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Alkyne Hydrofunctionalization and Dehomologative Olefin Synthesis

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Alkyne Hydrofunctionalization and Dehomologative Olefin Synthesis

DISSERTATION

submitted in partial satisfaction of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

in Chemistry

by

Faben A. Cruz

Dissertation Committee:
Professor Vy M. Dong, Chair
Professor Larry E. Overman
Professor Elizabeth R. Jarvo

2018

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Cruz, F. A.*; Zhu, Y.*; Tercenio, Q. D.; Shen, Z.; Dong, V. M. *J. Am. Chem. Soc.* **2017,** *139,* 10641.

5. Stereodivergent Coupling of Aldehydes and Alkynes via Synergistic Catalysis using Rh and Jacobsen's Amine
Cruz, F. A.; Dong, V. M. *J. Am. Chem. Soc.* **2017,** *139,* 1029.

4. Tandem Rh-Catalysis: Decarboxylative Beta-Keto Acid and Alkyne Cross-Coupling
Cruz, F. A.; Chen, Z.; Kurtoic, S. I.; Dong, V. M. *Chem. Commun.* **2016,** *52,* 5836.

3. Rh-Catalyzed Decarbonylation of Conjugated Ynones via Carbon-Alkyne Bond Activation: Reaction Scope and Mechanistic Exploration via DFT Calculations
Dermenci, A.; Whittaker, R. E.; Gao, Y.; **Cruz, F. A.;** Yu, Z.; Dong, G. *Chem. Sci.* **2015,** *6,* 3201.

2. Alkyne Hydroacylation: Switching Regioselectivity by Tandem Ruthenium Catalysis
Chen. Q. A.; **Cruz, F. A.;** Dong, V. M. *J. Am. Chem. Soc.* **2015,** *137,* 3157.

1. Rh-Catalyzed C–C Bond Cleavage by Transfer Hydroformylation
Murphy, S. K.; Park, J.-W.; **Cruz, F. A.;** Dong, V. M. *Science* **2015,** *347,* 56.

Presentations

Metal-Hydride Catalysis: Alkyne Hydrofunctionalization
Cruz, F. A.; Dong, V. M. Abbvie Scholars Symposium; August 7, 2017; North Chicago, IL. *Poster Presentation*

Metal-Hydride Catalysis: Alkyne Hydrofunctionalization
Cruz, F. A.; Dong, V. M. ACS Division of Organic Chemistry – Graduate Student Research Symposium; July 20-23, 2017; Portland, OR. *Oral Presentation.*

Metal-Hydride Catalysis: Alkyne Hydrofunctionalization
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Rhodium-Hydride Catalysis: Alkyne Hydrofunctionalization
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Tandem Rhodium Catalysis: Alkyne Isomerization-Functionalization
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Abstract of the Dissertation

Alkyne Hydrofunctionalization and Dehomologative Olefin Synthesis

By

Faben A. Cruz

Doctor of Philosophy in Chemistry

University of California, Irvine, 2018

Professor Vy M. Dong, Chair

The dehydroformylation of aldehydes to generate olefins occurs during the biosynthesis of various sterols, including cholesterol in humans. A mild and chemoselective synthetic version has been developed that features the transfer of a formyl group and hydride from an aldehyde substrate to a strained olefin acceptor. A Rh(Xantphos)(benzoate) catalyst activates aldehyde C–H bonds with high chemoselectivity to trigger C–C bond cleavage and generate olefins at low loadings (0.3 to 2 mol%) and temperatures (22 to 80 °C). This mild protocol is tolerant of several functional groups and can be applied to various natural products, including a deoxycholic acid derivative.

Previous efforts to directly transform alcohols to olefins via dehomologation have been limited to isolated examples and/or occur at harsh conditions (>380 ºC). This same Rh(Xantphos)(benzoate) catalyst enables access to olefins from primary alcohols by a C–C bond cleavage that results in dehomologation. This functional group interconversion proceeds by an oxidation-dehydroformylation enabled by *N*,*N*-dimethylacrylamide as a sacrificial acceptor of hydrogen gas. Alcohols with diverse functionality and structure undergo oxidative dehydroxymethylation to access the corresponding olefins. This catalyst protocol enables a two-step semi-synthesis of (+)-yohimbenone and dehomologation of feedstock olefins. Under mild conditions, the olefin remains intact without further reduction or isomerization.

Hydrofunctionalization is an attractive method for transforming alkynes that addresses the need for atom-economic, green, and sustainable processes. Alkyne hydrofunctionalizations typically generate *achiral* poly-substituted olefins. We envisioned that using metal-hydride catalysis would enable novel alkyne activation and functionalization. We have developed metal-hydride catalysts that isomerize alkynes to generate metal-allyl species which are then coupled with a variety of partners to generate new alkyne hydrofunctionalization motifs bearing a *chiral* center and terminal olefin. By careful choice of metal-hydride catalyst, we can control the polarity of the generated metal-allyl species (nucleophilic vs. electrophilic) and engage with an appropriate coupling partner to achieve (1) alkyne hydroacylation with unprecedented regiocontrol via Ru–H catalysis, (2) decarboxylative alkyne hydroalkylation with β-keto acids via Rh–H catalysis, (3) stereodivergent alkyne hydroalkylation with aldehydes via synergistic Rh–H/enamine catalysis, and (4) enantioselective alkyne hydroheteroarylation via Rh–H catalysis. Ultimately, we hope that this new mode of alkyne functionalization would enable chemists to use alkynes as an alternative synthetic disconnection.

Chapter 1 - Olefin Synthesis *via* Dehomologative C–C Bond Cleavage

1.1 Rh-Catalyzed C–C Bond Cleavage by Transfer Hydroformylation[i]

1.1.1 Introduction

Nature's enzymes have inspired chemists to develop transition metal catalysts that mimic their reactivity and selectivity, and as a result, valuable synthetic transformations have been developed. For example, monooxygenases have served as inspiration for olefin epoxidation[1] and C–H bond oxidation catalysts.[2] In addition to monooxygenases, the cytochrome P450 family of enzymes have demethylases that cleave C–C bonds.[3] Lanosterol demethylase is responsible for the conversion of aldehydes to olefins *via* dehydroformylation in the biosynthesis of sterols in bacteria, algae, fungi, plants, and animals (Figure 1.1A).[4] Inspired by this key step found ubiquitously in nature, our goal was to develop a transition metal catalyst to cleave C–C bonds of aldehydes by dehydroformylation.

We aimed to trigger C–C bond cleavage[5] by chemoselectively activating aldehyde C–H bonds[6] using rhodium-catalysis (Figure 1.1B). Oxidative addition into the C–H bond gives acyl-Rh(III)-hydride **X**, which is an intermediate common to both hydroacylation[7] and decarbonylation pathways.[8] Given that acyl-Rh(III)-hydrides can be diverted in a variety of distinct pathways, we needed a strategy to favor dehydroformylation. Some reports have shown the dehomologation of aldehydes to olefins, though in low yields.[9] One report describes the use of stoichiometric ruthenium for the dehydroformylation of butyraldehyde,[10] while another uses heterogeneous

[i] From Murphy, S. K.; Park, J.–W.; Cruz, F. A.; Dong, V. M. *Science* **2015,** *347*, 56. Reprinted with permission from AAAS.

rhodium or palladium catalysts to transform steroidal aldehydes in a similar manner at 160–300 °C.[11] In contrast, an Fe-peroxo complex cleaves aldehyde C–C bonds at room temperature, but this complex must be used in stoichiometric amounts and can lead to olefin epoxidation.[12]

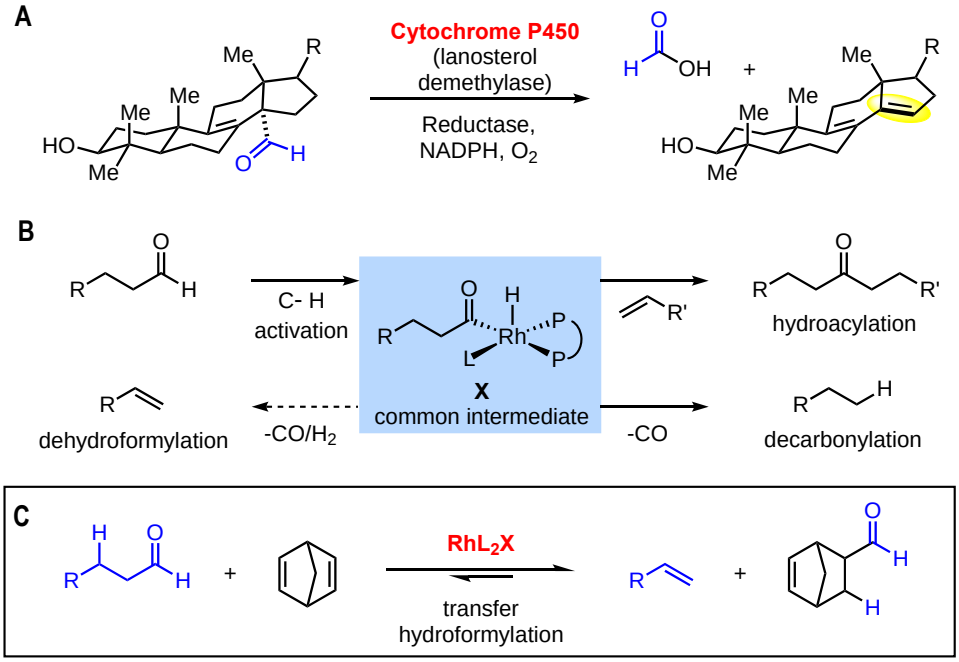
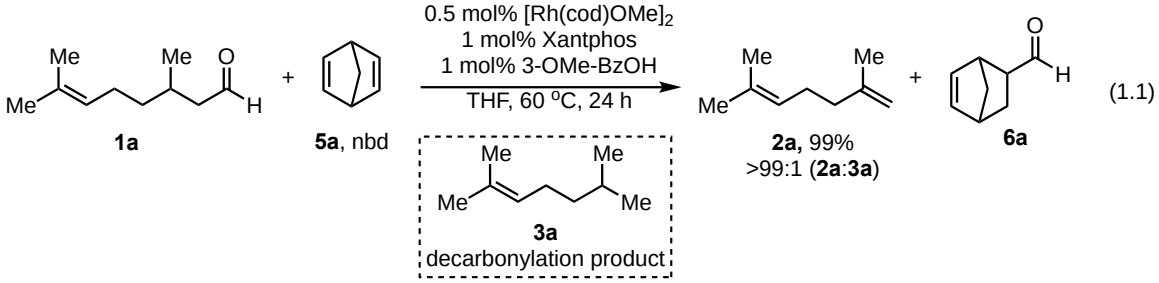


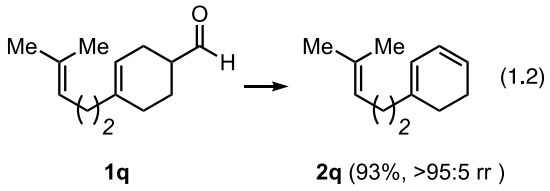
Figure 1.1. Dehydroformylation in nature and organic synthesis. (A) Dehydroformylation during sterol biosynthesis. **(B)** Reactivity of acyl-Rh^{III}-hydrides. **(C)** Proposed transfer hydroformylation.

Given this challenge, we designed a strategy where aldehyde dehydroformylation is driven by concomitant hydroformylation of a strained olefin acceptor (Figure 1.1C).[13] This transfer hydroformylation avoids the accumulation of CO gas, which acts as a catalyst poison in related aldehyde dehomologations. Here, we report a Rh-catalyst for transfer hydroformylation that operates in the 22–80 °C temperature range, with catalyst loadings as low as 0.3 mol%. This mild protocol for dehydroformylation can be applied to a wide range of aldehydes, including those derived from alkaloid, terpene, steroid, and macrolide natural products.

1.1.2 Results and Discussion



My contributions to this project involved investigating aldehyde substrate scope and mechanistic studies. Stephen Murphy optimized the reaction conditions for selective dehydroformylation, over decarbonylation, of citronellal **1a** to olefin **2a**. The optimized conditions used a rhodium precursor, $[Rh(cod)OMe]_2$, in combination with a wide bite-angle bisphosphine ligand, Xantphos, a benzoic acid additive (*i.e.*, 3-methoxybenzoic acid, 3-OMe-BzOH), and norbornadiene **5a** (nbd) as an acceptor. In addition to dehydroformylation, a novel *transfer* hydroformylation was observed by the formation of 5-norbornene-2-carboxaldehyde (**6a**) (eq. 1.1). Under these reaction conditions, no decarbonylation product is observed.



This transfer hydroformylation protocol enables access to olefins from a wide range of aldehyde precursors (Figure 1.2).[14] We hypothesized that conjugation and *syn* selective β-hydride elimination would dictate selectivity for dehydroformylation. The *trans* Diels-Alder adduct **1b** underwent selective (93:7 *rr*) dehydroformylation to yield conjugated 1,3-diene **2b**, in the presence of two inequivalent *syn* β-hydrogens. Dehydroformylation of **1c** to afford 1,3-diene **2c** resulted in decreased selectivity (73:27 *rr*); likely as a result of competitive formation of the olefin conjugated

to the phenyl substituent. The *cis* Diels-Alder adduct **1d** afforded 1,3-diene **2d** exclusively, as a result of having only one accessible *syn* β-hydrogen. Exclusive formation of conjugated 1,3-diene **2q** over the 1,4-diene suggests that conjugation drives selectivity (eq. 1.2).

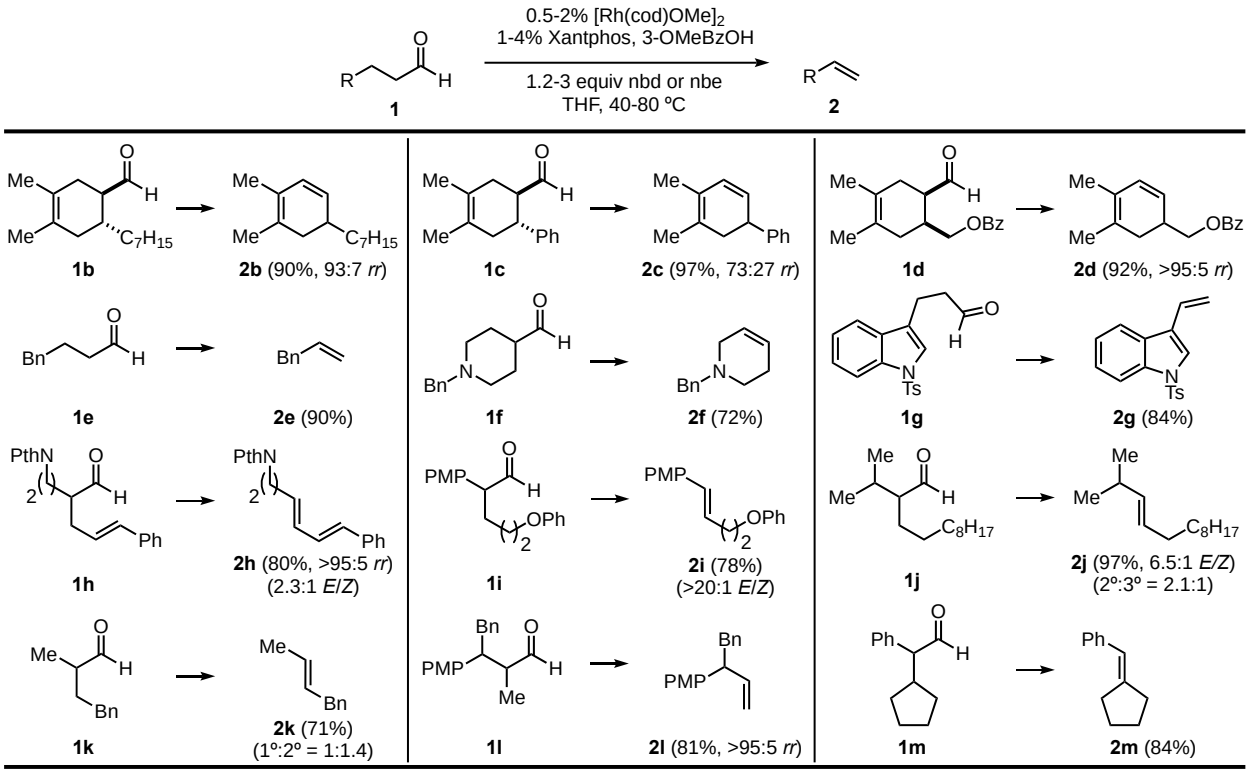
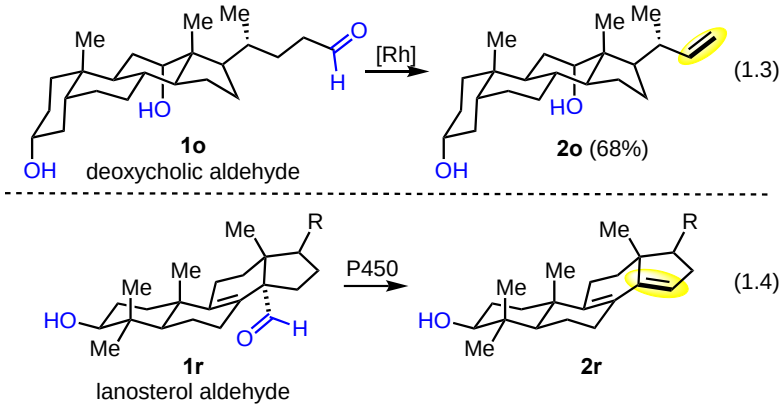


Figure 1.2. Substrate scope. Yields are of isolated materials and mixtures of regioisomers where indicated; rr = regioisomeric ratio; rr values were determined by ^{1}H NMR analysis of the reaction mixtures; the yields of **2e** and **2k** were determined by ^{1}H NMR analysis of the reaction mixtures using durene as an internal standard; see the supplementary materials for details.

We reason that the observed regioselectivities are controlled by kinetics because 4-phenylbutanal **1e** yielded the terminal olefin **2e** without any isomerization to the styrene derivative. In general, Lewis basic functionalities, such as esters, amines, phthalimides, and ethers are tolerated (**1d**, **1f**, **1h**, **1i**). Dehydroformylation of indole containing aldehyde **1g** to afford vinylindole **2g** demonstrates compatibility with heterocycles and *N*-tosyl protecting groups. A prototypical intramolecular olefin hydroacylation substrate, such as 4-pentenal **1h**, underwent chemoselective dehydroformylation to yield conjugated diene **2h**. The dehydroformylation of α-arylated aldehyde **1i** preferentially afforded (*E*)-disubstituted olefin **2i**. Substrates that do not form

conjugated products upon dehydroformylation were transformed with modest regioselectivities (**1j** and **1k**); however, steric congestion favored terminal olefin **2l** over tri-substituted products. Nonetheless, tri-substituted olefin **2m** was generated from a substrate containing a single *syn*-β-hydrogen such as **1m**.



Given the potential for alcohol oxidation under Rh-catalysis,[15] *I aimed to test the chemoselectivity of our dehydroformylation catalyst*. The choice of deoxycholic aldehyde **1o** allowed me to test chemoselectivity and use a substrate similar to that used by our enzymatic inspiration. The dehydroformylation of deoxycholic aldehyde **1o**, bearing two alcohols, to **2o** proceeded in 68% yield with no alcohol oxidation (eq. 1.3). Dehydroformylation with no alcohol oxidation further demonstrates the ability of this catalyst system to chemoselectively activate aldehyde C–H bonds and initiate C–C bond cleavage. Successful dehydroformylation of deoxycholic aldehyde **1o**, in analogy to lanosterol aldehyde **1r** (eq. 1.4), shows parallel reactivity and selectivity to our enzymatic inspiration, lanosterol demethylase. In contrast to lanosterol demethylase, our dehydroformylation catalyst can transform a variety of aldehydes.

We propose that the catalyst mixture mentioned above can form Rh(I)-benzoate **15a** *in situ* and can activate an aldehyde C–H bond by oxidative addition to generate acyl-Rh(III)-hydride **15b**. Reductive elimination of benzoic acid affords acyl-Rh(I) **15c**, which after CO deinsertion to

an alkyl-Rh complex **15d** and β-H elimination yields Rh(I)-hydrido carbonyl **15e**. Exchange of the olefin with a strained olefin acceptor **5a** leads to **15f**, which can undergo transfer hydroformylation to yield the dehydroformylation olefin product **2** and regenerate catalyst **15a** (Figure 1.3A). Thus, the ring-strain of the olefin acceptor and the ability of the counterion to act as a proton-shuttle by reversible redox processes afford high reactivity and selectivity.

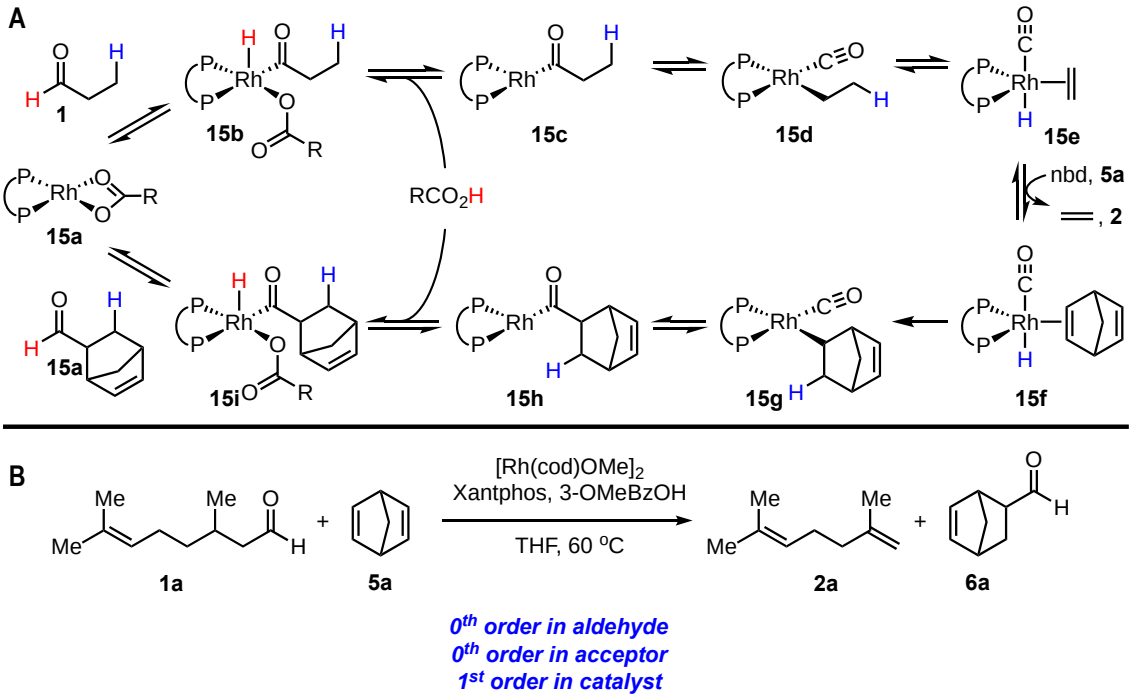


Figure 1.3. Mechanistic studies. (A) Proposed catalytic cycle. **(B)** Initial rate kinetics studies.

To gain insight into our proposed mechanism, *I performed initial rate kinetics experiments* (Figure 1.3B, see Supporting Information). Changing the concentration of aldehyde **1a** resulted in little to no change in initial rates. Similarly, changing the concentration of norbornadiene led to no significant changes in initial reaction rates. These data indicate zeroth-order dependence in both aldehyde and norbornadiene, suggesting that both reactants are bound to the catalyst in the turnover-limiting step. Finally, increasing the concentration of catalyst resulted in an initial rate increase consistent with a first order dependence.

1.1.3 Conclusion and Future Work

Using Rh-catalysis we have developed a small-molecule mimic of lanosterol demethylase for the dehydroformylation of complex aldehydes to olefins. In addition, a strained olefin acceptor allowed for a novel transfer hydroformylation mechanism and mild dehydroformylation conditions. We are currently exploring transfer hydroformylation and tandem oxidation-dehydroformylation as related novel transformations.

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(14) I showed that aldehydes could undergo dehydroformylation to yield olefins **2d, 2f, 2g, 2o,** and **2q**.

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1.2 Tandem Catalysis: Transforming Alcohols to Alkenes by an Oxidative Dehydroxymethylation[ii]

1.2.1 Introduction

Inventing ways to access olefins remains a primary focus due to their versatility as building blocks for materials and medicines.[1] Established strategies for constructing olefins, including the Wittig olefination,[2] the Heck reaction,[3] and olefin metathesis,[4] generate carbon-carbon bonds. In contrast, there are emerging routes to olefins that involve C–C bond cleavage.[5] These methods represent examples of a one-carbon dehomologation of carbon frameworks and thus hold promise for the conversion of biomass into feedstocks.[6] Moreover, such transformations increase retrosynthetic flexibility by allowing the interconversion of two common functional groups. While carboxylic acid derivatives are typically used,[7] there have been efforts to transform alcohols directly into alkenes *via* a one-carbon dehomologation.[8] These *oxidative dehydroxymethylations* occur in low yields, have limited scope, and require harsh conditions (>380 °C). In contrast, enzymes perform one-carbon dehomologations of alcohols *via* the intermediacy of an aldehyde. For example, DNA demethylases oxidize alcohols to aldehydes that are decarbonylated to generate alkanes and arenes.[9,10] In analogy, lanosterol demethylase performs a tandem oxidation-dehydroformylation to generate alkenes (Figure 1.4A). Herein, we report a Rh-catalyst for accessing olefins from primary alcohols by cascade involving oxidation and dehydroformylation.

Inspired by lanosterol demethylase, our laboratory reported a Rh-catalyst for aldehyde transfer hydroformylation (i.e., the shuttling of a formyl group and hydride from an aldehyde

[ii] Reproduced with permission from *J. Am. Chem. Soc.*, submitted for publication. Unpublished work copyright 2018 American Chemical Society.

substrate to a strained olefin acceptor).[11] Additionally, transfer hydrogenation of alcohols to generate aldehydes has been achieved under Rh-catalysis by using ketones as a hydrogen acceptor.[12] Bearing these studies in mind, we reasoned that combining Rh-catalyzed transfer hydrogenation of alcohols with transfer hydroformylation would enable our proposed one-carbon dehomologation (Figure 1.4B).[13,14]

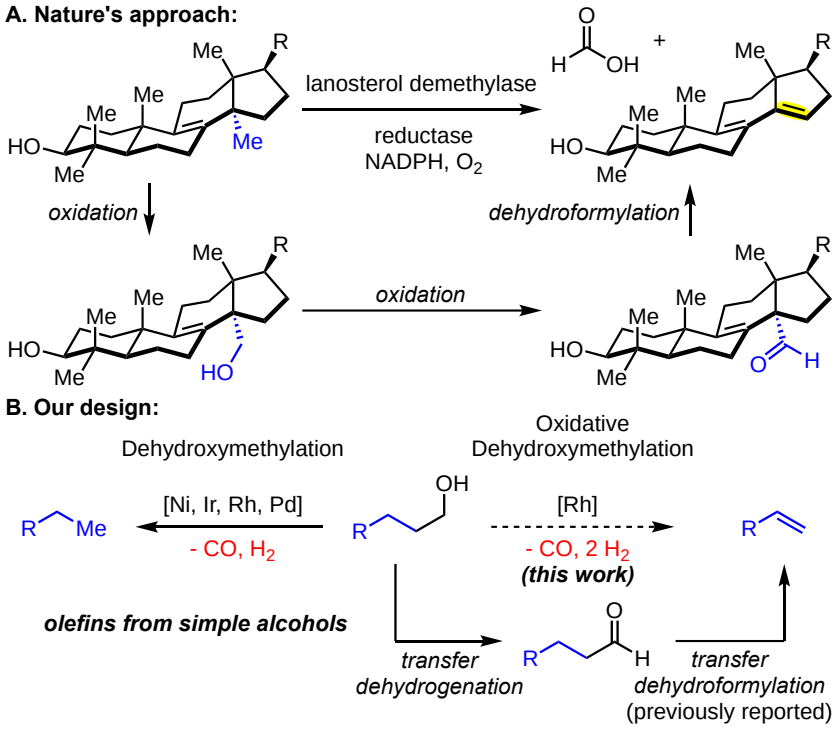


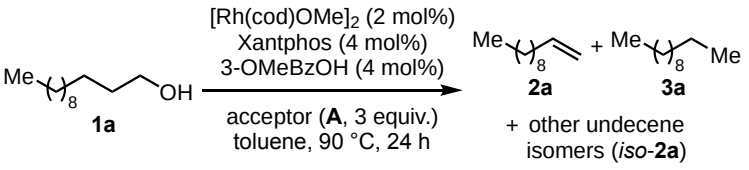
Figure 1.4. Inspiration for proposed alcohol oxidative dehydroxymethylation.

1.2.2 Results and Discussion

We set out to identify one catalyst capable of both transfer hydrogenation and transfer hydroformylation. Using 1-dodecanol **1a** as a model substrate, we began our studies with a catalyst known to activate aldehyde C–H bonds ([Rh(cod)OMe]$_2$, 3-OMeBzOH and Xantphos, Table 1.1).[11a] Upon successful oxidation of alcohol **1a,** we imagined the resulting aldehyde could undergo dehydroformylation to the alkene **2a** or decarbonylation to the alkane **3a**. From an initial

survey, we discovered that selectivity for alkene versus alkane was influenced by the acceptor. In the absence of an acceptor, we observed undecane **3a** as the only product (10% yield). In stark contrast, by using strained olefin acceptors **A1** and **A2,** we observed 1-undecene (**2a**, 32% and 18%, respectively), along with undecene isomers (*iso*-**2a**, 16:1 and 2.3:1, **2a**:*iso*-**2a**). Using ketones as acceptors (**A3**–**4**) resulted in decarbonylation to undecane **3a**. While using electron-deficient olefin acceptors, such as enone **A5** or acrylonitrile **A6**, a mixture of 1-undecene **2a** and undecane **3a** was observed (1.4:1 and 1:3, **2a**:**3a**). Using ester or amide Michael acceptors provided a major breakthrough in selectivity for the desired alkene **2a**.

Table 1.1. Effect of Acceptor on Selectivity for Oxidative Dehydroxymethylation[a]



no acceptor **2a** : **3a** : *iso*-**2a** <1 : 10 : <1	**A1**, 32 : <1 : 2	**A2**, 18 : <1 : 8	**A3**, <1 : 15 : <1
A4, <1 : 12 : <1	**A5**, 10 : 7 : 2	**A6**, 3 : 9 : <1	**A7**, 33 : 1 : 1
A8, 35 : 2 : 1	**A9**, 3 : - : -	**A10**, 5 : - : -	**DMAA**, 95 : 1 : 2

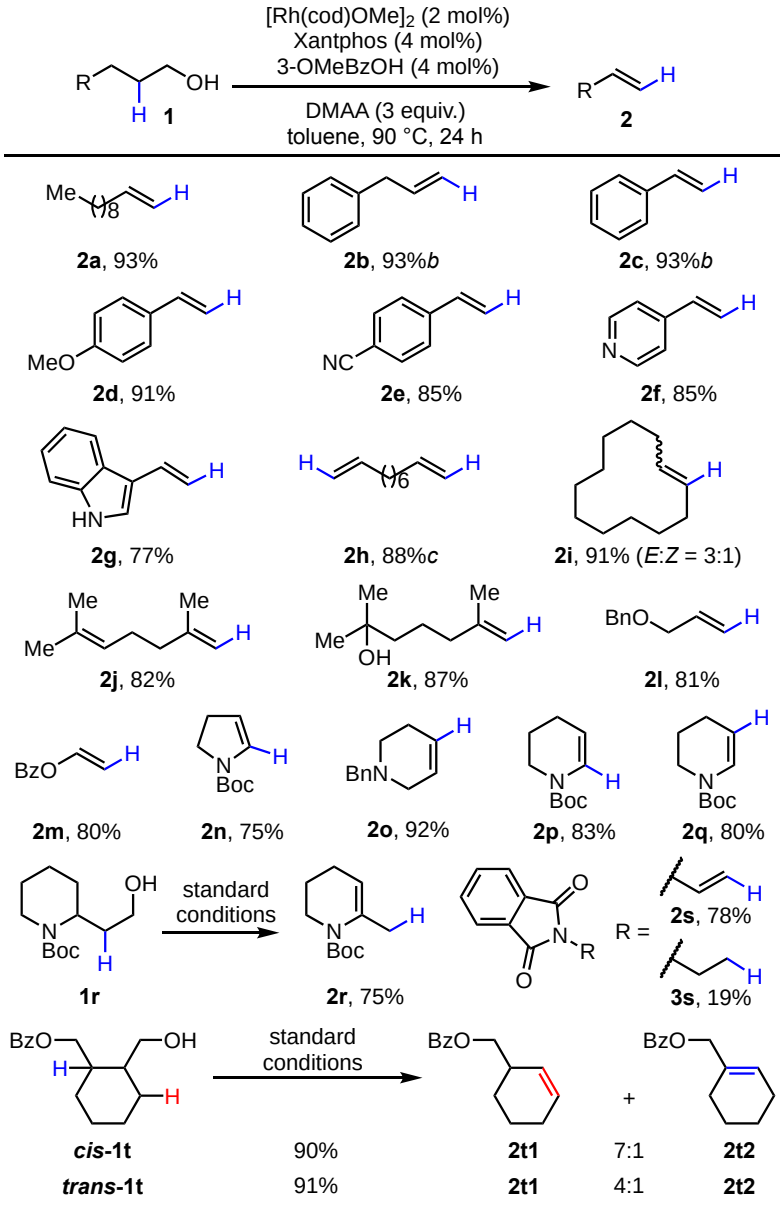
[a]Conditions: **1a** (0.2 mmol), $[Rh(cod)OMe]_2$ (2 mol%), 3-OMeBzOH (4 mol%), Xantphos (4 mol%) and acceptor (3 equiv.) in toluene (0.4 mL), 90 ˚C, 24 h. Yields were determined by GC using durene as an internal standard.

Ester and amide Michael acceptors (**A7**–**A8**) enabled selective formation of 1-undecene (**2a**, 33–35%, >20–17.5:1, **2a**:**3a**). Use of *N*,*N*-dimethylacrylamide (**DMAA**) as an acceptor gave 1-undecene **2a** in 95% yield and >20:1 selectivity.[15] We hypothesize that **DMAA** affords improved reactivity because it is can more efficiently bind to the Rh-catalyst in comparison to other Michael

acceptors (**A5**–**A8, A10**). We found that the byproduct was *N*,*N*-dimethylpropionamide, which arises from the hydrogenation of DMAA. Altering the electronics of the olefin acceptor by using *N*-vinylpyrrolidone (**A9**) or increasing substitution on the acrylamide by using **A10** resulted in diminished reactivity (3–5%). Previously, we found that both CO and H_2 were transferred to our strained olefin acceptor, norbornadiene **A1**.[11a] In contrast, we do not observe transfer hydroformylation, yet catalyst turnover still proceeds in the presence of CO generation.[16]

With this catalyst-acceptor combination, we performed the dehomologation of primary alcohols (Table 1.2). Allyl benzene **2b** was obtained (93% yield) from 4-phenyl-1-butanol, without isomerization to a conjugated olefin. 3-Phenyl-1-propanol and derivatives with electron-donating and electron-withdrawing groups gave styrenes (**2c**–**e**) in 85–93% yields. Heterocyclic alcohols, such as those with pyridine and indole, were tolerated (**2f**, 85%; **2g**, 77%). A primary diol gave diene **2h** in 88% yield, in the presence of doubled the amount of DMAA (6 equivalents). A *β*,*β*-disubstituted alcohol transformed to internal olefin **2i** in 91% yield. Alcohols bearing alkenes and tertiary alcohols underwent dehomologation (**2j**, 82%; **2k**, 87%). Next, we explored 1,3- or 1,4-diols and 2-, 3- or 4-amino derived alcohols (**2l**–**s**). Allylic ether **2l** and amine **2o** were obtained in 81% and 92% yields respectively, without allylic C–O or C–N bond cleavage or debenzylation. Enol and enamine derivatives (**2m**, **2n**, **2p**–**s**) can be accessed (75–83% yields). Enamine formation occurred preferentially over allyl amine formation to afford **2q** (80% yield). The more substituted endocyclic enamide **2r** was observed rather than the less substituted exocyclic regioisomer in 75% yield. With most alcohols, excellent chemoselectivities (>20:1) were observed. In contrast, use of 3-phthalimido-1-propanol gave a 4:1 mixture of oxidation-dehydroformylation (**2s**) and oxidation-decarbonylation (**3s**). When *cis*- or *trans*-**1t** was used, *β*-hydride elimination occurred preferentially at the less substituted position to give **2t1**.

