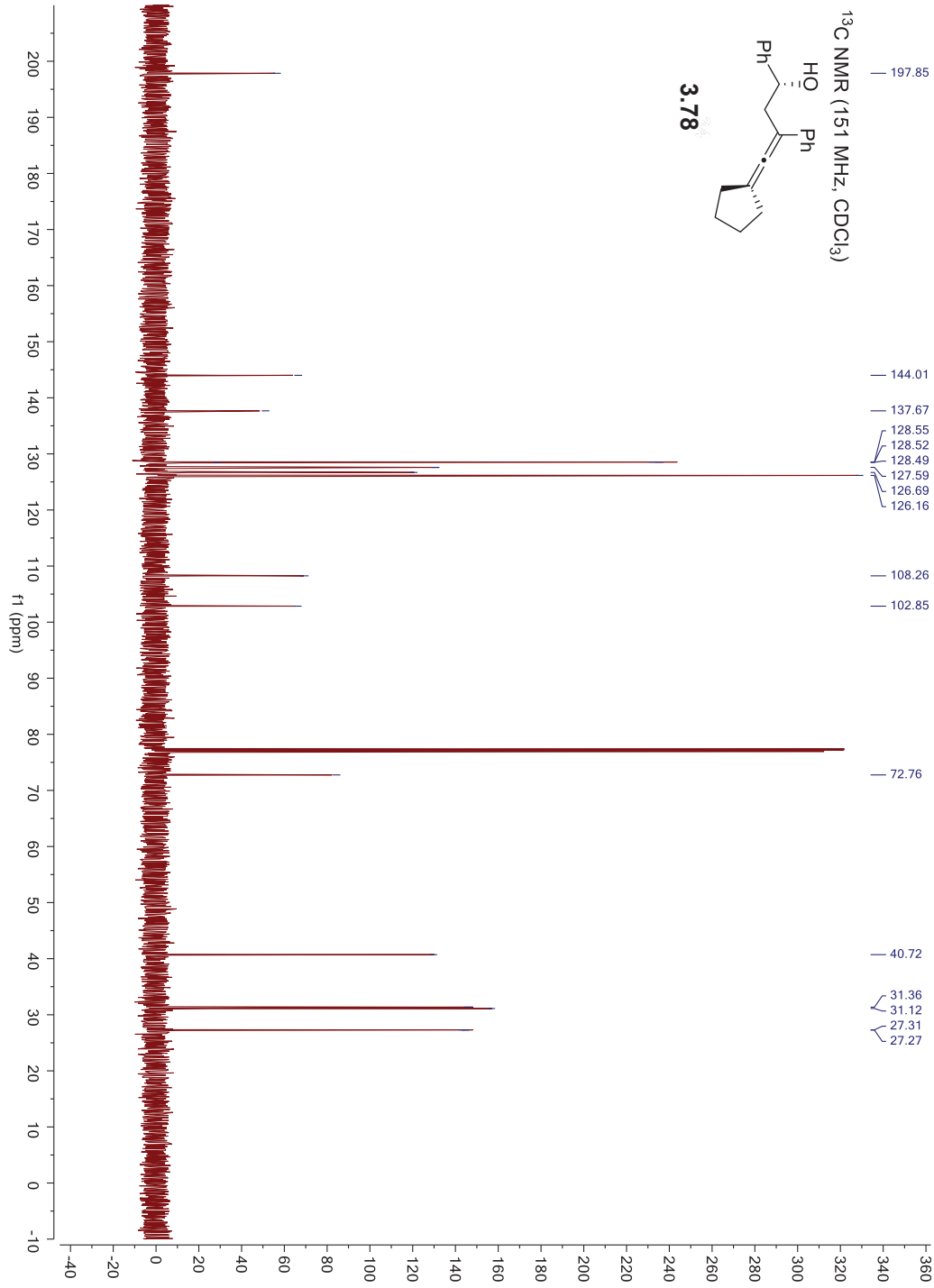

^{1}H NMR (500 MHz, CDCl$_3$)
3.76
HO
Ph
OTBS
Me
Me
7.40
7.39
7.35
7.33
7.32
7.25
7.24
7.23
4.83
4.81
4.13
3.64
2.56
2.55
2.53
2.52
2.42
2.40
2.39
2.37
1.68
1.62
0.94
0.12
1.84
2.00
1.05
1.08
1.93
1.05
1.04
1.17
2.83
2.76
9.96
5.79
f1 (ppm)

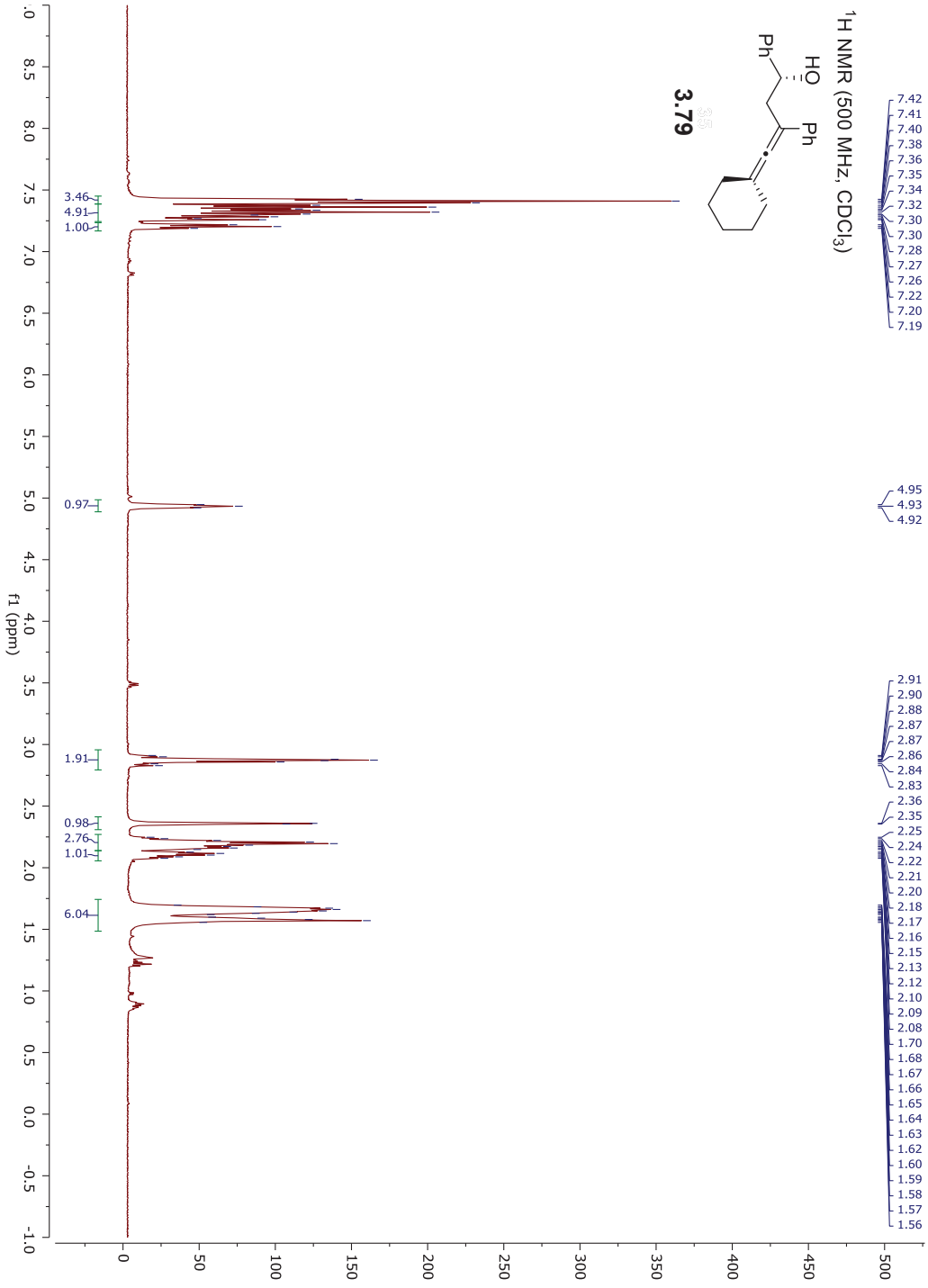

^{13}C NMR (151 MHz, CDCl$_3$)
3.76
HO
Ph
OTBS
Me
Me
200.73
144.45
128.29
127.18
126.04
98.52
96.52
73.43
65.92
41.54
26.02
20.66
20.63
18.49
-5.16
f1 (ppm)

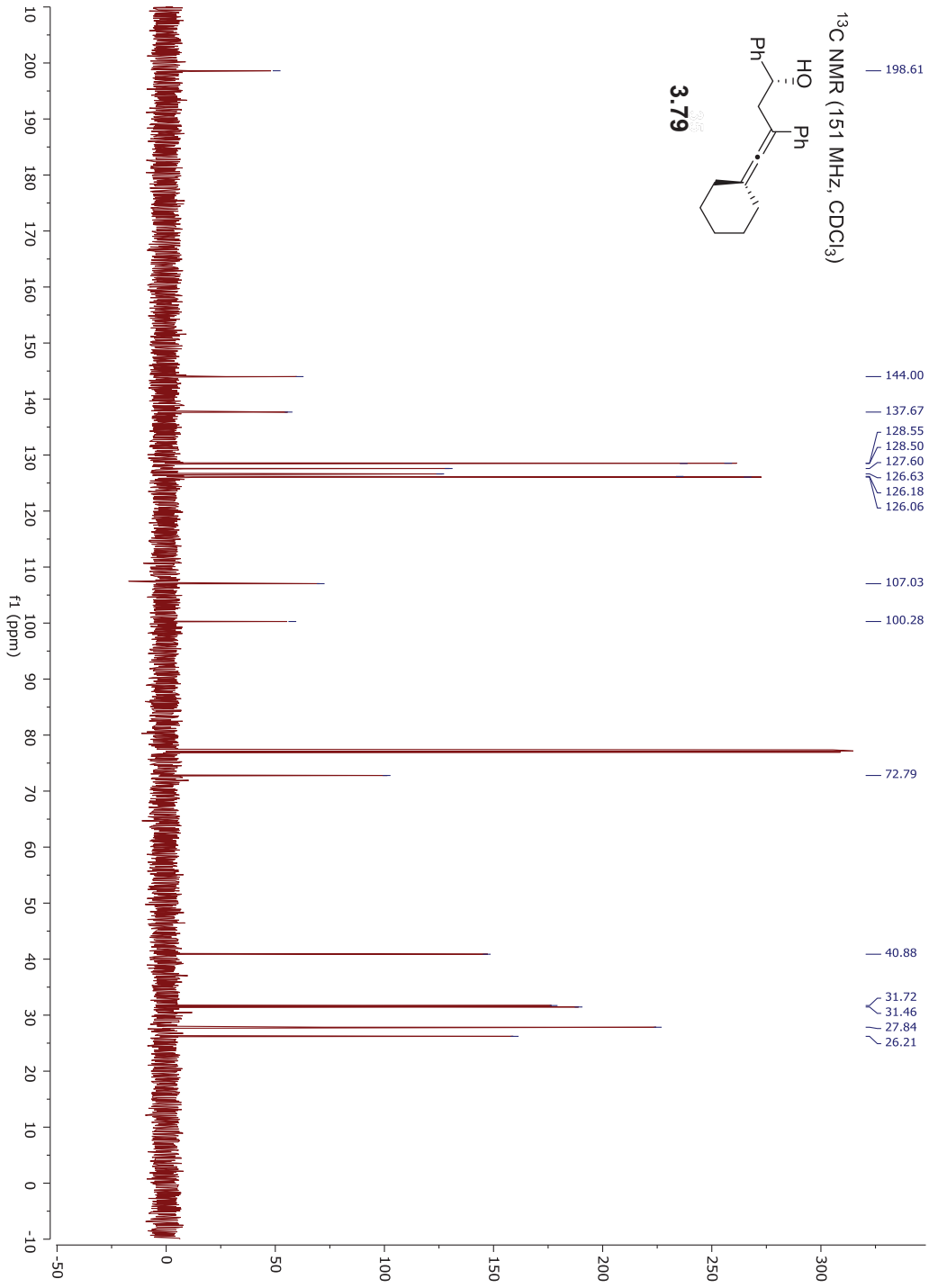

3.77
Ph
HO
Ph
^{1}H NMR (500 MHz, CDCl$_3$)
7.45
7.44
7.43
7.42
7.39
7.37
7.36
7.35
7.33
7.32
7.31
7.29
7.28
7.24
7.22
7.21
4.97
4.96
4.95
4.94
4.94
3.05
3.04
3.03
3.03
3.02
3.02
3.01
3.00
3.00
2.99
2.99
2.98
2.97
2.96
2.96
2.94
2.94
2.93
2.92
2.91
2.90
2.90
2.88
2.87
2.86
2.85
2.83
2.39
2.38
2.07
2.06
2.06
2.05
2.04
2.04
2.03
2.02
2.02
2.01
2.01
2.00
1.99
1.98
4.00
2.00
2.01
1.02
1.00
1.00
2.03
4.01
1.00
2.01
f1 (ppm)
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
0
50
100
150
200
250
300

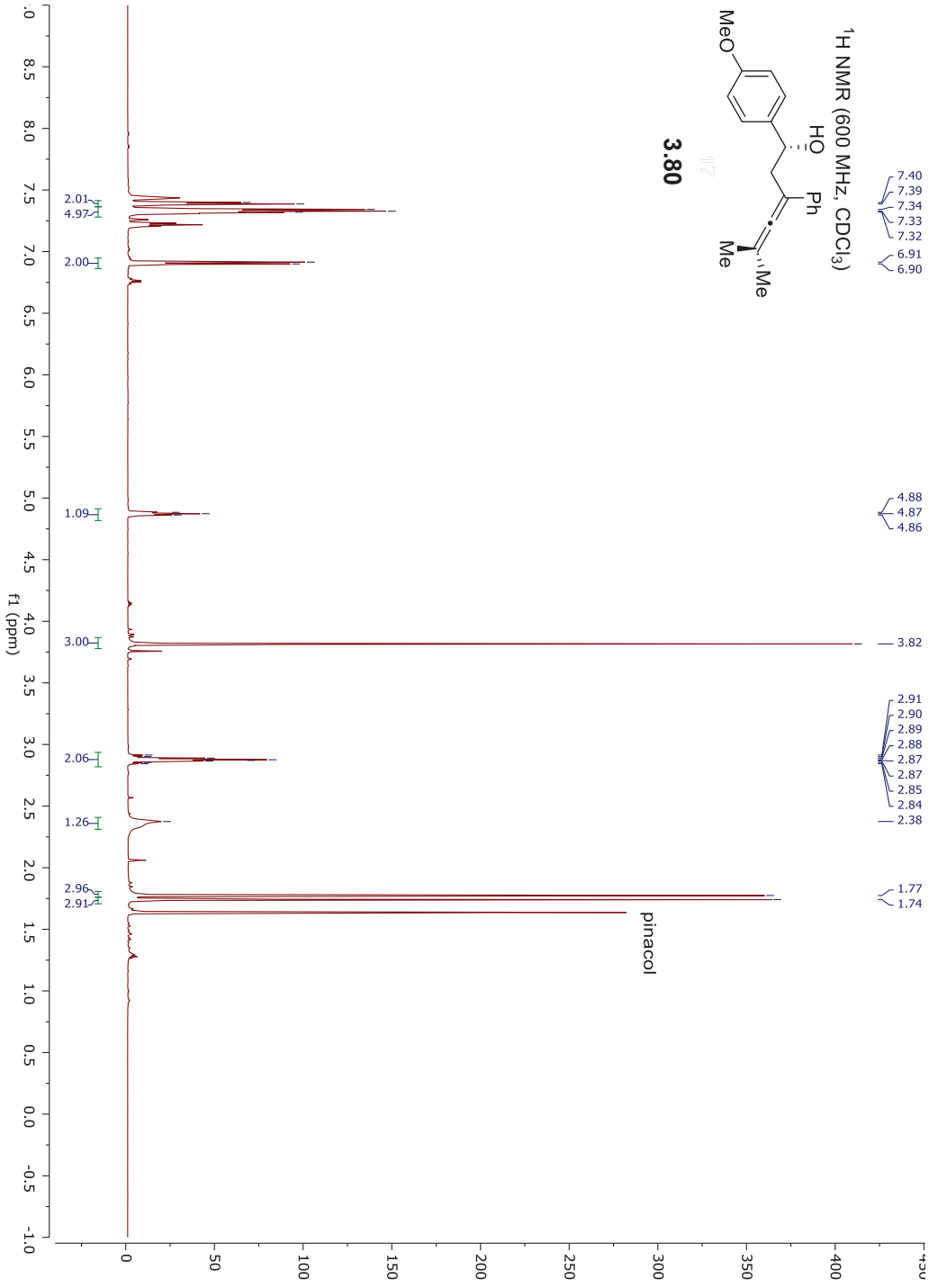

^{13}C NMR (126 MHz, CDCl$_3$)
3.77
HO
Ph
Ph
195.68
143.97
137.37
128.55
128.52
127.61
127.01
126.27
126.14
105.19
104.85
72.72
40.94
30.20
30.01
17.61
f1 (ppm)

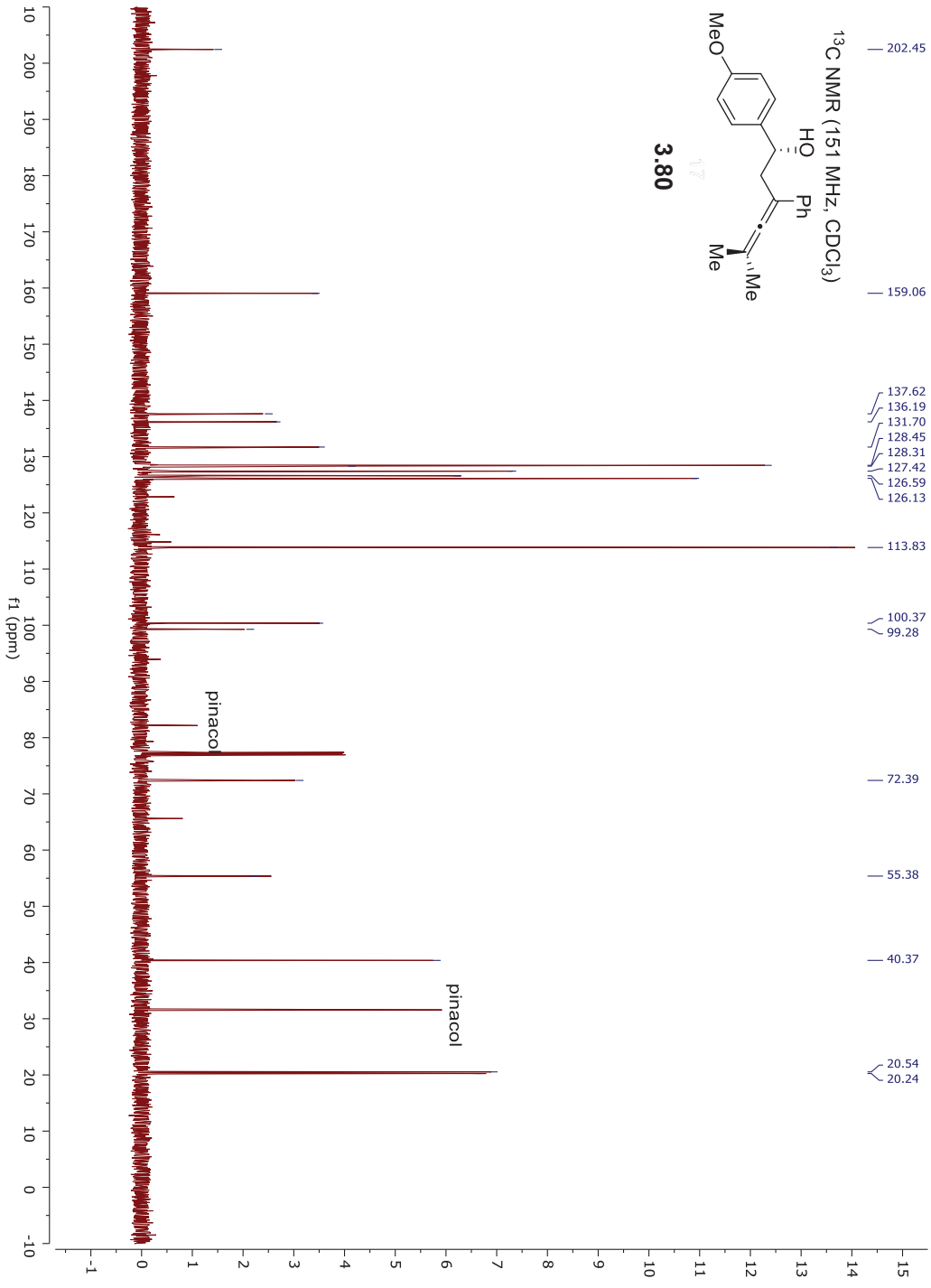

3.78
Ph
HO
Ph
^{1}H NMR (600 MHz, CDCl$_3$)
f1 (ppm)
2.02
4.01
2.04
1.00
1.00
1.00
1.01
1.01
2.03
3.02
4.02
7.43
7.43
7.42
7.39
7.39
7.39
7.38
7.37
7.35
7.33
7.32
7.31
7.30
7.29
7.27
7.21
7.21
7.20
7.19
4.93
4.93
4.93
4.92
4.91
4.91
4.91
2.93
2.93
2.91
2.90
2.87
2.86
2.85
2.83
2.50
2.50
2.49
2.48
2.47
2.47
2.46
2.45
2.45
2.45
2.44
2.44
2.37
2.36
2.35
2.34
2.34
2.33
2.33
2.32
2.32
2.31
1.76
1.75
1.75
1.75
1.74
1.74
1.73
1.73
1.73

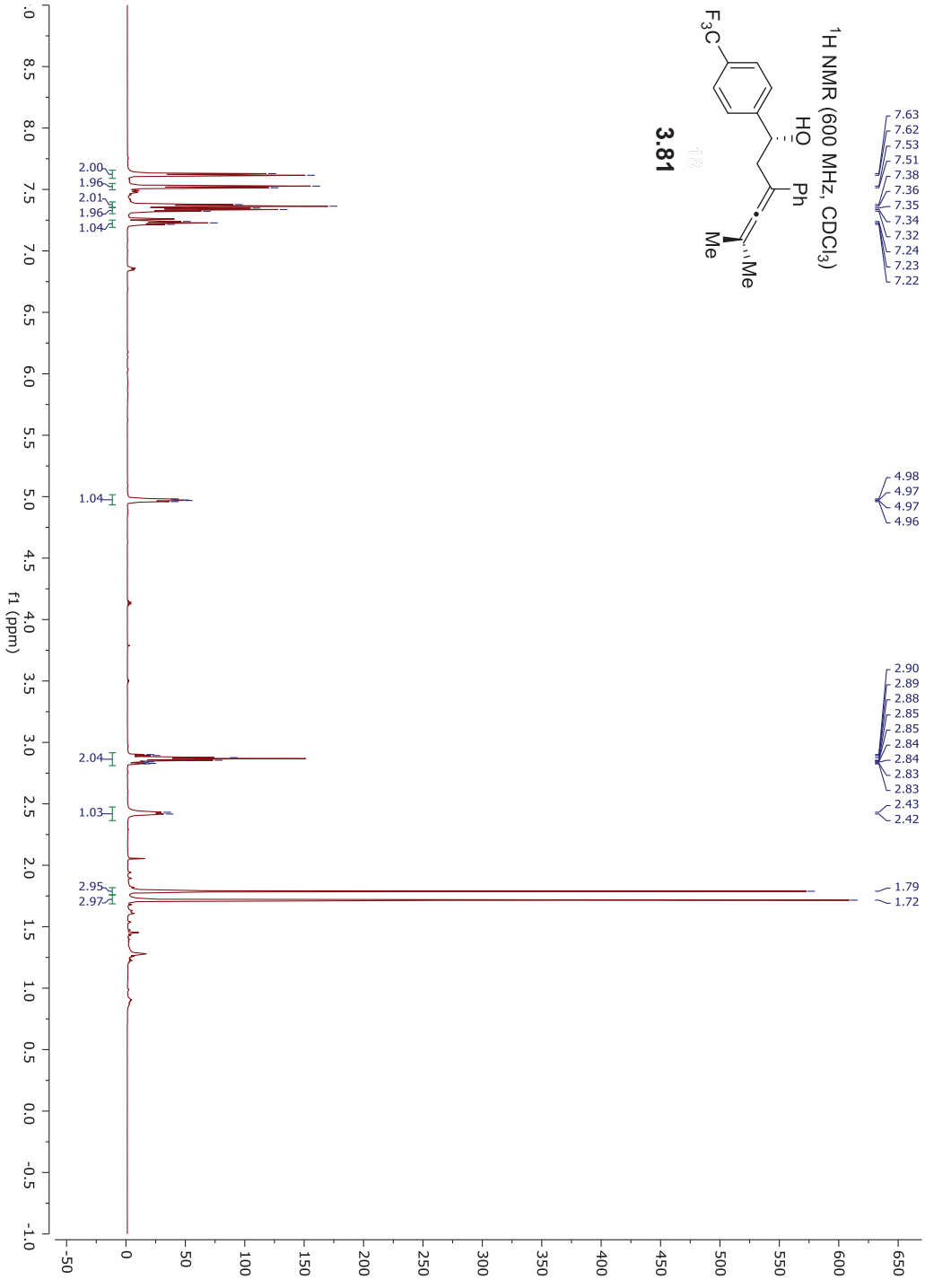

^{13}C NMR (151 MHz, CDCl$_3$)
3.78
Ph
HO
Ph
197.85
144.01
137.67
128.55
128.52
128.49
127.59
126.69
126.16
108.26
102.85
72.76
40.72
31.36
31.12
27.31
27.27
f1 (ppm)


3.79
Ph
HO
Ph
^{1}H NMR (500 MHz, CDCl$_3$)
7.42
7.41
7.40
7.38
7.36
7.35
7.34
7.32
7.30
7.30
7.28
7.27
7.26
7.22
7.20
7.19
4.95
4.93
4.92
2.91
2.90
2.88
2.87
2.87
2.86
2.84
2.83
2.36
2.35
2.25
2.24
2.22
2.21
2.20
2.18
2.17
2.16
2.15
2.13
2.12
2.10
2.09
2.08
1.70
1.68
1.67
1.66
1.65
1.64
1.63
1.62
1.60
1.59
1.58
1.57
1.56
3.46
4.91
1.00
0.97
1.91
0.98
2.76
1.01
6.04
f1 (ppm)


^{13}C NMR (151 MHz, CDCl$_3$)
3.79
HO
Ph
Ph
198.61
144.00
137.67
128.55
128.50
127.60
126.63
126.18
126.06
107.03
100.28
72.79
40.88
31.72
31.46
27.84
26.21
f1 (ppm)


3.80
MeO
HO
Ph
Me
Me
^{1}H NMR (600 MHz, CDCl$_3$)
7.40
7.39
7.34
7.33
7.32
6.91
6.90
4.88
4.87
4.86
3.82
2.91
2.90
2.89
2.88
2.87
2.87
2.85
2.84
2.38
1.77
1.74
pinacol
2.01
4.97
2.00
1.09
3.00
2.06
1.26
2.96
2.91
f1 (ppm)


13C NMR (151 MHz, CDCl3)
3.80
MeO
HO
Ph
Me
Me
202.45
159.06
137.62
136.19
131.70
128.45
128.31
127.42
126.59
126.13
113.83
100.37
99.28
72.39
55.38
40.37
20.54
20.24
pinacol
pinacol
f1 (ppm)