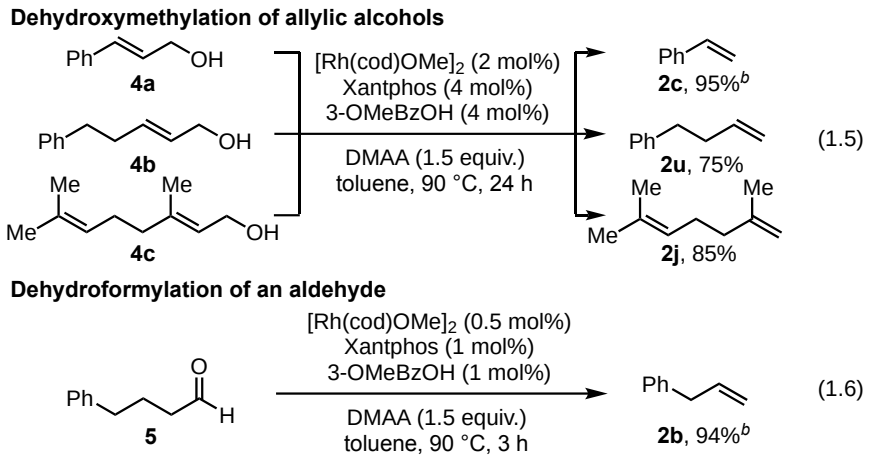
Table 1.2. Oxidative Dehydroxymethylation of Alcohols[a]



[a]Conditions: **1** (0.2 mmol), $[Rh(cod)OMe]_2$ (2 mol%), 3-OMeBzOH (4 mol%), Xantphos (4 mol%) and DMAA (3 equiv.) in toluene (0.4 mL), 90 ˚C, 24 h. Isolated yields. [b]GC yields using durene as an internal standard. [c]DMAA (6 equiv.) used.

In addition, we found that allylic alcohols (**4a-c**) underwent oxidative dehydroxymethylation (75–95% yields), with only 1.5 equivalents of DMAA needed (eq. 1.5).[17] Because our protocol enables both transfer hydrogenation and dehydroformylation, we tested

aldehydes as substrates (eq. 1.6). Dehydroformylation of aldehyde **5** provided olefin **2b** (94% yield), with lower catalyst loading and acceptor equivalents compared to the transformation from alcohol **1b** (Table 1.2). This new protocol shows similar reactivity to our previous report,[11a] but with a more economical acceptor (i.e., norbornadiene vs DMAA).



Next, we explored applications (Figure 1.5). By combining hydroboration-oxidation with oxidative dehydroxymethylation, a one-carbon dehomologation of 1-dodecene **6** was achieved on gram scale to give 1-undecene **2a** (82% yield) (Figure 1.5A). This two-step process provides valuable odd-numbered carbon olefins from readily available even-numbered carbon olefins.[7c] A two-carbon dehomologation of olefins can be achieved by combining olefin dihydroxylation and oxidative dehydroxymethylation. For example, we found that 1-dodecene **6** could be transformed to 1-decene **2v** (Figure 1.5A). The transformation occurs efficiently with molecules that are more structurally complex (Figure 1.5B). Benzyl protected deoxycholic acid derivative **8a** gave olefin **9a** (81% yield), with no debenzylation. We probed chemoselectivity by using triol **8b**, with alcohols bearing different steric bulk. We observed oxidation-dehydroformylation of the primary alcohol and selective oxidation of the less hindered secondary alcohol to afford **9b** (66% yield).

Diol **8c** underwent oxidative dehydroxymethylation and secondary alcohol oxidation to access (+)-yohimbenone **9c**. Based on this result, we improved our previous synthesis of (+)-yohimbenone **9c** by shortening the sequence to two steps.[11a, 18]

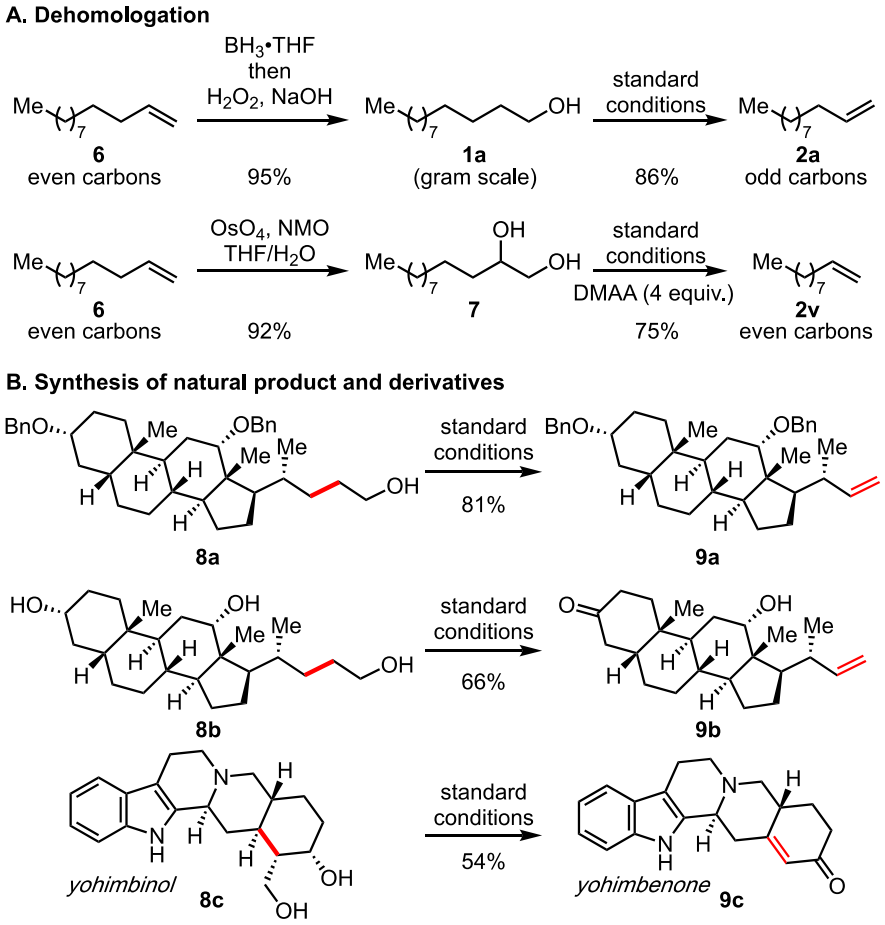


Figure 1.5. Synthetic Applications

On the basis of literature reports[10,11,15,19] and our own observations, we propose the following pathway (Figure 1.6). Exchange between the benzoate counterion in Rh-complex **A** and an alcohol affords **B**. Intermediate **B** undergoes *β*-hydride elimination to give Rh-hydride **C**. Coordination of DMAA to **C** generates coordinately saturated intermediate **D**. Hydrometallation of DMAA followed by protodemetalation provides the aldehyde and regenerates complex **A**. Oxidative addition into the aldehyde C–H bond by **A** generates acyl-Rh-hydride **F**. Reductive

elimination of 3-methoxybenzoic acid generates acyl-Rh **G**. Decarbonylation, followed by *β*-hydride elimination, yields Rh-hydrido-carbonyl **I**. Olefin exchange with DMAA generates Rh-hydride **J**. Finally, hydrometalation of DMAA, CO extrusion, and protodemetalation regenerates complex **A**.

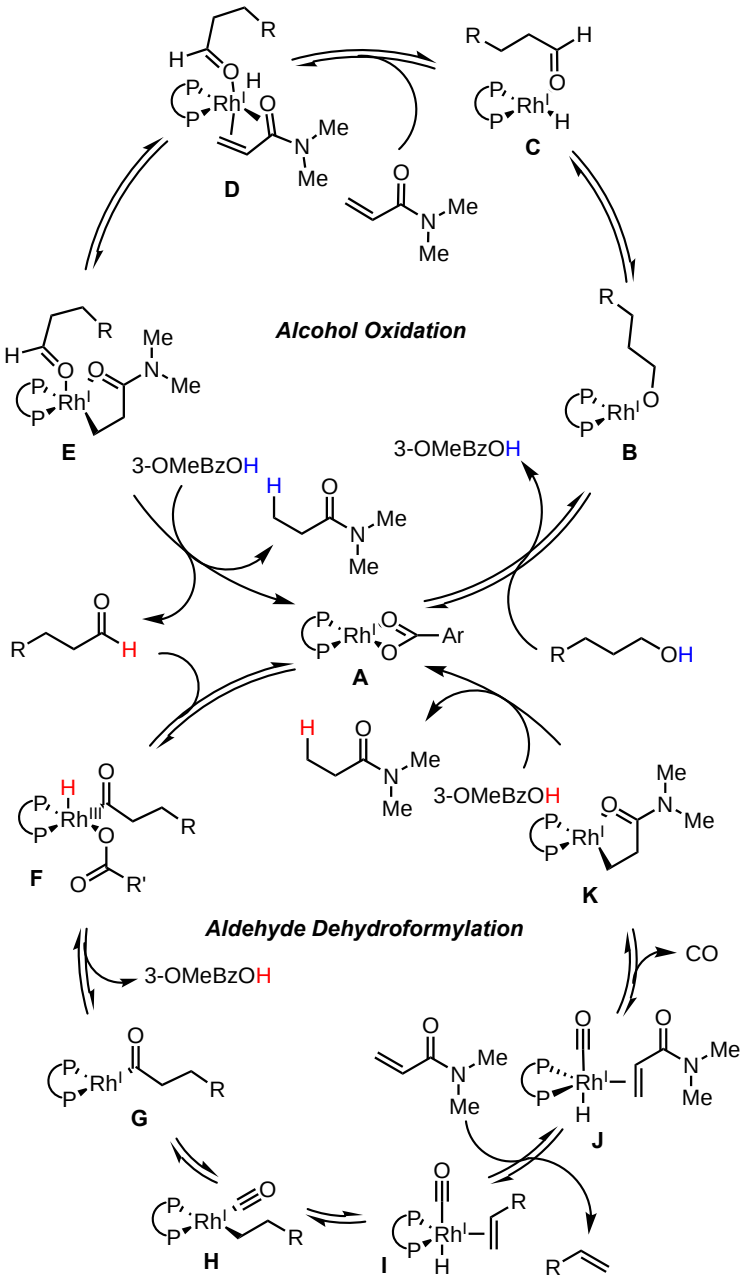


Figure 1.6. Proposed Mechanism

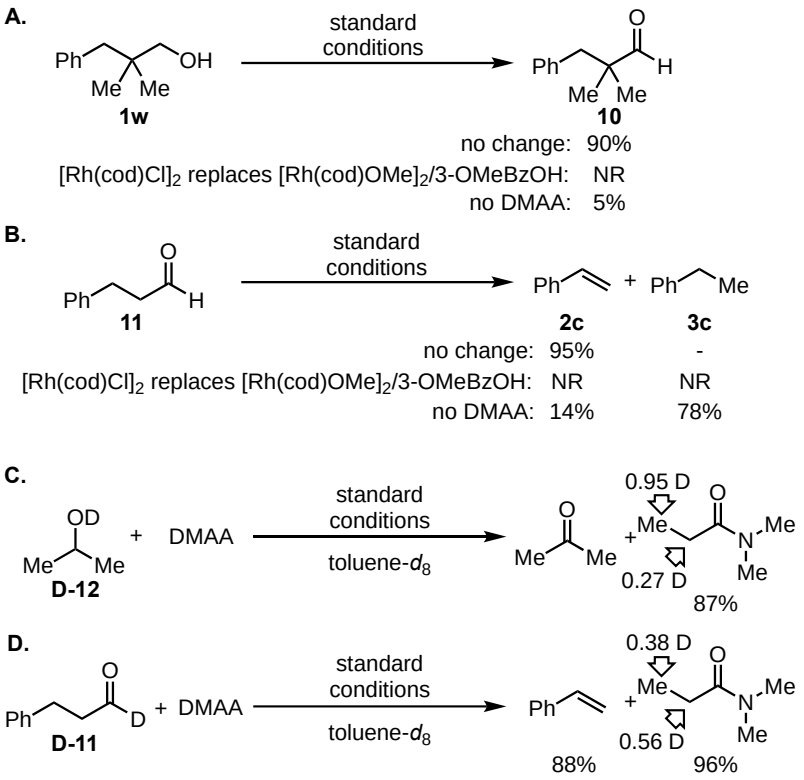


Figure 1.7. Mechanistic Probes

To support the proposed mechanism, control experiments and deuterium-labeling experiments were carried out. Under standard conditions, neopentylic alcohol **1w** was oxidized to aldehyde **10** in 90% yield (Figure 1.7A). Incorporation of a quaternary carbon alpha to the carbonyl suppressed dehydroformylation. This result supports the intermedicacy of an aldehyde in the catalytic cycle. Of note, aldehyde **11** undergoes transformation under standard conditions (Figure 1.7A). Replacing the benzoate counterion with chloride suppressed both oxidation and dehydroformylation (Figure 1.7A and B). In the absence of DMAA, dehydrogenation of alcohol **1w** was not observed (Figure 1.7A); rather, decarbonylation gave ethyl benzene **3c** from aldehyde **11** (78% yield, 1:5.5 **2c**:**3c**, Figure 1.7B). These observations highlight the importance of both the benzoate counterion and DMAA. In support of the protonation of intermediate **E** (Figure 1.6), we observed deuterium incorporation at the β-position of DMAA when using deuterated isopropanol

D-12 (Figure 1.7C). Hydrogen-deuterium exchange is possible during dehydroformylation *via* the benzoate counterion acting as a proton shuttle (Figure 1.7C and D).[11a]

1.2.3 Conclusion

We have developed a Rh catalyst to transform alcohols into olefins via one-carbon dehomologation. The combination of a benzoate counterion and DMAA acceptor enables tandem oxidation-dehydroformylation, with high selectivity and efficiency. In addition, this catalyst allows access to olefins from aldehydes by dehydroformylation. Finally, this alcohol dehomologation strategy enables the construction of a wide-range of olefins, without competitive isomerization or reduction.

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Chapter 2 - Alkyne Hydrofunctionalization

2.1: Alkyne Hydroacylation: Switching Regioselectivity by Tandem Ru-Catalysis[iii]

2.1.1 Introduction

The coupling of an aldehyde to an alkyne is a promising route to ketones, which has been studied using both metal catalysts[1] and organocatalysts[2] (Figure 2.1A). Alkyne hydroacylation provides access to α,β-unsaturated ketones as the major constitutional isomer. Most of these methods require terminal or symmetric alkynes to achieve high regioselectivity. Others require aldehydes bearing directing groups to promote C–H bond functionalization in preference to decarbonylation. In light of these challenges, we proposed using a metal-hydride as a tandem catalyst to perform a cascade involving (1) alkyne-allene isomerization and (2) allene-aldehyde coupling (Figure 2.1B). We judged this cascade feasible on the basis of literature precedence for metal-hydride catalysis of the independent transformations. First, alkyne-allene isomerization was initially demonstrated by Yamamoto in Pd–H catalyzed alkyne hydroamination.[3] Since then, Ishii[4] and Breit[5] have used Ir- and Rh-catalysis to achieve alkyne isomerizations by metal-hydride pathways. Second, allene-aldehyde couplings were demonstrated by Willis, who reported allene hydroacylations with chelating

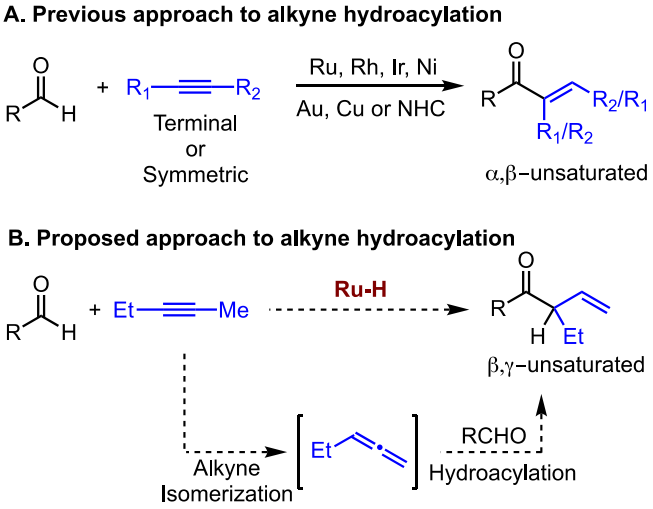


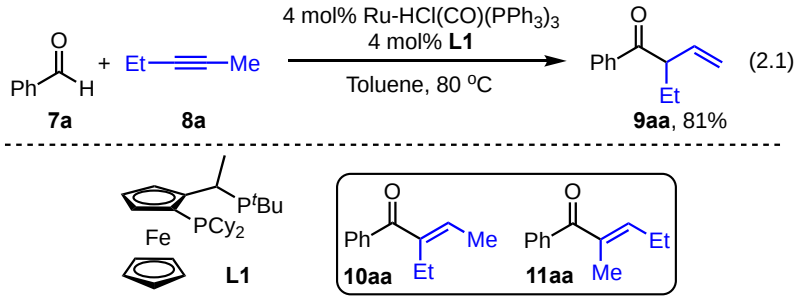
Figure 2.1. Intermolecular alkyne hydroacylation.

[iii] Reproduced in part with permission from Chen. Q.–A.; Cruz, F. A.; Dong, V. M. *J. Am. Chem. Soc.*, **2015,** *137*, 3157. Copyright 2015 American Chemical Society.

aldehydes.[6] We envisioned the resulting allene would undergo insertion into the metal-hydride to generate a metal-allyl species that could couple to non-chelating aldehydes (Figure 2.1B).[7] In our proposal, subsequent *β*-hydride elimination would be key in affording the desired *β,γ*-unsaturated ketone while regenerating the metal-hydride catalyst. Thus, we set out to identify a single metal catalyst that could promote both transformations in a sequence to afford a novel alkyne hydroacylation.

2.1.2 Results and Discussion

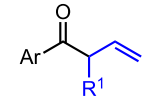
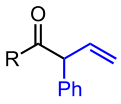
Dr. Qing-An Chen initiated these studies and found that using $RuHCl(CO)(PPh_3)_3$ and racemic Josiphos ligand **L1** provided the desired β,γ-unsaturated ketone **9aa** in 81% yield with 27:1 selectivity over *α,β*-unsaturated ketones **10aa** and **11aa** (eq. 2.1). In addition to optimizing the reaction conditions, Dr. Qing-An Chen performed the hydroacylation of 2-pentyne **8a** with various aldehydes **7**.



Dr. Qing-An Chen and I examined the scope of alkynes (Table 2.1). *I varied the substituents on the alkynes and coupled them with p–OMe–benzaldehyde (**7b**).* I found that secondary (Cy) and tertiary (^{t}Bu) alkyl substituted alkynes could be coupled with alkyne **8** in 68% and 93% yields, respectively, and with >20:1 regioselectivity for the *β,γ*-unsaturated ketone

(entries 1 and 2). The hydroacylation of 1-phenyl-1-propyne with a variety of aromatic and heteroaromatic aldehydes proceeded in yields ranging from 83–95% with >20:1 regioselectivity for the respective β,γ-unsaturated ketone (entries 9–15).

Table 2.1. Variation in Alkyne and Aldehyde[a]

Entry	Product **9**	R^1	Yield (%)[b]	Entry	Product **9**	R	Yield (%)[b]
1		Cy	68 (**9bb**)	9		Ph	95 (**9ad**)
2		^{t}Bu	93 (**9bc**)	10		4-$OMeC_6H_4$	94 (**9bd**)
3		4-ClC_6H_4	77 (**9be**)	11		3-$OMeC_6H_4$	90 (**9gd**)
4		4-BrC_6H_4	61 (**9bf**)	12		2-Furyl	87 (**9id**)
5	Ar = 4-$OMeC_6H_4$	4-$CF_3C_6H_4$	82 (**9bg**)	13		3-Furyl	94 (**9jd**)
6		4-$OMeC_6H_4$	82 (**9bh**)	14		2-Thienyl	88 (**9kd**)
7		3-MeC_6H_4	83 (**9bi**)	15		3-N-Ts-indoyl	83 (**9ld**)
8		2-MeC_6H_4	67 (**9bj**)				

[a]**7** (0.20 mmol), **8** (0.24-0.40 mmol), $RuHCl(CO)(PPh_3)_3$ (4 mol%), **L1** (4 mol%), toluene (0.5-1.0 mL), 80-90 °C, 15-18 h. [b] Isolated yields of **9**, >20:1 regioselectivity of crude mixtures (determined by ^{1}H NMR or GC-FID).

I found that alkynes bearing phenyl groups of varying electronic and steric properties could be coupled to aldehyde **7b** with yields ranging from 61–83% (entries 3–8). Alkynes with aryl halides could be coupled (entries 3 and 4). Both electron-poor (*p*-CF_3) and electron-rich (*p*-OMe) alkynes gave the desired β,γ-unsaturated ketone in 20:1 regioselectivity. Even a sterically bulky *o*-tolyl substituted alkyne yielded the desired product in 67% yield (entry 8).

Figure 2.2 depicts our proposed mechanism. Reversible insertion of 2-pentyne (**8a**) into Ru–H can yield either Ru-vinyl intermediate **A** or **B**. The interception of intermediate **A** with aldehyde **7** generates isomer **11**. We proposed the formation of **11** to be feasible by this pathway as this is the major product when using *rac*-BINAP or TangPhos. After β-hydride elimination, Ru–vinyl complex **A** will form allene **C** *in situ* and regenerate a Ru–H species. While formation of both **A** and **B** are feasible, we propose that β-hydride elimination from **B** to generate 1,3-

disubstituted allene **D** will be disfavored due to higher allylic strain.[8] In contrast, *β*-hydride elimination from **A** will generate 1-substituted allene **C**. Regioselective addition of Ru–H across terminal allene **C** yields Ru–allyl **E**. Trapping of **E** with aldehyde **7** yields ruthenium alkoxide **G**. Finally, *β*-hydride elimination from **F** delivers the observed ketone **9** and regenerates the Ru–H catalyst.

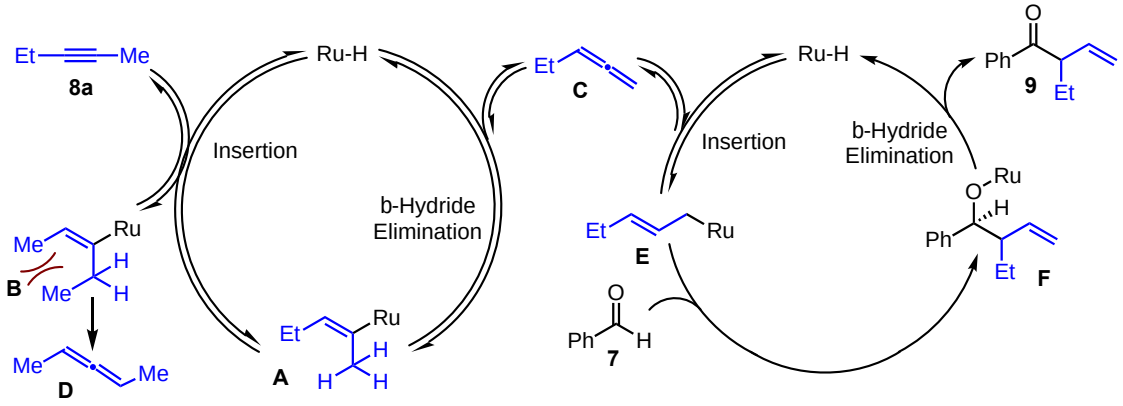
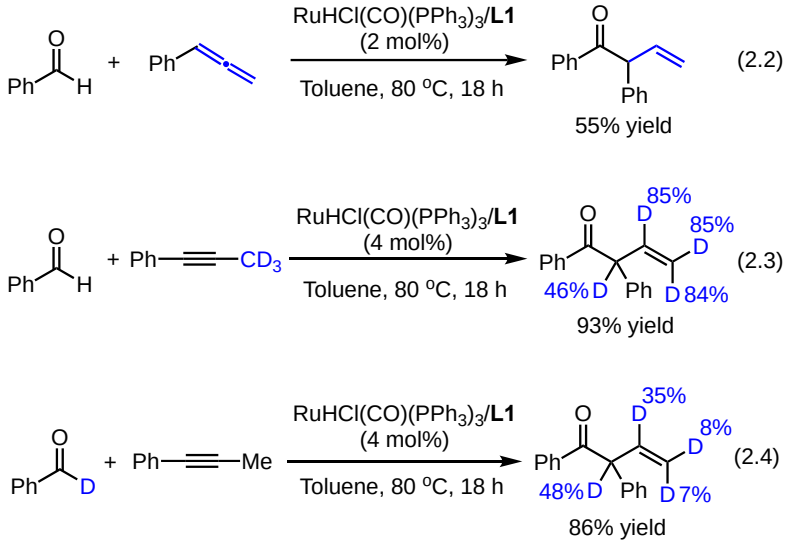


Figure 2.2. Proposed mechanism

To support the proposed allene intermediate, Dr. Qing-An Chen subjected phenylallene **12** and benzaldehyde **7a** to standard reaction conditions and obtained the same product **9ad** (55% yield) indicating that the allene is a competent intermediate in our catalytic cycle (eq. 2.2). We hypothesized that *β*–H elimination to generate allene **C** was reversible. To test this hypothesis, I synthesized and subjected deutero-alkyne **8d-***d*$_3$ to standard reaction conditions and observed incorporation of deuterium in the α-, β- and γ-positions of ketone **9ad-***d*$_3$ (eq. 2.3). The incorporation of deuterium into the α- position of ketone **9ad-***d*$_3$ suggests that the Ru–H species generated from both β–H elimination steps (Figure 2.2, **A** to **C** and **F** to **9**) are indistinguishable and rapidly exchanging (eq. 2.3). The observed incorporation of hydrogen at the *γ*-position of product **9ad-***d*$_3$ indicates reversibility of *β*-hydride elimination in allene formation (eq. 2.3).

Reversible β-hydride elimination to form an allene is also supported by scrambling in the deuterium-labeling study with aldehyde **1a-***d*$_1$ (eq. 2.4).



2.1.3 Conclusion and Future Work

Tandem ruthenium catalysis has enabled a switch in regioselectivity for the hydroacylation of alkynes. The *in situ* isomerization of alkynes to allenes by a ruthenium hydride leads to the formation of β,γ-unsaturated ketones. Due to the regioselective formation of 1-substituted allene, this protocol differentiates a methyl from an ethyl substituent on 2-pentyne. Insights from these studies will contribute to the emerging use of alkynes as allene surrogates and guide future developments in tandem catalysis.

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2.2: Tandem Rh-Catalysis: Decarboxylative β-Keto Acid and Alkyne Cross-Coupling[iv]

2.2.1 Introduction

A range of natural processes are driven by the loss of carbon dioxide, from polyketide synthesis to γ-aminobutyric acid (GABA) production.[1] Various synthetic strategies have emerged using the formation of CO_2 gas as the driving force. Tsuji and Saegusa independently reported decarboxylative allylation of β-keto allyl esters.[2,3] Shair developed a decarboxylative aldol using malonic acid half thioesters,[4] while Gooßen pioneered decarboxylative biaryl cross-couplings.[5] More recently, MacMillan and Doyle have used CO_2 gas extrusion and photoredox catalysis to generate a wide range of cross-couplings, including those that generate Csp^2–Csp^3 bonds.[6] Most relevant to our study, Breit has developed a bioinspired coupling of β-keto acids with allenes under Rh-hydride catalysis.[7,8] It occurred to us that by using tandem Rh-catalysis, we could achieve a complementary cross-coupling of β-keto acids with alkynes. We chose alkynes as allyl electrophiles because they are a common and readily accessible functional group. Our approach would enable unique access to ketones under mild conditions, without the need for generating enolates or the use of activated allylating agents.[9-13]

Based on previous studies from Yamamoto,[14] Breit,[15] and our laboratory,[16] we proposed a pathway involving tandem Rh-catalysis to enable decarboxylative coupling between β-keto acids **1** and alkynes **2** (Figure 2.3).[17] First, β-keto acid **1** and a Rh(I) species combine to generate a Rh(III)-hydride intermediate.[18] Insertion of alkyne **2** into the Rh(III)–H bond

[iv] Reproduced from F. A. Cruz, Z. Chen, S. I. Kurtoic and V. M. Dong, *Chem. Commun.*, 2016, **52**, 5836 with permission from The Royal Society of Chemistry.

gives Rh-vinyl species **5**. Subsequent β-hydride elimination generates allene **6** and regenerates the Rh(III)-hydride species. Insertion of allene **6** into the Rh(III)-H bond then forms Rh(III)-allyl species **7** that can be trapped with a carbon-based nucleophile.[19] Indeed, Breit recently reported the coupling of 1,3-diketones with terminal alkynes.[20] In the presence of β-keto acid **1**, C–C bond formation yields allylated β-keto acid **8**.[21] Finally, decarboxylation affords the desired ketone **3**.

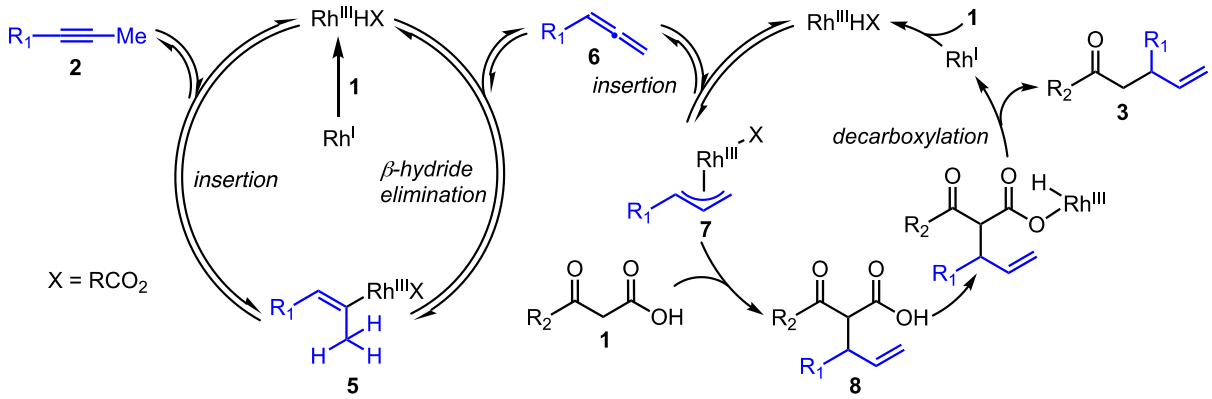


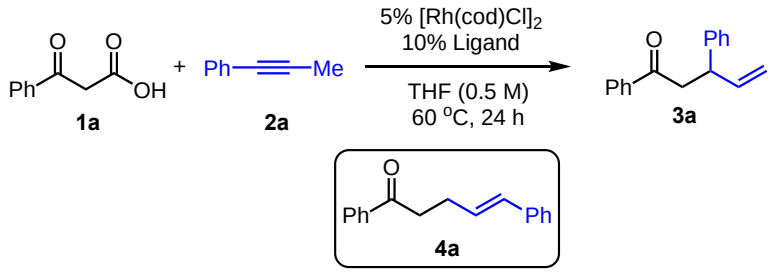
Figure 2.3. Proposed decarboxylative β-keto acid and alkyne coupling via tandem Rh-catalysis.

2.2.2 Results and Discussion

To test our mechanistic proposal, we investigated the cross-coupling of benzoylacetic acid (**1a**) and 1-phenyl-1-propyne (**2a**). In the presence of 5 mol% of $[Rh(cod)Cl]_2$ and 10 mol% 1,3-bis(diphenylphosphino)propane (dppp), the desired branched γ, δ–unsaturated ketone **3a** was observed in 5% yield with >20:1 branched to linear regioselectivity (Table 2.2). Notably, no allyl ester formation was observed despite the precedence for C–O bond formation between carboxylic acids and alkynes.[22] The major by-product observed was acetophenone arising from decarboxylation of benzoylacetic acid (**1a**). From further evaluation of bidentate phosphine ligands, we observed a relationship between ligand bite

angle and reactivity. Bisphosphine ligands with larger bite angles than dppp, such as 1,4-bis(diphenylphosphino)butane (dppb) and 1, 1'-bis(diphenylphosphino)ferrocene (dppf), resulted in increased reactivity. Further increasing the bite angle by use of Xantphos as a ligand resulted in a dramatic decrease in reactivity. Using DPEphos provided an optimal bite angle of approximately 101° for promoting the desired transformation.[23] By switching from THF to 2-MeTHF and increasing the equivalents of benzoylacetic acid (**1a**), the catalyst loading can be decreased while increasing the yield to 97%.

Table 2.2. Ligand Effects on Decarboxylative Coupling[a]



Ligand (bite angle)	dppe (83°)	dppp (92°)	dppb (97°)
yield[b], **3a**:**4a**	No product observed	5%, >20:1	12%, >20:1

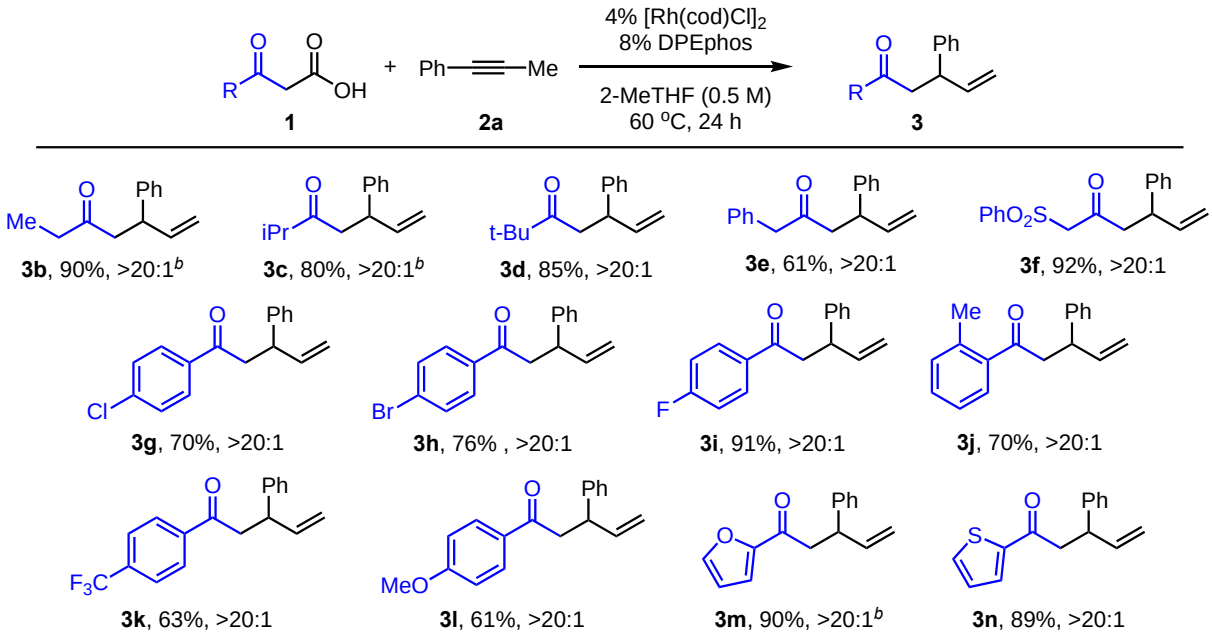
dppf (99°)	DPEphos (101°)	Xantphos (105°)
18%, >20:1	88% (97%)[c], >20:1	<5%, >20:1

[a]Reaction conditions: 0.1 mmol **1a**, 0.1 mmol **2a**, 5 mol% $[Rh(cod)Cl]_2$, 10 mol% ligand, 0.2 mL THF (0.5 M), 60 °C, 24 hours. [b]Determined by GC-FID analysis using mesitylene as internal standard. [c]Using 0.2 mmol **1a**, 4 mol% $[Rh(cod)Cl]_2$, 8 mol% DPEphos, and 2-MeTHF instead.

With this protocol in hand, we explored the coupling of various *β*–keto acids **1** with 1-phenyl-1-propyne (**2a**). Aliphatic *β*–keto acids, bearing multiple acidic *α*-hydrogens, were

alkylated with >20:1 regioselectivity (Table 2.3). Primary (**3b, 3e,** and **3f**), secondary (**3c**), and tertiary (**3d**) substitution are all tolerated (61–92%). Notably, *β*–keto acids with electron-withdrawing groups (phenyl and phenylsulfonyl) can be used to give ketones formally derived from the methyl-ketone dianions (highlighted in blue, **3e** and **3f**). *β*–keto acids bearing aromatic rings with a variety of substituents underwent alkylation with high branched to linear regioselectivity. Halogenated aromatic rings are well tolerated (**3g**–**3i**, 70–91%). Regioselective coupling still occurs when the aromatic ring has an *ortho*-methyl group (**3j**). In addition, electron-deficient *para*-trifluoromethyl and electron-rich *para*-methoxy substituted rings are tolerated (**3k** and **3l**, 63% and 61%, respectively). Finally, *β*–keto acids with heterocycles (*e.g.*, furan and thiophene) can be used as carbon pronucleophiles to yield **3m** and **3n** (90% and 89%, respectively).