^{1}H NMR (600 MHz, CDCl$_3$)
3.81
F$_3$C
HO
Ph
Me
Me
7.63
7.62
7.53
7.51
7.38
7.36
7.35
7.34
7.32
7.24
7.23
7.22
4.98
4.97
4.97
4.96
2.90
2.89
2.88
2.85
2.85
2.84
2.84
2.83
2.83
2.43
2.42
1.79
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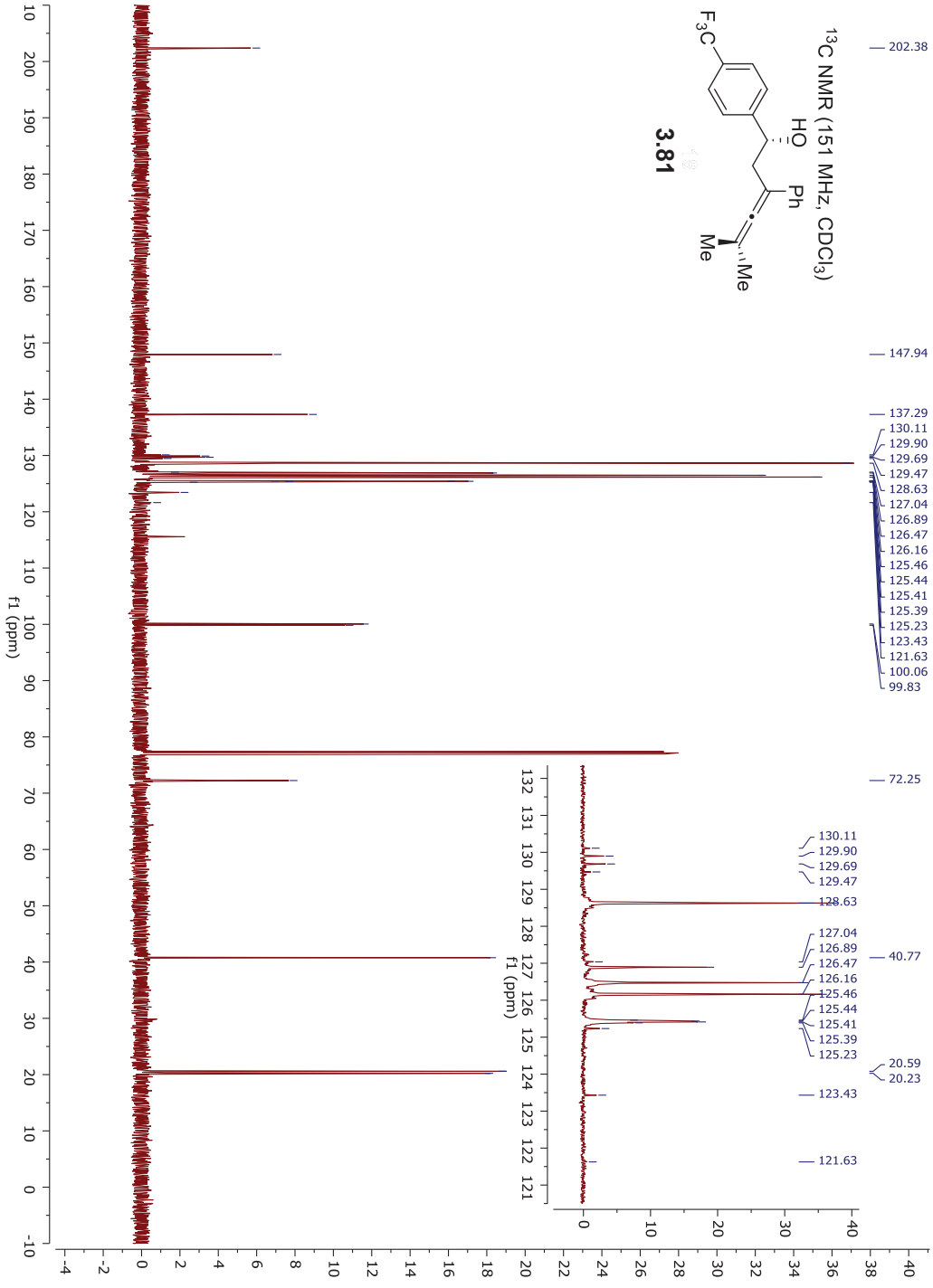
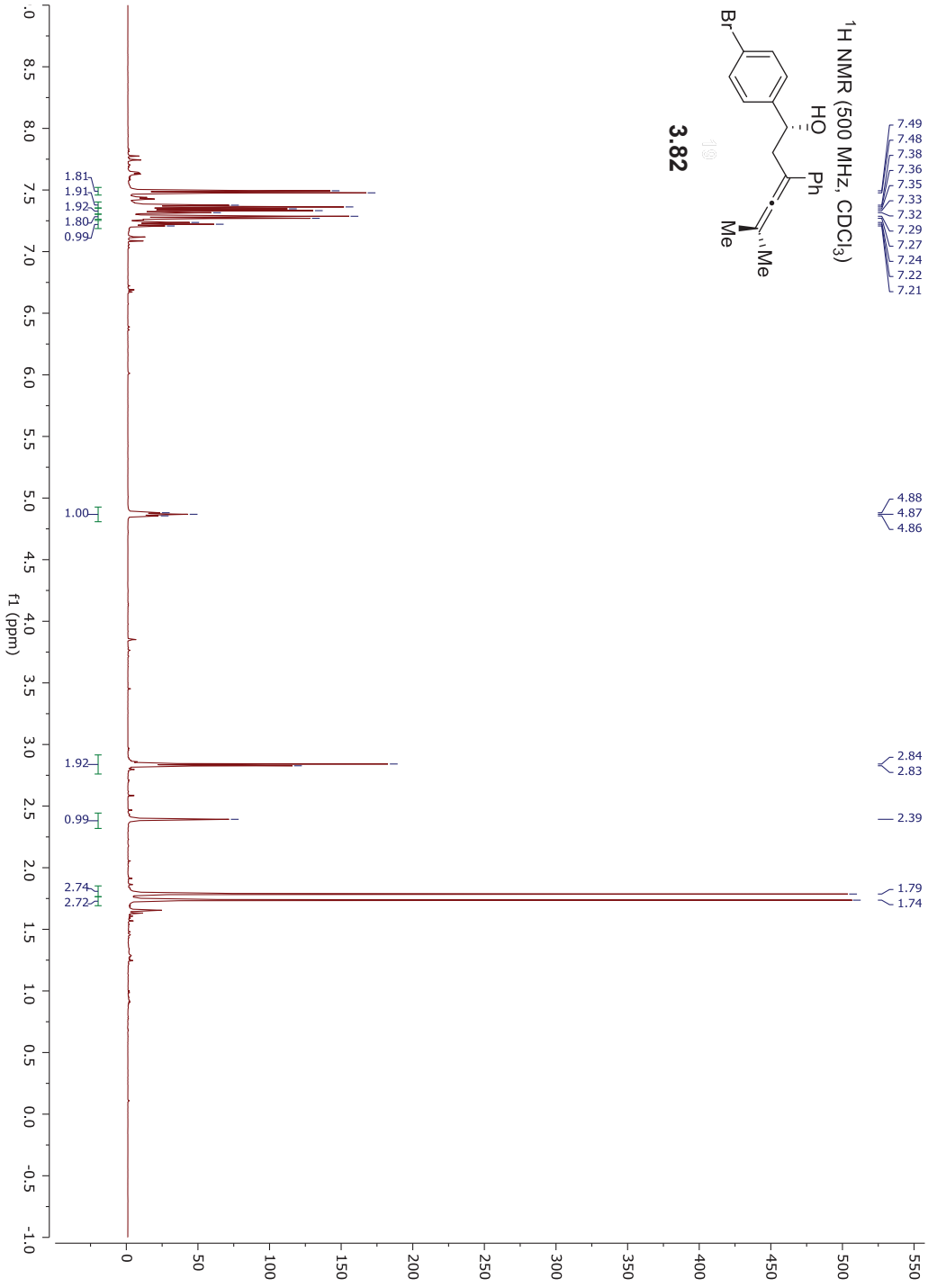
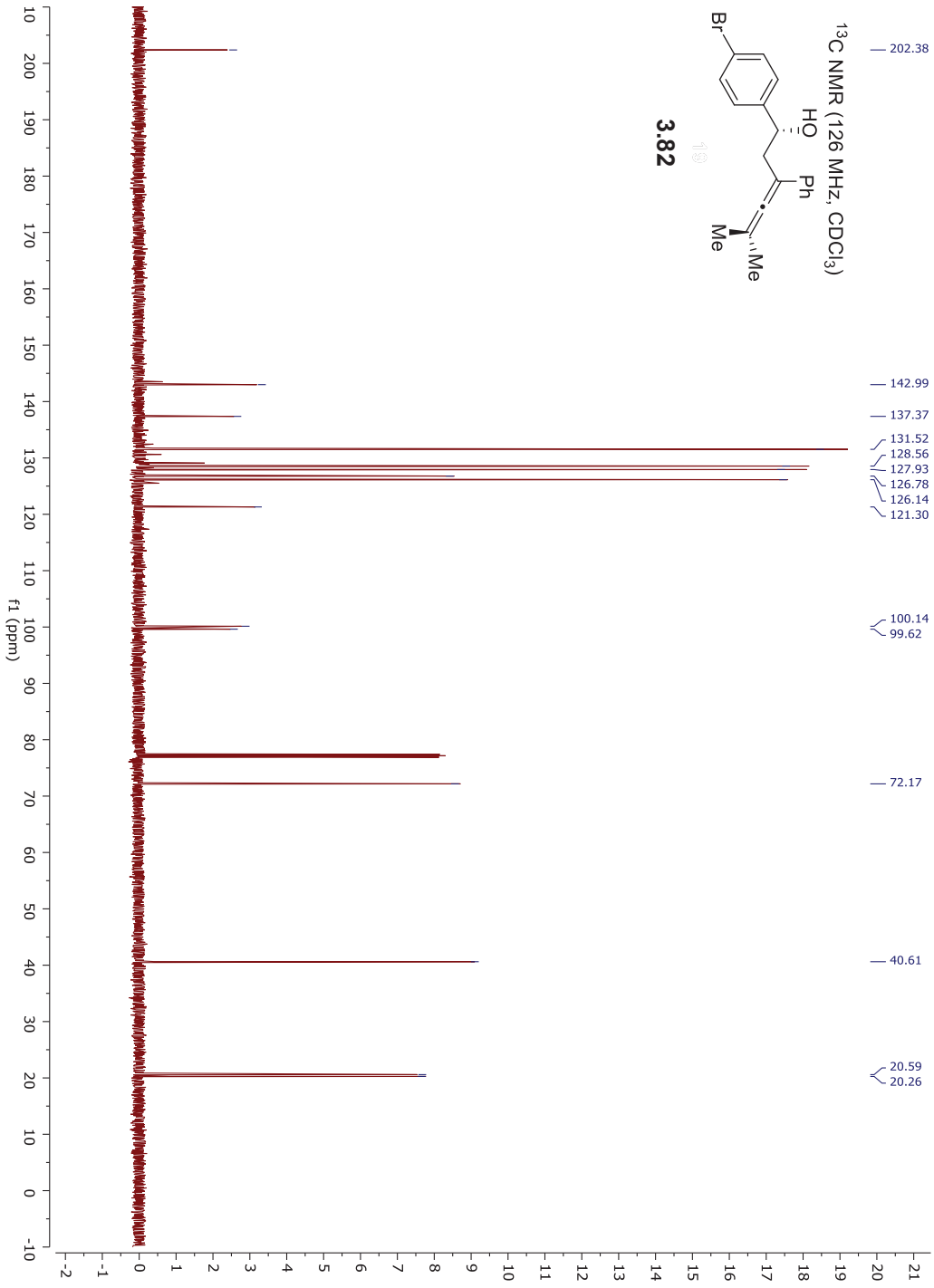
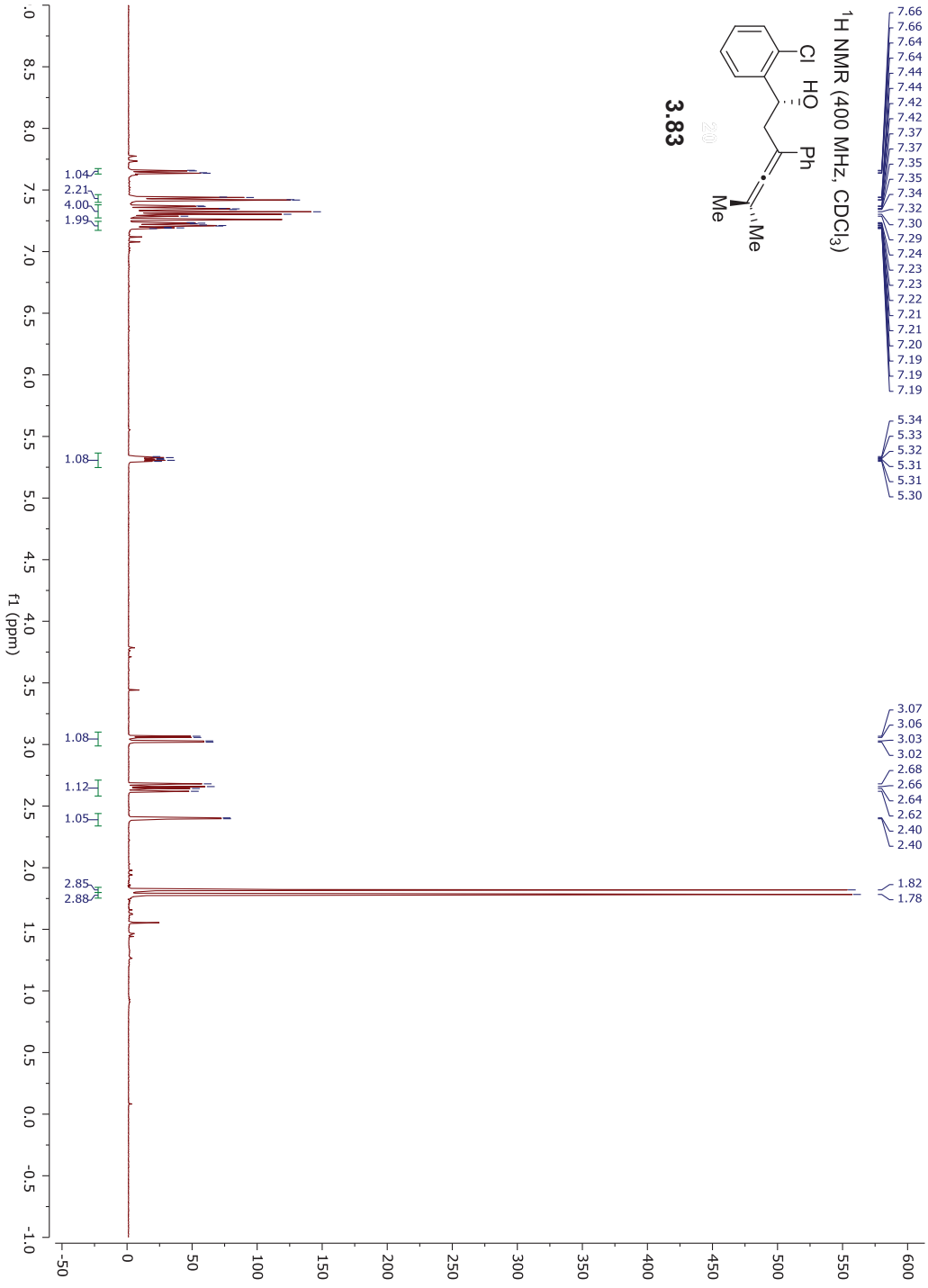
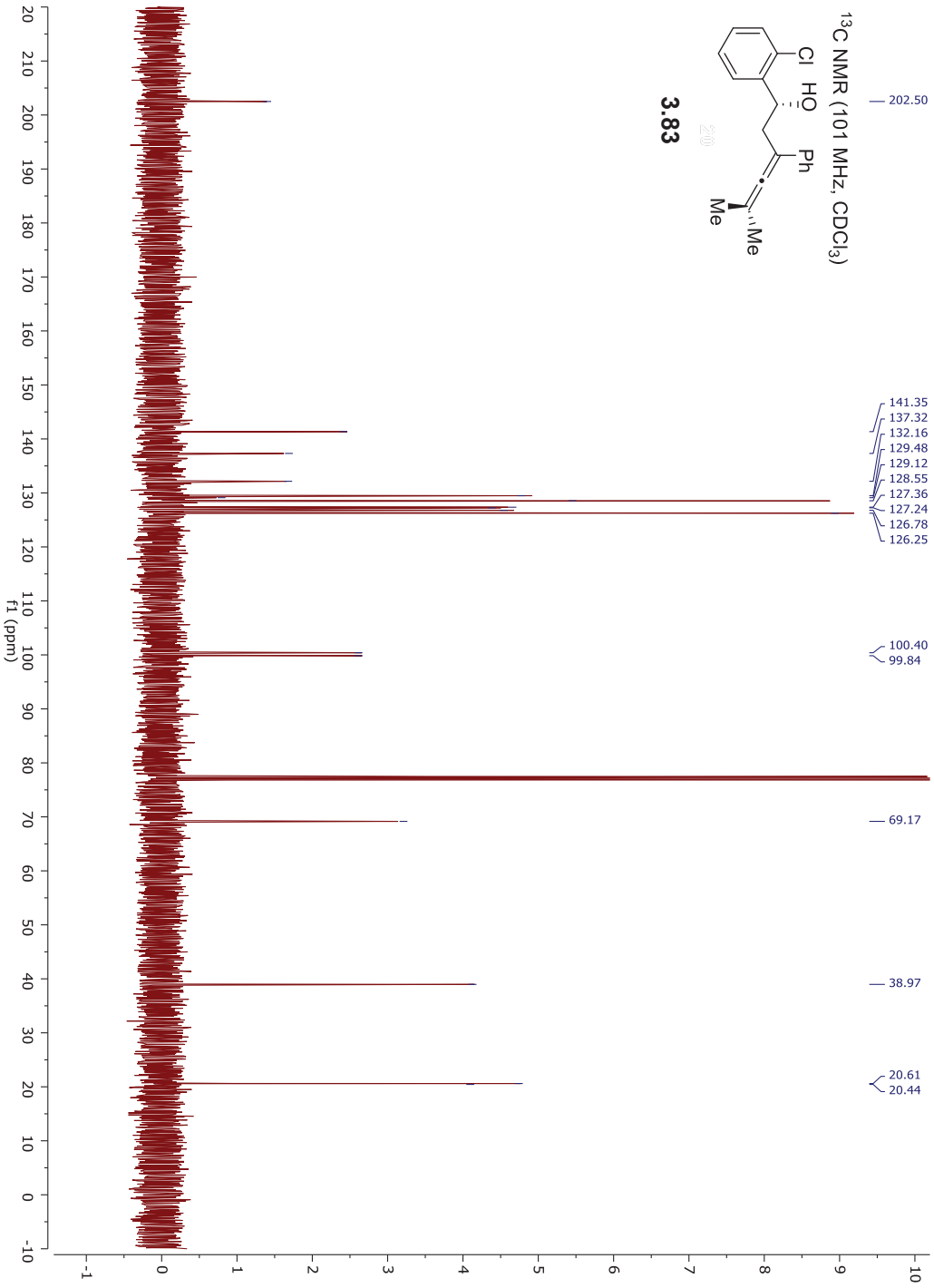
1.04
2.04
1.03
2.95
2.97
f1 (ppm)