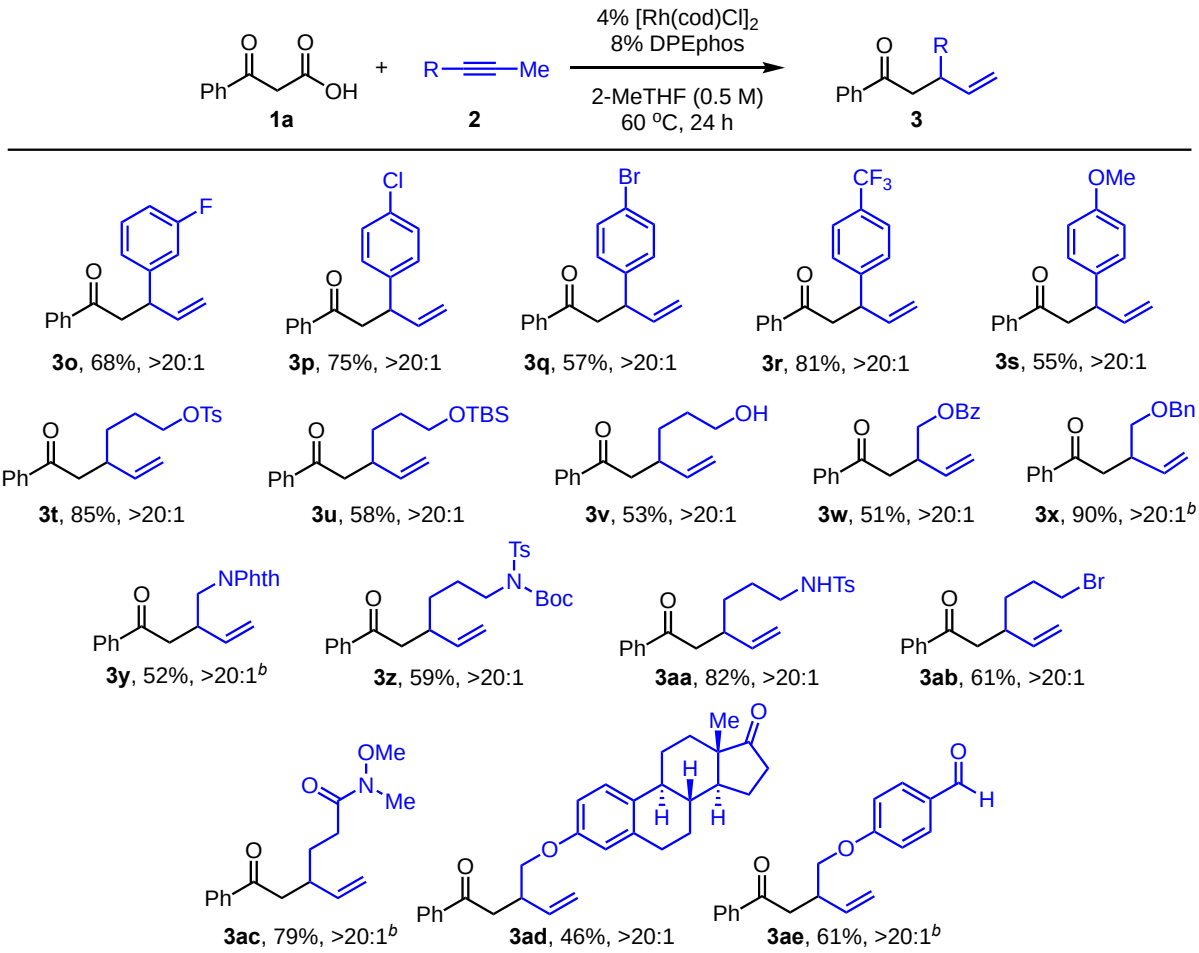
Table 2.3. Branched Selective Decarboxylative Coupling of Alkyne **2a** with Various b-Keto Acids



[a]Reaction conditions: 0.4 mmol **1**, 0.2 mmol **2a**, 4 mol% $[Rh(cod)Cl]_2$, 8 mol% DPEphos, 0.4 mL 2-MeTHF, 60 °C, 24 hours. >20:1 denotes the ratio of **3**:**4**. [b]Reaction ran with 50 mol% benzoic acid.

Next, we examined the coupling benzoylacetic acid (**1a**) with various alkynes **2** (Table 2.4). Halogenated 1-aryl-1-propynes were used to alkylate benzoylacetic acid (**1a**) with >20:1 regioselectivity (**3o**–**3q**, 57–75%). In addition, alkynes with electron-deficient *para*-trifluoromethyl and electron-rich *para*-methoxy phenyl rings are amenable to alkylating **1a** to afford ketones **3r** and **3s** (81% and 55%, respectively). Benzoylacetic acid (**1a**) can be alkylated using alkynes with aliphatic substitution in place of aromatic. Aliphatic alkynes present a challenge because of having more than one possible site for β-hydride elimination for allene formation. Given this challenge, we were pleased to find that using alkynes bearing aliphatic substituents gave the branched ketone product bearing a terminal olefin. Both free and protected alcohols are tolerated. A sensitive functional group handle (*e.g.*, the tosyl group) remains intact under these alkylating conditions (**3t**, 85%). Silylated, benzoylated, and benzylated alcohols are all also well tolerated (**3u**, **3w**, and **3x**, 51–90%). Phthalimide protected amines, as well as Boc and Ts protected amines can be installed on the alkyne coupling partner (**3y** and **3z**, 52% and 59%, respectively). Acidic N–H bonds are tolerated as shown by the formation of ketone **3aa** in 82% yield. Notably, using alkynes with free alcohols or amines, as in **3v** and **3aa**, does not result in intramolecular cyclization to form the corresponding tetrahydrofuran or pyrrolidine. These results highlight the high chemoselectivity of this protocol. Finally, electrophilic functionalities can be tolerated as evidenced by the formation of ketones **3ab**–**3ae** bearing an alkyl bromide, Weinreb amide, ketone, and aldehyde, respectively (46–79%).

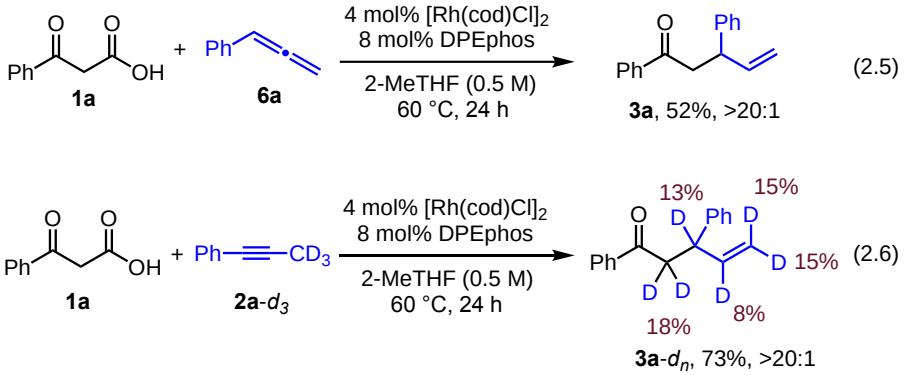
Table 2.4. Branched Selective Decarboxylative Coupling of b-Keto Acid **1a** with Various Alkynes

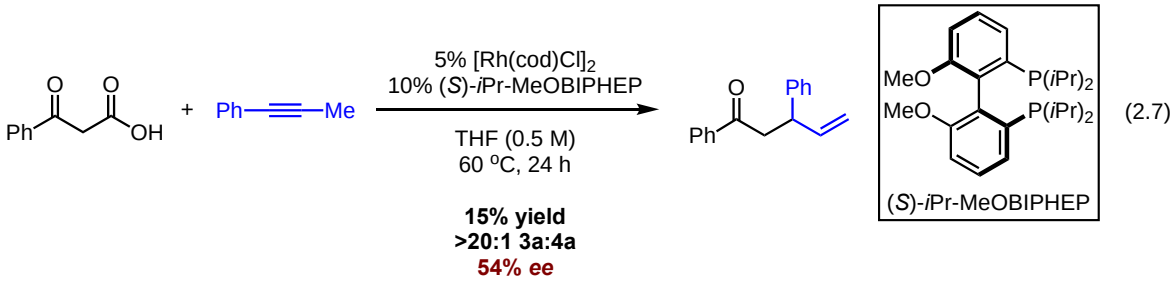


[a]Reaction conditions: 0.4 mmol **1a**, 0.2 mmol **2**, 4 mol% $[Rh(cod)Cl]_1$, 8 mol% DPEphos, 0.4 mL 2-MeTHF, 60 °C, 24 hours. >20:1 denotes the ratio of **3**:**4.** [b]Reaction ran with 50 mol% benzoic acid.

To provide evidence for the proposed allene intermediate, we used allene **6a** as a substitute for alkyne **2a** under standard reaction conditions. Ketone **3a** was obtained in 52% yield with >20:1 regioselectivity (eq. 2.6). This result suggests the feasibility of an allene intermediate in the catalytic cycle. To better understand the proposed *β*-hydride elimination, we performed an experiment with deuterated 1-phenyl-1-propyne **2a**-d_3 (eq. 2.7). Ketone **3a**-d_n was obtained in 73% yield with high-branched regioselectivity. We observed deuterium scrambling which suggests reversible *β*-hydride elimination during

allene formation. Initial studies with chiral ligands resulted in moderate enantioselectivities (up to 54% *ee*) using a MeOBIPHEP-based ligand (eq. 2.8).[24] These results support the proposed role of the Rh-phosphine complex in the key C-C bond formation, however, developing highly enantioselective variants warrants further efforts.





2.2.3 Conclusion

This Rh-catalyzed decarboxylative coupling between *β*-keto acids and alkynes provides a complementary approach to generate ketones, without need for enolate generation and activated allylic electrophiles. In addition, alkylation at specific sites can be performed in the presence of multiple reactive sites due to the directing effect of the carboxylic acid. Our study contributes to the emerging use of alkynes in various cross-couplings to generate C–O,[25] C–N,[26] C–S,[27] and C–C bonds.[28] Further studies are underway to expand the scope of

carbon pronucleophiles and identify more enantioselective variants for tandem Rh-catalysis.

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2.3: Stereodivergent Coupling of Aldehydes and Alkynes via Synergistic Catalysis Using Rh and Jacobsen's Amine[v]

2.3.1 Introduction

While common in Nature, using two catalysts to synergistically activate two substrates has emerged as a powerful strategy for chemical synthesis.[1] In comparison to enzymes, the relative configuration in a pair of chiral synthetic catalysts is readily altered. Seizing this advantage, Carreira and co-workers achieved stereodivergence in their α-alkylation of aldehydes with allylic alcohols,[2a-c] where any stereoisomer could be favored based on the Ir and amine combination chosen. While efficient and modular, stereodivergent dual catalysis remains rare and warrants further study.[3] Recently, Zhang has used dual Ir and Zn catalysis to achieve a stereodivergent α-allylation of α-hydroxyketones.[2d] Herein, we communicate a complementary method to access γ,δ-unsaturated aldehydes by coupling aldehydes and alkynes (Figure 2.4). While expanding stereodivergent hydrofunctionalization,[4] our study also highlights how different modes of catalysis can provide access to different constitutional isomers.

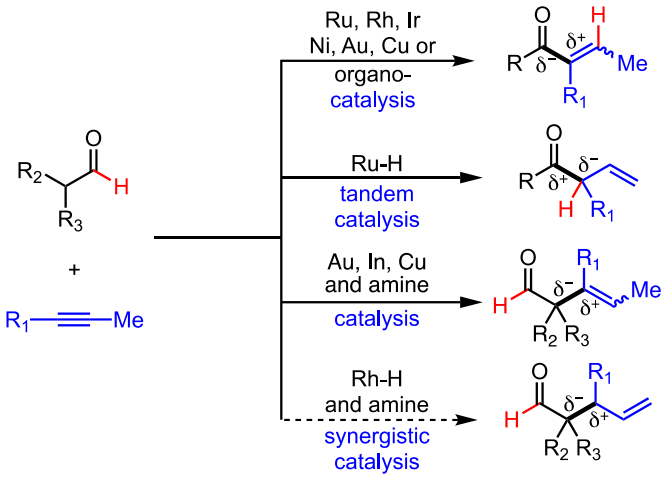

Figure 2.4. Divergence in aldehyde-alkyne coupling enabled by different modes of catalysis.

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Functional groups have inherent polarities that can be activated or inverted by catalysis. Discovered over twenty-five years ago,[5] the hydroacylation of alkynes represents a classic *umpolung* transformation where the aldehyde's natural electrophilic polarity has been inverted to generate a nucleophilic acyl-metal-hydride species.[6] The hydroacylation of alkynes typically generates the α,β-unsaturated isomer under a wide-range of protocols.[7] By using tandem Ru-hydride catalysis, we and others switched the conventional regioselectivity to generate β,γ-unsaturated isomers *via* a *nucleophilic* π-allyl species.[8] We envisioned that a Rh-hydride and amine catalyst duo[9] could enable unprecedented access to the γ,δ-unsaturated aldehyde *via* an *electrophilic* π-allyl complex.[10] This synergistic pairing produces α-allylated aldehydes, in contrast to previous metal-organocatalyst studies (where intramolecular alkyne coupling gave α-vinylated aldehydes).[11]

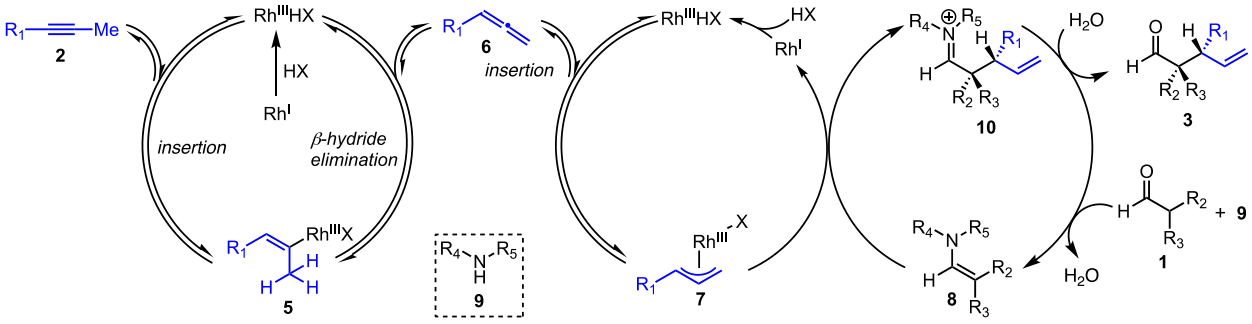


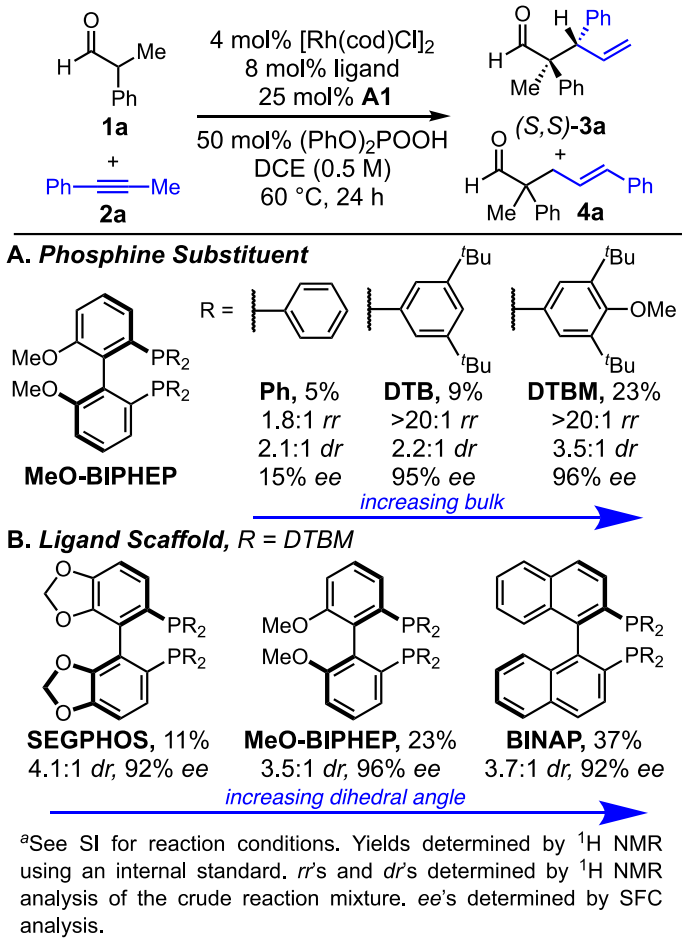
Figure 2.5. Proposed dual-catalytic aldehyde-alkyne coupling via a triple cascade.

We designed this atom-economic transformation on the basis of the triple cascade mechanism depicted in Figure 2.5.[12] Breit first demonstrated that Rh-hydride catalysts can promote the isomerization of alkynes (**2**) to generate allenes (**6**).[13a] Such allenes (**6**) undergo Rh-hydride insertion to generate electrophilic Rh-π-allyl species (**7**), which have been intercepted by various heteroatom-based nucleophiles.[13b-e] However, use of this strategy to achieve enantioselective C–C

bond formation has been elusive.[13f-h] To address this challenge, we proposed that an enamine (**8**), generated *in situ* from an aldehyde (**1**) and amine (**9**), would trap Rh-π-allyl **7** and generate **3**. In light of Carreira's study,[2a] we recognized the challenge would lie with identifying the appropriate Rh and amine combination for both reactivity and selectivity.

2.3.2 Results and Discussion

Table 2.5. Ligand Effects[a]



[a]See SI for reaction conditions. Yields determined by ^{1}H NMR using an internal standard. *rr*'s and *dr*'s determined by ^{1}H NMR analysis of the crude reaction mixture. *ee*'s determined by SFC analysis.

To test our hypothesis, we chose to study the coupling of 2-phenylpropanal (**1a**) and 1-phenyl-1-propyne (**2a**). Using α-branched aldehydes would help avoid aldol-dimerization pathways *via* enamine catalysis.[2b, 14] Moreover, successful transformation of α-branched

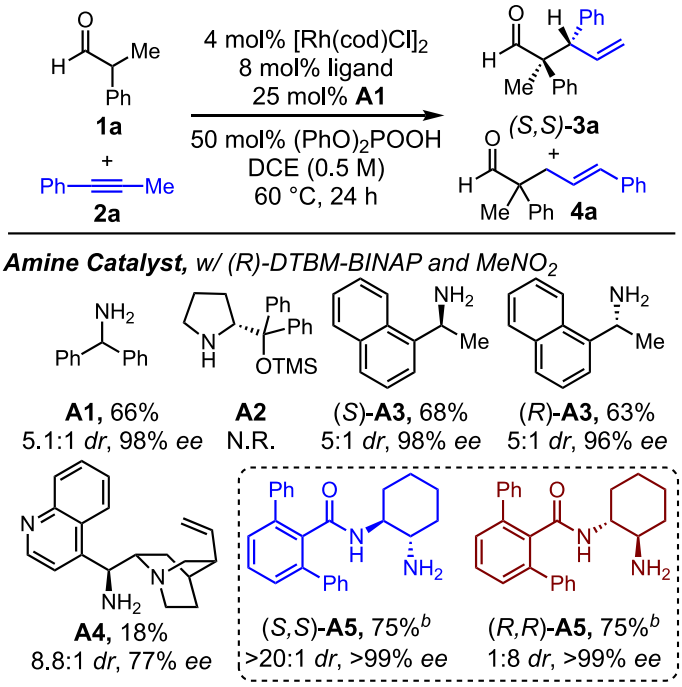
aldehydes would result in formation of either products **3a** or **4a**, both bearing a quaternary carbon stereocenter.[15] The regioselectivity reflects where C–C bond formation occurs on Rh-π-allyl **7** (*i.e.*, at the more or less substituted carbon). The phosphoric acid allows for generation of the requisite Rh–H catalyst, and aids with enamine formation. With this model system, we discovered that biaryl atropisomeric bisphosphine ligands were most promising for our aldehyde-alkyne coupling. Examination of various MeO-BIPHEP derivatives revealed that phosphine substitution influenced regio- and enantioselectivity (Table 2.5A). A phenyl-substituted MeO-BIPHEP afforded (*S,S*)-**3a** in 5% yield with modest selectivities (1.8:1 *rr*, 2.1:1 *dr*, 15% *ee*). Increasing the steric bulk of the phosphine substituents gave improved regio- and enantioselectivity (>20:1 *rr*, 96% *ee*) albeit in 23% yield and 3.5:1 *dr*.

Dihedral angles of biaryl ligands can be tuned by changing the backbone of the ligand and this angle is known to impact the efficiency in enantioselective hydrogenation.[16a] Thus, we next investigated a series of DTBM-variants with varying dihedral angles and observed improved yields with larger dihedral angles (Table 2.5B).[16b] (*R*)-DTBM-SEGPHOS afforded (*S,S*)-**3a** in 11% yield, while (*R*)-DTBM-MeO-BIPHEP gave (*S,S*)-**3a** in 23% yield. Increasing the ligand dihedral angle further, *via* (*R*)-DTBM-BINAP, resulted in an improved 37% yield. Changing solvent from DCE to $MeNO_2$ gave (*S*,*S*)-**3a** in 66% yield (Table 2.6).[17]

While aiming to maintain high levels of regio- and enantioselectivity, we turned our attention towards improving diastereoselectivity. A variety of amine catalysts (*e.g.*, diaryl prolinol, diamines, amino alcohols and cinchona alkaloids) were examined, but these scaffolds did not provide high reactivity and selectivity (Table 2.6). Amine (*S*)-**A3** gave similar results to **A1**. However, switching the enantiomer of **A3** had no effect on diastereoselectivity. Next, we

investigated Jacobsen's recently reported primary amine catalyst **A5**,[18a] which was used for enantioselective aldehyde α-hydroxlyation and α-fluorination. This catalyst features an amide that imparts facial bias *via* hydrogen-bonding.[18b] In our study, Jacobsen's amine (*S,S*)-**A5** provided excellent diastereoselectivity and reactivity (75%, >20:1 *dr*, >99% *ee*).[19] Diastereoselectivity can be switched by using (*R,R*)-**A5** instead of (*S,S*)-**A5** in combination with a Rh-(*R*)-DTBM-BINAP catalyst, to enable access to the *syn*-diastereomer (*R,S*)-**3a** (75%, 8:1 *dr*, >99% *ee*).

Table 2.6. Amine Effects[a]

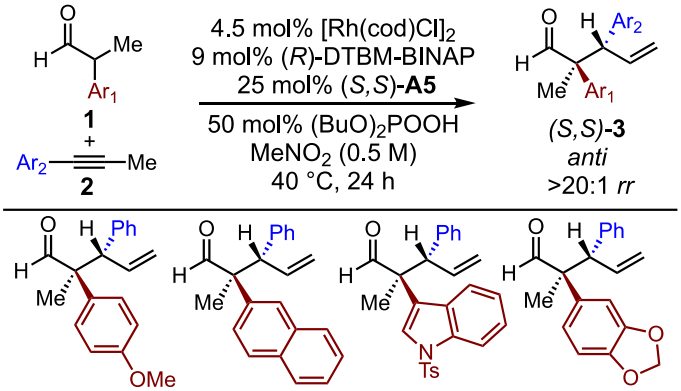


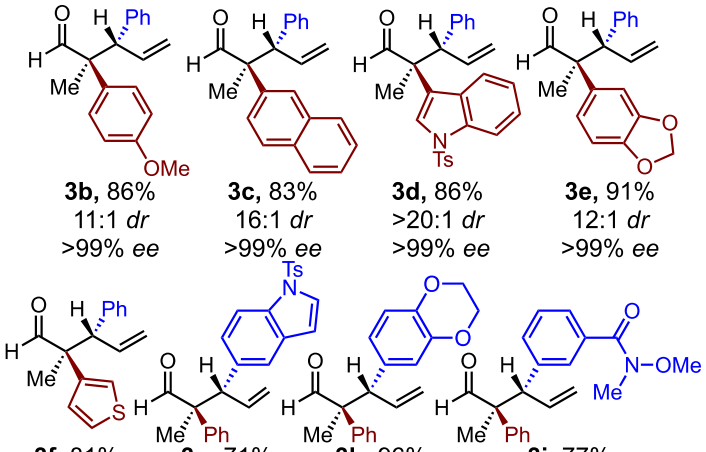
[a]See SI for reaction conditions. Yields determined by ^{1}H NMR using an internal standard. *rr*'s and *dr*'s determined by ^{1}H NMR analysis of the crude reaction mixture. *ee*'s determined by SFC analysis. [b]4.5 mol% $[Rh(cod)Cl]_2$, 50 mol% $(BuO)_2POOH$ instead, run at 40 C.

With this catalyst-combination in hand, we investigated the *anti*-selective coupling of various aldehydes **1** and alkynes **2** (Table 1). An aldehyde with an electron-rich phenyl ring underwent stereoselective coupling in 86% yield (**3b**). Aldehydes with aromatic and

heteroaromatic rings, like 2-naphthylene, *N*-tosyl-3-indole, benzodioxole, and 3-thiophene also undergo efficient and selective coupling (**3c**–**3f**). Electron-rich, electron-deficient, and bromine-containing alkynes (**3k**–**3l**) can be used. Alkynes with silyl (**3m**) and nitro groups (**3o**) are also suitable coupling partners, however the nitro-containing alkyne gave diminished *ee*'s (72% *ee*). Alkynes with heterocycles, such as indoles and benzodioxanes can also be used (**3g**–**3h**, 71–96%, >20:1 *rr*, 16:1– >20:1 *dr*, 93–>99% *ee*). Chemoselective aldehyde-alkyne coupling occurs with alkynes bearing electrophilic functionality like Weinreb amides (**3i**) or methyl esters (**3n**), but low *ee* (4% *ee*) with high *dr* (17:1 *dr*) is observed with amide **3i**.

Table 2.7. *Anti*-selective Aldehyde-Alkyne Coupling[a]





3b, 86%
11:1 *dr*
>99% *ee*

3c, 83%
16:1 *dr*
>99% *ee*

3d, 86%
>20:1 *dr*
>99% *ee*

3e, 91%
12:1 *dr*
>99% *ee*

3f, 81%
10:1 *dr*
>99% *ee*

3g, 71%
20:1 *dr*
93% *ee*

3h, 96%
16:1 *d*
>99% *ee*

3i, 77%
17:1 *dr*
4% *ee*

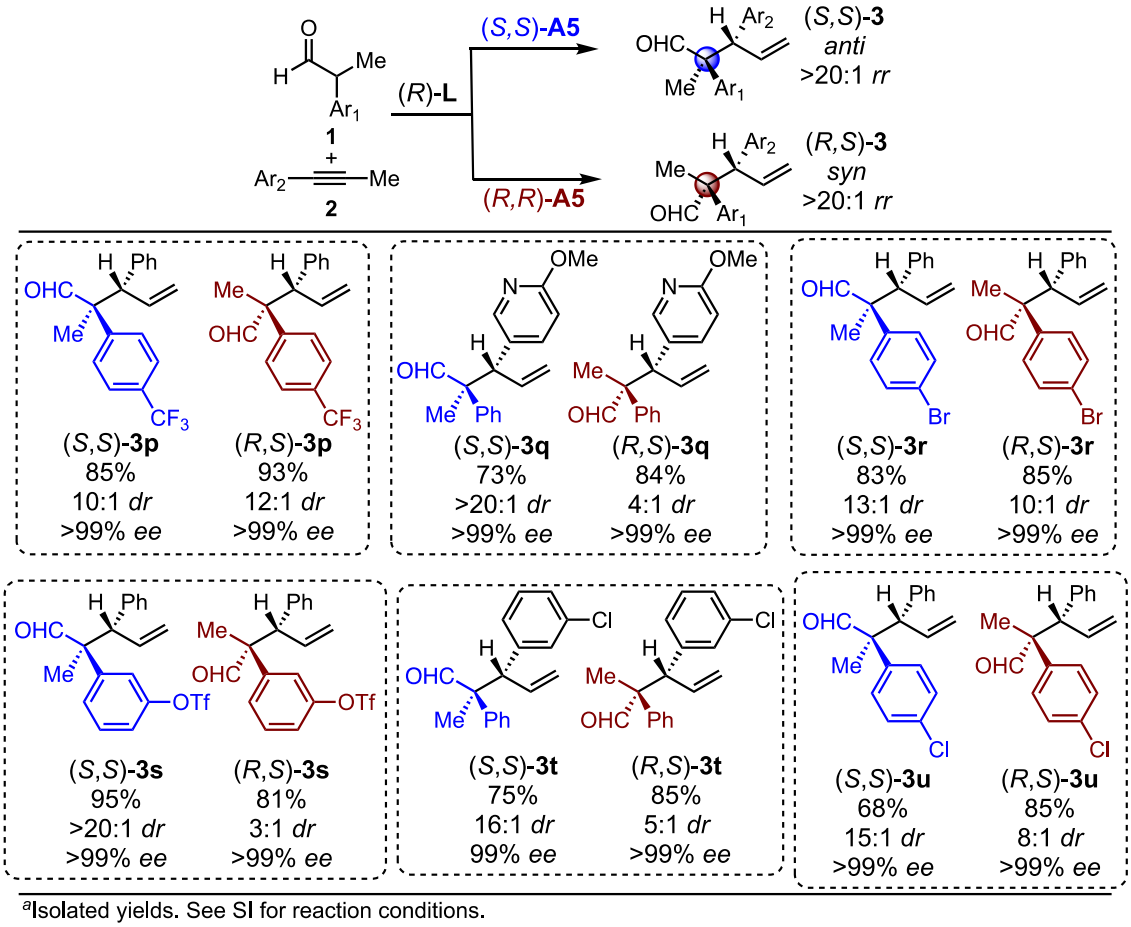
Ar$_1$ = **Ph**, **Ar$_2$** =

4-OMeC$_6$H$_4$	4-CF$_3$C$_6$H$_4$	4-BrC$_6$H$_4$	4-TMSC$_6$H$_4$	4-CO$_2$MeC$_6$H$_4$	3-NO$_2$C$_6$H$_4$
3j, 64%	**3k**, 81%	**3l**, 69%	**3m**, 83%	**3n**, 80%	**3o**, 75%
17:1 *dr*	15:1 *dr*	16:1 *dr*	20:1 *dr*	>20:1 *dr*	>20:1 *dr*
>99% *ee*	>99% *ee*	>99% *ee*	>99% *ee*	>99% *ee*	72% *ee*

[a]Isolated yields. See SI for reaction conditions.

Finally, we compared the efficiency for *syn*- versus *anti*-selective coupling using a second set of model substrates (Table 2.8). By simply altering the relative chirality of the catalyst combination, we could access either diastereomer. Notably, the *syn*- (*R*,*S*) and *anti*-motifs (*S*,*S*) can be accessed with comparably high selectivities when using aldehydes containing trifluoromethyl groups (**3p**) or bromine (**3r**). However, relatively lower diastereoselectivities were observed for the *syn*-diastereomers when using aldehydes with chlorine (**3u**, 8:1 vs. 15:1 *dr*) or triflates (**3s**, 3:1 vs. >20:1 *dr*), or alkynes with *meta*-chloride substitution (**3t**, 5:1 vs. 16:1 *dr*) or pyridine (**3q**, 4:1 vs. >20:1 *dr*); these results suggest partial matching between the enamine and Rh-allyl species.[20]

Table 2.8. Stereodivergent Aldehyde-Alkyne Coupling[a]



[a]Isolated yields. See SI for reaction conditions.

2.3.3 Conclusion

Our dual-catalyst protocol provides an atom-economic route to γ,δ-unsaturated aldehydes *via* alkyne hydrofunctionalization. The use of a Rh-catalyst and Jacobsen's amine allows for enantio-, diastereo-, and regioselective access to all possible stereoisomers, by simply changing the handedness of each catalyst. In addition, this synergistic system demonstrates how different modes of catalysis can enable divergent coupling of aldehydes and alkynes to generate different constitutional isomers. Insights from this study will guide future enantioselective alkyne hydrofunctionalizations *via* C–C bond formation.

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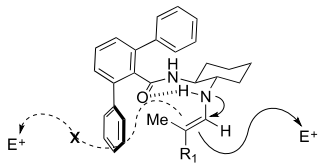

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2.4: Alkyne Hydroheteroarylation: Enantioselective Coupling of Indoles and Alkynes via Rh-Hydride Catalysis[vi]

2.4.1 Introduction

Aryl and heteroaryl rings can be used to increase non-bonding and electrostatic interactions between a small molecule and its macromolecule target.[1] Among the top selling therapeutics, more than half contain such aryl structures (Figure 2.6A).[2] Given the relevance of chirality in medicine, inventing enantioselective tools for introducing aromatic nucleophiles warrants pursuit.[3] The hydroarylation of alkynes is a modern strategy for functionalizing aryl-structures,[4] where two simple functional groups are coupled with high atom economy.[5] To date, however, this approach has been limited to generating achiral olefins (Figure 2.6B, Eq. a). Classic alkyne hydroarylations generate achiral vinylated-arenes *via* mechanisms that involve alkyne activation with π-acids or arene activation to access aryl-metal species.[4d-n] In contrast, we imagined using metal-hydride catalysis to couple arenes with alkynes to form allylated products (Figure 2.6B, Eq. b).[6] In this communication, we disclose a regio- and enantioselective alkyne hydroheteroarylation using indoles.[7-9]

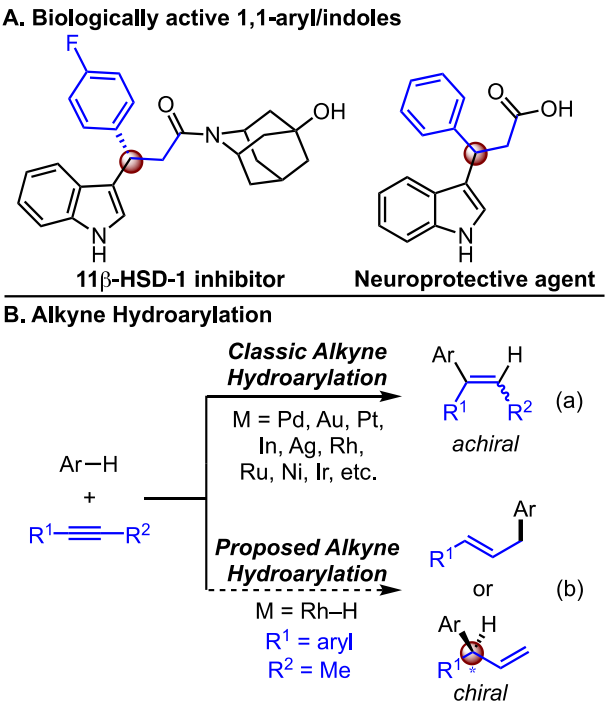

Figure 2.6. Inspiration for asymmetric alkyne hydroarylation.

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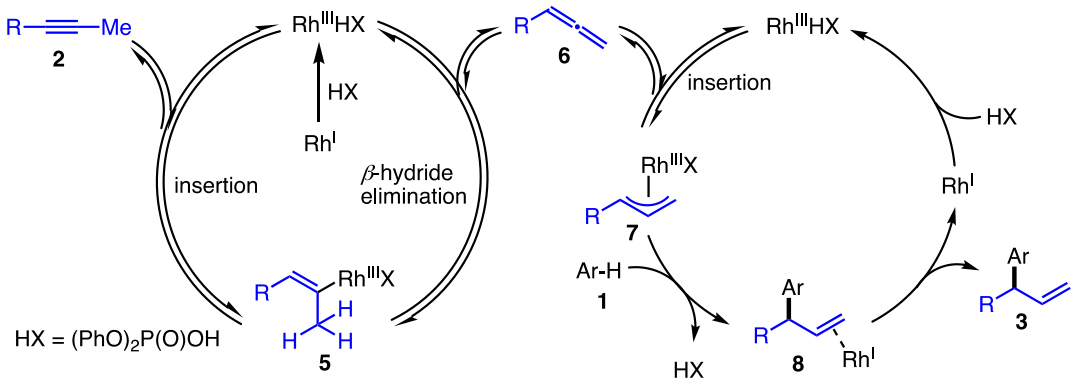
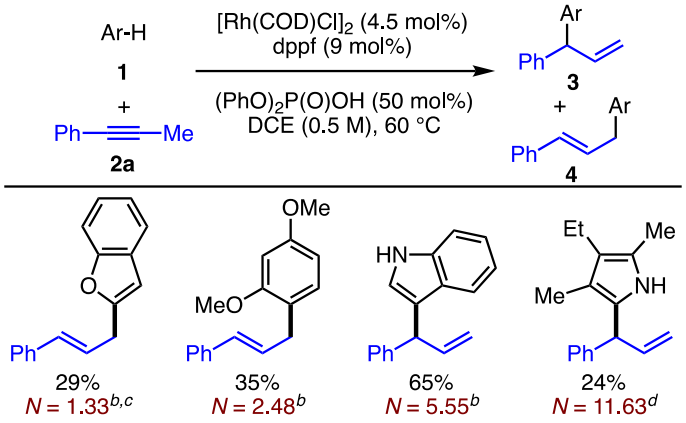


Figure 2.7. Proposed Rh-hydride catalyzed alkyne hydroarylation.

On the basis of previous studies, Rh-hydride catalysts can isomerize alkynes (**2**) to allenes (**6**) *via* a Rh-vinyl species (**5**) as depicted in Figure 2.7.[10] Subsequent allene insertion into a Rh–H generates a Rh-π-allyl species (**7**). Various oxygen-,[11] sulfur-,[12] and nitrogen-based[13] nucleophiles have been used to trap **7** and generate carbon-heteroatom bonds with stereocontrol. However, enantioselective C–C bond formation has thus far been only achieved with aldehydes *via* enamine catalysis.[14e] We recognized that the key challenge to achieving alkyne hydroarylation would be trapping Rh-π-allyl **7** with an arene **1** (an inherently weaker nucleophile) to generate **3**, with high enantio- and regiocontrol. However we were encouraged by Carreira's Ir-catalyzed polyene cyclization that demonstrates the use of arenes and hetereoarenes as terminating nucleophiles.[15]

2.4.1 Results and Discussion

Table 2.9. Alkyne Hydroarylation using Arenes with a Range of Nucleophilicities[a]

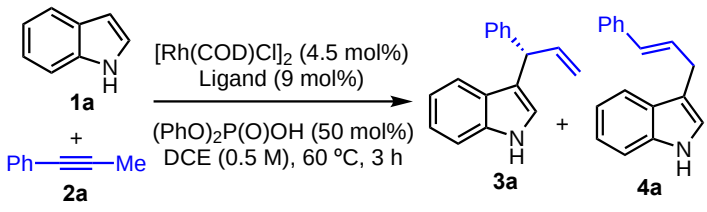


[a]**1** (0.1 mmol), **2a** (0.12 mmol), $[Rh(COD)Cl]_2$ (4.5 mol%), dppf (9.0 mol%), $(PhO)_2P(O)OH$ (50 mol%), DCE (0.2 mL), 60 °C, [b]Nucleophilicity in DCM. [c]Nucleophilicity of furan. [d]Nucleophilicity in MeCN.

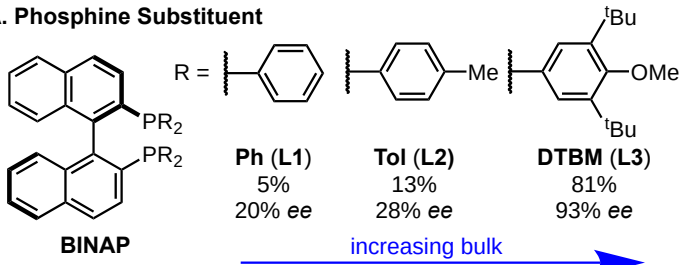
To test this hypothesis, we examined the coupling of various arenes and heteroarenes **1** and 1-phenyl-1-propyne (**2a**) (Table 2.9). Successful trapping of the Rh-π-allyl species affords either the branched (**3**) or the linear regioisomer (**4**). Using a combination of a Rh-bisphosphine and diphenyl phosphate,[11c, 14e] we observed that arenes and heteroarenes with a wide range of nucleophilicities, based on the Mayr scale (N = 1.33 to 11.63), were successful coupling partners.[16, 21] Initial studies using $[Rh(COD)Cl]_2$, dppf and diphenyl phosphate showed that the structure of the nucleophile impacted which regioisomer was favored. For example, with benzofuran and 1,3-dimethoxybenzene, we observed the linear isomers as the major product, in accordance with previous studies using Brønsted acid catalysis (>20:1 *rr*, 29% and 35%, respectively).[17] In contrast, 3-ethyl-2,4-dimethyl pyrrole and indole generated the branched isomers upon addition to alkyne **2a** (>20:1 *rr*, 24% and 65%, respectively). On the basis of related studies of alkyne hydroamination, we imagined that regioselectivity could be controlled by tuning the catalyst and acid.[13a] Indoles can be site-selectively prenylated at the *N*, 2-, 3-, 4-, or 7-position *via* enzymatic

or synthetic processes.[18] Despite the diverse reactivity of indoles, we observed selective bond formation at the 3-position upon coupling of alkyne **2a** and indole to yield **3** as the only regioisomer.

Table 2.10. Ligand Effects on Alkyne-Indole Coupling[a]



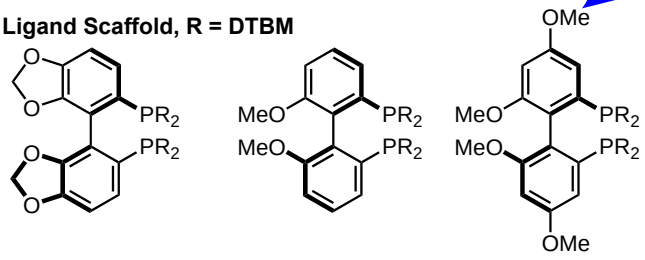
A. Phosphine Substituent



BINAP	**Ph (L1)**	**Tol (L2)**	**DTBM (L3)**
	5%	13%	81%
	20% *ee*	28% *ee*	93% *ee*

increasing bulk

B. Ligand Scaffold, R = DTBM



SEGPHOS (L4)	**MeO-BIPHEP (L5)**	**GARPHOS (L6)**
31%	18%	23%
90% *ee*	89% *ee*	96% *ee*

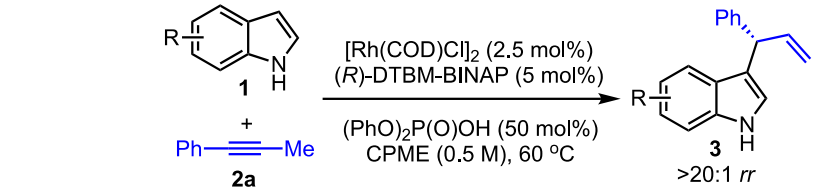
[a]**1a** (0.1 mmol), **2a** (0.12 mmol), $[Rh(COD)Cl]_2$ (4.5 mol%), ligand (9.0 mol%), $(PhO)_2P(O)OH$ (50 mol%), DCE (0.2 mL), 60 °C, 3 hours. [b]Yields determined by ^1H NMR with 1,2,4,5-tetramethylbenzene as internal standard. [c]Enantioselectivities determined by chiral SFC.

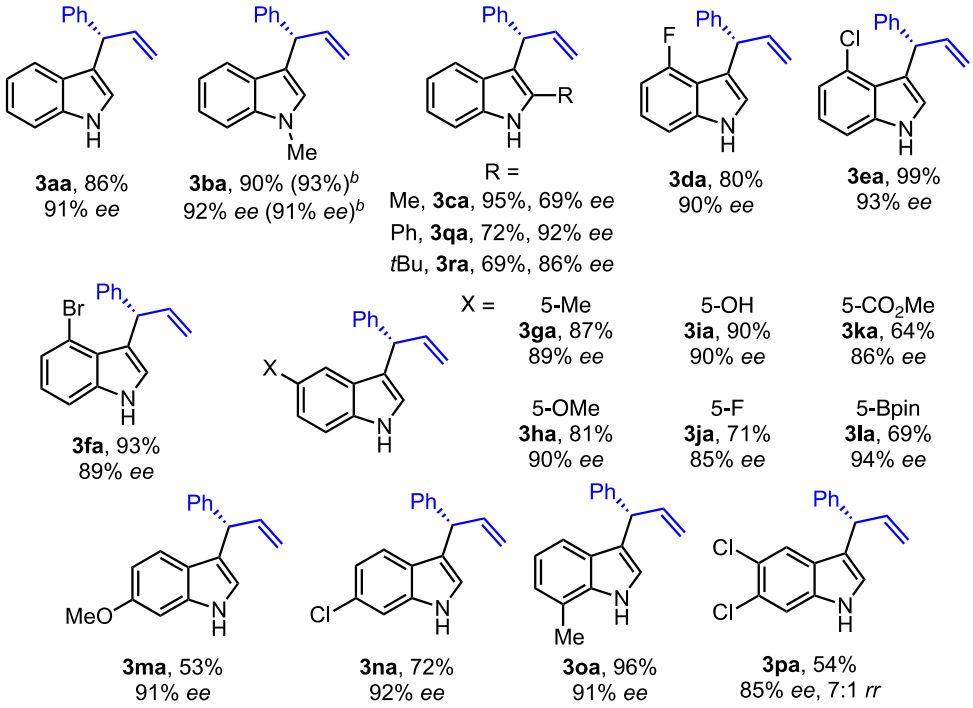
With this promising reactivity demonstrated, we focused on developing an enantioselective coupling using indoles due to the importance of these heterocycles in natural and pharmaceutical products.[19] We found that a protocol consisting of $[Rh(COD)Cl]_2$, (*R*)-Ph-BINAP (**L1**), and diphenyl phosphate gave the desired branched product (**3a**) in 5% yield and 20% *ee* (Table 2.10).[20]

In contrast to previous studies where carboxylic acids were used,[14a-d] more acidic acids (*e.g.,* sulfonic and phosphoric acids) were necessary for reactivity. Increasing the steric bulk of the phosphine substituent improved enantioselectivity (**L2**, 28% *ee* and **L3**, 93% *ee*). The electron-rich DTBM-BINAP (**L3**) also dramatically improved the yield to 81% yield. Other biaryl bisphosphine ligands bearing the DTBM-phosphine substituents such as SEGPHOS (**L4**), GARPHOS (**L5**), or MeO-BIPHEP (**L6**) provided similar enantioselectivity but lower reactivity (18–31% yield). With ligand **L3**, we found that a number of solvents could be used but found that using cyclopentyl methyl ether (CPME) was optimal; **3a** was obtained in 92% yield and 91% *ee*, with lower (2.5 mol%) catalyst loadings.[21]

With this protocol in hand, we explored the hydroheteroarylation of alkyne **2a** with various indoles (Table 2.11). Efficient and selective indole-alkyne coupling occurs with a variety of indole substitution patterns. For example, a methyl group can be incorporated at the *N*-, 5-, and 7-positions of indole to afford the corresponding allylated indoles with up to 96% yield, >20:1 *rr*, and 92% *ee* (**3ba**, **3ga**, **3oa**). In comparison, lower *ee* is observed with 2-methyl indole (**3ca**, 69% *ee*). In general, we observe lower enantioselectivity with 2-methyl indole using various aryl-substituted alkynes.[21] However, when a phenyl or tert-butyl group is incorporated at the 2-position higher *ee* is observed (**3qa** and **3ra**, 92% and 86% *ee*, respectively). Halogenated indoles were successfully coupled with high selectivities (**3da**, **3ea**, **3fa**, **3ja**, **3na**, **3pa**). Chemoselective C–C bond formation was observed in the presence of a nucleophilic phenol (**3ia**) and an electrophilic methyl ester (**3ka**). A substrate bearing a pinacol borane, a convenient functional handle, was transformed smoothly (**3la**).

Table 2.11. Alkyne Hydroheteroarylation with Various Indoles[a]



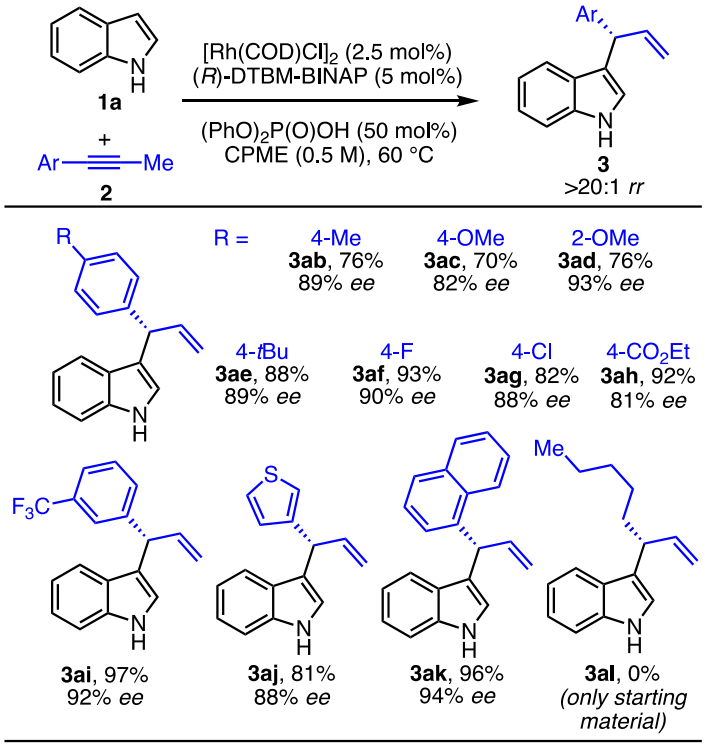


[a]**1** (0.1 mmol), **2a** (0.12 mmol), $[Rh(COD)Cl]_2$ (2.5 mol%), (*R*)-DTBM-BINAP (5.0 mol%), $(PhO)_2P(O)OH$ (50 mol%), CPME (0.2 mL), 60 °C. Isolated yields. *rr*'s (**3**:**4**) determined by ^1H NMR analysis of the unpurified reaction mixture. Enantioselectivities determined by chiral SFC. [b]Values in parentheses are for the transformation performed on a 1.0 mmol scale.

Next, we studied the coupling of indole **1a** with structurally diverse alkynes (Table 2.12). Electron-rich alkynes with alkyl or ether substitution undergo efficient and selective coupling with indole (**3ab**–**3ae**, 70–88%, >20:1 *rr*, 82–93% *ee*). Fluorinated and chlorinated alkynes act as efficient coupling partners (**3af** and **3ag**, 82–93%, >20:1 *rr*, 88-90% *ee*). In addition, electron-deficient alkynes with trifluoromethyl substitution undergo hydroarylation with indole to provide **3ai** in 97% yield and 92% *ee*. Chemoselective functionalization occurs even in the presence of electrophilic ethyl ester (**3ah**). Aromatic and heteroaromatic alkynes (3-thiophene and 1-

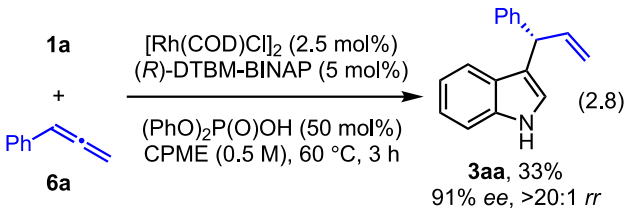
naphthalene) also undergo hydroarylation (**3aj** and **3ak**). We found that an aromatic or heteroaromatic group on the alkyne is critical for reactivity. For example, an alkyl-substituted alkyne, such as 2-octyne, proved to be unreactive under these conditions (**3al**).

Table 2.12. Hydroheteroarylation of Various Alkynes with Indole[a]



[a]**1a** (0.1 mmol), **2** (0.12 mmol), $[Rh(COD)Cl]_2$ (2.5 mol%), (*R*)-DTBM-BINAP (5.0 mol%), $(PhO)_2P(O)OH$ (50 mol%), CPME (0.2 mL), 60 °C. Isolated yields. *rr*'s (**3**:**4**) determined by ^1H NMR analysis of the unpurified reaction mixture. Enantioselectivities determined by chiral SFC.

To support the intermediacy of an allene, we replaced alkyne **2a** with phenylallene **6a** (Eq. 2.8).[21] Under standard reaction conditions, the desired coupling product **3aa** was obtained with similar enantio- and regioselectivity, although in lower yield (33% yield, 91% *ee*, and >20:1 *rr*). This result supports the possibility of an allene intermediate. But the diminished yields suggest that high concentrations of allene may be detrimental due to competing decomposition and thus, *in situ* generation results in better efficiency.[11c, 13a]



2.4.3 Conclusion

We have demonstrated a regio- and enantioselective method to hydrofunctionalize alkynes using indoles. The use of Rh-hydride catalysis to isomerize alkynes has enabled access to a complementary hydroheteroarylation motif. Moreover, our study demonstrates the potential of generating C–C bonds under mild conditions using both aromatic and heteroaromatic motifs. Given these promising results, our future studies will focus on enantio- and regioselective coupling using other classes of aromatic nucleophiles.

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(10) For a review, see: (a) Koschker, P.; Breit, B. *Acc. Chem. Res.* **2016**, *49,* 1524. For select examples using Pd, see: (b) Kadota, I.; Shibuya, A.; Gyoung, Y. S.; Yamamoto, Y. *J. Am. Chem. Soc.* **1998,** *120,* 10262; (c) Gao, Z. Wu, Z.; Fang, X.; Lin, A.; Yao, H. *Org. Lett.* **2016,** *18,* 3906; (d) Yang, C.; Zhang, K.; Wu, Z.; Yao, H.; Lin, A. *Org. Lett.* **2016,** *18,* 5332. For select examples of metal-catalyzed alkyne isomerization followed by trapping with electrophiles, see: (e) Obora, Y.; Hatanaka, S.; Ishii, Y. *Org. Lett.* **2009,** *11,* 3510; (f) Park, B. Y.; Nguyen, K. D.; Chaulagain, M. R.; Komanduri, V.; Krische, M. J. *J. Am. Chem. Soc.* **2014,** *136,* 11902; (g) Liang, T.; Nguyen, K. D.; Zhang, W. D.; Krische, M. J. *J. Am. Chem. Soc.* **2015,** *137,* 3161; (h) Chen, Q.-A.; Cruz, F. A.; Dong, V. M. *J. Am. Chem. Soc.* **2015,** *137,* 3157; (i) Liang, T.; Zhang, W.; Chen, T.-Y.; Nguyen, K. D.; Krische, M. J. *J. Am. Chem. Soc.* **2015,** *137,* 13066; (j) Liang, T.; Zhang, W.; Krische, M. J. *J. Am. Chem. Soc.* **2015,** *137,* 16024.

(11) For examples of C–O bond formation, see: (a) Lumbroso, A.; Koschker, P.; Vautravers, N.R.; Breit, B. *J. Am. Chem. Soc.* **2011**, *133*, 2386; (b) Koschker, P.; Kähny, M.; Breit, B. *J. Am. Chem. Soc*. **2015**, *137*, 3131; (c) Liu, Z.; Breit. B. *Angew. Chem. Int. Ed.* **2016**, *55*, 8440.

(12) For an example of C–S bond formation, see: Xu, K.; Khakyzadeh, V.; Bury, T.; Breit, B.; *J. Am. Chem. Soc.* **2014**, *136*, 16124.

(13) For examples of C–N bond formation, see: (a) Chen, Q.-A.; Chen, Z.; Dong, V. M. *J. Am. Chem. Soc.* **2015**, *137*, 8392; (b) Haydl, A. M.; Hilpert, L. J.; Breit, B. *Chem. Eur. J.* **2016,** *22*, 6547.

(14) For examples of C–C bond formation, see: (a) Beck, T. M.; Breit, B. *Org. Lett.* **2016,** *18,* 124; (b) Cruz, F. A.; Chen, Z.; Kurtoic, S. I.; Dong, V. M. *Chem. Commun.* **2016**, *52*, 5836; (c) Li,

C.; Grugel, C.; Breit, B. *Chem. Commun.* **2016,** *52,* 5840; (d) Beck, T. M.; Breit, B. *Eur. J. Org. Chem.* **2016,** 5839; (e) Cruz, F. A.; Dong, V. M. *J. Am. Chem. Soc.,* **2017,** *139,* 1029.

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(17) Bras, J. L.; Muzart, J. *Tetrahedron* **2007,** *63,* 7942.

(18) For select reviews, see: (a) Williams, R. M.; Stocking, E. M.; Sanz-Cerveza, J. F. *Top. Curr. Chem.* **2000,** *209,* 97; (b) Li, S.-M. *Nat. Prod. Rep.* **2010,** *27,* 57; (c) Lindel, T.; Marsch, N.; Adla, S. K. *Top. Curr. Chem.* **2012,** *309,* 67. For select examples, see: (d) Kranen, E.; Steffan, N.; Maas, R.; Li, S.-M.; Jose, J. *ChemCatChem* **2011**, *3*, 1200; (e) Schwarzer, D. D.; Gritsch, P. J.; Gaich, T. *Angew. Chem. Int. Ed.* **2012**, *51*, 11514; (f) Wollinsky, B.; Ludwig, L.; Hamacher, A.; Yu, X.; Kassack, M. U.; Li, S.-M. *Bioorg. Med. Chem. Lett.* **2012**, *22*, 3866; (g) Yu, X.; Liu, Y.; Xie, X.; Zheng, X.-D.; Li, S.-M. *J. Biol. Chem.* **2012**, *287*, 1371; (h) Johnson, K. F.; Zeeland, R. V.; Stanley, L. M. *Org. Lett.* **2013**, *15*, 2798; (i) Ruchti, J.; Carreira, E. M. *J. Am. Chem. Soc.* **2014**, *136*, 16756; (j) Müller, J. M.; Stark, C. B. W. *Angew. Chem. Int. Ed.* **2016**, *55*, 4798.

(19) (a) Joule, J. A.; Mills, K. *Heterocyclic Chemistry*, *4th ed.*, Blackwell Science: Oxford, 2000. (b) Faulkner, D. J. *Nat. Prod. Rep.* **2002**, *19*, 1. (c) O'Connor, S. E.; Maresh, J. J. *Nat. Prod. Rep.* **2006**, *23*, 532; (d) Goetz, A. E.; Silberstein, A.L.; Corsello, M. A.; Garg, N. K. *J. Am. Chem. Soc.* **2014,** *136,* 3036; (e) Moreno, J.; Picazo, E.; Morrill, J. A.; Smith, J. M.; Garg, N. K. *J. Am. Chem. Soc.* **2016,** *138,* 1162.

(20) Absolute configuration was determined by comparison of optical rotation, see SI.

(21) See SI for further experimental details, including other substrates evaluated, solvent evaluation, and use of a deuterated alkyne.

Appendix for Alkyne Hydrofunctionalization and Dehomologative Olefin Synthesis

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Appendix 1.1: Supporting Information for Chapter 1.1

Rh-Catalyzed C–C Bond Cleavage by Transfer Hydroformylation[1]

Table of Contents: **Page**

1. Materials and Methods

All syntheses were performed in oven-dried or flame-dried glassware under an atmosphere of N_2. Tetrahydrofuran, dichloromethane, toluene and diethyl ether were purified using an Innovative Technologies Pure Solv system, degassed by three freeze-pump-thaw cycles, and stored over 3 Å MS within an N_2 filled glove box. 1,4-Dioxane, 1,2-dimethoxyethane and dimethylsulfoxide were refluxed with CaH_2 and distilled prior to use. The molarity of organolithium reagents was determined by titration with *iso*-propanol/1,10-phenanthroline. Reactions were monitored either *via* gas chromatography using an Agilent Technologies 7890A GC system equipped with an Agilent Technologies 5975C inert XL EI/CI MSD or by analytical thin-layer chromatography on EMD Silica Gel 60 F_{254} plates. Visualization of the developed plates was performed under UV light (254 nm) or using either $KMnO_4$ or *p*-anisaldehyde stain. Column chromatography was performed with Silicycle Silia-P Flash Silica Gel using glass columns. Automated column chromatography was performed using either a Biotage SP1 or Teledyne Isco CombiFlash Rf 200 purification system. ^{1}H, ^{13}C, ^{19}F, and ^{31}P NMR spectra were recorded on a Bruker DRX-400 (400 MHz ^{1}H, 100 MHz ^{13}C, 376.5 MHz ^{19}F, 161.9 MHz ^{31}P), GN-500 (500 MHz ^{1}H, 125.7 MHz ^{13}C) or CRYO-500 (500 MHz ^{1}H, 125.7 MHz ^{13}C) spectrometer. ^{1}H NMR spectra were internally referenced to the residual solvent signal or TMS. ^{13}C NMR spectra were internally referenced to the residual solvent signal. Data for ^{1}H NMR are reported as follows: chemical shift (δ ppm), multiplicity (s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet, br = broad), coupling constant (Hz), integration. Data for ^{13}C NMR are reported in terms of chemical shift (□, ppm). Infrared spectra were obtained on a Thermo Scientific Nicolet iS5 FT-IR spectrometer equipped with an iD5 ATR accessory. High resolution mass spectra (HRMS) was performed by the University of California, Irvine Mass Spectrometry Center. All new compounds were characterized by ^{1}H NMR, ^{13}C NMR, HRMS, and optical rotation. For known compounds, we have cited the published characterization data that we used to compare to our synthesized compounds and we have included a ^{1}H NMR spectrum to establish purity of the isolated material.

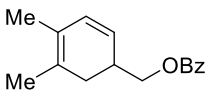
[1] See Murphy, S. K.; Park, J.–W.; Cruz, F. A.; Dong, V. M. *Science* **2015,** *347,* 56. for additional details.

2. Olefin Synthesis

General Procedure for Transfer hydroformylation

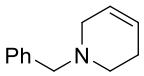
To a 1 dram vial was added the indicated amount of $[Rh(cod)OMe]_2$, Xantphos, 3-OMeBzOH, and any solid substrates (aldehyde or acceptor), in a N_2-flled glovebox. The indicated amounts of THF and liquid substrates (aldehyde or acceptor) were then added. When norbornadiene was used as an acceptor, it was crucial to add the norbornadiene last to achieve the fastest reaction rates. The vial was then sealed with a Teflon-lined screw cap and heated at the indicated temperature and time. Chemo- and regio- selectivity were determined from analysis of the reaction mixture by ^1H NMR analysis. The olefin product was isolated by either column chromatography or preparatory TLC. Alternatively, the yields of volatile products were determined either by GC–FID or ^1H NMR analysis.

***rac*-(4,5-Dimethylcyclohexa-2,4-dien-1-yl)methyl benzoate (2d)**



The title compound was synthesized according to the general procedure using $[Rh(cod)OMe]_2$ (1.9 mg, 0.004 mmol, 0.5 mol%), Xantphos (4.6 mg, 0.008 mmol, 1 mol%), 3-OMeBzOH (1.2 mg, 0.008 mmol, 1 mol%), 6-formyl-3,4-dimethylcyclohex-3-en-1-yl)methyl benzoate (**1d**, 218.0 mg, 0.8 mmol, 1 equiv), norbornadiene (98 µL, 0.96 mmol, 1.2 equiv), and THF (200 µL). After stirring at 90 °C for 8 hours, the regioselectivity (>95:5) was assessed by ^1H NMR analysis of the reaction mixture. The product **2d** was isolated by column chromatography (0–10% ethyl acetate in hexanes) as a clear colorless oil (193 mg, 99% yield). The experiment was repeated using an identical procedure and an 85% yield was obtained in that case (92% average yield over two experiments). ^1H NMR (500 MHz, $CDCl_3$) δ 8.11 (d, *J* = 7.3 Hz, 2H), 7.62 (t, *J* = 7.3 Hz, 1H), 7.50 (t, *J* = 7.3 Hz, 2H), 5.92 (d, *J* = 9.5 Hz, 1H), 5.67 (d, *J* = 9.5 Hz, 1H), 4.30 (d, *J* = 6.8 Hz, 2H), 2.81 (s, 1H), 2.39–2.27 (m, 1H), 2.24–2.14 (m, 1H), 1.82 (s, 3H), 1.78 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 166.7, 132.9, 131.4, 130.4, 129.6, 128.4, 126.8, 123.9, 123.1, 66.9, 33.8, 32.8, 19.4, 17.2; IR (ATR) 1716, 1268, 1109, 709 cm^{-1}; HRMS (CI+) calculated for $C_{16}H_{16}O_2$ $[M - H_2]^+$, 240.1150, found 240.1161.

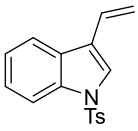
1-(Phenylmethyl)-1,2,3,6-tetrahydropyridine (2f)



The title compound was synthesized according to the general procedure using $[Rh(cod)OMe]_2$ (1.9 mg, 0.004 mmol, 1 mol%), Xantphos (4.6 mg, 0.008 mmol, 2 mol%), 3-OMeBzOH (1.2 mg, 0.008 mmol, 2 mol%), 4-carboxaldehyde-1-phenylmethylpiperidine (**1f**, 81.3 mg, 0.4 mmol, 1 equiv), norbornadiene (49 µL, 0.48 mmol, 1.2 equiv), and THF (100 µL). After stirring at 60 °C for 72 hours, the product **2f** was isolated by column chromatography (30% diethyl ether in pentanes) as a clear colourless oil (47 mg, 67% yield). The ^1H NMR spectrum matched the literature reported values.[2] ^1H NMR (400 MHz, $CDCl_3$) δ 7.38–7.24 (m, 5H), 5.79–5.73 (m, 1H), 5.69–5.63 (m 1H), 3.60 (s, 2H), 2.99 (quintet, *J* = 2.7 Hz, 2H), 2.58 (t, *J* = 5.7 Hz, 2H), 2.17 (m, 2H).

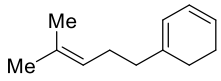
[2] Cresswell, A. J., Davies, S. G., Lee, J. A. Morris, M. J., Roberts, P. M., Thomson, J. E. *J. Org. Chem.*, **2012,** *77*, 7262.

3-Ethenyl-1-[(4-methylbenzene)sulfonyl]-1H-indole (**2g**)



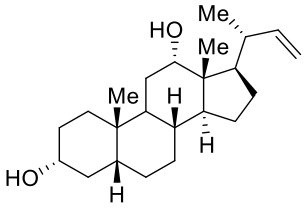
The title compound was synthesized according to the general procedure using $[Rh(cod)OMe]_2$ (1.0 mg, 0.002 mmol, 1 mol%), Xantphos (2.3 mg, 0.004 mmol, 2 mol%), 3-OMeBzOH (0.6 mg, 0.004 mmol, 2 mol%), 3-(1-tosyl-1H-indol-3-yl)propanal (**1g**, 65.5 mg, 0.2 mmol, 1 equiv), norbornadiene (24 □L, 0.24 mmol, 1.2 equiv), and THF (50 μL). After stirring at 80 °C for 24 hours, the product **2g** was isolated by column chromatography (10% EtOAc in Hexanes) as white solid (50 mg, 84% yield). The ^{1}H NMR spectrum matched the literature reported values.[3] ^{1}H NMR (400 MHz; $CDCl_3$) δ 8.01 (dt, *J* = 8.2, 0.4 Hz, 1H), 7.79–7.73 (m, 3H), 7.62 (s, 1H), 7.34 (ddd, *J* = 8.2, 7.2, 1.1 Hz, 1H), 7.29–7.25 (m, 1H), 7.22–7.19 (m, 2H), 6.78 (ddd, *J* = 17.8, 11.3, 0.7 Hz, 1H), 5.80 (dt, *J* = 17.8, 0.6 Hz, 1H), 5.35 (dd, *J* = 11.3, 1.1 Hz, 1H), 2.32 (s, 3H).

1-(4-Methylpent-3-en-1-yl)cyclohexa-1,3-diene (eq. 2-**2q**)



The title compound was synthesized according to the general procedure using $[Rh(COD)OMe]_2$ (1.9 mg, 0.004 mmol, 0.5 mol%), xantphos (4.6 mg, 0.008 mmol, 1 mol%), 3-OMeBzOH (1.2 mg, 0.008 mmol, 1 mol%), 4-(4-methylpent-3-en-1-yl)cyclohex-3-ene-1-carbaldehdye (165 μL, 0.8 mmol, 1 equiv, a 93.5:6.5 mixture of regioisomers from the Diels-Alder reaction), norbornadiene (98 μL, 0.96 mmol, 1.2 equiv), and THF (200 μL). After stirring at 60 °C for 24 hours, the product was isolated by column chromatography (100% pentanes) as a clear colourless oil (121 mg, 93% yield, 93:7 mixture of regioisomers arising from regioselective dehydroformylation of the minor isomer from the Diels-Alder reaction). ^{1}H NMR (500 MHz, $CDCl_3$) δ 5.96–5.85 (m, 1H), 5.77–5.66 (m, 2H), 5.18 (s, 1H), 2.32–2.05 (m, 8H), 1.75 (s, 3H), 1.68 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 139.9, 131.7, 124.8, 124.2, 123.6, 118.5, 37.5, 26.6, 26.3, 25.8, 23.0, 17.8; IR (ATR) 3002, 2955, 1663, 1539, 1420 cm^{-1}; LRMS (EI) calculated for $C_{12}H_{18}$ $[M]^+$, 160.1, found 160.1.

24-Nor-5β-chol-22-ene-3α,12α-diol (**2o**)

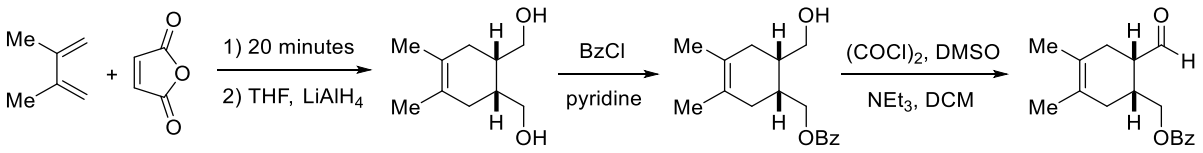


The title compound was synthesized according to the general procedure using $[Rh(cod)OMe]_2$ (1.0 mg, 0.004 mmol, 1 mol%), Xantphos (2.3 mg, 0.008 mmol, 2 mol%), 3-OMeBzOH (0.6 mg, 0.008 mmol, 2 mol%), 3α.12α-dihydroxy-5β-cholanal-(24) (**1o**, 75.3 mg, 0.2 mmol, 1 equiv), norbornadiene (24 μL, 0.24 mmol, 1.2 equiv), and THF (50 μL). After stirring at 80 °C for 72 hours, the product **2o** was isolated by column chromatography (50% EtOAc in Hexanes) as a pale yellow solid (45 mg, 64% yield). ^{1}H NMR (500 MHz, $CDCl_3$) δ 5.73–5.63 (m, 1H), 4.91 (dd, *J* = 17, 1 Hz, 1H), 4.83 (dd, *J* = 10, 1.5 Hz, 1H), 3.98 (t, *J* = 3 Hz, 1H), 3.66–3.56 (m, 1H), 2.11–2.00 (m, 1H), 1.88–1.75 (m, 3H), 1.75–1.64 (m, 3H), 1.64–1.48 (m, 6H), 1.48–1.30 (m, 4H), 1.31–1.18 (m, 2H), 1.14 (td, *J* = 14, 3.5 Hz, 1H), 1.08 (d, *J* = 6.5 Hz, 3H), 0.98 (td, *J* = 14, 3 Hz, 2H), 0.91 (s, 3H), 0.89–0.82 (m, 1H), 0.71 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 145.0, 112.0, 73.3, 72.0, 48.5, 47.1, 46.6, 42.2, 41.1, 36.6, 36.2, 35.4, 34.3, 33.9, 30.7, 28.8, 27.9, 27.3, 26.3, 23.8, 23.3, 19.5, 13.1; IR (ATR) 2932, 2863, 1447, 1373, 1089, 1040, 905 cm^{-1}; HRMS (ESI+) calculated for $C_{23}H_{38}O_2Na$ $[M + Na]^+$ 369.2769 found 369.2777; mp = 153–155 °C

[3] Waser, J., Gaspar, B., Nambu, H., Carreira, E. M. *J. Am. Chem. Soc.*, **2006,** *128*, 11693.

3. Aldehyde Synthesis

***rac*-(*cis*-6-formyl-3,4-dimethylcyclohex-3-en-1-yl)methylbenzoate (1d)**[4]



Step 1: 2,3-dimethylbutadiene (1.00 mL, 8.79 mmol, 1 equiv) was added dropwise to a stirring solution of maleic anhydride (0.862 g, 8.79 mmol, 1 equiv) in THF (2 mL). CAUTION: The reaction is highly exothermic. After 45 minutes, an additional 45 mL of THF were added and the vessel was cooled to 0 ºC in an ice bath. $LiAlH_4$ (1.335 g, 35.2 mmol, 4 equiv) was added slowly. The solution was stirred for 5 hours and then quenched using the Fieser method. The solution was dried with $MgSO_4$, filtered, and concentrated *in vacuo*. The residue was dissolved in EtOAc and precipitated with hexanes to give the pure diol as a white solid (0.860 g, 57% yield). The ^{1}H NMR spectrum matched the literature reported values.[5] ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.75 (dd, *J* = 11.0, 6.9 Hz, 2H), 3.62 (dd, *J* = 11.1, 3.8 Hz, 2H), 3.19 (s, 2H), 2.17–2.05 (m, 4H), 1.98 (t, *J* = 12.8 Hz, 2H), 1.64 (s, 6H).