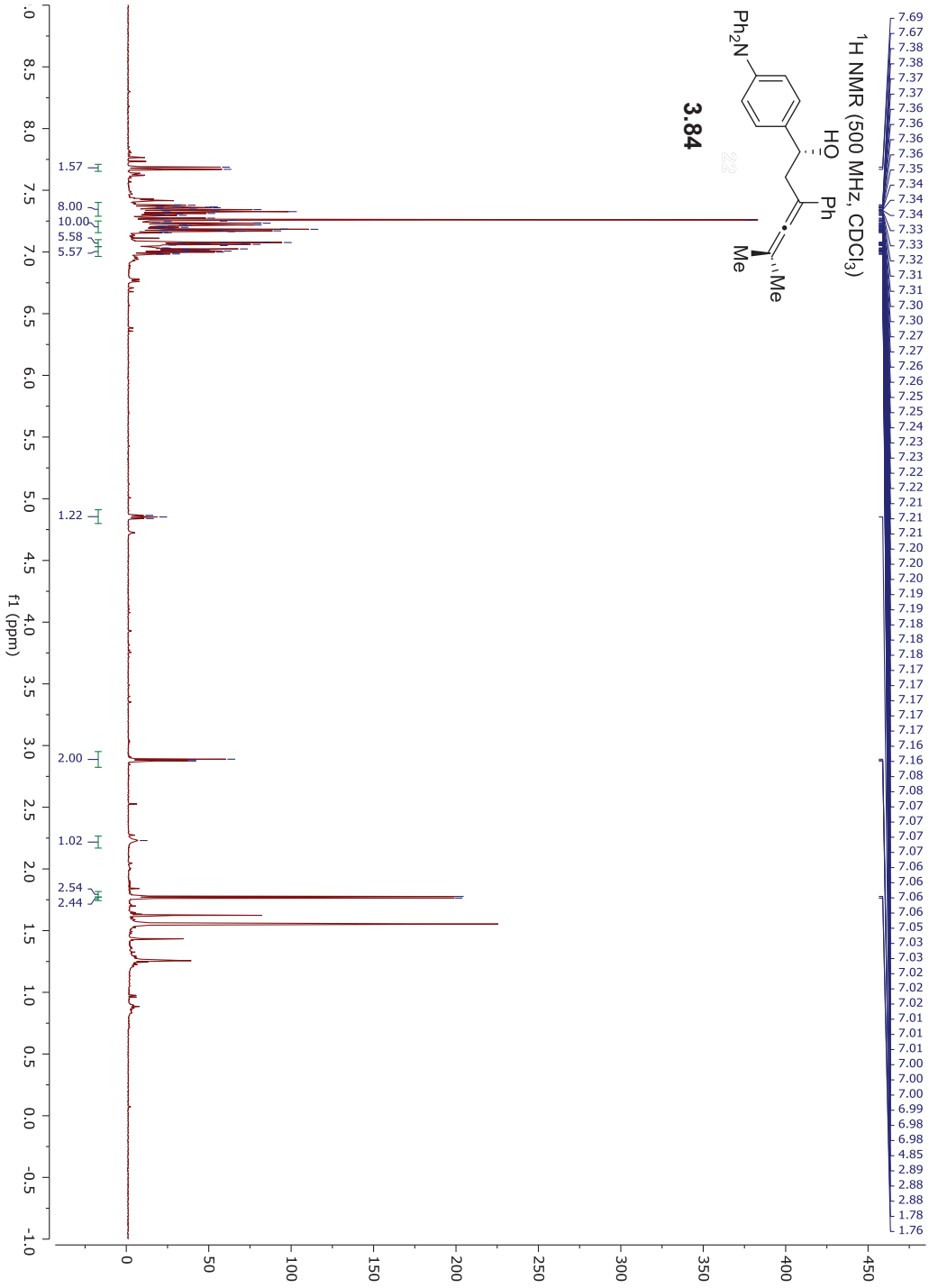

^{13}C NMR (151 MHz, CDCl$_3$)
3.81
F$_3$C
HO
Ph
Me
Me
202.38
147.94
137.29
130.11
129.90
129.69
129.47
128.63
127.04
126.89
126.47
126.16
125.46
125.44
125.41
125.39
125.23
123.43
121.63
100.06
99.83
72.25
40.77
20.59
20.23
f1 (ppm)

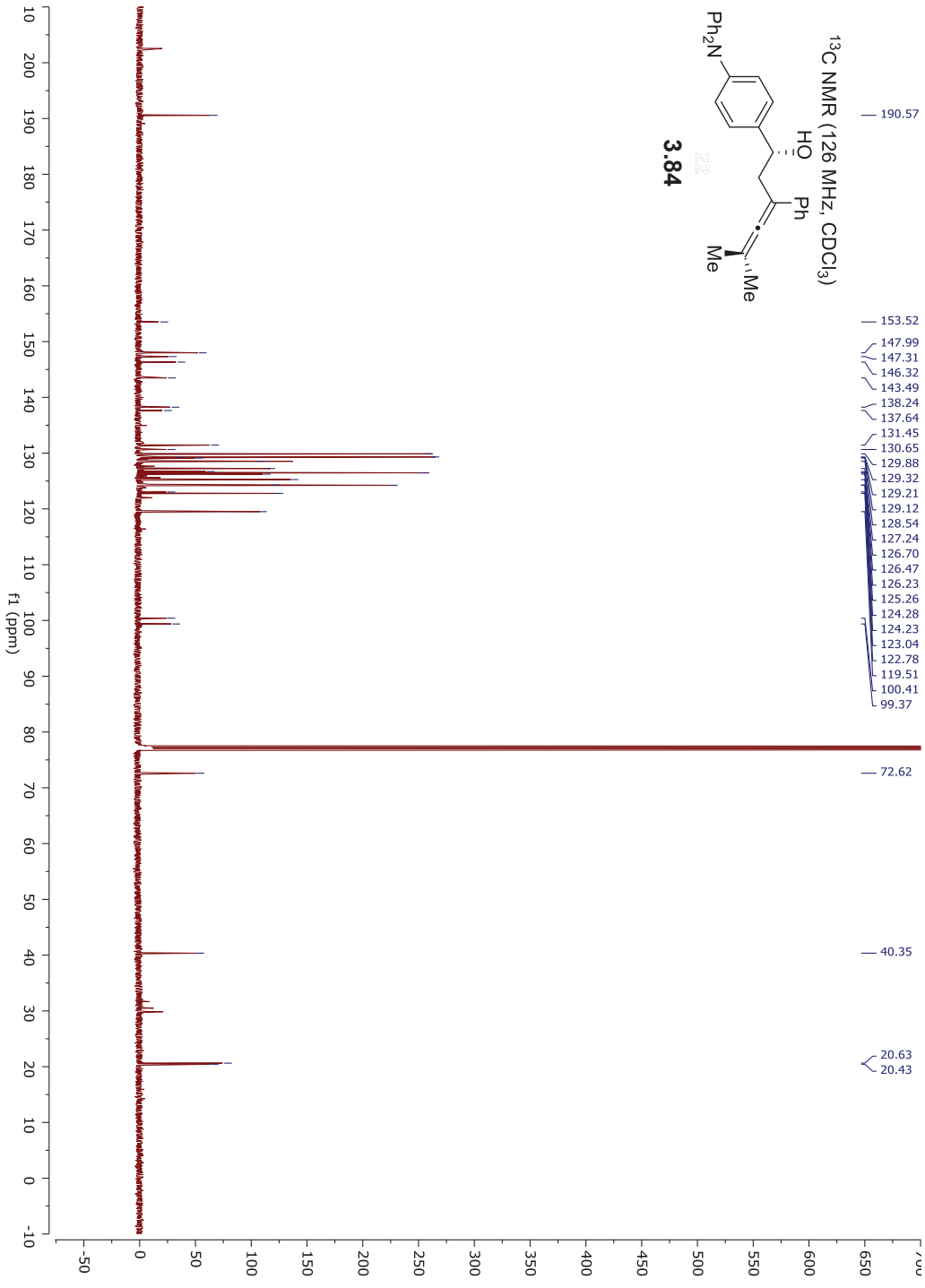

^{1}H NMR (500 MHz, CDCl$_3$)
3.82
Br
HO
Ph
Me
Me
7.49
7.48
7.38
7.36
7.35
7.33
7.32
7.29
7.27
7.24
7.22
7.21
4.88
4.87
4.86
2.84
2.83
2.39
1.79
1.74
1.81
1.91
1.92
1.80
0.99
1.00
1.92
0.99
2.74
2.72
f1 (ppm)

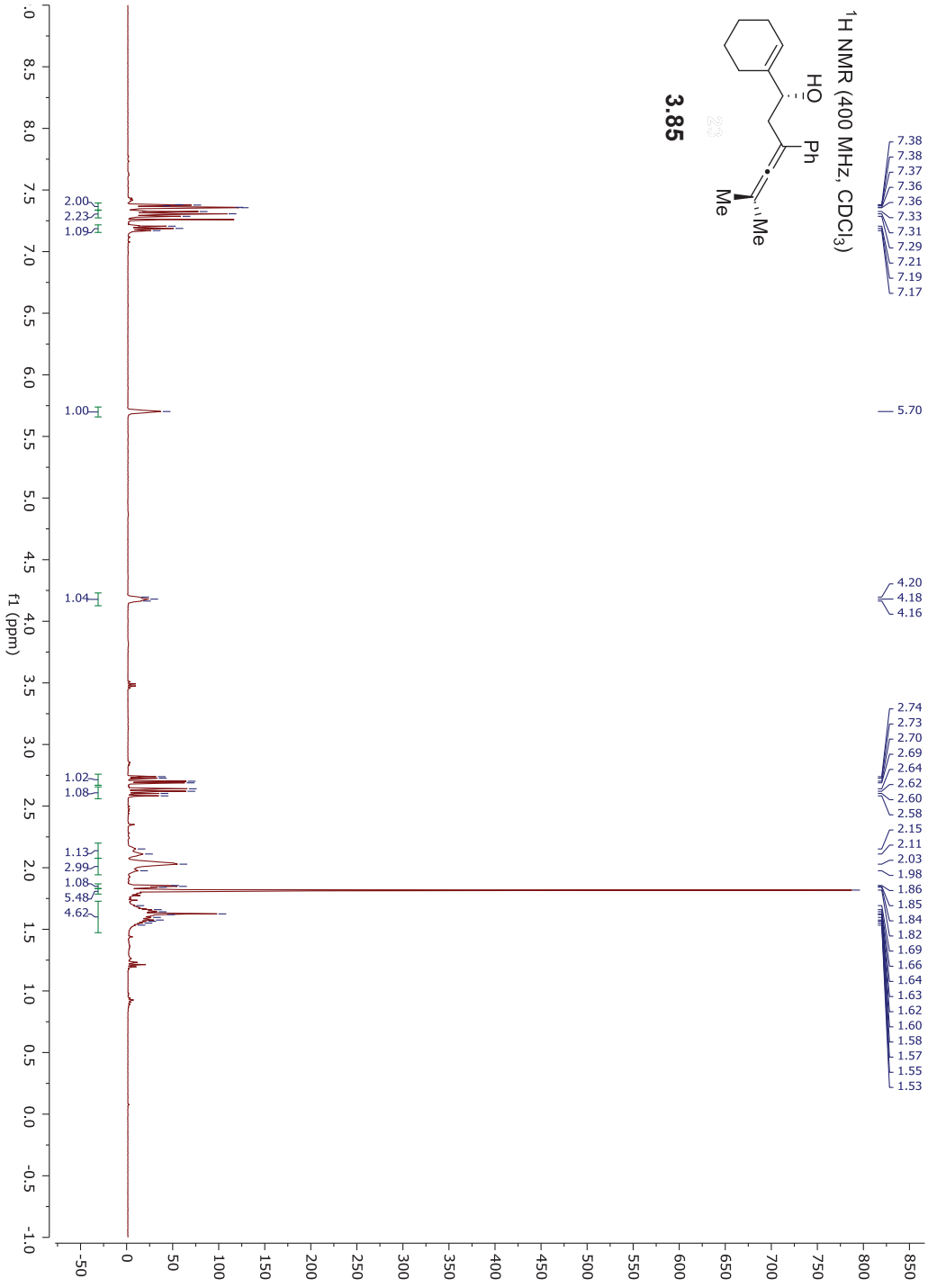

^{13}C NMR (126 MHz, CDCl$_3$)
3.82
Br
HO
Ph
Me
Me
202.38
142.99
137.37
131.52
128.56
127.93
126.78
126.14
121.30
100.14
99.62
72.17
40.61
20.59
20.26
f1 (ppm)

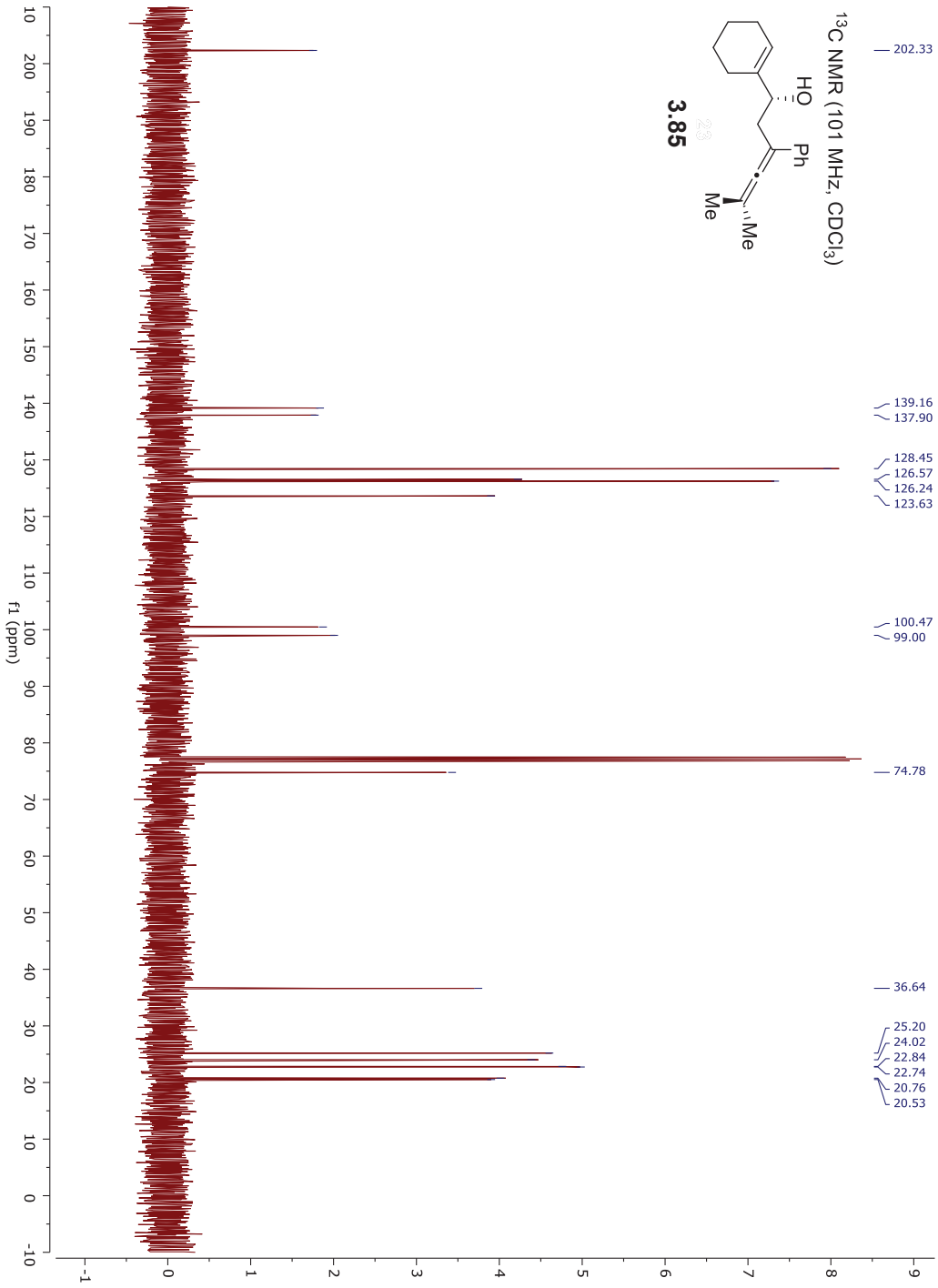

^{1}H NMR (400 MHz, CDCl$_3$)
3.83
Cl
HO
Ph
Me
Me
7.66
7.66
7.64
7.64
7.44
7.44
7.42
7.42
7.37
7.37
7.35
7.35
7.34
7.32
7.30
7.29
7.24
7.23
7.23
7.22
7.21
7.21
7.20
7.19
7.19
7.19
5.34
5.33
5.32
5.31
5.31
5.30
3.07
3.06
3.03
3.02
2.68
2.66
2.64
2.62
2.40
2.40
1.82
1.78
1.04
2.21
4.00
1.99
1.08
1.08
1.12
1.05
2.85
2.88
f1 (ppm)