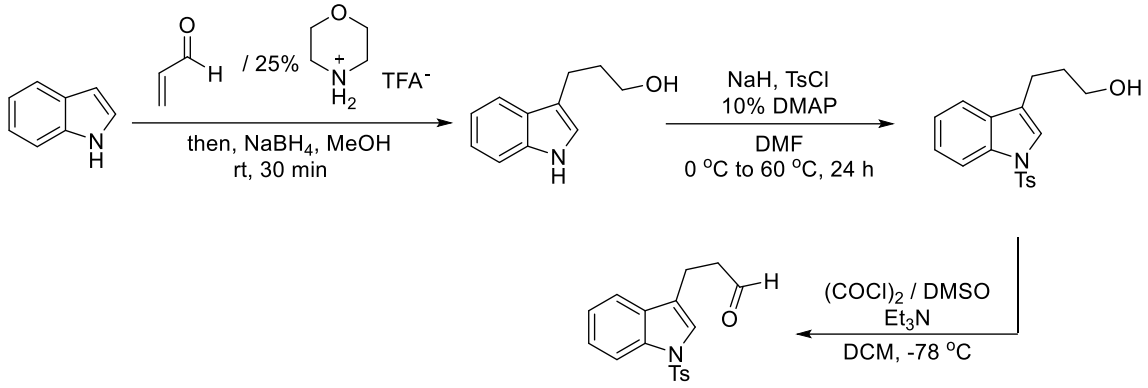
Step 2: Benzoyl chloride (0.59 mL, 4.70 mmol, 1 equiv) was added dropwise to a stirring solution of diol from step 1 (0.800 g, 4.70 mmol, 1 equiv) in pyridine (10 mL). After 3 hours, the solution was concentrated *in vacuo* and then re-dissolved in EtOAc. The solution was washed with saturated aq. NH_4Cl solution and then water. The organic layer was separated, dried with $MgSO_4$, filtered, and concentrated *in vacuo*. The resulting residue was subjected to silica gel chromatography (0–35% EtOAc in hexane) to afford a 10:1 mixture of mono- to di-benzoylated products (0.7266 g, 56% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.09 (dd, *J* = 8.2, 1.0 Hz, 2H), 7.62 (t, *J* = 7.4 Hz, 1H), 7.50 (t, *J* = 7.7 Hz, 2H), 4.48 (dd, *J* = 11.0, 6.1 Hz, 1H), 4.23 (dd, *J* = 10.9, 7.6 Hz, 1H), 3.83 (s, *J* = 57.9 Hz, 1H), 3.76–3.62 (m, 1H), 2.48–2.40 (m, 1H), 2.28–1.81 (m, 6H), 1.68 (s, 6H).

Step 3: DMSO (0.41 mL, 5.82 mmol, 2.2 equiv) was added dropwise to a stirring solution of oxalyl chloride (0.25 mL, 2.91 mmol, 1.1 equiv) in DCM (10 mL) at –78 °C. The solution was stirred until gas evolution ceased (*ca.* 10 min), then the alcohol from step 2 (0.7266 g, 2.65 mmol, 1 equiv) in DCM (2 mL) was added dropwise. After 10 minutes, triethylamine (1.85 mL, 13.2 mmol, 5 equiv) was added. The solution was stirred for 2 hours and then the cold bath was removed and the solution was stirred for a further 15 minutes. Saturated aq. NH_4Cl was added. The product was extracted with DCM, and the resulting solution was dried with $MgSO_4$, filtered, and concentrated *in vacuo*. The resulting oil was subjected to silica gel chromatography (0–15% EtOAc in Hexane) to afford **1d** as a clear, colourless oil (0.566 g, 78% yield). ^{1}H NMR (500 MHz, $CDCl_3$) δ 9.86 (s, 1H), 8.05 (d, *J* = 7.6 Hz, 2H), 7.62 (t, *J* = 7.4 Hz, 1H), 7.50 (t, *J* = 7.7 Hz, 2H), 4.47–4.33 (m, 2H), 2.83–2.71 (m, 2H), 2.43–2.25 (m, 3H), 2.10 (d, *J* = 17.1 Hz, 1H), 1.73 (s, 3H), 1.70 (s, 3H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 204.0, 166.5, 133.1, 130.0, 129.7, 128.5, 124.4, 123.6,

[4] Synthesized by Stephen Murphy
[5] Havis, N. D., Walters, D. R., Martin, W. P., Cook, F. M., Robins, D. J. *J. Agric. Food. Chem.*, **1996,** *44*, 2835.

65.4, 48.2, 34.0, 33.5, 29.2, 19.1, 19.0; HRMS (ESI+) calculated for $C_{17}H_{20}O_3Na$ [M + Na]$^+$ 295.1310, found 295.1312.

3-(1-Tosyl-1H-indol-3-yl)propanal (1g)



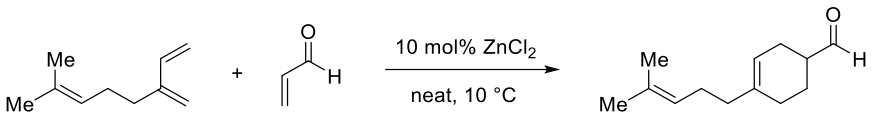
Step 1: To a solution of indole (6.0 g, 51.2 mmol, 1 equiv) in THF (200 mL) was added acrolein (10.3 mL, 153.6 mmol, 3 equiv), and morpholine-TFA salt (2.57 g, 12.8 mmol) at room temperature. After 2 hours at 30 °C, the reaction mixture was concentrated *in vacuo*. The resulting residue was dissolved in MeOH (100 mL) and cooled to 0 °C in an ice bath. To the resulting solution was added $NaBH_4$ (3.875 g, 102.4 mmol, 2 equiv) portionwise. After the addition of $NaBH_4$, the ice bath was removed and the reaction mixture was stirred at room temperature for 30 minutes. The reaction mixture was then concentrated *in vacuo*. The resulting residue was dissolved in EtOAc and washed with brine. The organic layer was separated then dried with anhydrous $MgSO_4$, filtered, and concentrated *in vacuo*. The crude residue was purified by silica gel column chromatography (30% ethyl acetate in hexanes) to afford a dark yellow oil (3.891 g, 43% yield). The ^{1}H NMR spectrum matched the literature reported values.[6] ^{1}H NMR (400 MHz; $CDCl_3$) δ 7.63 (dd, *J* = 7.9, 0.7 Hz, 1H), 7.36 (dd, *J* = 8.1, 0.7 Hz, 1H), 7.20 (td, *J* = 7.6, 0.9 Hz, 1H), 7.13 (td, *J* = 7.4, 1.0 Hz, 1H), 6.99 (s, 1H), 3.74 (t, *J* = 6.4 Hz, 2H), 2.87 (t, *J* = 7.5 Hz, 2H), 2.04–1.97 (m, 2H).

Step 2: To a stirring solution of 3-(1H-indol-3-yl)-propan-1-ol in DMF was added NaH (0.354 g, 8.85 mmol, 1.1 equiv) portionwise at 0 °C in an ice bath. The reaction mixture was stirred for 1 h at 0 °C. Tosyl chloride (1.687g, 8.85 mmol, 1.1 equiv) and DMAP (99 mg, 0.81 mmol, 0.1 equiv) were then added at 0 °C. The reaction mixture was allowed to warm to room temperature before heating to 60 °C for 24 h. The reaction mixture was quenched with saturated aq. NH_4Cl solution and extracted with EtOAc. The organic layer was washed with water, dried with anhydrous $MgSO_4$, filtered, and concentrated *in vacuo*. The crude residue was purified by column chromatography (30–50% ethyl acetate in hexanes) to afford a dark orange oil (1.15 g, 43% yield, <10% free indole). ^{1}H NMR (400 MHz; $CDCl_3$) δ 7.99 (d, 1H), 7.75 (d, 2H), 7.50 (d, 1H), 7.352 (td, *J* = 8, 0.8 Hz, 2H), 7.25–7.17 (m, 3H), 3.71 (t, *J* = 6.4 Hz, 2H), 2.77 (t, *J* = 7.6 Hz, 2H), 2.33 (s, 3H), 1.98–1.91 (m, 2H); ^{13}C NMR (126 MHz; DMSO) δ 145.3, 134.6, 134.2, 130.8, 130.2, 126.6, 124.7, 123.23, 123.14, 123.04, 119.8, 113.3, 60.0, 39.5, 31.7, 21.0, 20.6; IR (ATR) 1446, 1360, 1168,1118, 743, 667 cm^{-1}; HRMS (ESI+) calculated for $C_{18}H_{19}NO_3SNa$ [M + Na]$^+$ 352.0983, found 352.0984.

[6] Gore, S., Baskaran, S., Konig, B. *Org. Lett.,* **2012,** *14*, 4568.

Step 3: DMSO (0.30 mL, 4.18 mmol, 2.2 equiv) was added dropwise to a solution of oxalyl chloride (0.18 mL, 2.09 mmol, 1.1 equiv) and DCM (40 mL) at –78 °C, then stirred for 5 minutes. A solution of *N*-tosyl indole alcohol in DCM was added dropwise at –78 °C and stirred for 5 minutes. Triethylamine (1.3 mL, 9.50 mmol, 5 equiv) was added dropwise at –78 °C. The resulting solution was then warmed to room temperature and stirred for 2 hours. The reaction mixture was quenched with a solution of saturated aq. NH_4Cl and extracted with DCM. The organic layer was washed with water, dried with anhydrous $MgSO_4$, filtered, and concentrated *in vacuo*. The crude residue was purified by silica gel column chromatography (20% ethyl acetate in hexanes) to afford **1g** as a red solid (0.355 g, 57% yield). The ^1H NMR spectrum matched the literature reported values.[7] ^1H NMR (400 MHz; $CDCl_3$) δ 9.84 (s, 1H), 7.99–7.97 (m, 1H), 7.73 (d, *J* = 8.3 Hz, 2H), 7.48–7.46 (m, 1H), 7.34–7.30 (m, 2H), 7.24–7.20 (m, 3H), 3.02–2.98 (m, 2H), 2.86–2.83 (m, 2H), 2.33 (s, 3H).

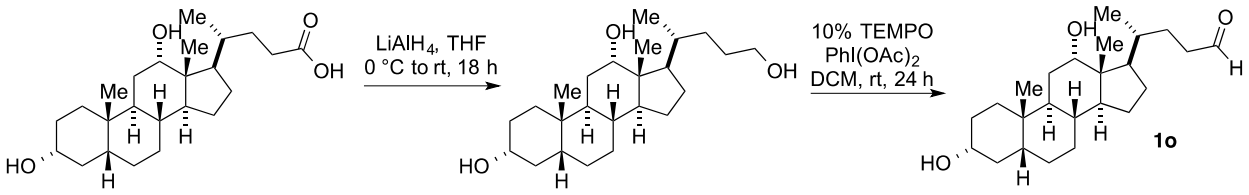
***rac*-4-(4-methylpent-3-en-1-yl)cyclohex-3-ene-1-carbaldehdye (1q)**[8]



Myrcene (0.5 mL, 2.91 mmol, 1 equiv) was added to vial containing $ZnCl_2$ (40 mg, 0.192 mmol, 0.1 equiv) under N_2 and the vial was sealed with a septum. The vial was immersed in a 10 °C cooling bath and then acrolein (0.214 mL, 3.21 mmol, 1.1 equiv) was added. The solution was stirred for 16 hours, and then EtOAc and brine were added. The organic layer was separated, dried with $MgSO_4$, filtered, and concentrated. The resulting oil was purified by Kugelrohr distillation to afford the product as a colorless oil with 93.5:6.5 *r.r.* determined by GC–FID (0.300 g, 54% yield). The ^1H NMR spectrum matched the literature reported values.[9] ^1H NMR (400 MHz, $CDCl_3$) δ 9.70 (d, *J* = 1.3 Hz, 1H), 5.47–5.40 (m, 1H), 5.14–5.04 (m, 1H), 2.51–2.41 (m, 1H), 2.28–2.20 (m, 2H), 2.14–1.91 (m, 8H), 1.69 (s, 3H), 1.61 (s, 3H).

[7] Friden–Saxin, M., Pemberton, N., da Silva Andersson, K., Dyrager, C., Friberg, A., Grotli, M., Luthman, K. *J. Org. Chem.*, **2009,** *74*, 2755.
[8] Synthesized by Stephen Murphy
[9] Yin, D., Li, C., Li, B., Tao, L., Yin, D. *Adv. Synth. Catal.*, **2005,** *347*, 137.

3α.12α-Dihydroxy-5β-cholanal-(24) (1o)

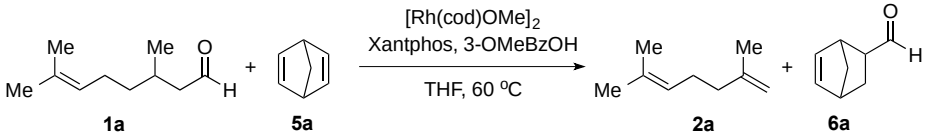


Step 1: $LiAlH_4$ (0.773 g, 20.4 mmol, 4 equiv) was added slowly to a stirring solution of deoxycholic acid (2.0 g, 5.1 mmol, 1 equiv) in 150 mL THF at 0 °C. The ice bath was removed and the reaction mixture was allowed to stir at room temperature for 16 hours. The reaction mixture was quenched using the Fieser method and the resulting solution was dried with $MgSO_4$, filtered, and concentrated *in vacuo*. The residue was dissolved in DCM and hexanes to precipitate a white powder, then concentrated *in vacuo* to afford a white powder (1.5121 g, 78% yield). ^{1}H NMR spectrum matched the literature reported value.[10] ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.00 (s, 1H), 3.70–3.52 (m, 3H), 1.93–0.93 (m, 38H), 0.92 (s, 3H), 0.69 (s, 3H).

Step 2: TEMPO (16.6 mg, 0.106 mmol, 0.1 equiv) and $PhI(OAc)_2$ (0.3865 g, 1.2 mmol, 1.1 equiv) were added to a solution of 3α,12α,24-trihydroxy-5β-14α-cholane from step 1 (0.400 g, 1.06 mmol, 1 equiv) in DCM (16 mL) at room temperature. The mixture was stirred at room temperature for 18 hours. The reaction mixture was concentrated *in vacuo* and purified by silica gel column chromatography (0–100% ethyl acetate in DCM) to afford **1o** as a white solid (286 mg, 76% yield). ^{1}H NMR (500 MHz, $CDCl_3$): δ 9.76 (s, 1H), 3.98 (t, 1H), 3.65–3.58 (m, 1H), 2.50–2.33 (m, 2H), 1.90–1.46 (m, 16H), 1.46–1.29 (m, 6H), 1.28–1.22 (m, 2H), 1.17–1.00 (m, 3H), 0.97 (d, J = 7.6 Hz, 3H), 0.93–0.87 (s, 3H), 0.67 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 203.3, 73.3, 71.9, 48.4, 47.4, 46.6, 42.2, 41.1, 36.5, 36.1, 35.31, 35.20, 34.2, 33.8, 30.6, 28.8, 28.0, 27.6, 27.2, 26.2, 23.8, 23.3, 17.5, 12.9; IR (ATR) 2930, 2861, 1720, 1446, 1376, 1040, 1013 cm^{-1}; HRMS (ESI+) calculated for $C_{24}H_{40}O_3Na$ $[M + Na]^+$ 399.2875, found 399.2872; mp = 145–148 °C

[10] Bhat, S., Maitra, U. *Tetrahderon* **2007,** *63,* 7309.

4. Initial Rate Kinetics Experiments



The kinetic profile of the reaction was studied by probing the initial rates of the reaction and varying the concentrations of **1a**, **5a** and Rh-catalyst. No products of decomposition were observed with this system. The rates were monitored by GC–FID using durene as an internal standard. Experiments were run in duplicate.

Representative Procedure (Table S1, entry 9)

In a N_2-flled glovebox, $[Rh(cod)OMe]_2$ (3.9 mg, 0.008 mmol), Xantphos (9.3 mg, (0.016 mmol), 3-OMeBzOH (2.4 mg, 0.016 mmol), and durene (16.2 mg, 0.12 mmol) were added to a 1 dram vial equipped with a stir bar and then dissolved in THF (200 µL). After addition of citronellal **1a** (144 µL, 0.8 mmol), the vial was sealed with a Teflon-lined screw cap and heated at 60 °C for 10 minutes. Upon cooling to room temperature over 5 minutes, norbornadiene **5a** (98 µL, 0.96 mmol) was added to the reaction mixture. After addition of **5a**, the reaction mixture was heated at 60 °C. Aliquots of the reaction mixture were taken every 10 minutes over 1 hour and analyzed by GC–FID.

Table S1. Kinetic Data for Rh-catalyzed Dehydroformylation.

Entry	[**1a**] (M)	[**5a**] (M)	[catalyst] (M)	Initial rate (M/min)
1	0.9	2.2	0.072	0.0110
2	1.8	2.2	0.072	0.0140
3	2.7	2.2	0.072	0.0162
4	3.6	2.2	0.072	0.0142
5	1.8	1.1	0.072	0.0163
6	1.8	2.2	0.072	0.0143
7	1.8	3.3	0.072	0.0104
8	1.8	4.4	0.072	0.0102
9	1.8	2.2	0.036	0.0077
10	1.8	2.2	0.072	0.0139
11	1.8	2.2	0.108	0.0191
12	1.8	2.2	0.144	0.0208

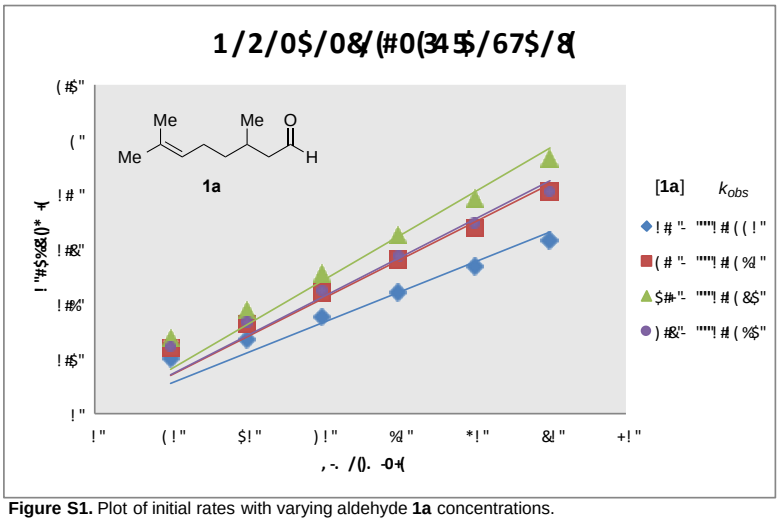


Figure S1. Plot of initial rates with varying aldehyde **1a** concentrations.

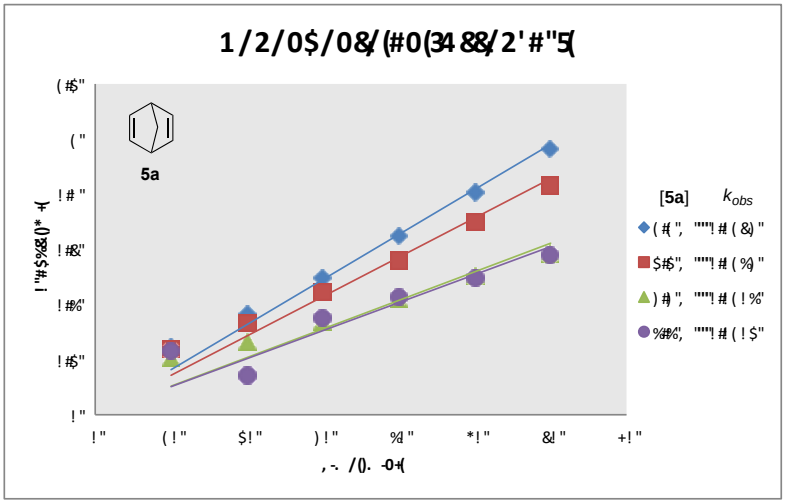


Figure S2. Plot of initial rates with varying acceptor **5a** concentrations.

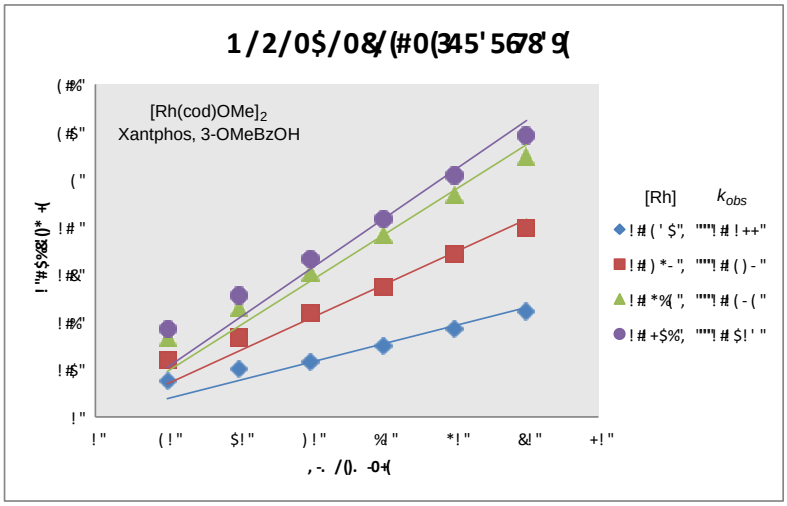
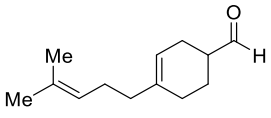
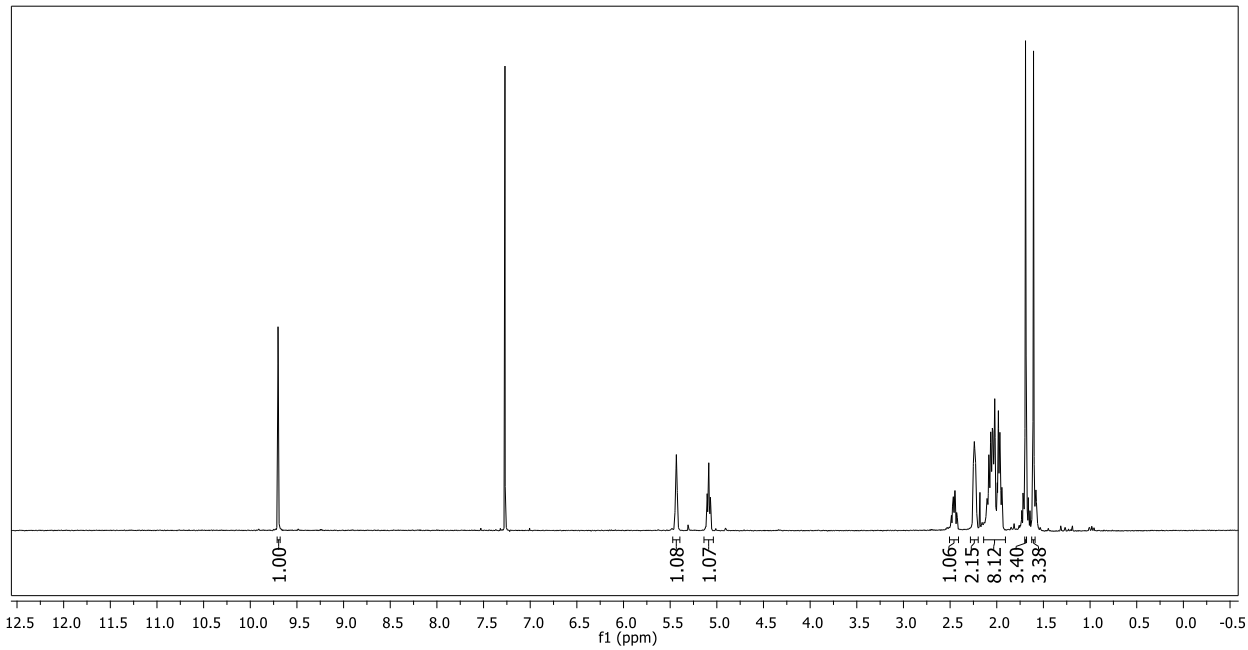


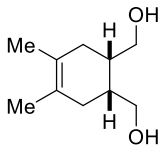
Figure S3. Plot of initial rates with varying Rh-catalyst concentrations.

7. NMR Spectra



(**1q**)

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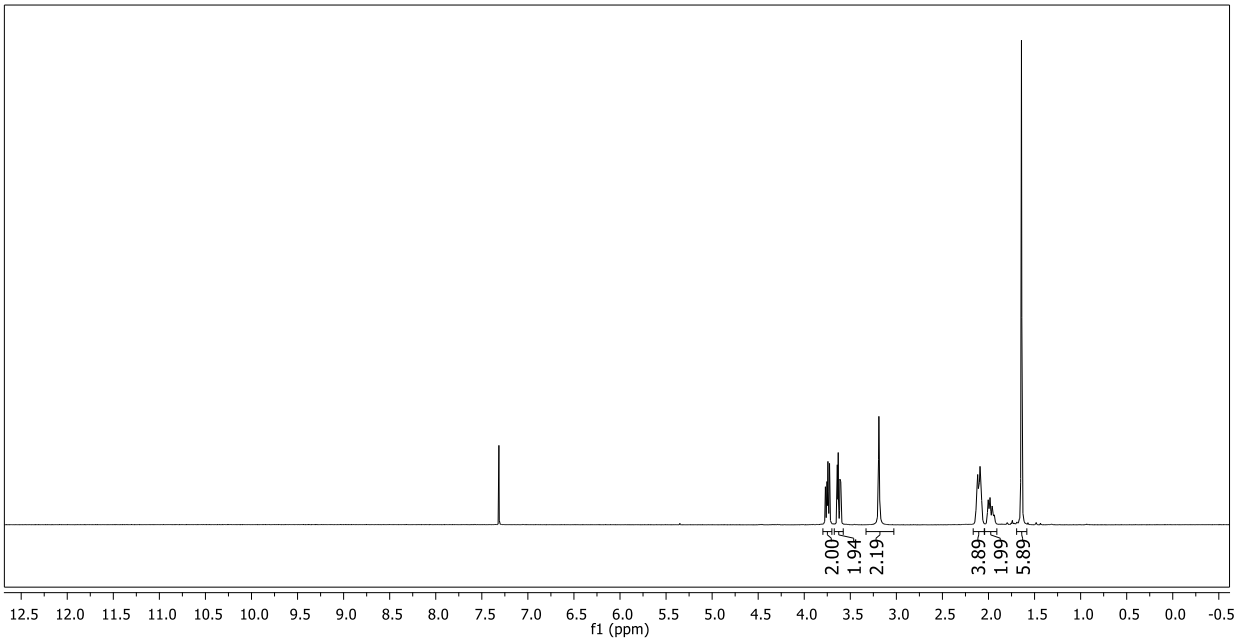
H
Me
Me
H
OH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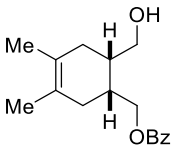
2.19
3.89
1.99
5.89
12.5 12.0 11.5 11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)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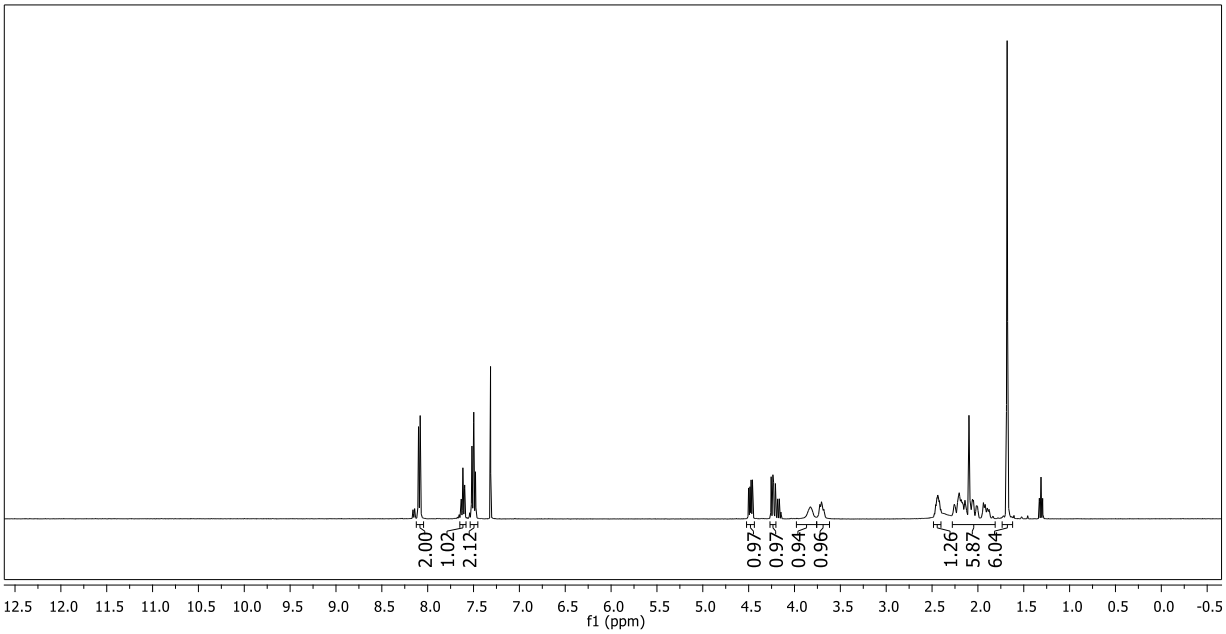
H
Me
Me
H
OBz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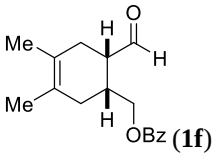
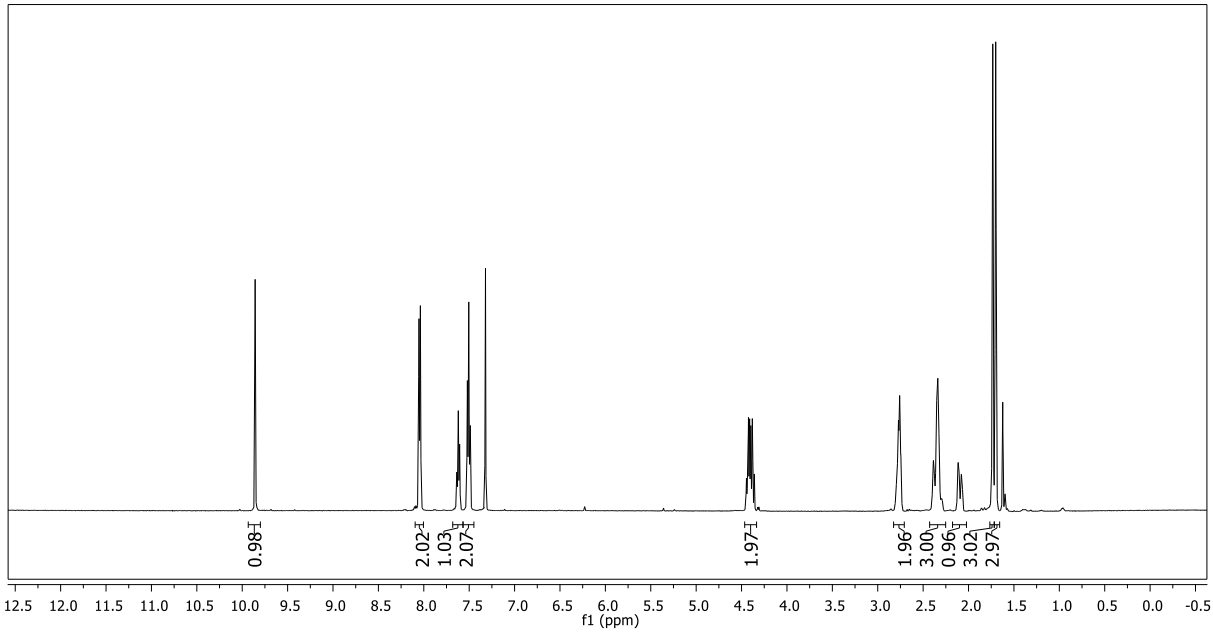
2.12
0.97
0.97
0.94
0.96
1.26
5.87
6.04
12.5 12.0 11.5 11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)


O
H
Me
H
Me
H
OBz

(**1f**)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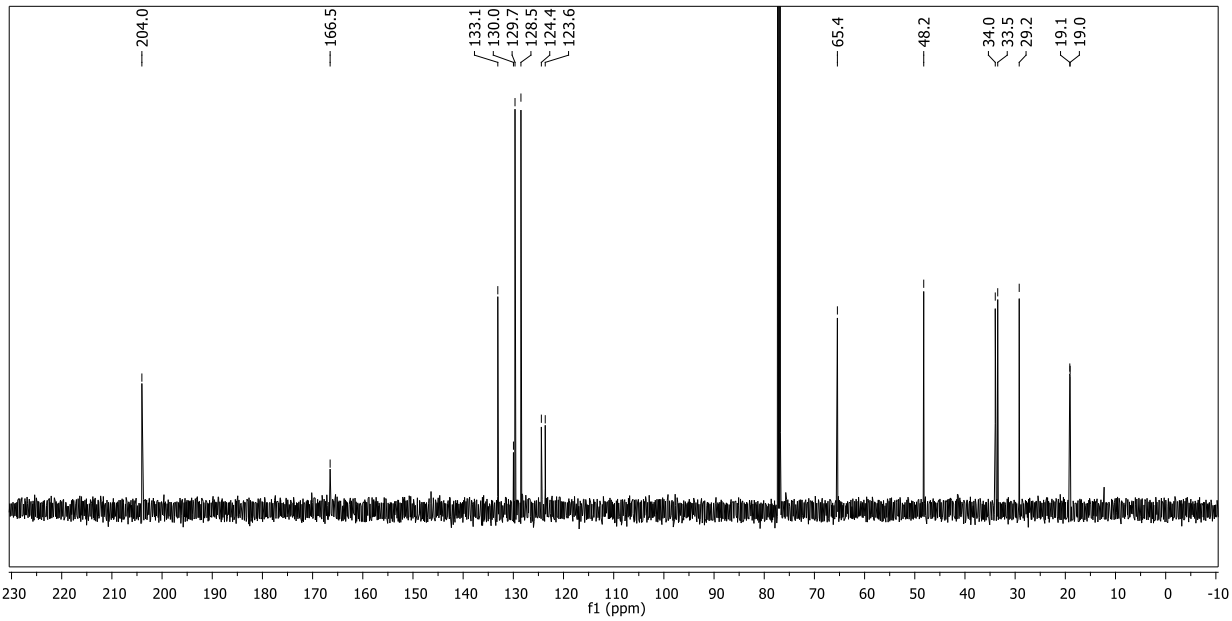
1.03
2.07
1.97
1.96
3.00
0.96
3.02
2.97
12.5 12.0 11.5 11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)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130.0
129.7
128.5
124.4
123.6
65.4
48.2
34.0
33.5
29.2
19.1
19.0
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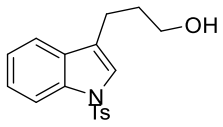
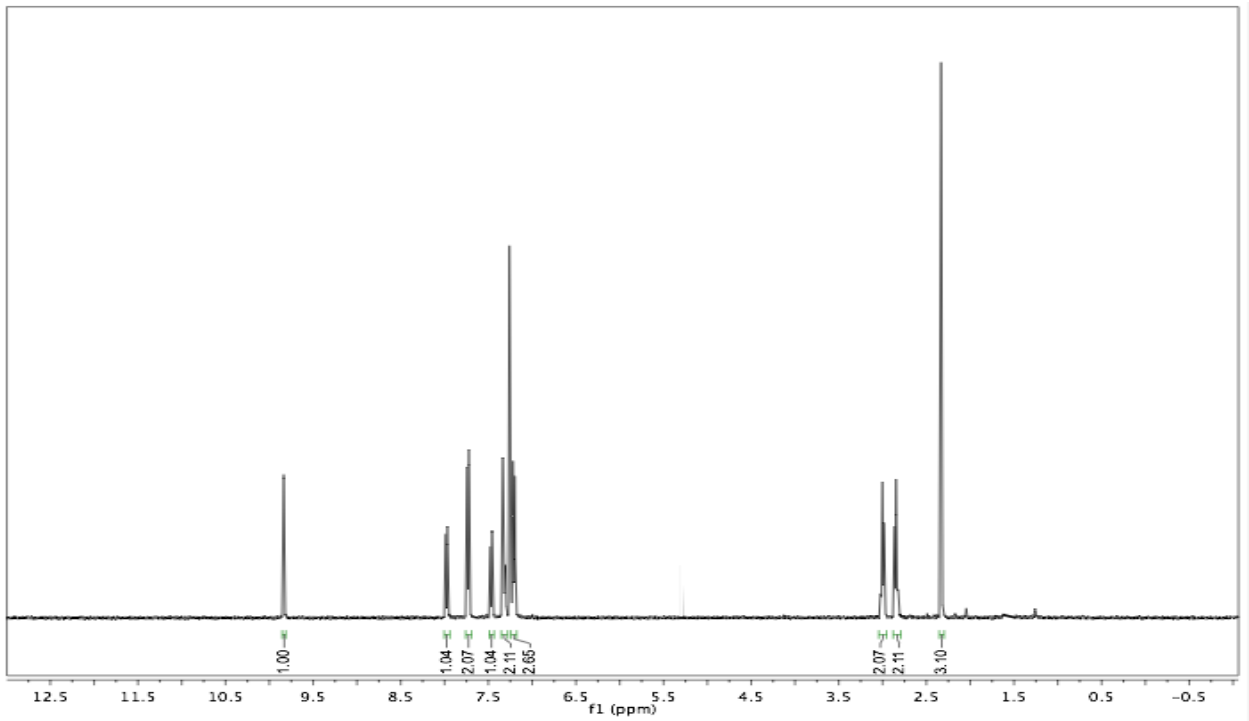
f1 (ppm)


OH
N
Ts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2.11
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1.5
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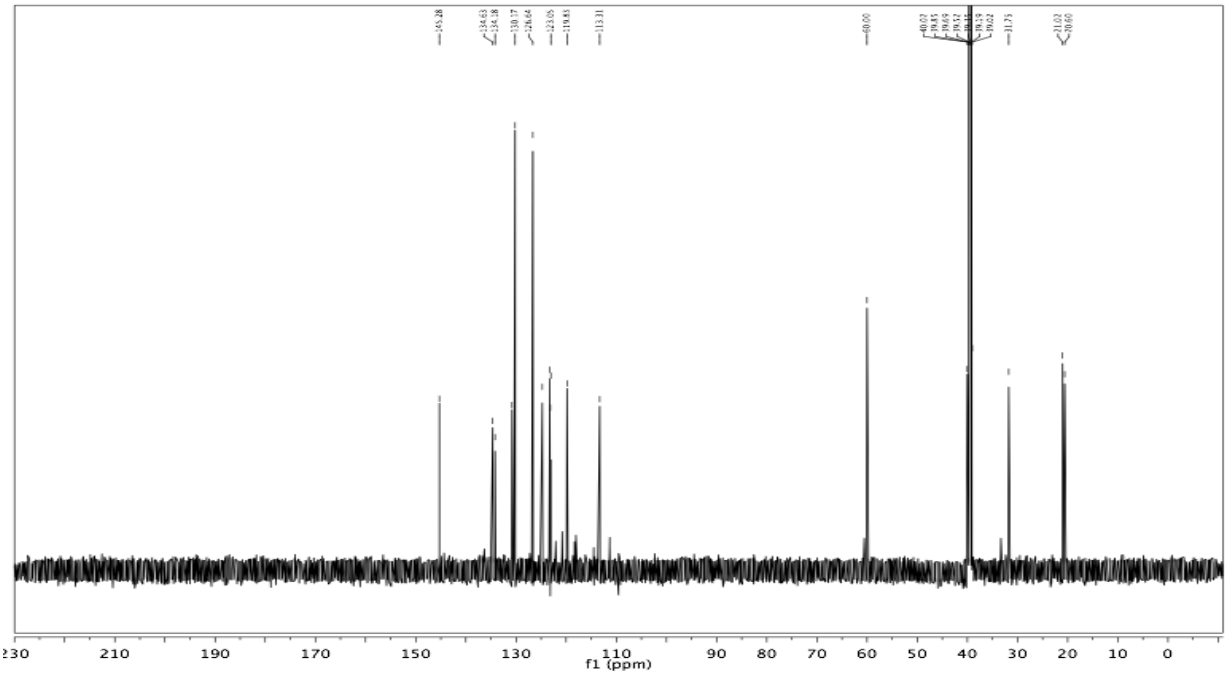
f1 (ppm)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33.38
130.77
126.64
123.05
119.83
113.31
60.00
40.02
19.85
19.52
19.19
19.02
11.75
21.02
20.60
230
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170
150
130
110
90
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70
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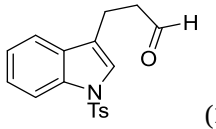
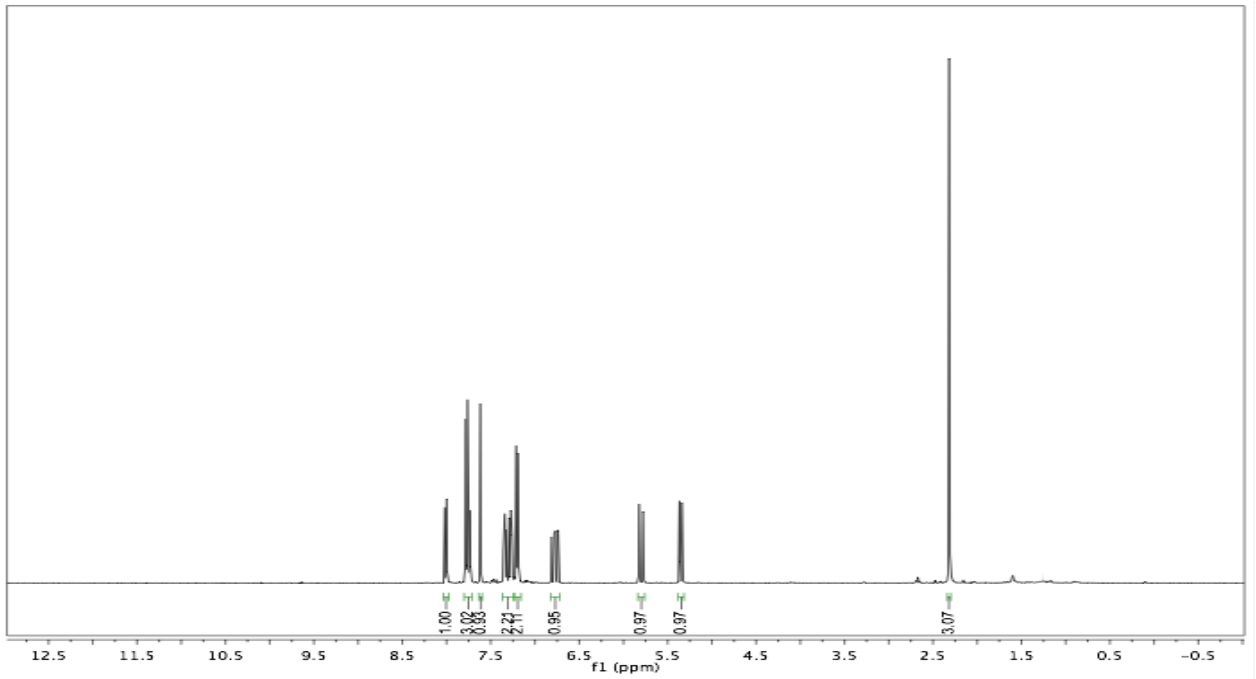
50
40
30
20
10
0
f1 (ppm)


H
O
N
Ts

(**1j**)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0.97
0.97
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12.5
11.5
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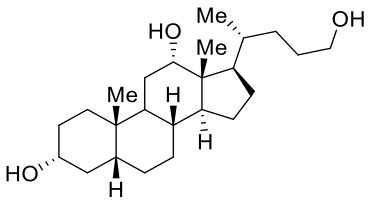
8.5
7.5
6.5
5.5
4.5
3.5
2.5
1.5
0.5
-0.5
f1 (ppm)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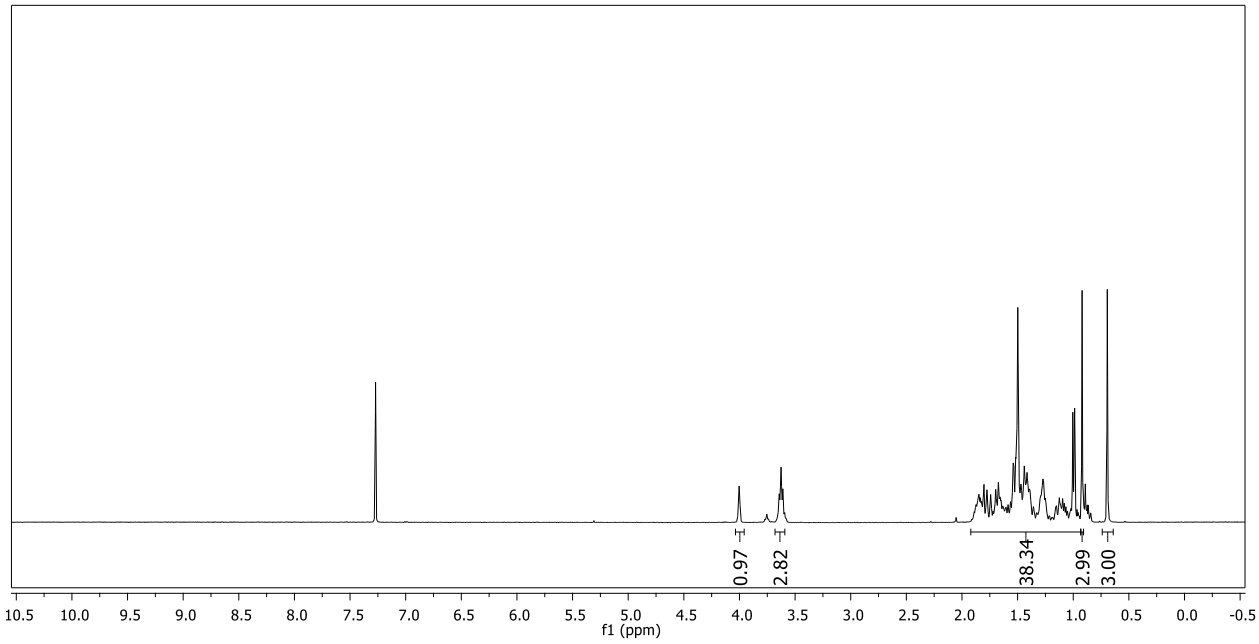
Me
Me
OH
Me
H
H
HO
H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2.82
38.34
2.99
3.00
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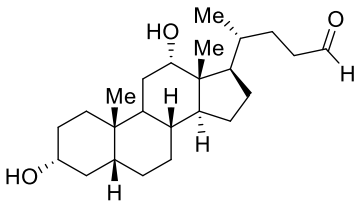
f1 (ppm)



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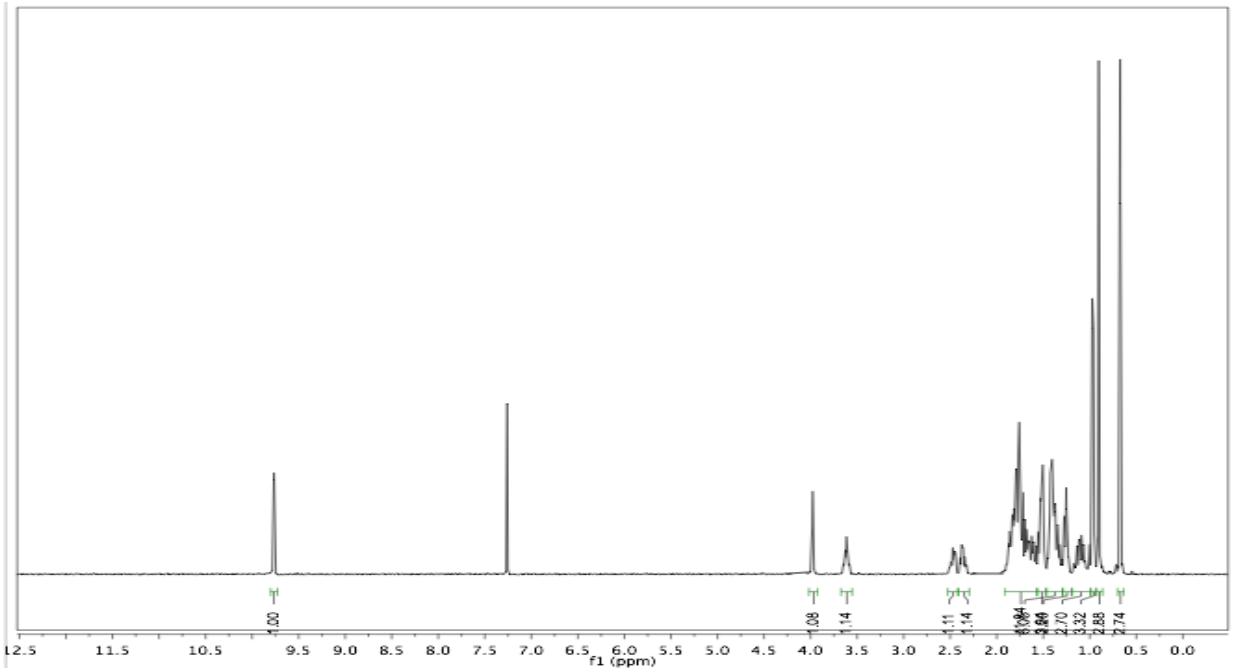
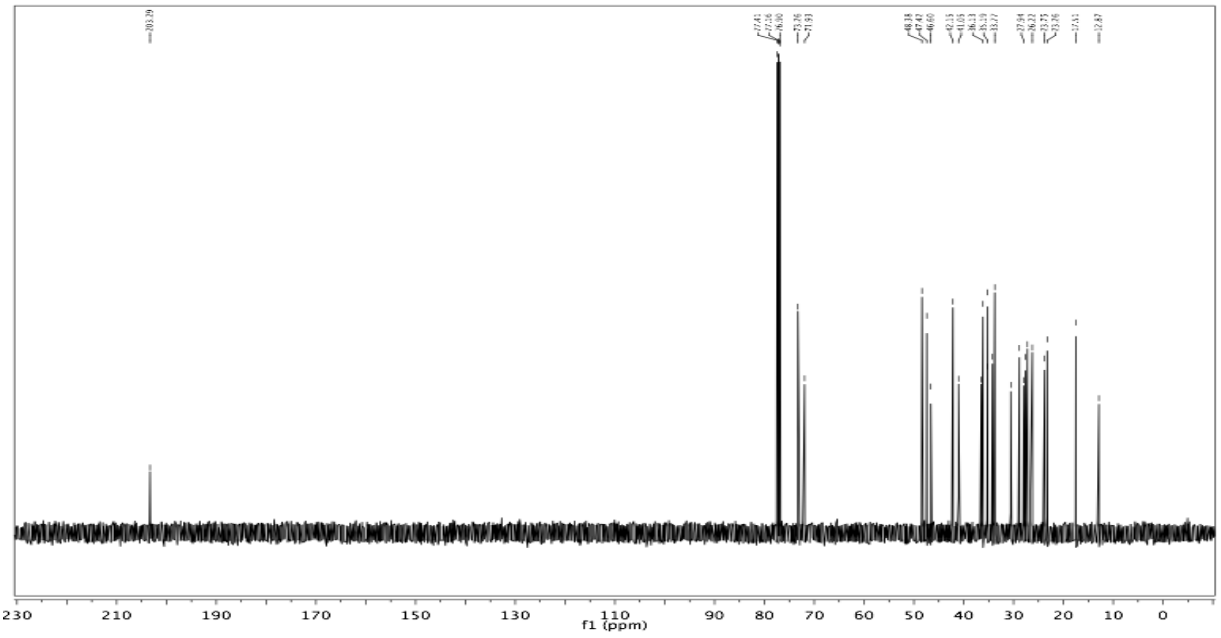
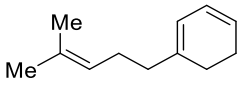
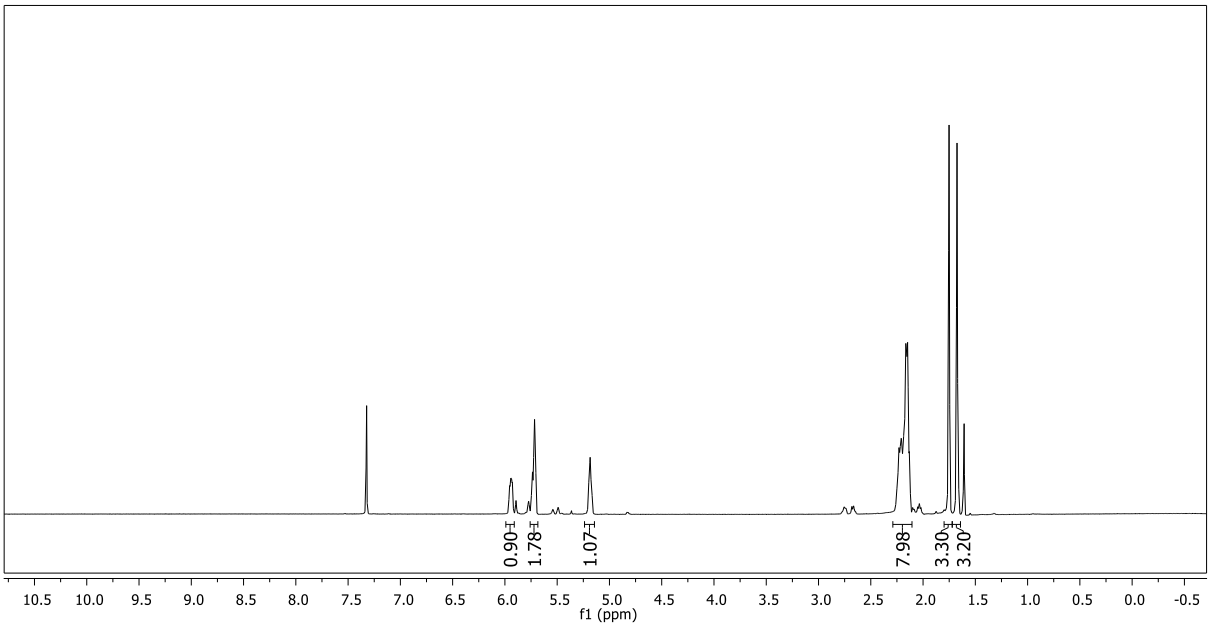





Me
Me

(**2c**)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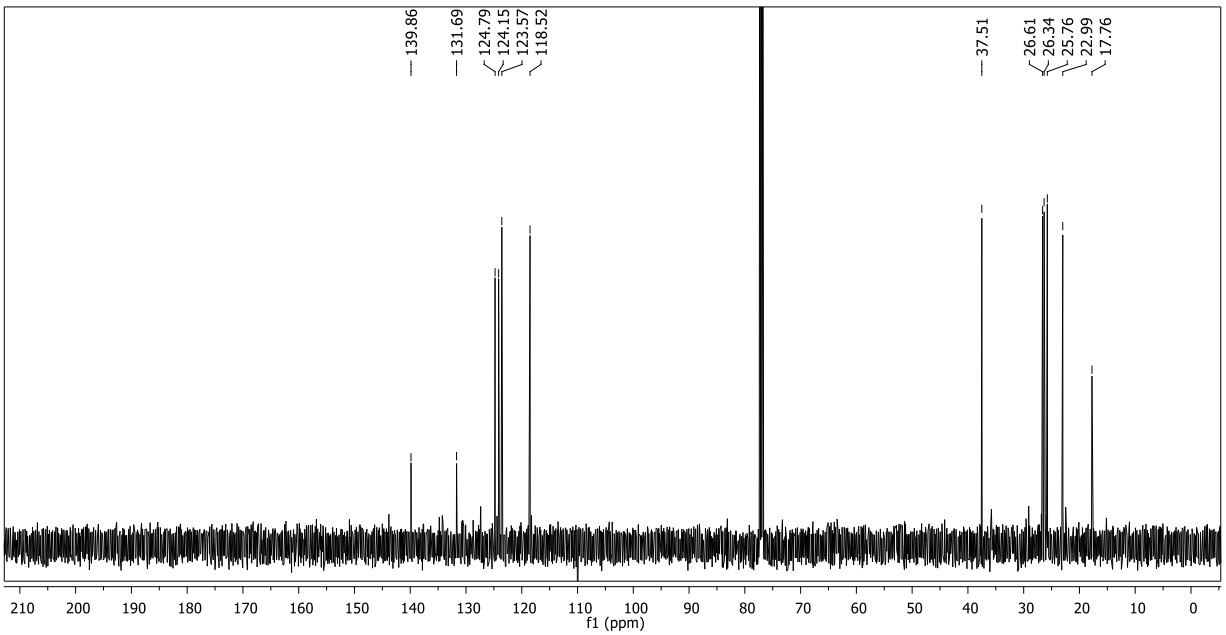
1.07
7.98
3.30
3.20
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)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131.69
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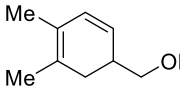
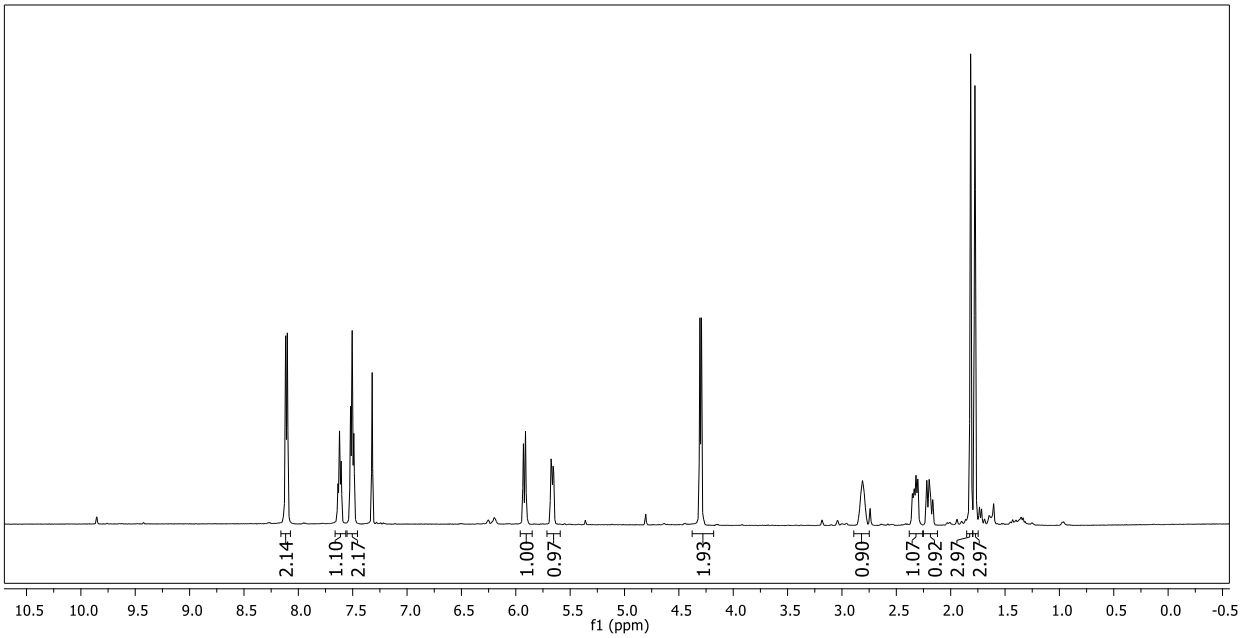
124.15
123.57
118.52
37.51
26.61
26.34
25.76
22.99
17.76
210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)


Me
Me
OBz

(**2f**)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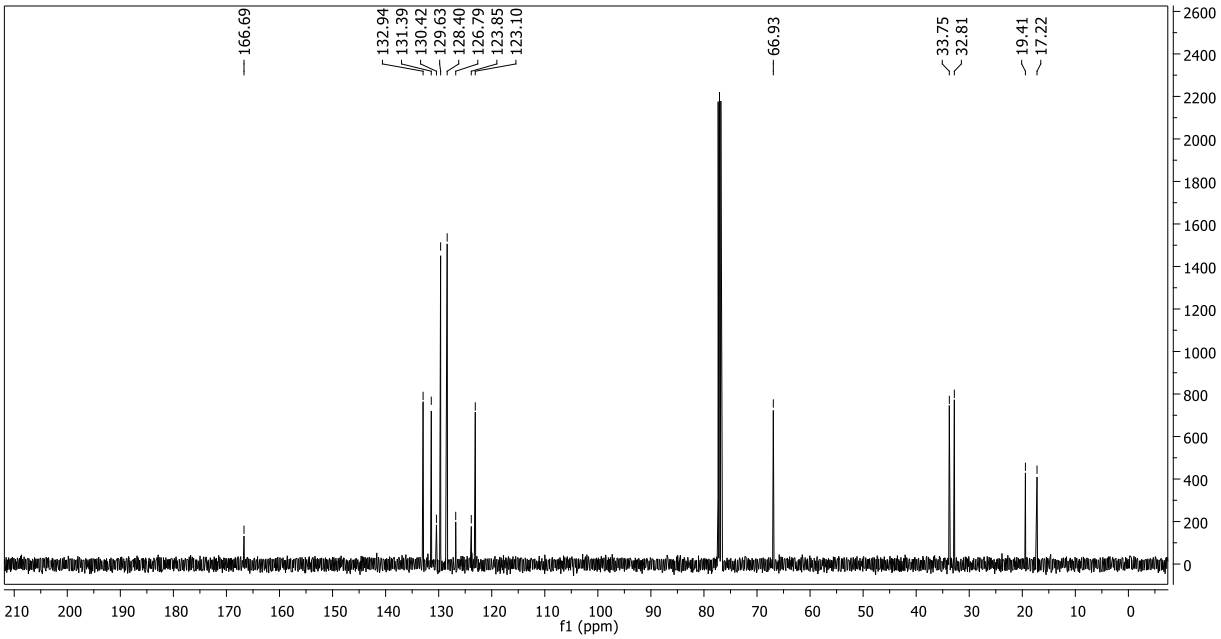
2.17
1.00
0.97
1.93
0.90
1.07
0.92
2.97
2.97
f1 (ppm)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130.42
129.63
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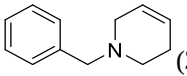
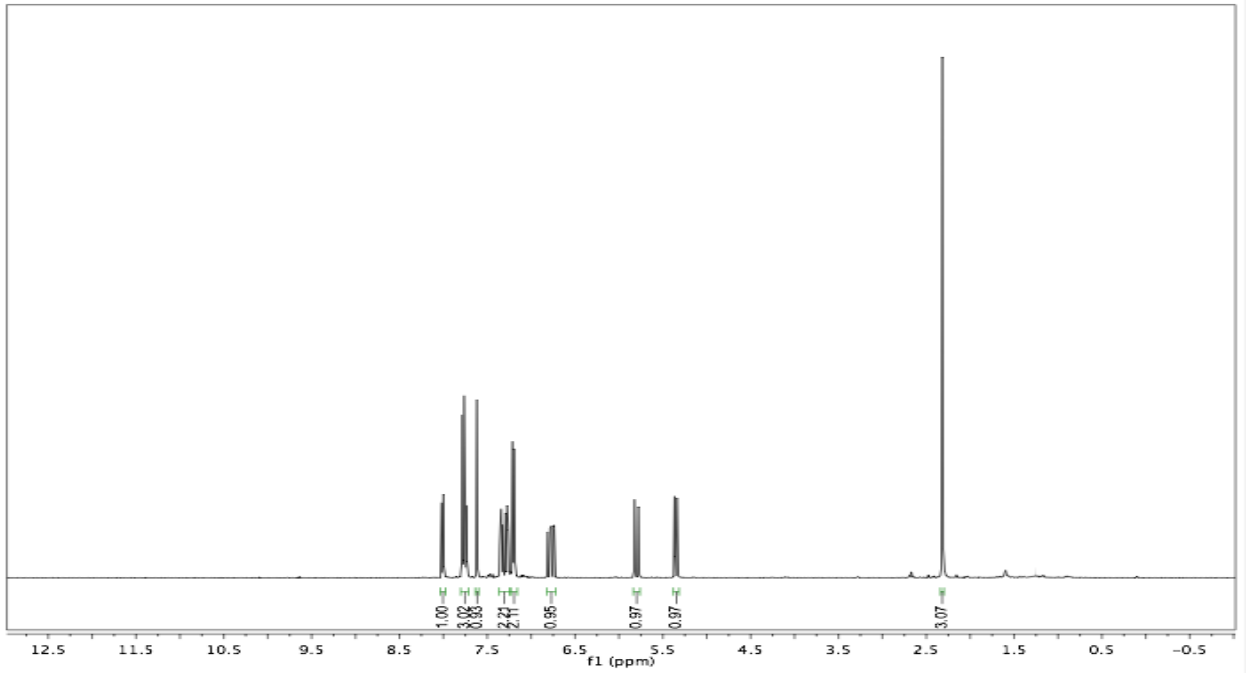
123.85
123.10
66.93
33.75
32.81
19.41
17.22
f1 (ppm)



(2g)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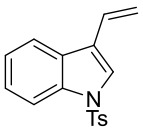
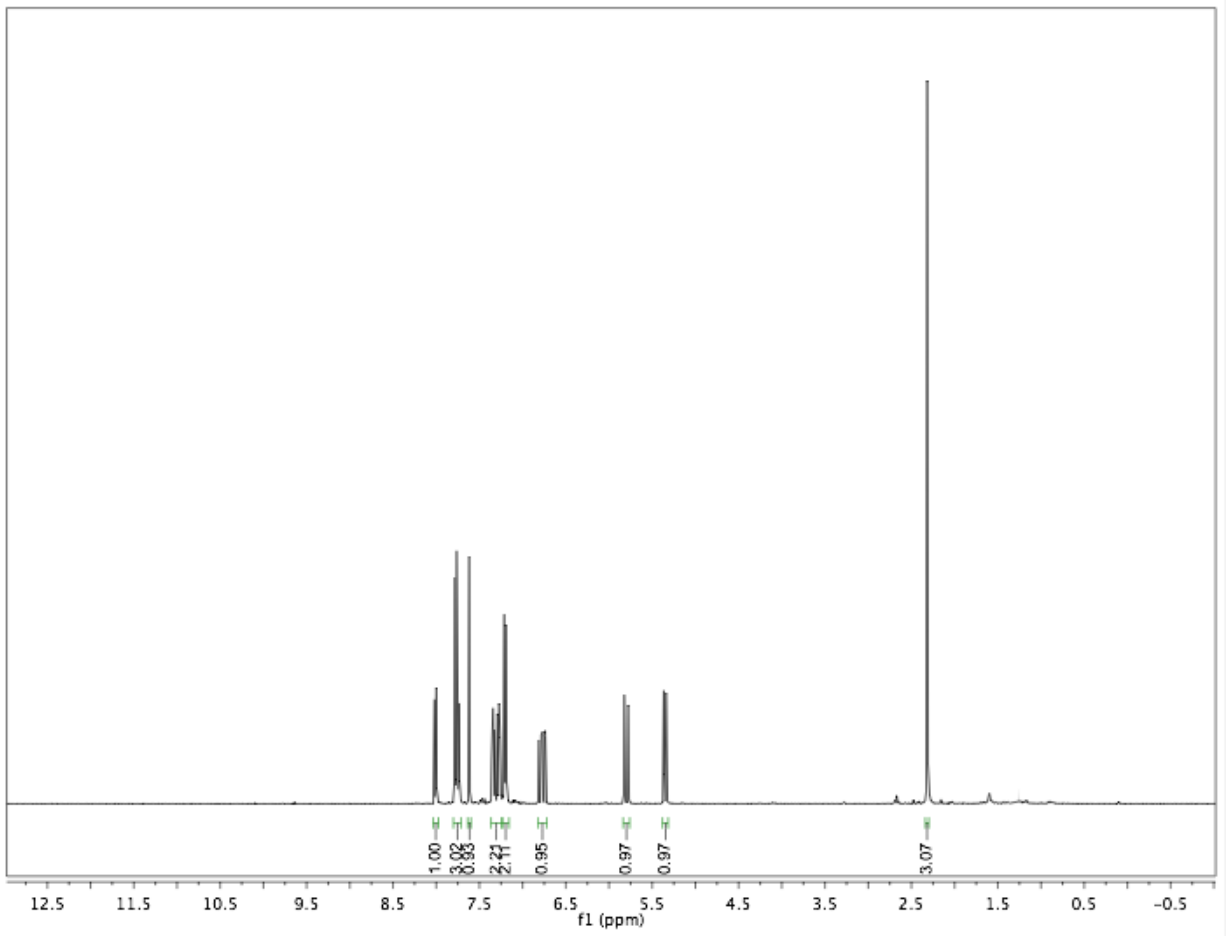
3.03
2.21
2.11
0.95
0.97
0.97
3.07
12.5
11.5
10.5
9.5
8.5
7.5
6.5
5.5
4.5
3.5
2.5
1.5
0.5
-0.5
f1 (ppm)


N
Ts

(**2j**)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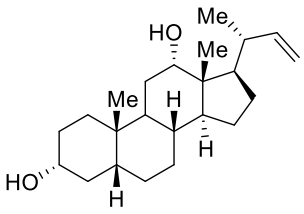
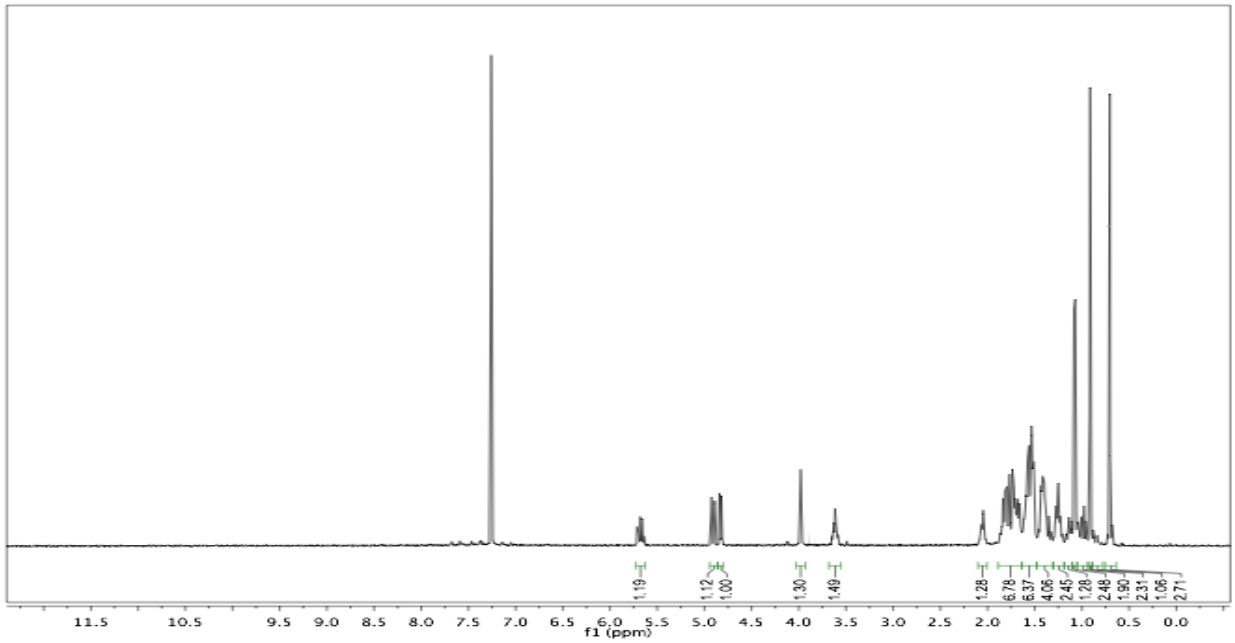
3.02
0.93
2.21
0.95
0.97
0.97
3.07
12.5
11.5
10.5
9.5
8.5
7.5
6.5
5.5
4.5
3.5
2.5
1.5
0.5
-0.5
f1 (ppm)


HO
Me
Me
Me
H
H
HO
H

(**2p**)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1.00
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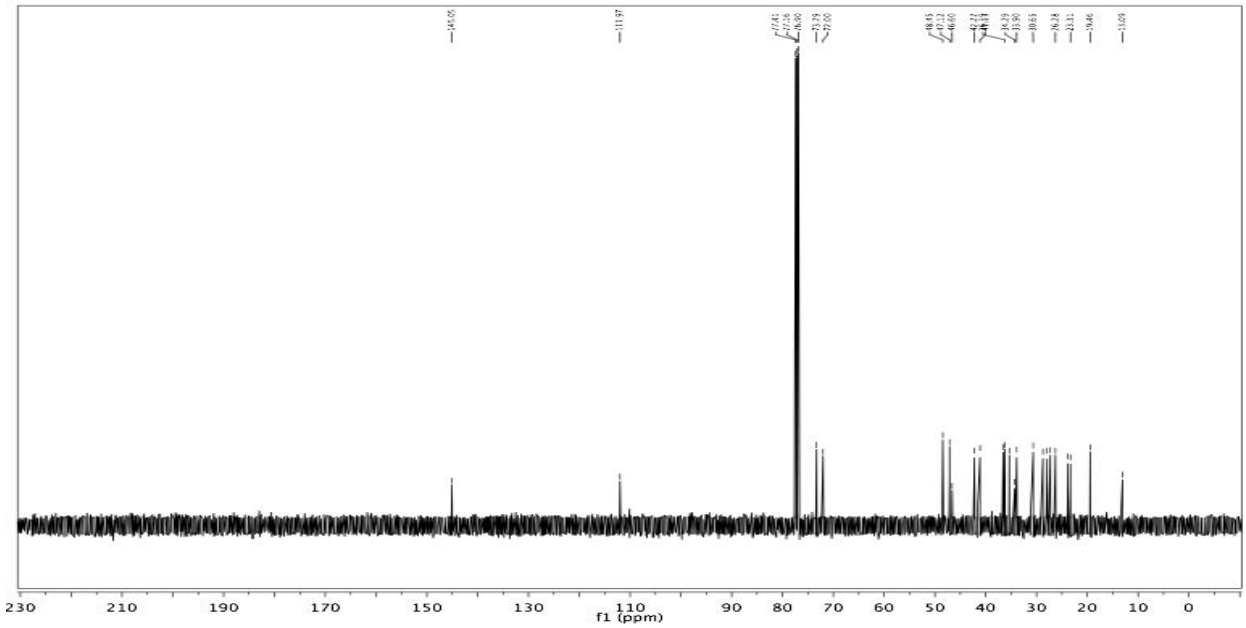
1.49
1.28
6.78
6.37
4.06
2.45
1.28
2.48
1.90
2.31
1.06
2.71
11.5
10.5
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
f1 (ppm)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111.97
77.41
77.16
76.90
73.35
73.00
48.45
47.12
46.80
42.72
40.30
35.90
30.65
26.28
22.31
20.46
13.69
230
210
190
170
150
130
110
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

Appendix 1.2: Supporting Information for Chapter 1.2

Tandem Catalysis: Transforming Alcohols to Alkenes by an Oxidative Dehydroxymethylation

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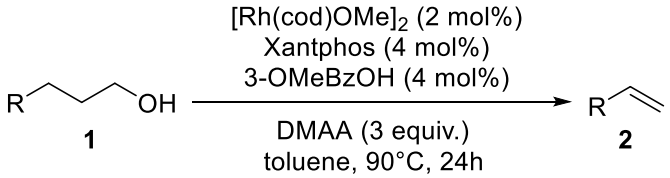
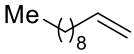
1. Materials and Methods

Commercially reagents were purchased from Sigma Aldrich, Strem, Acros Organics, TCI or Alfa Aesar and used without further purification. All experiments were performed in oven-dried or flame-dried glassware under an atmosphere of N_2. Acetonitrile and tetrahydrofuran were purified using an Innovative Technologies Pure Solv system, degassed by three freeze-pump-thaw cycles, and stored over 3Å MS within a N_2 filled glove box. Reactions were monitored either via gas chromatography using an Agilent Technologies 7890A GC system equipped with an Agilent Technologies 5975C inert XL EI/CI MSD or by analytical thin-layer chromatography on EMD Silica Gel 60 F_{254} plates. Visualization of the developed plates was performed under UV light (254 nm) or using $KMnO_4$ stain. Purification and isolation of products were performed via silica gel chromatography (both column and preparative thin-layer chromatography). Column chromatography was performed with Silicycle Silia-P Flash Silica Gel using glass columns. ^1H, and ^{13}C NMR spectra were recorded on a Bruker DRX-400 (400 MHz ^1H, 100 MHz ^{13}C) spectrometer. ^1H NMR spectra were internally referenced to the residual solvent signal or TMS. ^{13}C NMR spectra were internally referenced to the residual solvent signal. Data for ^1H NMR are reported as follows: chemical shift (δ ppm, δ 7.26 for $CDCl_3$), multiplicity (s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet, br = broad), coupling constant (Hz), integration. Data for ^{13}C NMR are reported in terms of chemical shift (δ ppm, δ 77.16 for $CDCl_3$). Infrared spectra were obtained on a Thermo Scientific Nicolet iS5 FT-IR spectrometer equipped with an iD5 ATR accessory, and were reported in terms of frequency of absorption (cm^{-1}). High-resolution mass spectra (HRMS) were obtained on a micromass 70S-250 spectrometer (EI) or an ABI/Sciex QStar Mass Spectrometer (ESI), performed by the University of California, Irvine Mass Spectrometry Center.