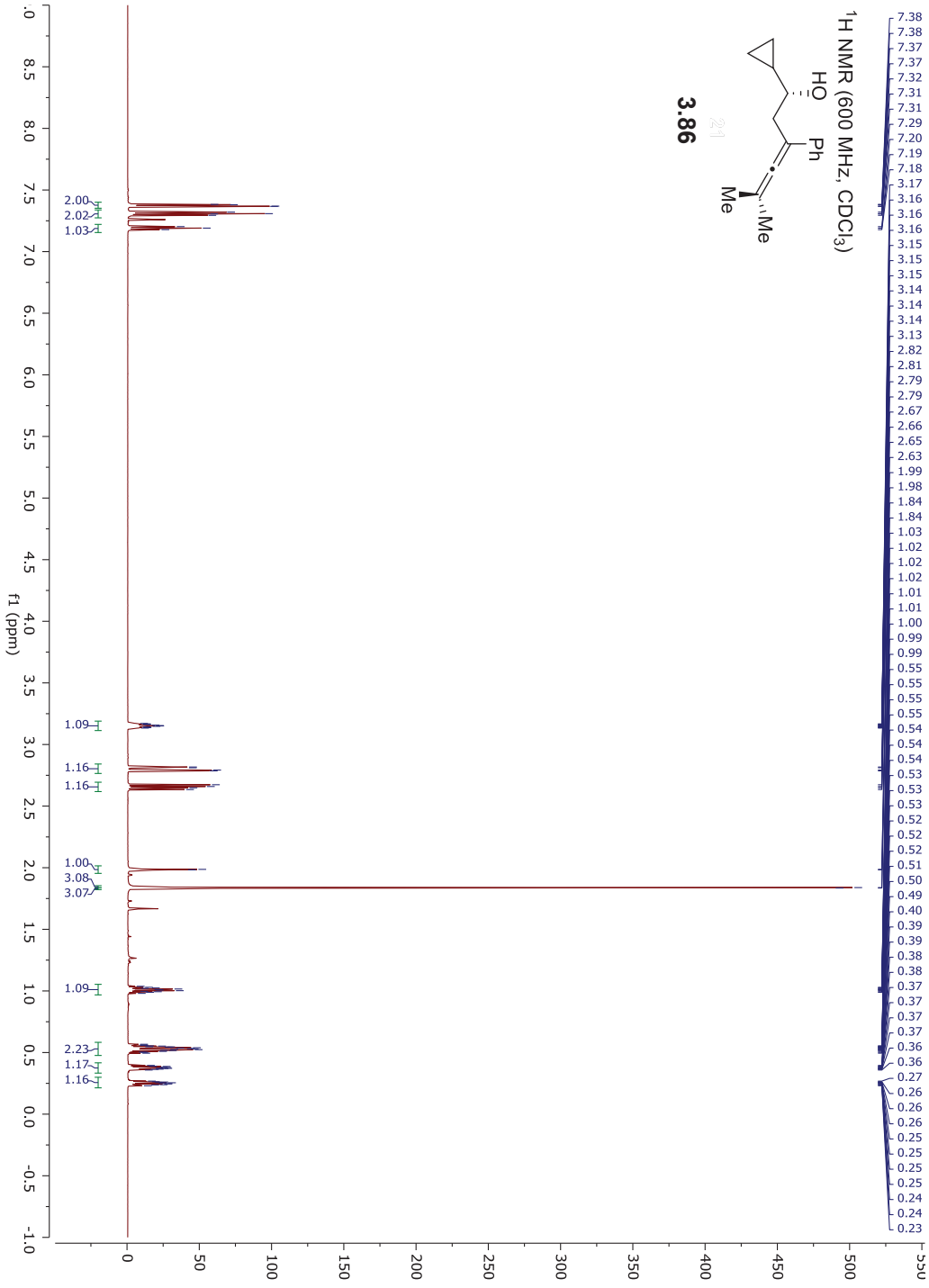

^{13}C NMR (101 MHz, CDCl$_3$)
3.83
Cl
HO
Ph
Me
Me
202.50
141.35
137.32
132.16
129.48
129.12
128.55
127.36
127.24
126.78
126.25
100.40
99.84
69.17
38.97
20.61
20.44
f1 (ppm)

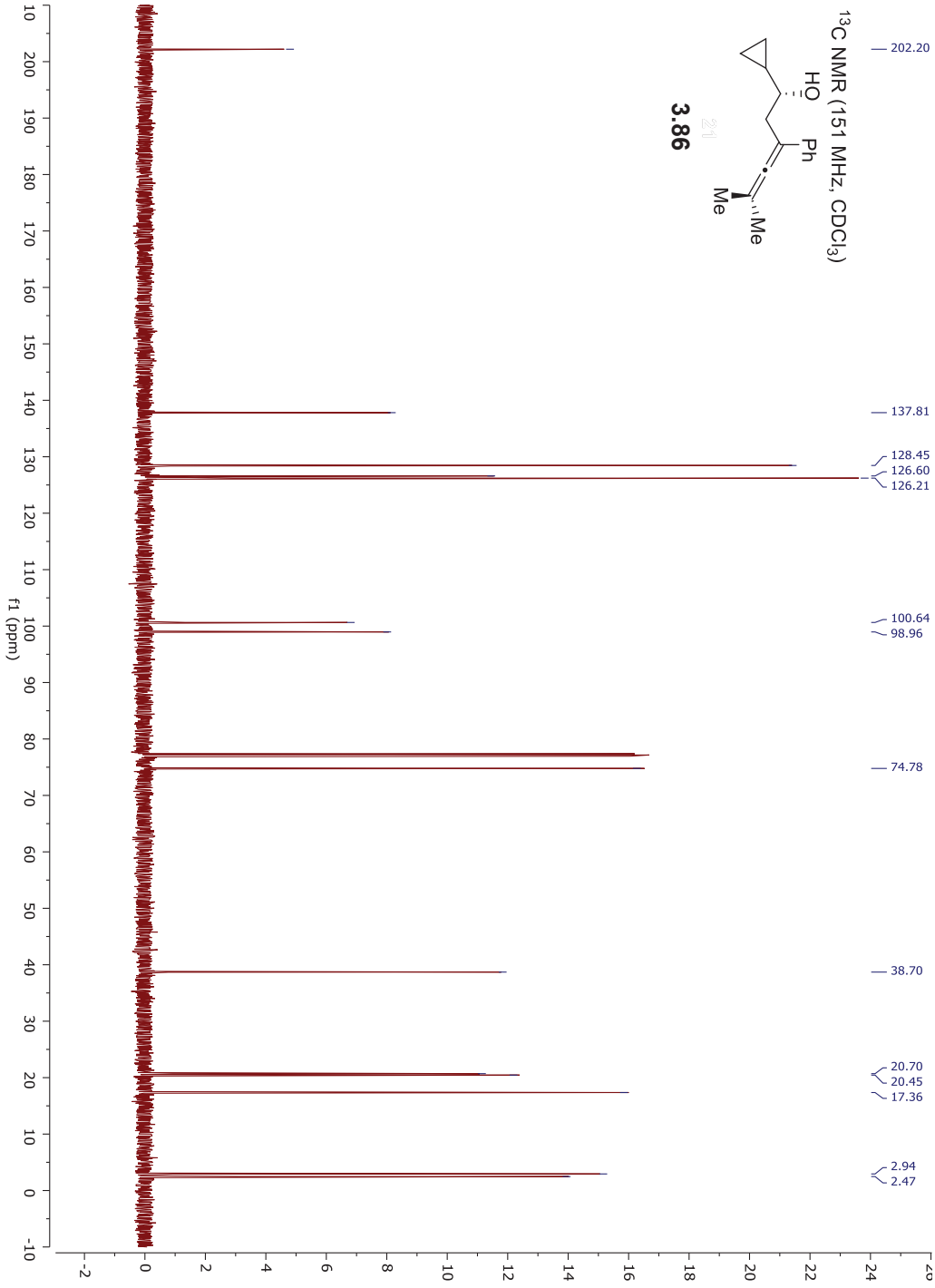

3.84
Ph2N
HO
Ph
Me
Me
22
1H NMR (500 MHz, CDCl3)
f1 (ppm)
1.57
8.00
10.00
5.58
5.57
1.22
2.00
1.02
2.54
2.44

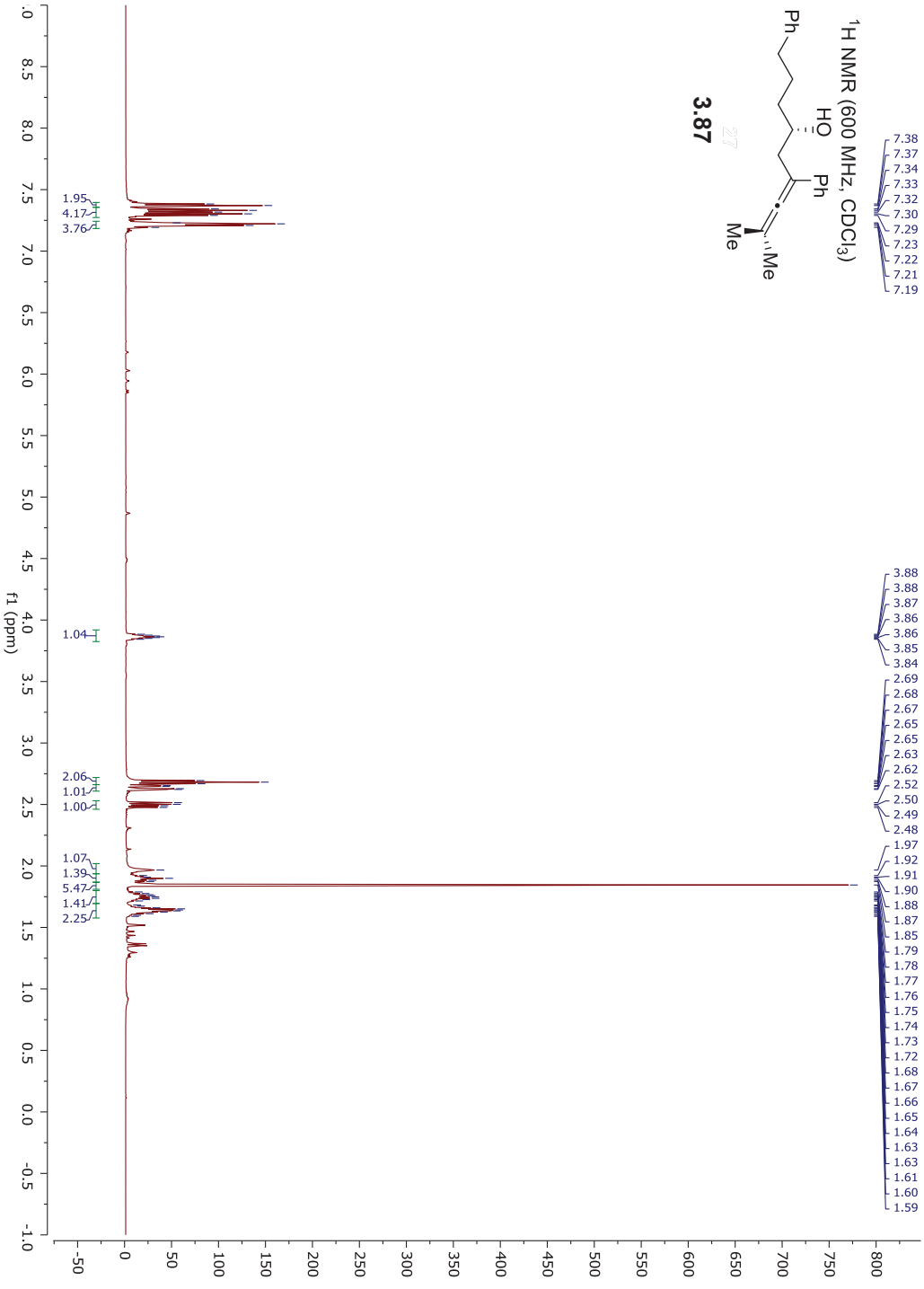

^{13}C NMR (126 MHz, CDCl$_3$)
Ph$_2$N
HO
Ph
Me
Me
3.84
190.57
153.52
147.99
147.31
146.32
143.49
138.24
137.64
131.45
130.65
129.88
129.32
129.21
129.12
128.54
127.24
126.70
126.47
126.23
125.26
124.28
124.23
123.04
122.78
119.51
100.41
99.37
72.62
40.35
20.63
20.43
f1 (ppm)

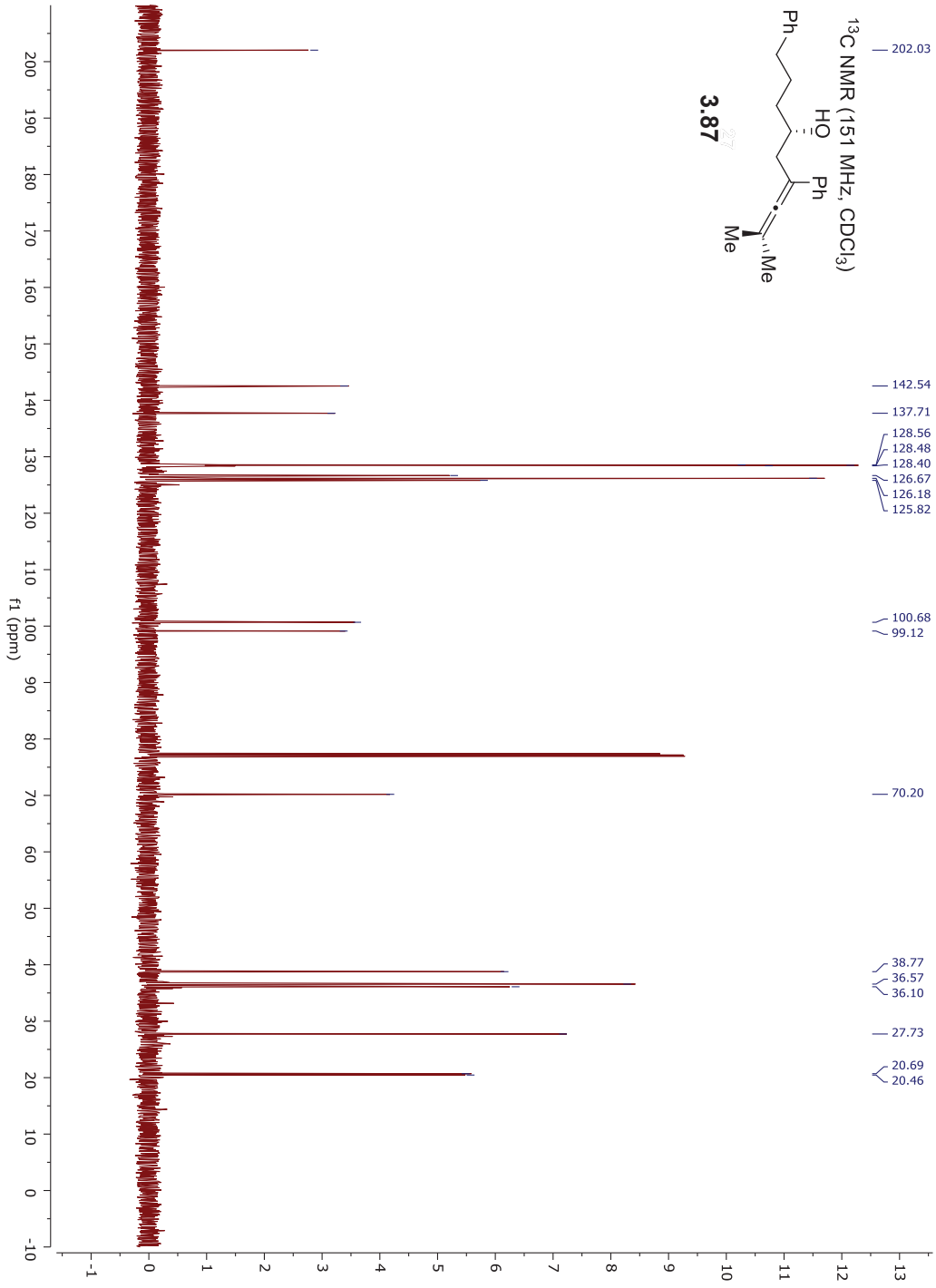

3.85
HO
Ph
Me
Me
^{1}H NMR (400 MHz, CDCl$_3$)
7.38
7.38
7.37
7.36
7.36
7.33
7.31
7.29
7.21
7.19
7.17
5.70
4.20
4.18
4.16
2.74
2.73
2.70
2.69
2.64
2.62
2.60
2.58
2.15
2.11
2.03
1.98
1.86
1.85
1.84
1.82
1.69
1.66
1.64
1.63
1.62
1.60
1.58
1.57
1.55
1.53
2.00
2.23
1.09
1.00
1.04
1.02
1.08
1.13
2.99
1.08
5.48
4.62
f1 (ppm)

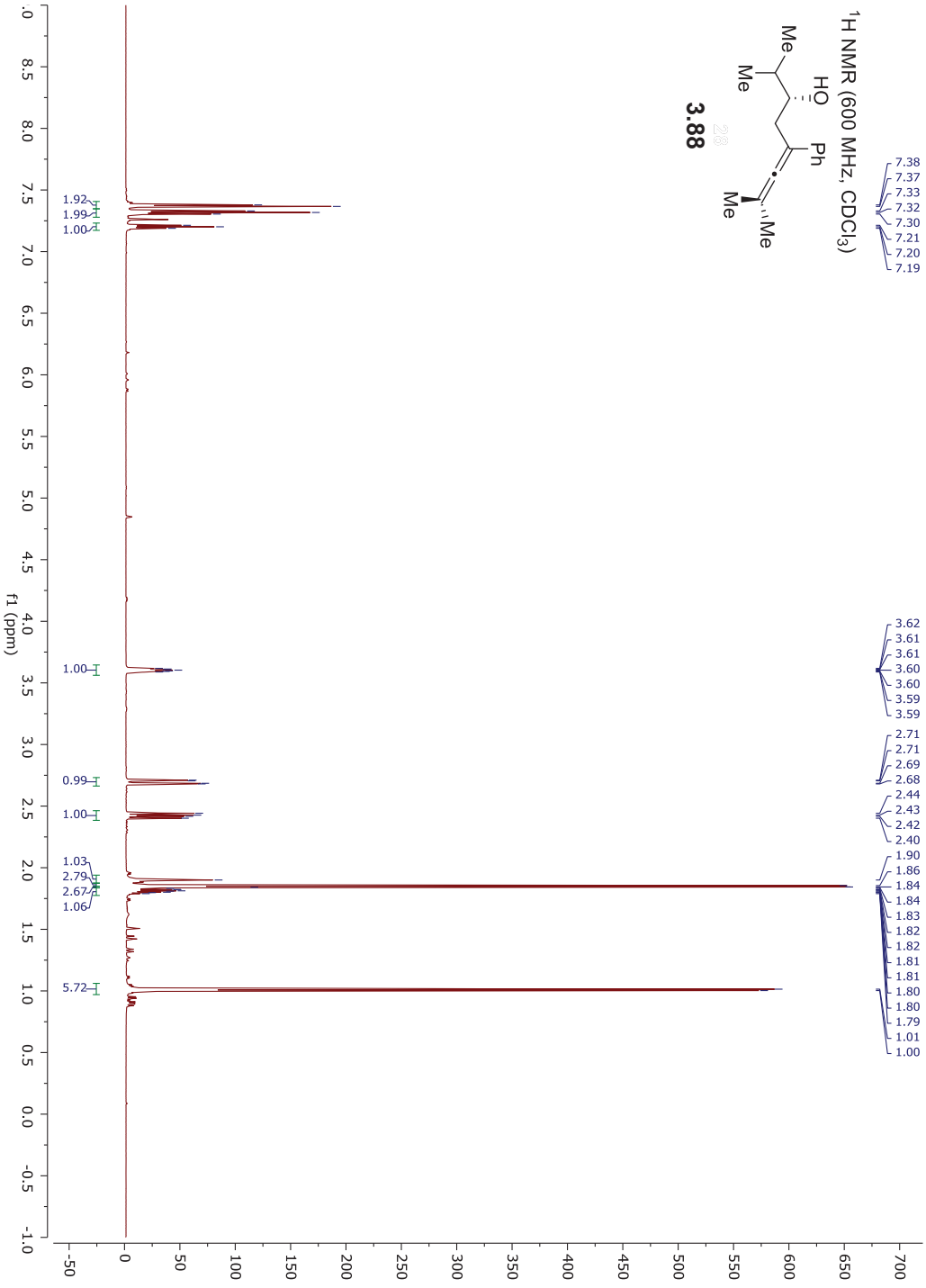

^{13}C NMR (101 MHz, CDCl$_3$)
3.85
HO
Ph
Me
Me
202.33
139.16
137.90
128.45
126.57
126.24
123.63
100.47
99.00
74.78
36.64
25.20
24.02
22.84
22.74
20.76
20.53
f1 (ppm)

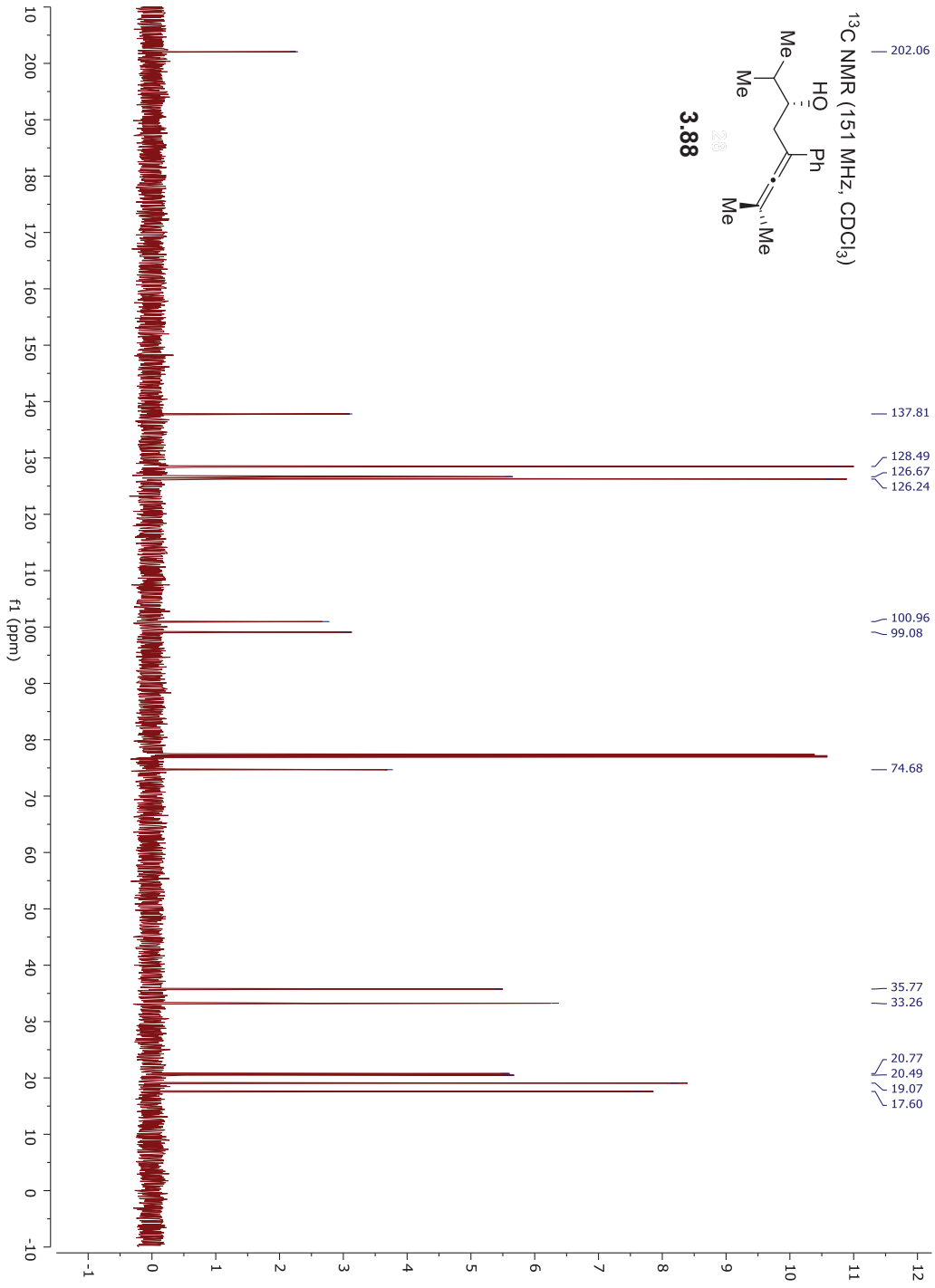

^{1}H NMR (600 MHz, CDCl$_3$)
3.86
HO
Ph
Me
Me
f1 (ppm)

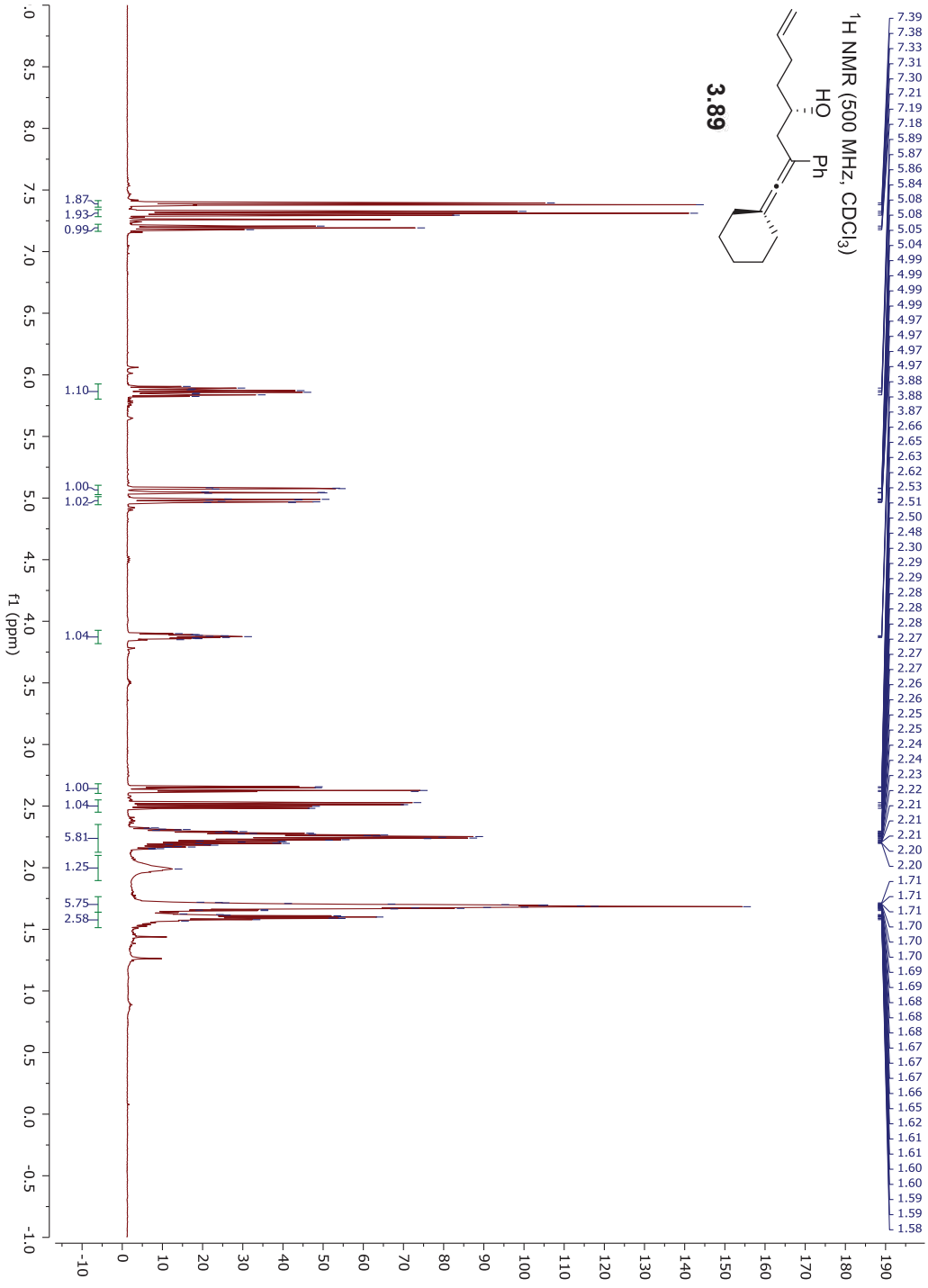

^{13}C NMR (151 MHz, CDCl$_3$)
3.86
HO
Ph
Me
Me
202.20
137.81
128.45
126.60
126.21
100.64
98.96
74.78
38.70
20.70
20.45
17.36
2.94
2.47
f1 (ppm)