2. General Procedures for the Dehomologation of Alcohols

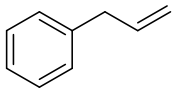


In a N_2-filled glovebox, $[Rh(cod)OMe]_2$ (1.9 mg, 0.004 mmol), Xantphos (4.6 mg, 0.008 mmol), 3-methoxybenzoic acid (1.2 mg, 0.008 mmol) and toluene (0.40 mL) were added to a 1 dram vial. After stirring for 3 min, *N*,*N*-dimethylacrylamide (63 μL, 60 mg, 0.60 mmol) and alcohol (**1**, 0.20 mmol) were added successively. The vial was sealed completely by a screw cap with a Teflon septum. Then, the reaction mixture was stirred at 90 ˚C for 24 h. Chemo- and regioselectivity were determined from analysis of the reaction mixture by either GC or ^{1}H NMR analysis. The olefin product was isolated by either column chromatography or preparatory TLC. Alternatively, the yields of volatile products were determined by either GC or ^{1}H NMR analysis.

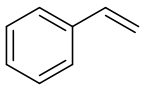


2a

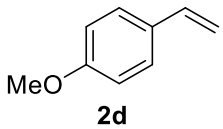
1-Undecene (Table 1.2, **2a**): The title compound was isolated by column chromatography (pentane) as a colorless oil (28.7 mg, 93% yield, >20:1 **2a**:**3a**+other alkene isomers). GC yields from Table 1 were determined with durene as an internal standard (response factor of 1.58 for 1-undecene and 1.82 for n-undecane). ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.82 (ddt, *J* = 16.9, 10.2, 6.7 Hz, 1H), 5.04 – 4.89 (m, 2H), 2.09 – 2.00 (m, 2H), 1.44 – 1.19 (m, 14H), 0.89 (t, *J* = 6.9 Hz, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 139.4, 114.2, 34.0, 32.1, 29.8, 29.7, 29.5, 29.3, 29.1, 22.9, 14.3. This compound is known.[1]


2b

Allylbenzene (Table 1.2, **2b**): The yield was determined by GC analysis using durene as an internal standard (93% GC yield, response factor of 1.27, >20:1 **2b**:**3b**+other alkene isomers). The title compound was isolated by column chromatography (pentane) as a colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.38 – 7.29 (m, 2H), 7.28 – 7.17 (m, 3H), 6.02 (ddt, *J* = 16.9, 10.2, 6.7 Hz, 1H), 5.16 – 5.05 (m, 2H), 3.43 (d, *J* = 6.7 Hz, 2H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 140.2, 137.6, 128.7, 128.6, 126.2, 115.9, 40.4. This compound is known.[2]

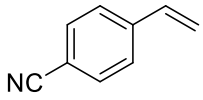

2c

Styrene (Table 1.2, **2c**): The yield was determined by GC analysis using durene as an internal standard (95% GC yield, response factor of 2.10, >20:1 **2c**:**3c**).



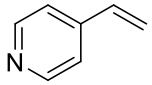
2d

1-Methoxy-4-vinylbenzene (Table 1.2, **2d**): The title compound was isolated by column chromatography (2% ethyl acetate in hexanes) as a colorless oil (24.4 mg, 91% yield, >20:1 **2d**:**3d**). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.37 (d, *J* = 8.8 Hz, 2H), 6.88 (d, *J* = 8.7 Hz, 2H), 6.68 (dd, *J* = 17.6, 10.9 Hz, 1H), 5.63 (d, *J* = 17.6 Hz, 1H), 5.14 (d, *J* = 10.9 Hz, 1H), 3.82 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 159.5, 136.4, 130.6, 127.5, 114.0, 111.7, 55.4. This compound is known.[3]



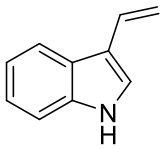
2e

4-Vinylbenzonitrile (Table 1.2, **2e**): The title compound was isolated by column chromatography (5% ethyl acetate in hexanes) as a colorless oil (22.0 mg, 85% yield, >20:1 **2e**:**3e**). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.59 (d, *J* = 8.4 Hz, 2H), 7.47 (d, *J* = 8.3 Hz, 2H), 6.72 (dd, *J* = 17.6, 10.9 Hz, 1H), 5.86 (d, *J* = 17.6 Hz, 1H), 5.44 (d, *J* = 10.9 Hz, 1H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 142.0, 135.4, 132.4, 126.8, 119.0, 117.8, 111.2. This compound is known.[4]



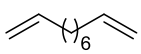
2f

4-Vinylpyridine (Table 1.2, **2f**): The yield was determined by GC analysis using durene as an internal standard (87% GC yield, >20:1 **2f**:**3f**). The title compound was isolated by column chromatography (1% methanol in DCM) as a yellow oil (17.8 mg, 85% yield, >20:1 **2f**:**3f**). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.53 (d, *J* = 6.0 Hz, 2H), 7.24 (d, *J* = 6.1 Hz, 2H), 6.64 (dd, *J* = 17.6, 10.9 Hz, 1H), 5.94 (d, *J* = 17.6 Hz, 1H), 5.46 (d, *J* = 10.9 Hz, 1H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 150.2, 144.8, 134.9, 120.8, 118.7. This compound is known.[5]



2g

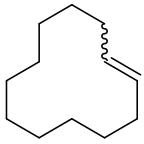
3-Vinylindole (Table 1.2, **2g**): The title compound was isolated by column chromatography (20% ethyl acetate in hexanes) as a yellow oil (22.1 mg, 77% yield, >20:1 **2g**:**3g**). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.06 (brs, 1H), 7.99 – 7.95 (m, 1H), 7.42 – 7.36 (m, 1H), 7.33 – 7.22 (m, 3H), 6.97 (dd, *J* = 17.8, 11.3 Hz, 1H), 5.79 (dd, *J* = 17.8, 1.4 Hz, 1H), 5.26 (dd, *J* = 11.3, 1.4 Hz, 1H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 136.8, 129.6, 125.7, 123.7, 122.6, 120.5, 120.2, 115.9, 111.5, 110.9. This compound is known.[6]



2h

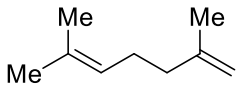
Deca-1,9-diene (Table 1.2, **2h**): The yield was determined by GC analysis using durene as an internal standard (88% GC yield, >20:1 **2h**:**3h**+other alkene isomers). The title compound was isolated by column chromatography (pentane) as a colorless oil (88% yield, 24.3 mg). ^{1}H NMR (400

MHz, $CDCl_3$) δ 5.81 (ddt, *J* = 16.9, 10.2, 6.7 Hz, 2H), 5.04 – 4.90 (m, 4H), 2.09 – 2.00 (m, 4H), 1.44 – 1.26 (m, 8H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 139.3, 114.3, 33.9, 29.1, 29.0. This compound is known.[7]



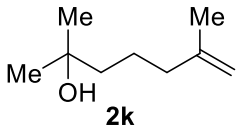
2i

Cyclododecene (Table 1.2, **2i**): The title compound was isolated by column chromatography (pentane) as a colorless oil (30.2 mg, 91% yield, 3:1 *E*/*Z*, >20:1 **2i**:**3i**+other alkene isomers). **(*E*)-2i:** ^1H NMR (400 MHz, $CDCl_3$) δ 5.40 – 5.36 (m, 2H), 2.09 – 2.03 (m, 4H), 1.49 – 1.22 (m, 16H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 131.6, 32.3, 26.4, 25.8, 25.1, 24.8. **(*Z*)-2i:** ^1H NMR (400 MHz, $CDCl_3$) δ 5.34 – 5.30 (m, 2H), 2.15 – 2.09 (m, 4H), 1.49 – 1.22 (m, 16H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 130.5, 27.1, 24.8, 24.5, 24.1, 22.2. This compound is known.[8]



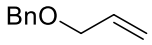
2j

2,6-Dimethylhepta-1,5-diene (Table 1.2, **2j**): The yield was determined by GC analysis using durene as an internal standard (89% GC yield, >20:1 **2j**:**3j**+other alkene isomers). The title compound was isolated by column chromatography (pentane) as a colorless oil (82% yield, 20.4 mg). ^1H NMR (400 MHz, $CDCl_3$) δ 5.17 – 5.10 (m, 1H), 4.74 – 4.67 (m, 2H), 2.13 (dt, *J* = 11.5, 3.9 Hz, 2H), 2.07 – 2.01 (m, 2H), 1.74 (s, 3H), 1.70 (d, *J* = 1.1 Hz, 3H), 1.63 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 146.0, 131.6, 124.3, 109.9, 38.0, 26.5, 25.8, 22.6, 17.8. This compound is known.[9]



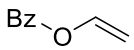
2k

2,6-Dimethylhept-6-en-2-ol (Table 2a, **2k**): The title compound was isolated by column chromatography (10% ethyl ether in pentane) as a colorless oil (24.7 mg, 87% yield, >20:1 **2k**:**3k**+other alkene isomers). ^1H NMR (400 MHz, $CDCl_3$) δ 4.71 – 4.66 (m, 2H), 2.01 (t, *J* = 6.9 Hz, 2H), 1.71 (s, 3H), 1.55 – 1.41 (m, 4H), 1.34 (brs, 1H), 1.21 (s, 6H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 145.9, 110.1, 71.1, 43.6, 38.3, 29.4, 22.4, 22.4. This compound is known.[10]



2l

Allyl benzyl ether (Table 1.2, **2l**): The title compound was isolated by column chromatography (2% ethyl acetate in hexanes) as a colorless oil (24.0 mg, 81% yield, >20:1 **2l**:**3l**+other alkene isomers). ^1H NMR (400 MHz, $CDCl_3$) δ 7.42 – 7.30 (m, 5H), 6.01 (ddt, *J* = 17.2, 10.4, 5.6 Hz, 1H), 5.36 (ddd, *J* = 17.2, 3.4, 1.7 Hz, 1H), 5.26 (ddd, *J* = 10.4, 3.1, 1.3 Hz, 1H), 4.57 (s, 2H), 4.08 (dt, *J* = 5.6, 1.4 Hz, 2H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 138.4, 134.8, 128.4, 127.8, 127.7, 117.1, 72.2, 71.2. This compound is known.[11]

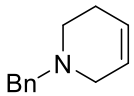


2m

Vinyl benzoate (Table 1.2, **2m**): The title compound was isolated by column chromatography (2% ethyl acetate in hexanes with 0.5% triethylamine) as a colorless oil (23.7 mg, 80% yield, >20:1 **2m**:**3m**). ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.14 – 8.09 (m, 2H), 7.63 – 7.57 (m, 1H), 7.52 (dd, *J* = 14.0, 6.3 Hz, 1H), 7.50 – 7.44 (m, 2H), 5.08 (dd, *J* = 14.0, 1.7 Hz, 1H), 4.71 (dd, *J* = 6.3, 1.7 Hz, 1H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 163.8, 141.6, 133.7, 130.1, 129.1, 128.7, 98.3. This compound is known.[12]

2n

***tert*-Butyl 2,3-dihydro-1*H*-pyrrole-1-carboxylate** (Table 1.2, **2n**): The title compound was isolated by column chromatography (5% ethyl acetate in hexanes with 1% triethylamine) as a colorless oil (a mixture of rotamers, 25.4 mg, 75% yield, >20:1 **2n**:**3n**+other alkene isomers). ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.60 – 6.35 (m, 1H), 5.02 – 4.88 (m, 1H), 3.75 – 3.57 (m, 2H), 2.65 – 2.53 (m, 2H), 1.44 (s, 9H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 151.7, 129.9, 107.6, 80.1, 44.9, 28.7, 28.5. This compound is known.[13]



2o

1-Benzyl-1,2,3,6-tetrahydropyridine (Table 1.2, **2o**): The title compound was isolated by column chromatography (10% ethyl acetate in hexanes with 1% triethylamine) as a colorless oil (31.8 mg, 92% yield, >20:1 **2o**:**3o**+other alkene isomers). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.40 – 7.30 (m, 4H), 7.29 – 7.23 (m, 1H), 5.80 – 5.73 (m, 1H), 5.71 – 5.64 (m, 1H), 3.59 (s, 2H), 3.01 – 2.96 (m, 2H), 2.57 (t, *J* = 5.7 Hz, 2H), 2.21 – 2.14 (m, 2H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 138.5, 129.3, 128.3, 127.1, 125.5, 125.4, 63.1, 53.0, 49.8, 26.3. This compound is known.[14]

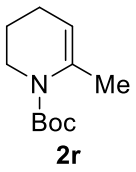
2p

***tert*-Butyl 3,4-dihydropyridine-1(2*H*)-carboxylate** (Table 1.2, **2p**): The title compound was isolated by column chromatography (5% ethyl acetate in hexanes with 1% triethylamine) as a colorless oil (a mixture of rotamers, 30.4 mg, 83% yield, >20:1 **2p**:**3p**+other alkene isomers). ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.88 – 6.66 (m, 1H), 4.93 – 4.74 (m, 1H), 3.58 – 3.48 (m, 2H), 2.08 – 1.96 (m, 2H), 1.84 – 1.75 (m, 2H), 1.47 (s, 9H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 152.5, 125.8, 105.3, 80.6, 41.6, 28.5, 21.9, 21.6. This compound is known.[15]

2q

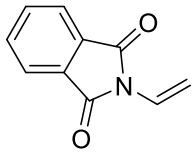
***tert*-Butyl 3,4-dihydropyridine-1(2*H*)-carboxylate** (Table 1.2, **2q**): The title compound was isolated by column chromatography (5% ethyl acetate in hexanes with 1% triethylamine) as a colorless oil (a mixture of rotamers, 29.3 mg, 80% yield, >20:1 **2q**:**3q**+other alkene isomers). ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.81 – 6.59 (m, 1H), 4.86 – 4.65 (m, 1H), 3.52 – 3.40 (m, 2H), 1.98 –

1.89 (m, 2H), 1.78 – 1.66 (m, 2H), 1.41 (s, 9H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 152.3, 125.6, 105.1, 80.3, 41.5, 28.3, 21.8, 21.5. This compound is known.[15]



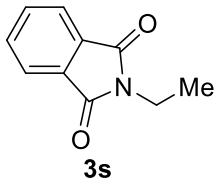
2r

***tert*-Butyl 6-methyl-3,4-dihydropyridine-1(2*H*)-carboxylate** (Table 1.2, **2r**): The title compound was isolated by column chromatography (5% ethyl acetate in hexanes with 1% triethylamine) as a colorless oil (29.5 mg, 75% yield, >20:1 **2r**:**3r**+other alkene isomers). ^{1}H NMR (400 MHz, $CDCl_3$) δ 4.83 – 4.77 (m, 1H), 3.53 – 3.46 (m, 2H), 2.04 – 1.96 (m, 5H), 1.75 – 1.67 (m, 2H), 1.45 (s, 9H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 153.8, 135.7, 111.3, 80.4, 44.7, 28.5, 23.3, 23.2, 22.8. This compound is known.[16]



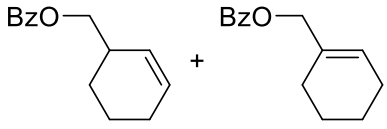
2s

***N*-Vinylphthalimide** (Table 1.2, **2s**): 4:1 **2s**:**3s**. The title compound was isolated by preparatory TLC (30% ethyl acetate in hexanes) as a white solid (27.0 mg, 78% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.88 – 7.82 (m, 2H), 7.76 – 7.70 (m, 2H), 6.86 (dd, *J* = 16.4, 9.9 Hz, 1H), 6.07 (d, *J* = 16.4 Hz, 1H), 5.03 (d, *J* = 9.9 Hz, 1H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 166.6, 134.6, 131.7, 123.9, 123.8, 104.6. This compound is known.[17]



3s

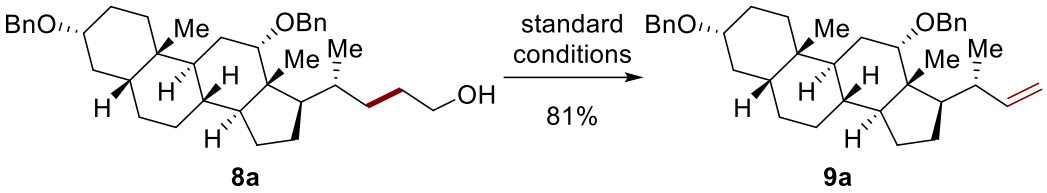
***N*-Ethylphthalimide** (Table 1.2, **3s**): The title compound was isolated by preparatory TLC (30% ethyl acetate in hexanes) as a white solid (6.6 mg, 19% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.85 – 7.79 (m, 2H), 7.72 – 7.65 (m, 2H), 3.73 (q, *J* = 7.2 Hz, 2H), 1.26 (t, *J* = 7.2 Hz, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 168.4, 134.0, 132.4, 123.3, 33.1, 14.1. This compound is known.[18]



2t1 **2t2**

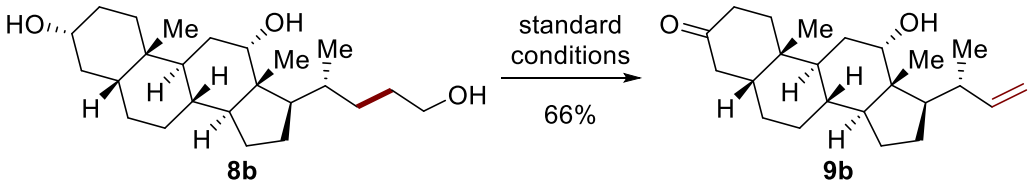
The mixture of compounds **2t1** and **2t2** was isolated by column chromatography (5% ethyl acetate in hexanes) as a colorless oil (from *cis*-**1t**: 38.9 mg, 90% yield, 3:1 **2t1**:**2t2**; from *trans*-**1t**: 39.1 mg, 91% yield, 4:1 **2t1**:**2t2**). **Cyclohex-2-en-1-ylmethyl benzoate** (Table 1.2, **2t1**): ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.08 – 8.04 (m, 2H), 7.58 – 7.52 (m, 1H), 7.47 – 7.41 (m, 2H), 5.86 – 5.80 (m, 1H), 5.69 – 5.63 (m, 1H), 4.21 (d, *J* = 6.9 Hz, 2H), 2.66 – 2.56 (m, 1H), 2.11 – 2.00 (m, 2H), 1.92 – 1.83 (m, 1H), 1.82 – 1.73 (m, 1H), 1.65 – 1.53 (m, 1H), 1.51 – 1.42 (m, 1H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 166.7, 132.9, 130.6, 129.7, 129.7, 128.4, 127.1, 68.6, 35.1, 25.9, 25.3, 20.8. **Cyclohex-1-en-1-ylmethyl benzoate** (Table 1.2, **2t2**): ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.08 – 8.04 (m, 2H), 7.58 – 7.52 (m, 1H), 7.47 –

7.41 (m, 2H), 5.86 – 5.80 (m, 1H), 4.70 (s, 2H), 2.20 – 1.95 (m, 4H), 1.80 – 1.40 (m, 4H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 166.6, 133.1, 130.6, 129.3, 128.3, 126.3, 125.5, 69.4, 26.0, 25.1, 22.5, 22.3. This compound is known.[19]



8a **9a**

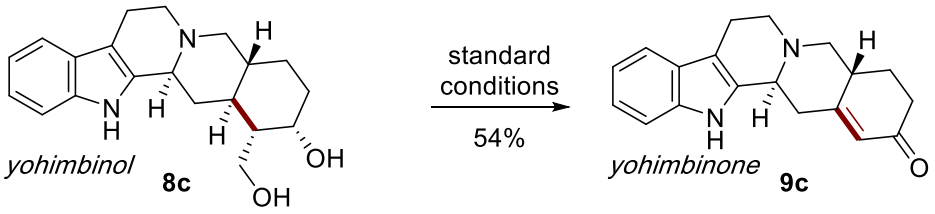
(*3R,5R,8R,9S,10S,12S,13R,14S,17R*)-3,12-bis(benzyloxy)-17-((*R*)-but-3-en-2-yl)-10,13-dimethylhexadecahydro-1*H*-cyclopenta[a]phenanthrene (Figure 1.5, **9a**): The title compound was isolated by preparatory TLC (3% ethyl acetate in hexanes) as a colorless oil (85.1 mg, 81% yield). Alcohol **8a** was prepared according to literature procedure.[20] ^{1}H NMR (600 MHz, $CDCl_3$) δ7.47 – 7.45 (m, 2H), 7.43 – 7.39 (m, 5H), 7.35 – 7.32 (m, 3H), 5.76 (dt, *J* = 17.3, 8.8 Hz, 1H), 4.96 (d, *J* = 17.3 Hz, 1H), 4.89 (d, *J* = 10.2 Hz, 1H), 4.69 (d, *J* = 11.4 Hz, 1H), 4.61 (s, 2H), 4.40 (d, *J* = 11.4 Hz, 1H), 3.75 (s, 1H), 3.46 – 3.42 (m, 1H), 2.17 – 2.11 (m, 2H), 1.98 – 1.87 (m, 6H), 1.83 – 1.74 (m, 2H), 1.70 – 1.68 (m, 1H), 1.64 – 1.61 (m, 1H), 1.52 – 1.22 (m, 9H), 1.11 (t, *J* = 6.1 Hz, 1H), 1.08 (d, *J* = 6.3 Hz, 3H), 1.08 – 1.03 (m, 2H), 1.01 (s, 3H), 0.80 (s, 3H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 145.5, 139.4, 128.41, 128.38, 127.7, 127.6, 127.39, 127.35, 111.6, 81.0, 78.7, 70.5, 69.7, 48.9, 46.7, 46.1, 42.4, 41.3, 36.2, 35.5, 34.7, 34.0, 33.4, 27.8, 27.54, 27.40, 26.2, 23.9, 23.5, 23.3, 19.8, 13.2. HRMS calculated from $C_{37}H_{54}O_2N$ $[M+NH_4]^+$ 544.4155, found 544.4159.



8b **9b**

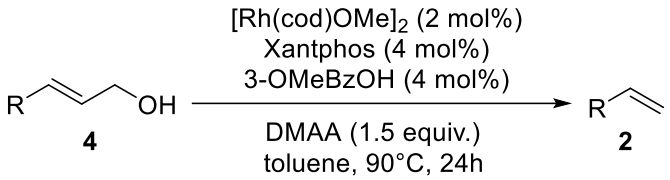
(*5R,8R,9S,10S,12S,13R,14S,17R*)-17-((*R*)-but-3-en-2-yl)-12-hydroxy-10,13-dimethylhexadecahydro-3*H*-cyclopenta[a]phenanthren-3-one (Figure 1.5, **9b**): The title compound was isolated by preparatory TLC (30% ethyl acetate in hexanes) as a white solid (45.5 mg, 66% yield). Alcohol **8b** was prepared according to literature procedure.[21] ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.67 (ddd, *J* = 17.1, 10.2, 8.4 Hz, 1H), 4.94 – 4.82 (m, 2H), 4.03 (t, *J* = 2.9 Hz, 1H), 2.72 (dd, *J* = 14.9, 13.5 Hz, 1H), 2.42 – 2.34 (m, 1H), 2.17 – 2.11 (m, 1H), 2.08 (t, *J* = 7.7 Hz, 1H), 2.06 – 1.94 (m, 2H), 1.93 – 1.88 (m, 1H), 1.87 – 1.78 (m, 2H), 1.76

– 1.70 (m, 2H), 1.70 – 1.66 (m, 1H), 1.66 – 1.64 (m, 1H), 1.64 – 1.53 (m, 5H), 1.49 (dquintet, *J* = 12.4, 2.9 Hz, 2H), 1.41 – 1.33 (m, 1H), 1.29 – 1.22 (m, 2H), 1.15 – 1.10 (m, 1H), 1.07 (d, *J* = 5.1 Hz, 3H), 1.00 (s, 3H), 0.74 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ213.4, 144.8, 112.1, 73.1, 48.3, 47.2, 46.7, 44.4, 42.5, 41.0, 37.2, 37.0, 35.9, 34.6, 34.1, 29.0, 27.8, 26.7, 25.6, 23.7, 22.5, 19.5, 13.1. HRMS calculated from $C_{23}H_{36}O_2Na$ $[M+Na]^+$ 367.2613, found 367.2617.

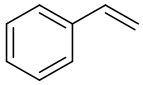


(4a*R*,13b*S*)-3,4,4a,5,8,13,13b,14-octahydroindolo[2',3':3,4]pyrido[1,2-b]isoquinolin-2(7*H*)-one (Figure 1.5, **9c**): The title compound was isolated by preparatory TLC (ethyl acetate) as a yellow solid (31.5 mg, 54% yield). Alcohol **8c** was prepared according to literature procedure.[27] ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.00 (s, 1H), 7.51 – 7.48 (m, 1H), 7.35 – 7.32 (m, 1H), 7.19 – 7.09 (m, 2H), 5.99 (s, 1H), 3.43 – 3.38 (m, 1H), 3.25 – 3.20 (m, 1H), 3.19 – 3.14 (m, 1H), 3.07 – 2.98 (m, 1H), 2.87 – 2.75 (m, 3H), 2.72 – 2.64 (m, 1H), 2.60 – 2.53 (m, 1H), 2.53 – 2.47 (m, 1H), 2.44 – 2.36 (m, 1H), 2.31 – 2.24 (m, 1H), 2.15 – 2.07 (m, 1H), 1.76 – 1.63 (m, 2H). This compound is known.[22]

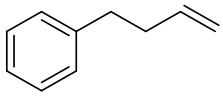
3. General Procedures for the Dehomologation of Allylic Alcohols



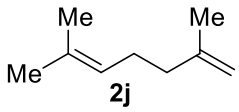
In a N_2-filled glovebox, $[Rh(cod)OMe]_2$ (1.9 mg, 0.004 mmol), Xantphos (4.6 mg, 0.008 mmol), 3-methoxybenzoic acid (1.2 mg, 0.008 mmol) and toluene (0.40 mL) were added to a 1 dram vial. After stirring for 3 min, *N*,*N*-dimethylacrylamide (31 μL, 30 mg, 0.30 mmol) and allylic alcohol (**4**, 0.20 mmol) were added successively. The vial was sealed completely by a screw cap with a Teflon septum. Then, the reaction mixture was stirred at 90 ˚C for 24 h. Chemo- and regioselectivity were determined from analysis of the reaction mixture by GC analysis. The olefin product was isolated by either column chromatography. Alternatively, the yields of volatile products were determined by GC analysis.


2c

Styrene (Equation 1.5, **2c**): The yield was determined by GC analysis using durene as an internal standard (95% GC yield, >20:1 **2c**:**3c**).


2u

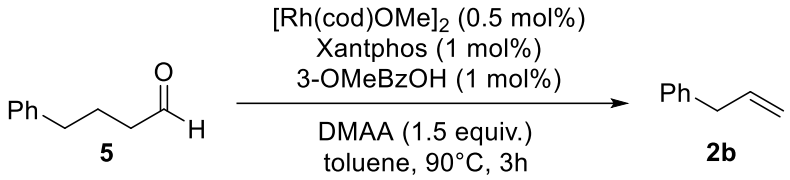
But-3-en-1-ylbenzene (Equation 1.5, **2u**): The yield was determined by GC analysis using durene as an internal standard (92% GC yield, >20:1 **2u**:**3u**+other alkene isomers). The title compound was isolated by column chromatography (pentane) as a colorless oil (75% yield, 19.8 mg). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.35 – 7.28 (m, 2H), 7.24 – 7.19 (m, 3H), 5.90 (ddt, *J* = 16.9, 10.2, 6.6 Hz, 1H), 5.12 – 4.98 (m, 2H), 2.78 – 2.71 (m, 2H), 2.46 – 2.37 (m, 2H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 142.0, 138.2, 128.6, 128.4, 126.0, 115.0, 35.7, 35.5. This compound is known.[23]



2j

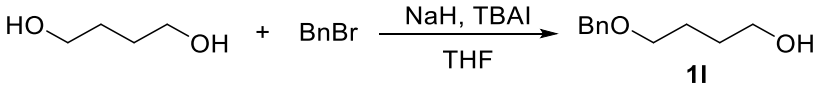
2,6-Dimethylhepta-1,5-diene (Equation 1.5, **2j**): The yield was determined by GC analysis using durene as an internal standard (85% GC yield, >20:1 **2j**:**3j**+other alkene isomers). The title compound was isolated by column chromatography (pentane) as a yellow oil (85% yield, 21.0 mg). ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.15 – 5.10 (m, 1H), 4.73 – 4.67 (m, 2H), 2.17 – 2.09 (m, 2H), 2.07 – 2.00 (m, 2H), 1.73 (s, 3H), 1.70 (s, 3H), 1.62 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 146.1, 131.7, 124.3, 109.9, 38.0, 26.5, 25.8, 22.6, 17.8. This compound is known.[9]

4. Procedure for the Dehomologation of Aldehydes

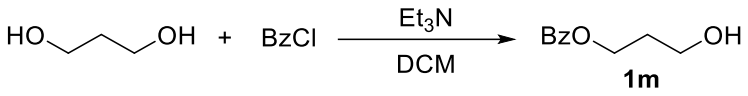


In a N_2-filled glovebox, $[Rh(cod)OMe]_2$ (0.5 mg, 0.001 mmol), Xantphos (1.2 mg, 0.002 mmol), 3-methoxybenzoic acid (0.3 mg, 0.002 mmol) and toluene (0.40 mL) were added to a 1 dram vial. After stirring for 3 min, *N*,*N*-dimethylacrylamide (31 μL, 30 mg, 0.30 mmol) and 4-phenylbutanal (**5**, 31.2 mg, 0.20 mmol) were added successively. The vial was sealed completely by a screw cap with a Teflon septum. Then, the reaction mixture was stirred at 90 ˚C for 3 h. The yield, chemo- and regioselectivity were determined from analysis of the reaction mixture by GC analysis (94% GC yield, >20:1 **2b**:**3b**+other alkene isomers). The product allylbenzene (**2b**) was isolated by column chromatography (pentane) as a colorless oil. **Allylbenzene** (Equation 1.6, **2b**): ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.35 – 7.30 (m, 2H), 7.26 – 7.20 (m, 3H), 6.01 (ddt, *J* = 16.9, 10.2, 6.7 Hz, 1H), 5.16 – 5.07 (m, 2H), 3.43 (d, *J* = 6.7 Hz, 2H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 140.2, 137.6, 128.7, 128.6, 126.2, 115.9, 40.4. This compound is known.[2]

5. Preparation of Substrates

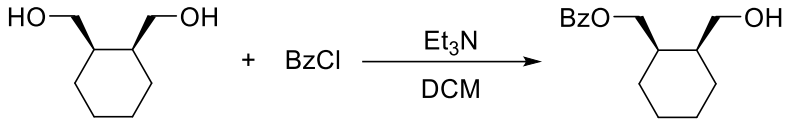


To a suspension of NaH (60 wt%, 40 mg, 1.0 mmol) in THF (2.5 mL) was added 1,4-butanediol (88 μL, 90 mg, 1.0 mmol) at 0 ˚C. After stirring at 0 ˚C for 2h, benzyl bromide (110 μL, 158 mg, 0.90 mmol) and tetrabutylammonium iodide (37 mg, 0.10 mmol) was added successively. The reaction mixture was stirred at rt for 5h. Then, the reaction mixture was quenched with saturated aqueous NH_4Cl (5 mL) and extracted with DCM (3 × 10 mL). The combined organic extracts were washed with brine, dried over Na_2SO_4, filtered and concentrated *in vacuo*. Purification of the crude residue by column chromatography (25% ethyl acetate in hexanes) afforded 4-(benzyloxy)butan-1-ol (**1l**) as a colorless oil (144 mg, 89% yield). **4-(Benzyloxy)butan-1-ol (1l)**: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.38 – 7.25 (m, 5H), 4.52 (s, 2H), 3.62 (t, *J* = 5.9 Hz, 2H), 3.52 (t, *J* = 5.9 Hz, 2H), 2.54 (brs, 1H), 1.77 – 1.60 (m, 4H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 138.3, 128.5, 127.8, 127.7, 73.1, 70.4, 62.6, 30.1, 26.7. This compound is known.[24]



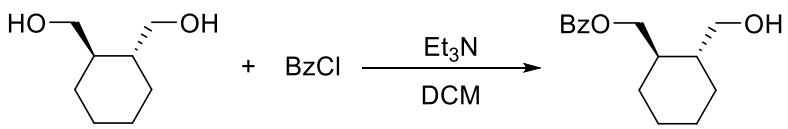
1m

To a solution of 1,3-propanediol (0.43 mL, 0.45 g, 6.0 mmol) and trimethylamine (0.56 mL, 0.40 g, 4.0 mmol) in DCM (10 mL) was slowly added benzoyl chloride (0.23 mL, 0.28 g, 2.0 mmol) at 0 ˚C. The solution was stirred at rt for 12h. Then, the reaction mixture was diluted with water (50 mL) and extracted with DCM (3 × 10 mL). The combined organic extracts were washed with brine, dried over Na_2SO_4, filtered and concentrated *in vacuo*. Purification of the crude residue by column chromatography (50% ethyl acetate in hexanes) afforded 3-hydroxypropyl benzoate (**1m**) as a colorless oil (0.30 g, 82% yield). **3-Hydroxypropyl benzoate (1m)**: ^{1}H NMR (400 MHz, $CDCl_3$) 8.08 – 7.98 (m, 2H), 7.60 – 7.50 (m, 1H), 7.48 – 7.39 (m, 2H), 4.52 – 4.46 (m, 2H), 3.81 – 3.74 (m, 2H), 2.08 (brs, 1H), 2.04 – 1.96 (m, 2H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 167.1, 133.1, 130.2, 129.7, 128.5, 61.9, 59.2, 32.0. This compound is known.[25]