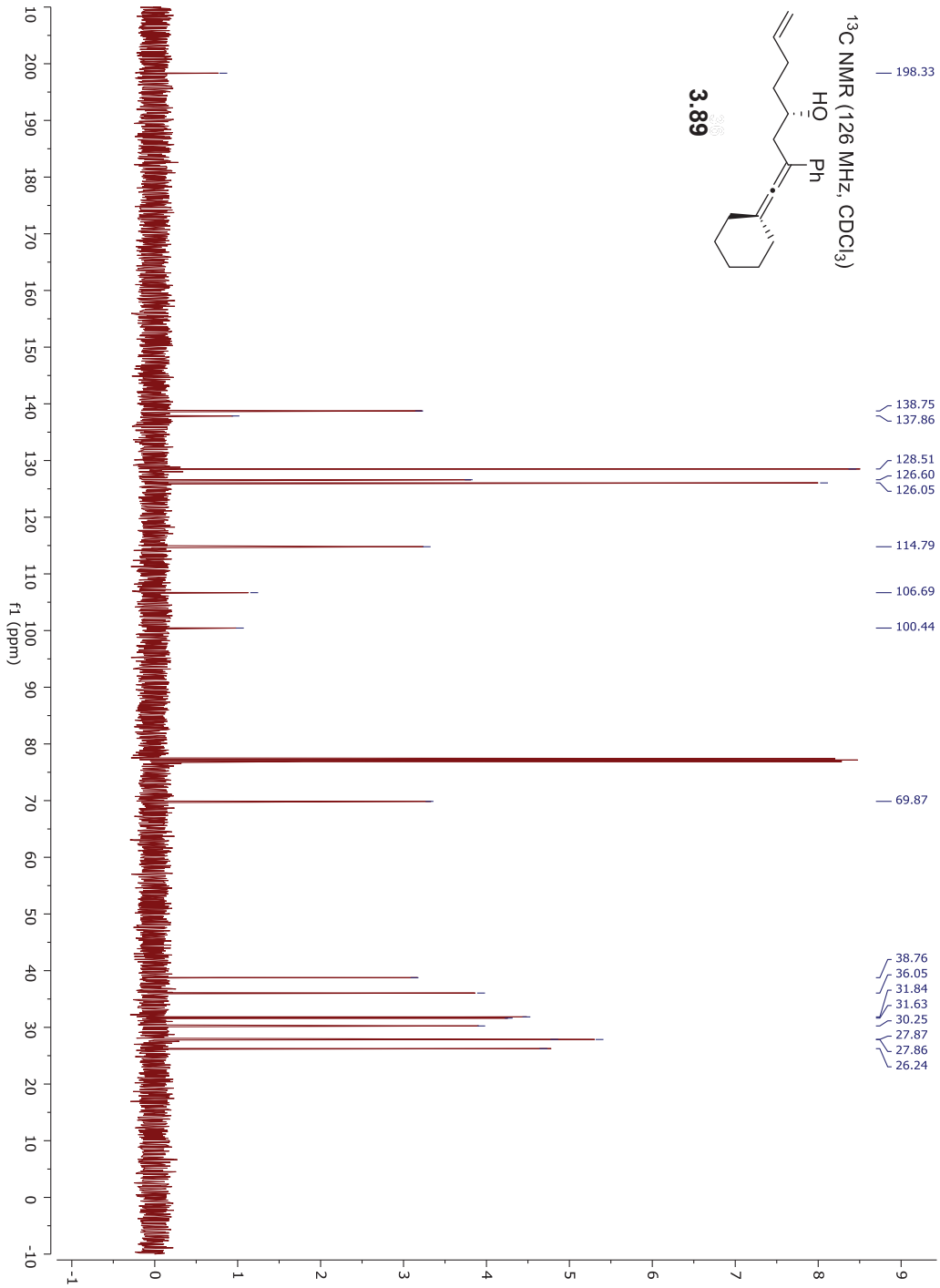

^{1}H NMR (600 MHz, CDCl$_3$)
3.87
Ph
HO
Ph
Me
Me
f1 (ppm)
1.95
4.17
3.76
1.04
2.06
1.01
1.00
1.07
1.39
5.47
1.41
2.25
7.38
7.37
7.34
7.33
7.32
7.30
7.29
7.23
7.22
7.21
7.19
3.88
3.88
3.87
3.86
3.86
3.85
3.84
2.69
2.68
2.67
2.65
2.65
2.63
2.62
2.52
2.50
2.49
2.48
1.97
1.92
1.91
1.90
1.88
1.87
1.85
1.79
1.78
1.77
1.76
1.75
1.74
1.73
1.72
1.68
1.67
1.66
1.65
1.64
1.63
1.63
1.61
1.60
1.59

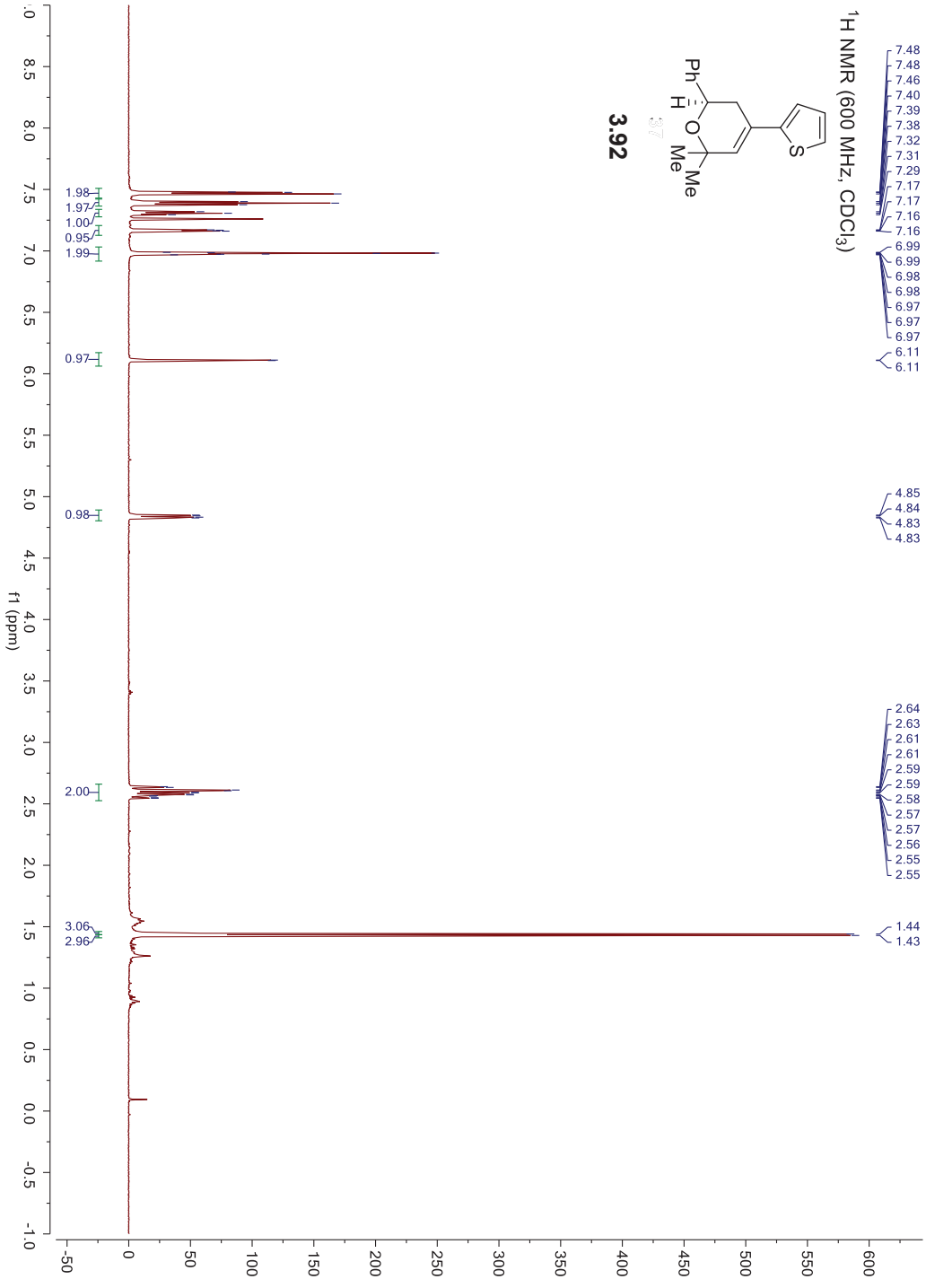

^{13}C NMR (151 MHz, CDCl$_3$)
3.87
Ph
HO
Ph
Me
Me
202.03
142.54
137.71
128.56
128.48
128.40
126.67
126.18
125.82
100.68
99.12
70.20
38.77
36.57
36.10
27.73
20.69
20.46
f1 (ppm)

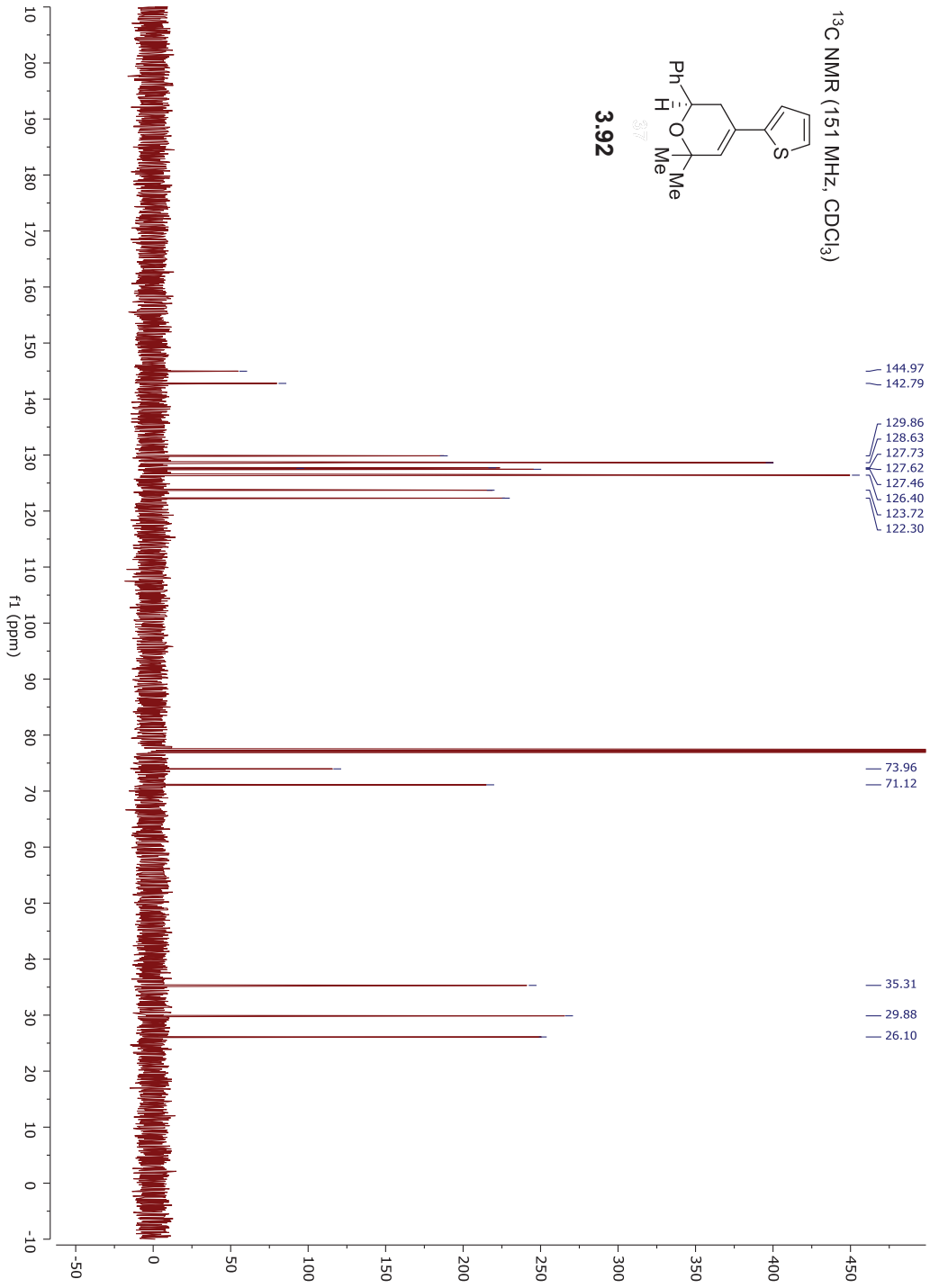

^{1}H NMR (600 MHz, CDCl$_3$)
3.88
Me
Me
HO
Ph
Me
Me
7.38
7.37
7.33
7.32
7.30
7.21
7.20
7.19
3.62
3.61
3.61
3.60
3.60
3.59
3.59
2.71
2.71
2.69
2.68
2.44
2.43
2.42
2.40
1.90
1.86
1.84
1.84
1.83
1.82
1.82
1.81
1.81
1.80
1.80
1.79
1.01
1.00
1.92
1.99
1.00
1.00
0.99
1.00
1.03
2.79
2.67
1.06
5.72
f1 (ppm)

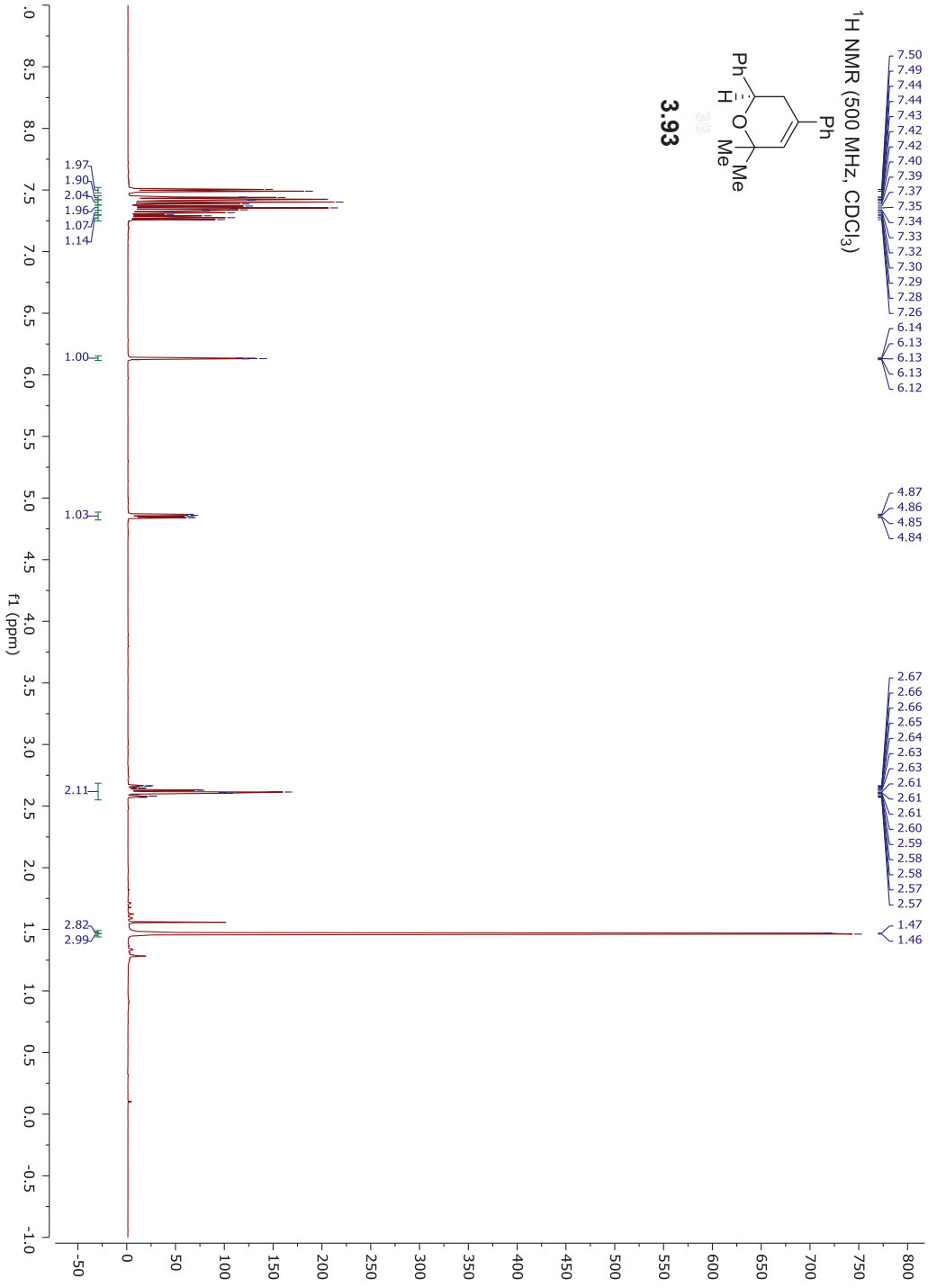

^{13}C NMR (151 MHz, CDCl$_3$)
3.88
Me
Me
HO
Ph
Me
Me
202.06
137.81
128.49
126.67
126.24
100.96
99.08
74.68
35.77
33.26
20.77
20.49
19.07
17.60
f1 (ppm)

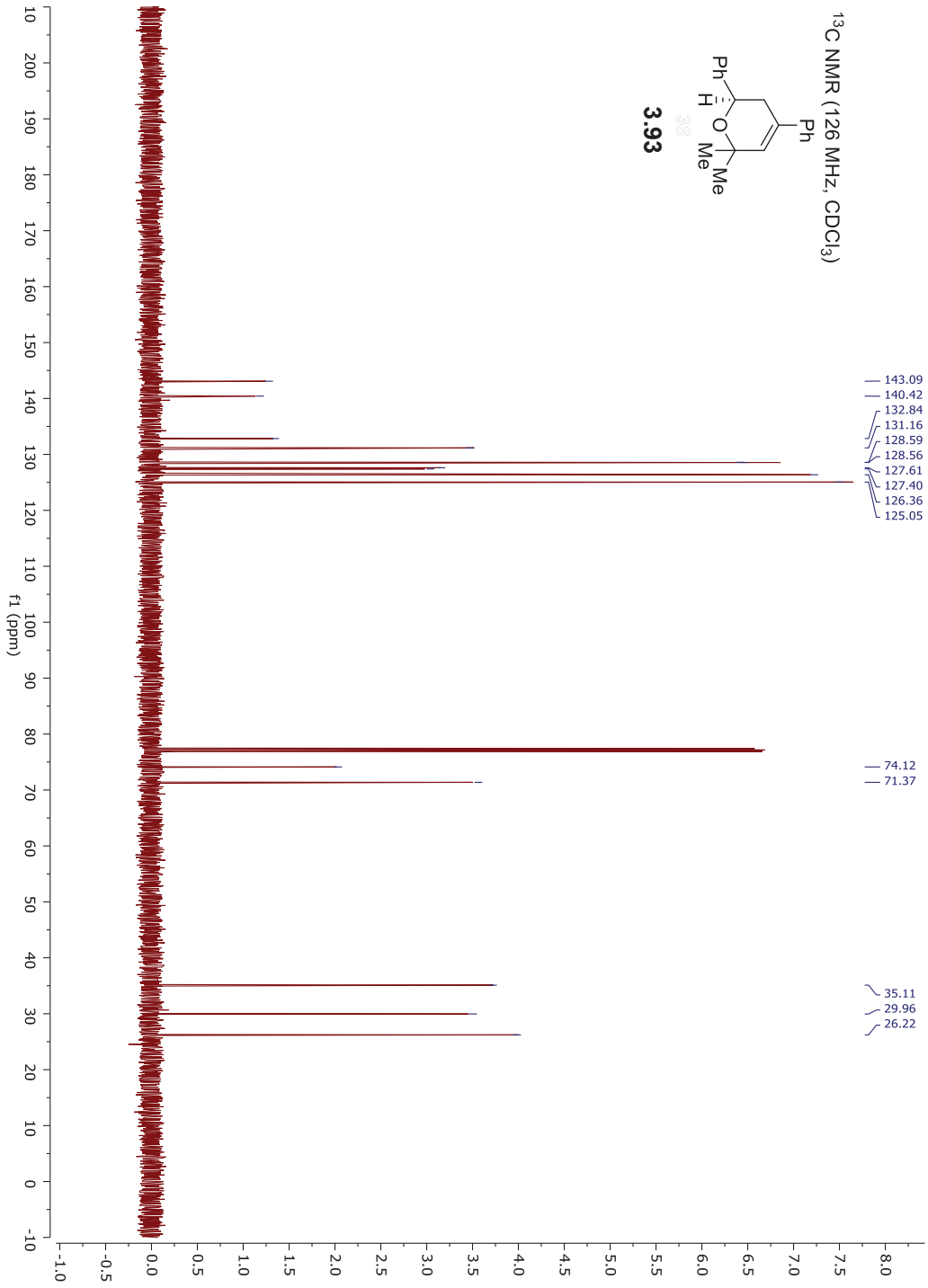

3.89
HO
Ph
^{1}H NMR (500 MHz, CDCl$_3$)
f1 (ppm)
1.87
1.93
0.99
1.10
1.00
1.02
1.04
1.00
1.04
5.81
1.25
5.75
2.58

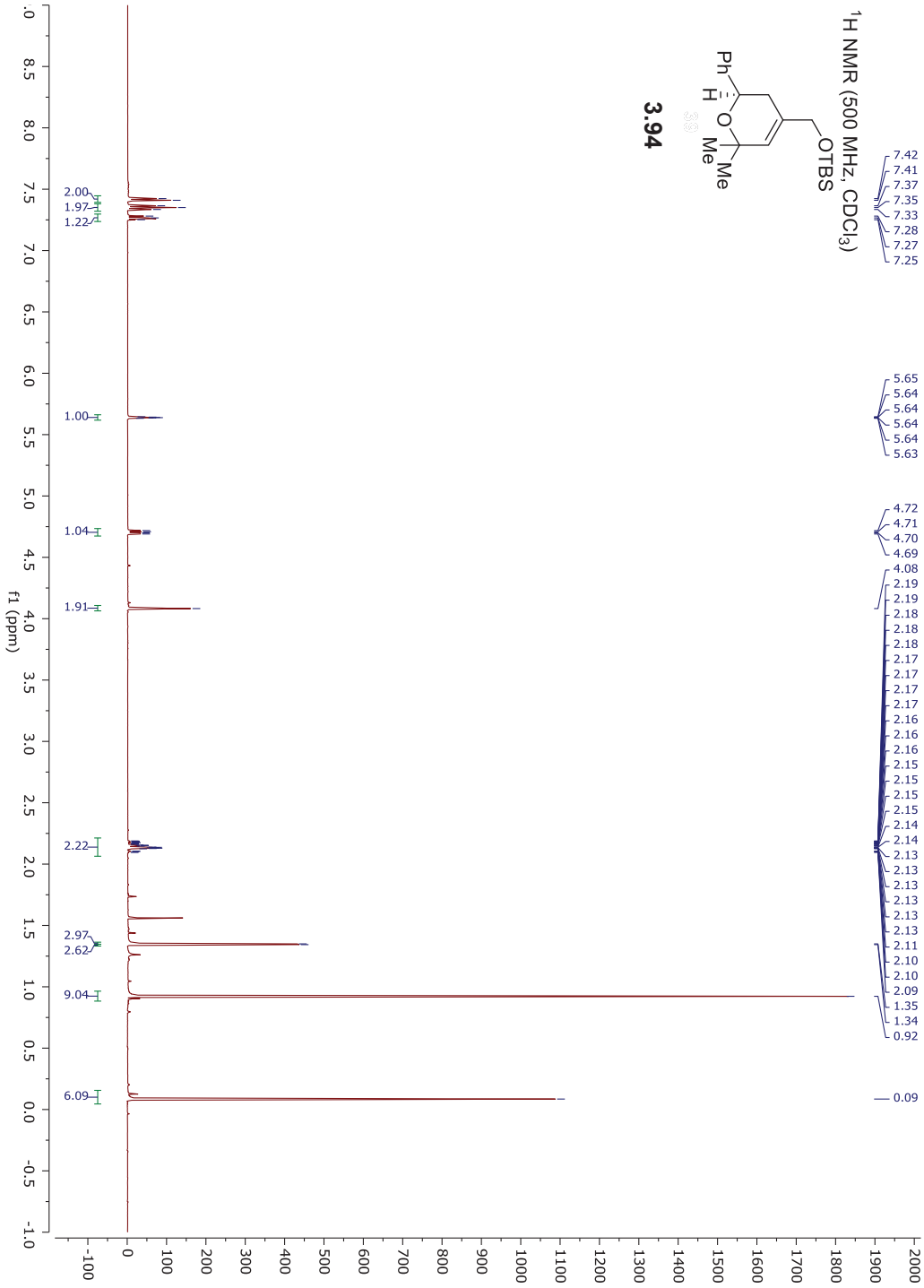

^{13}C NMR (126 MHz, CDCl$_3$)
3.89
HO
Ph
198.33
138.75
137.86
128.51
126.60
126.05
114.79
106.69
100.44
69.87
38.76
36.05
31.84
31.63
30.25
27.87
27.86
26.24
f1 (ppm)

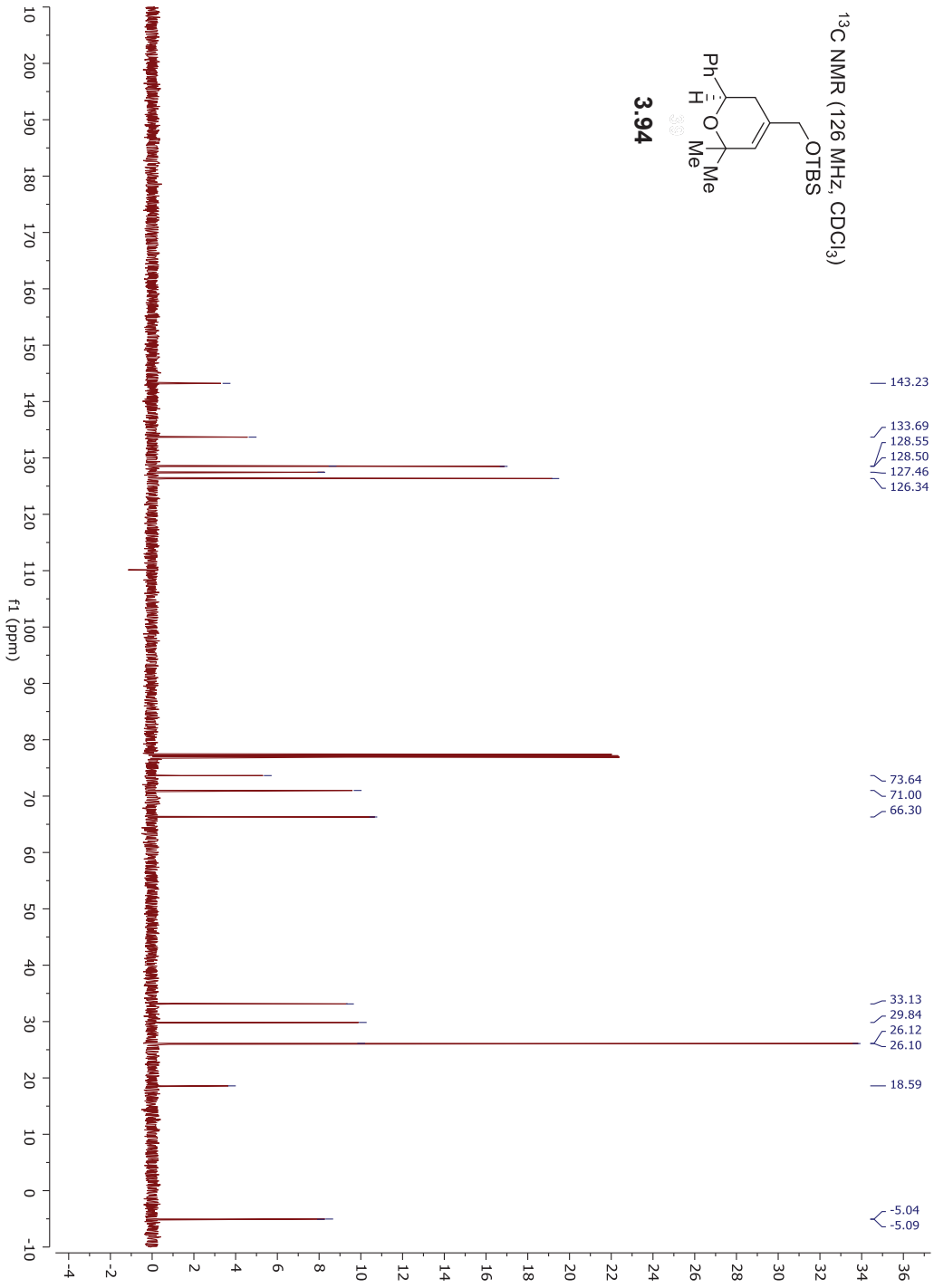

3.92
Ph
H
O
Me
Me
S
^{1}H NMR (600 MHz, CDCl$_3$)
7.48
7.48
7.46
7.40
7.39
7.38
7.32
7.31
7.29
7.17
7.17
7.16
7.16
6.99
6.99
6.98
6.98
6.97
6.97
6.97
6.11
6.11
4.85
4.84
4.83
4.83
2.64
2.63
2.61
2.61
2.59
2.59
2.58
2.57
2.57
2.56
2.55
2.55
1.44
1.43
1.98
1.97
1.00
0.95
1.99
0.97
0.98
2.00
3.06
2.96
f1 (ppm)


^{13}C NMR (151 MHz, CDCl$_3$)
3.92
Ph
H
O
Me
Me
S
144.97
142.79
129.86
128.63
127.73
127.62
127.46
126.40
123.72
122.30
73.96
71.12
35.31
29.88
26.10
f1 (ppm)


3.93
Ph
H
O
Me
Me
Ph
^{1}H NMR (500 MHz, CDCl$_3$)
7.50
7.49
7.44
7.44
7.43
7.42
7.42
7.40
7.39
7.37
7.35
7.34
7.33
7.32
7.30
7.29
7.28
7.26
6.14
6.13
6.13
6.13
6.12
4.87
4.86
4.85
4.84
2.67
2.66
2.66
2.65
2.64
2.63
2.63
2.61
2.61
2.61
2.61
2.60
2.59
2.58
2.58
2.57
2.57
1.47
1.46
1.97
1.90
2.04
1.96
1.07
1.14
1.00
1.03
2.11
2.82
2.99
f1 (ppm)


^{13}C NMR (126 MHz, CDCl$_3$)
3.93
Ph
Ph
H
O
Me
Me
143.09
140.42
132.84
131.16
128.59
128.56
127.61
127.40
126.36
125.05
74.12
71.37
35.11
29.96
26.22
f1 (ppm)


3.94
^{1}H NMR (500 MHz, CDCl$_3$)
Ph
H
O
Me
Me
OTBS
7.42
7.41
7.37
7.35
7.33
7.28
7.27
7.25
5.65
5.64
5.64
5.64
5.64
5.63
4.72
4.71
4.70
4.69
4.08
2.19
2.19
2.18
2.18
2.18
2.17
2.17
2.17
2.17
2.17
2.16
2.16
2.16
2.15
2.15
2.15
2.15
2.14
2.14
2.13
2.13
2.13
2.13
2.13
2.13
2.11
2.10
2.10
2.09
1.35
1.34
0.92
0.09
2.00
1.97
1.22
1.00
1.04
1.91
2.22
2.97
2.62
9.04
6.09
f1 (ppm)


^{13}C NMR (126 MHz, CDCl$_3$)
3.94
OTBS
Ph
H
O
Me
Me
143.23
133.69
128.55
128.50
127.46
126.34
73.64
71.00
66.30
33.13
29.84
26.12
26.10
18.59
-5.04
-5.09
f1 (ppm)