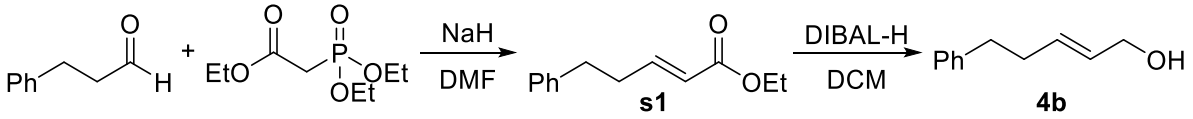
***cis*-1t**

To a solution of *cis*-1,2-cyclohexanedimethanol (0.88 g, 6.0 mmol) and trimethylamine (0.56 mL, 0.40 g, 4.0 mmol) in DCM (10 mL) was slowly added benzoyl chloride (0.23 mL, 0.28 g, 2.0 mmol) at 0 ˚C. The solution was stirred at rt for 12h. Then, the reaction mixture was diluted with water (50 mL) and extracted with DCM (3 × 10 mL). The combined organic extracts were washed with brine, dried over Na_2SO_4, filtered and concentrated *in vacuo*. Purification of the crude residue by column chromatography (50% ethyl acetate in hexanes) afforded *cis*-2-(hydroxymethyl)cyclohexyl)methyl benzoate (***cis*-1t**) as a colorless oil (0.42 g, 85% yield). ***cis*-2-(Hydroxymethyl)cyclohexyl)methyl benzoate (*cis*-1t)**: ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.06 – 8.00 (m, 2H), 7.58 – 7.51 (m, 1H), 7.47 – 7.39 (m, 2H), 4.41 (dd, *J* = 11.1, 6.4 Hz, 1H), 4.29 (dd, *J* = 11.1, 7.8 Hz, 1H), 3.72 (dd, *J* = 10.9, 7.4 Hz, 1H), 3.61 (dd, *J* = 10.9, 7.3 Hz, 1H), 2.30 – 2.21 (m, 1H), 2.00 – 1.92 (m, 1H), 1.90 (brs, 1H), 1.72 – 1.34 (m, 8H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 166.9, 133.1, 130.4, 129.6, 128.5, 65.2, 63.9, 40.7, 36.0, 27.2, 25.9, 24.2, 23.1. This compound is known.[26]



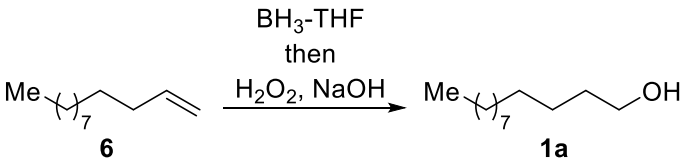
***trans*-1t**

To a solution of *trans*-1,2-cyclohexanedimethanol (0.65 g, 4.5 mmol) and trimethylamine (0.42 mL, 3.0 mmol) in DCM (7.5 mL) was slowly added benzoyl chloride (0.21 g, 1.5 mmol) at 0 ˚C. The solution was stirred at rt for 12h. Then, the reaction mixture was diluted with water (50 mL) and extracted with DCM (3 × 10 mL). The combined organic extracts were washed with brine, dried over Na_2SO_4, filtered and concentrated *in vacuo*. Purification of the crude residue by column chromatography (50% ethyl acetate in hexanes) afforded *trans*-2-(hydroxymethyl)cyclohexyl)methyl benzoate (***trans*-1t**) as a colorless oil (0.21 g, 57% yield). ***trans*-2-(Hydroxymethyl)cyclohexyl)methyl benzoate (*trans*-1t)**: ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.05 – 8.02 (m, 2H), 7.55 (ddt, *J* = 8.0, 6.8, 1.3 Hz, 1H), 7.46 – 7.41 (m, 2H), 4.40 (dd, *J* = 11.1, 4.3 Hz, 1H), 4.26 (dd, *J* = 11.1, 6.0 Hz, 1H), 3.70 (d, *J*= 4.6 Hz, 2H), 1.92 – 1.88 (m, 1H), 1.84 – 1.67 (m, 6H), 1.48 – 1.42 (m, 1H), 1.31 – 1.19 (m, 4H). This compound is known.[27]

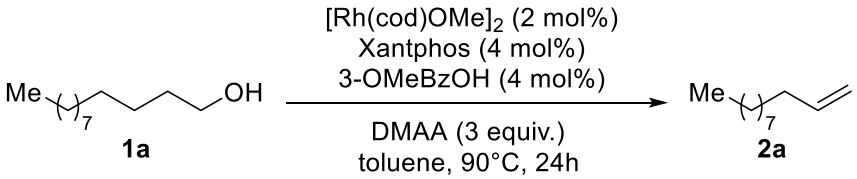


To a solution of sodium hydride (60 wt.%, 0.22 g, 5.5 mmol) in DMF (20 mL) was added triethyl phosphonoacetate (1.1 mL, 1.23 g, 5.5 mmol) at 0 ˚C. After stirring at 0 ˚C for 0.5h, 3-phenylpropanal (0.66 mL, 0.67 g, 5.0 mmol) was added. The reaction mixture was stirred at rt for 2h. Then, the reaction mixture was quenched with 1N HCl (10 mL) and extracted with ethyl acetate (50 mL). The extract was washed with water, dried over Na_2SO_4, filtered and concentrated *in vacuo*. Purification of the crude residue by column chromatography (5% ethyl acetate in hexanes) afforded ethyl 5-phenylpent-2-enoate (**s1**) as a colorless oil (0.95 g, 93% yield). To a solution of compound **S1** (0.82 g, 4.0 mmol) in DCM (20 mL) was added DIBAL-H (1 M in hexane, 8.0 mL, 8.0 mmol) slowly at -78 ˚C. The resulting mixture was stirred at -78 ˚C for 2h. Then, the reaction mixture was carefully quenched with saturated aqueous potassium sodium tartrate (20 mL) and extracted with DCM (3 × 30 mL). The combined organic extracts were washed with brine, dried over Na_2SO_4, filtered and concentrated *in vacuo*. Purification of the crude residue by column chromatography (25% ethyl acetate in hexanes) afforded 5-phenylpent-2-en-1-ol (**4b**) as a colorless oil (0.54 g, 83% yield). **5-Phenylpent-2-en-1-ol (4b)**: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.34 – 7.27 (m, 2H), 7.24 – 7.17 (m, 3H), 5.80 – 5.62 (m, 2H), 4.08 (dd, *J* = 5.5, 0.9 Hz, 2H), 2.77 – 2.69 (m, 2H), 2.44 – 2.35 (m, 2H), 1.65 (brs, 1H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 141.8, 132.2, 129.7, 128.5, 128.4, 126.0, 63.7, 35.6, 34.0. This compound is known.[28]

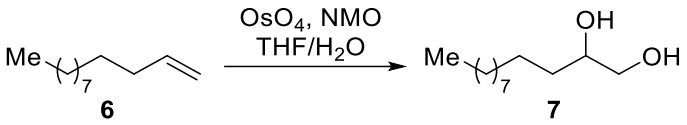
6. Dehomologation of Olefins



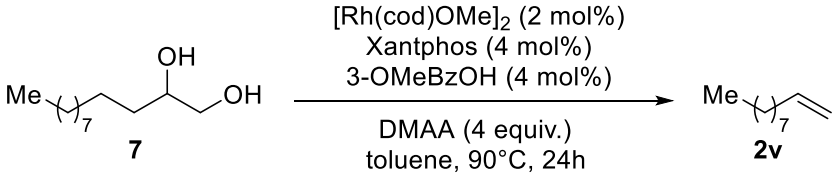
To a solution of 1-dodecene (**6**, 1.33 mL, 1.0 g, 6.0 mmol) in dry THF (20 mL) was added borane (1.0 M in THF, 6.0 mL, 6.0 mmol) dropwise at 0 ˚C under a N_2 atmosphere. The reaction mixture was stirred for 1h at 0 ˚C and 6h at rt. Then, the reaction mixture was cooled to 0 ˚C, and water (5 mL) was added dropwise followed by addition of aq. NaOH (3N, 5 mL) and H_2O_2 (30 wt.%, 5 mL). The resulting mixture was stirred for 0.5h at ˚C and additional 6h at rt. Then, the solution was saturated with solid NaCl and extracted with Et_2O (3 × 50 mL). The combined organic extracts were washed with brine, dried over Na_2SO_4, filtered and concentrated *in vacuo*. Purification of the crude residue by column chromatography (20% Et_2O in hexanes) afforded 1-dodecanol (**1a**) as a colorless oil (1.06 g, 95% yield). **1-Dodecanol** (Figure 1.5, **1a**): ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.64 – 3.57 (m, 2H), 1.67 (brs, 1H), 1.59 – 1.20 (m, 2H), 1.37 – 1.19 (s, 18H), 0.87 (t, *J* = 6.8 Hz, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 63.1, 32.9, 32.1, 29.8 (2C), 29.7 (2C), 29.6, 29.5, 25.9, 22.8, 14.2. This compound is known.[29]



In a N_2-filled glovebox, $[Rh(cod)OMe]_2$ (54 mg, 0.114 mmol), Xantphos (131 mg, 0.228 mmol), 3-methoxybenzoic acid (34 mg, 0.228 mmol) and toluene (10 mL) were added to a 50 mL Schlenk tube. After stirring for 3 min, *N*,*N*-dimethylacrylamide (1.8 mL, 1.7 g, 17 mmol) and 1-dodecanol (**1a**, 1.06 g, 5.7 mmol) were added successively. The Schlenk tube was sealed completely by a Teflon screw cap. Then, the reaction mixture was stirred at 90 ˚C for 24 h. Chemo- and regioselectivity were determined from analysis of the reaction mixture by GC analysis. The reaction mixture was concentrated carefully *in vacuo*. Purification of the crude residue by column chromatography (pentane) afforded 1-undecene (**2a**) as a colorless oil (0.76 g, 86% yield, >20:1 **2a**:**3a**+other alkene isomers). **1-Undecene** (Figure 1.5, **2a**): ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.82 (ddt, *J* = 16.9, 10.2, 6.7 Hz, 1H), 5.04 – 4.89 (m, 2H), 2.10 – 2.00 (m, 2H), 1.44 – 1.21 (m, 14H), 0.89 (t, *J* = 6.9 Hz, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 139.4, 114.2, 34.0, 32.1, 29.8, 29.7, 29.5, 29.4, 29.2, 22.9, 14.3. This compound is known.[1]

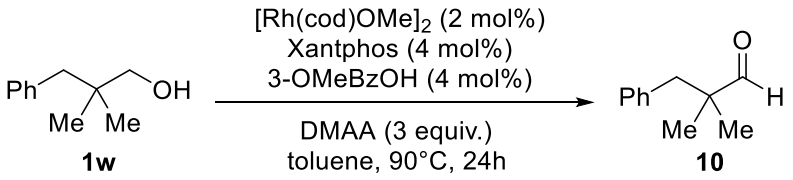


To a mixture of 1-dodecene (**6**, 1.0 mL, 0.76g, 4.5 mmol) , THF (40 mL) and water (4 mL) was added OsO_4 (4 wt.% in water, 0.29 mL, 0.045 mmol) at 0 ˚C. After stirring for 20 min at 0 ˚C, *N*-methylmorpholine *N*-oxide (0.53g, 4.5 mmol) was added. The resulting mixture was stirred overnight at rt. The saturated aqueous $NaHSO_3$ (5 mL) was added and mixture was stirred for 10 min. The THF was removed by evaporation. The residue was extracted with DCM (3 × 50 mL). The combined organic extracts were washed with brine, dried over Na_2SO_4, filtered and concentrated *in vacuo*. Purification of the crude residue by column chromatography (35% ethyl acetate in hexanes) afforded dodecane-1,2-diol (**7**) as a white solid (0.84 g, 92% yield). **Dodecane-1,2-diol (7)**: ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.74 – 3.58 (m, 2H), 3.45 – 3.36 (m, 1H), 2.83 (brs, 2H), 1.49 – 1.17 (m, 18H), 0.87 (t, *J* = 6.8 Hz, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 72.5, 67.0, 33.3, 32.0, 29.8, 29.7 (2C), 29.6, 29.5, 25.7, 22.8, 14.2. This compound is known.[30]



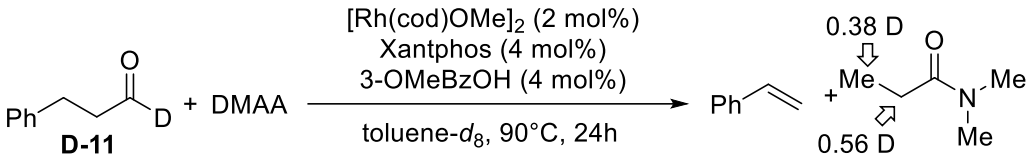
In a N_2-filled glovebox, $[Rh(cod)OMe]_2$ (1.9 mg, 0.004 mmol), Xantphos (4.6 mg, 0.008 mmol), 3-methoxybenzoic acid (1.2 mg, 0.008 mmol) and toluene (0.40 mL) were added to a 1 dram vial. After stirring for 3 min, *N*,*N*-dimethylacrylamide (84 μL, 80 mg, 0.80 mmol) and dodecane-1,2-diol (**7**, 41 mg, 0.20 mmol) were added successively. The vial was sealed completely by a screw cap with a Teflon septum. Then, the reaction mixture was stirred at 90 ˚C for 24 h. The yield, chemo- and regioselectivity were determined from analysis of the reaction mixture by GC analysis (75% GC yield, >20:1 **2v**:**3v**+other alkene isomers). The product 1-decene (**2v**) was isolated by column chromatography (pentane) as a colorless oil. **1-Decene** (Figure 1.5, **2v**): ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.82 (ddt, *J* = 16.9, 10.2, 6.7 Hz, 1H), 5.04 – 4.89 (m, 2H), 2.11 – 1.98 (m, 2H), 1.44 – 1.21 (m, 12H), 0.89 (t, *J* = 6.9 Hz, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 139.4, 114.2, 34.0, 32.1, 29.6, 29.5, 29.3, 29.1, 22.8, 14.3. This compound is known.[31]

7. Dehydrogenation of Aldehyde 1w

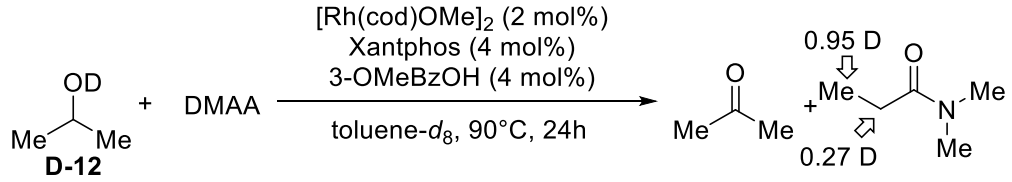


In a N_2-filled glovebox, $[Rh(cod)OMe]_2$ (1.9 mg, 0.004 mmol), Xantphos (4.6 mg, 0.008 mmol), 3-methoxybenzoic acid (1.2 mg, 0.008 mmol) and toluene (0.40 mL) were added to a 1 dram vial. After stirring for 3 min, *N*,*N*-dimethylacrylamide (63 μL, 60 mg, 0.60 mmol) and 2,2-dimethyl-3-phenyl-propan-1-ol (**1w**, 33.0 mg, 0.20 mmol) were added successively. The vial was sealed completely by a screw cap with a Teflon septum. Then, the reaction mixture was stirred at 90 ˚C for 24 h. Purification of the reaction mixture by column chromatography (50% DCM in pentane) afforded 2,2-dimethyl-3-phenylpropanal (**10**) as a colorless oil (29.2 mg, 90% yield). **2,2-Dimethyl-3-phenylpropanal (10)**: ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.63 (s, 1H), 7.35 – 7.23 (m, 3H), 7.16 – 7.11 (m, 2H), 2.83 (s, 2H), 1.10 (s, 6H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 205.9, 137.0, 130.3, 128.2, 126.6, 47.0, 43.3, 21.5. This compound is known.[32]

8. Deuterium-Labeling Experiments



In a N_2-filled glovebox, $[Rh(cod)OMe]_2$ (1.9 mg, 0.004 mmol), Xantphos (4.6 mg, 0.008 mmol), 3-methoxybenzoic acid (1.2 mg, 0.008 mmol) and toluene-d_8 (0.40 mL) were added to a 1 dram vial. After stirring for 3 min, *N*,*N*-dimethylacrylamide (21 μL, 20 mg, 0.20 mmol) and 3-phenylpropanal-1-D (**D-11**, 98% D, 27.0 mg, 0.20 mmol) were added successively. The vial was sealed completely by a screw cap with a Teflon septum. Then, the reaction mixture was stirred at 90 ˚C for 24 h. The yield and deuterium incorportion were determined from analysis of the reaction mixture by ^{1}H NMR analysis using 1,3,5-trimethoxybenzene as an internal standard (96% NMR yield, 20 second relaxation delay). ***N*,*N*-Dimethylpropionamide**: ^{1}H NMR (400 MHz, toluene-d_8) δ 2.65 (s, 3H), 2.25 (s, 3H), 1.84 (q, J = 7.4 Hz, 1.44H), 1.08 (t, J = 7.4 Hz, 2.62H).



In a N_2-filled glovebox, $[Rh(cod)OMe]_2$ (1.9 mg, 0.004 mmol), Xantphos (4.6 mg, 0.008 mmol), 3-methoxybenzoic acid (1.2 mg, 0.008 mmol) and toluene-d_8 (0.40 mL) were added to a 1 dram vial. After stirring for 3 min, *N*,*N*-dimethylacrylamide (21 μL, 20 mg, 0.20 mmol) and 2-propanol-OD (**D-12**, 98% D, 16μL, 12.8 mg, 0.21 mmol) were added successively. The vial was sealed completely by a screw cap with a Teflon septum. Then, the reaction mixture was stirred at 90 ˚C for 24 h. The yield and deuterium incorportion were determined from analysis of the reaction mixture by ^{1}H NMR analysis using 1,3,5-trimethoxybenzene as an internal standard (87% NMR yield, 20 second relaxation delay). ***N*,*N*-Dimethylpropionamide**: ^{1}H NMR (400 MHz, toluene-d_8) δ 2.64 (s, 3H), 2.26 (s, 3H), 1.84 (q, J = 7.4 Hz, 1.72H), 1.06 (t, J = 7.4 Hz, 2.05H).

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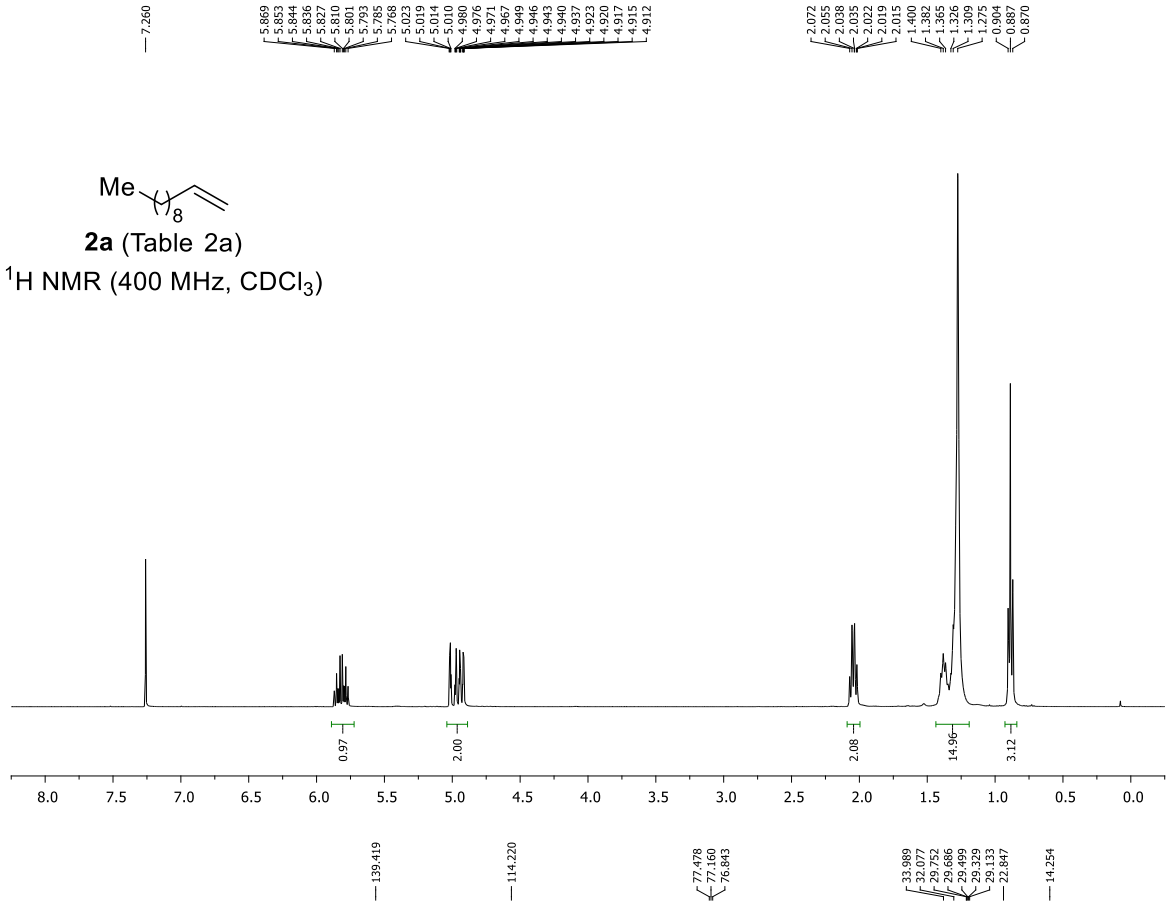
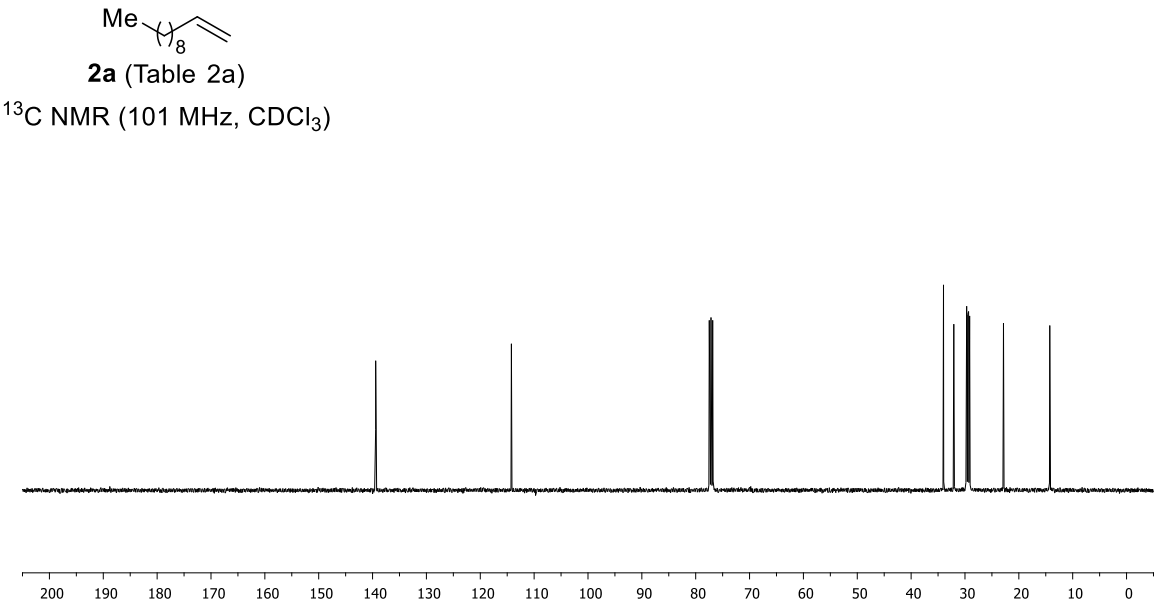
10. NMR spectra



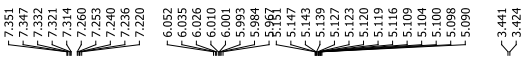
2a (Table 2a)

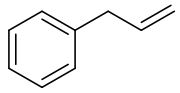
^{1}H NMR (400 MHz, $CDCl_3$)



2a (Table 2a)

^{13}C NMR (101 MHz, $CDCl_3$)





2b (Table 2a)

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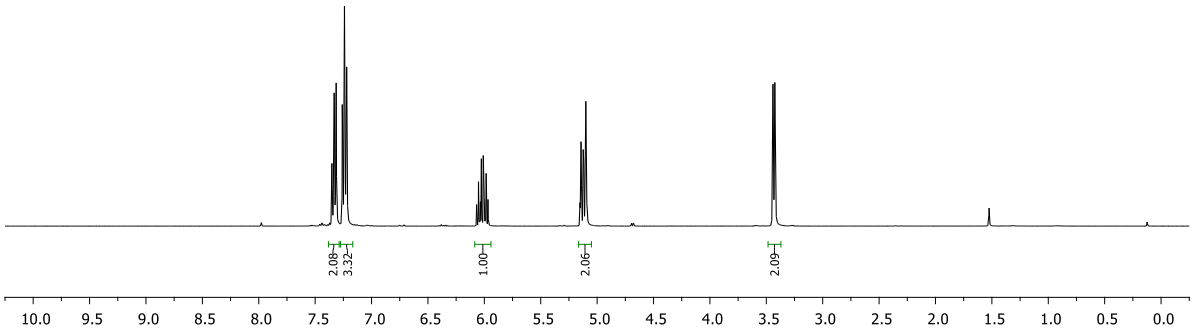
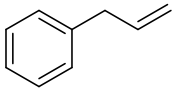
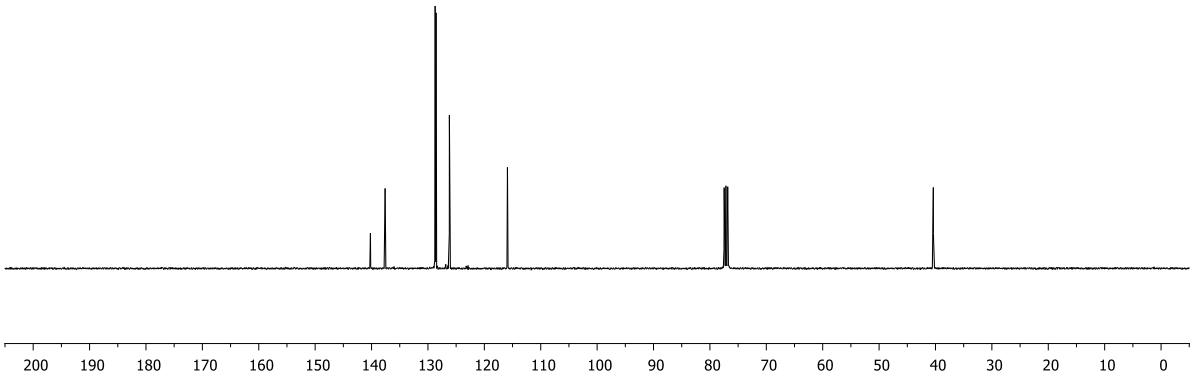
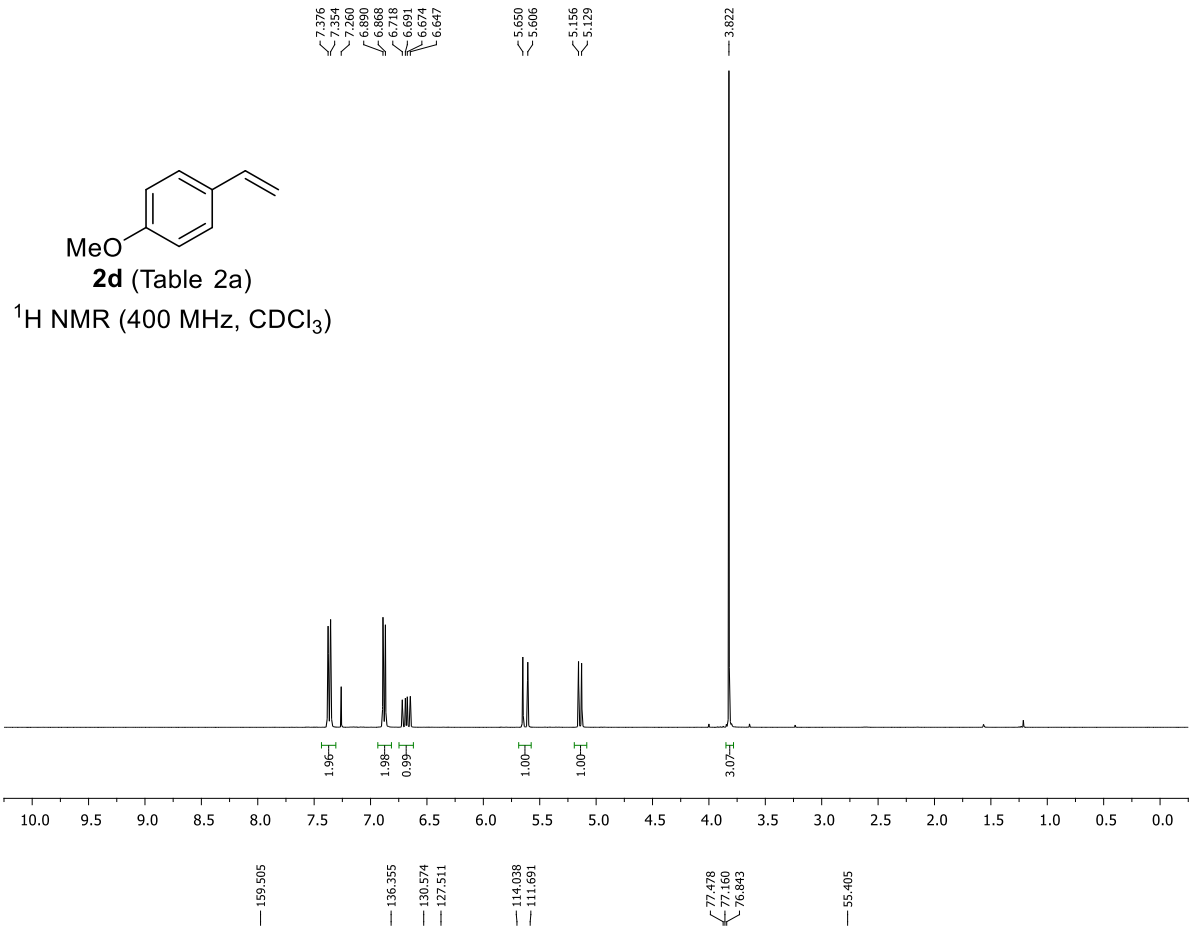




2b (Table 2a)

^{13}C NMR (101 MHz, $CDCl_3$)





2d (Table 2a)

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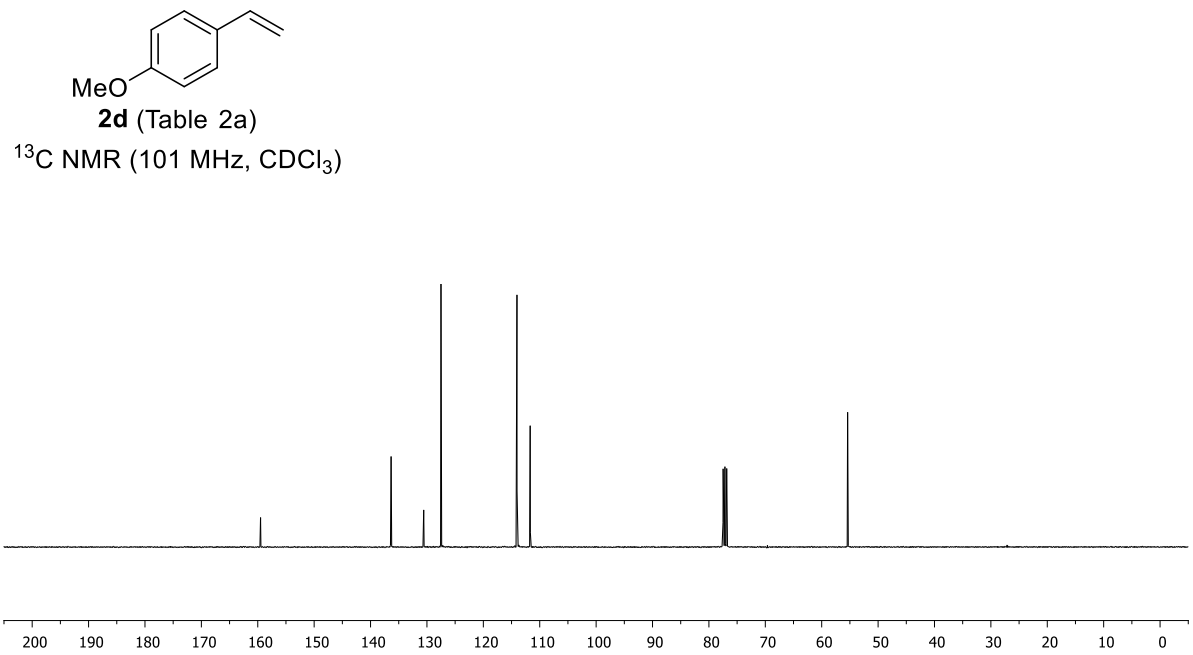
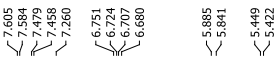
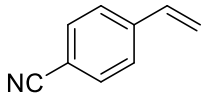


2d (Table 2a)

^{13}C NMR (101 MHz, $CDCl_3$)





2e (Table 2a)

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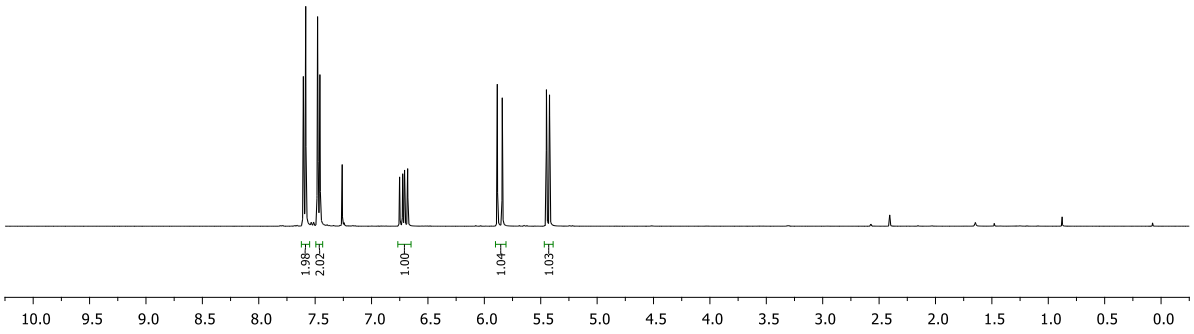
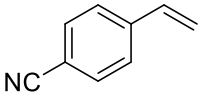
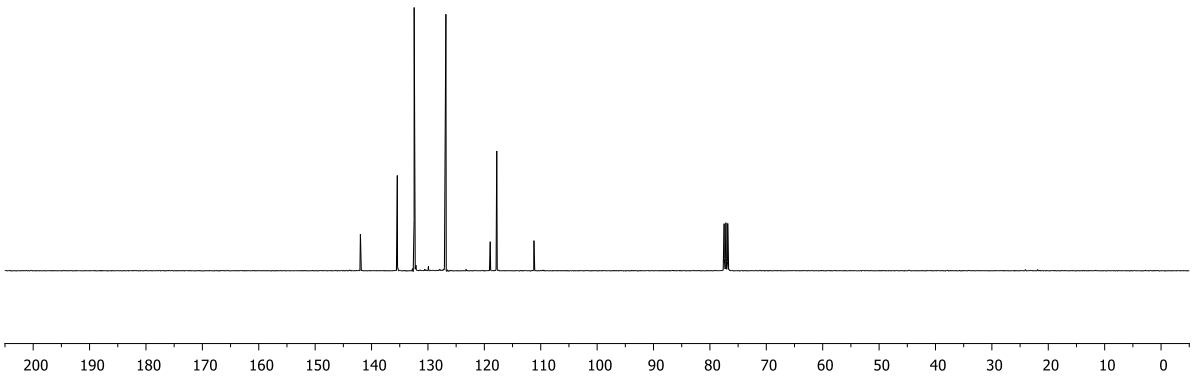
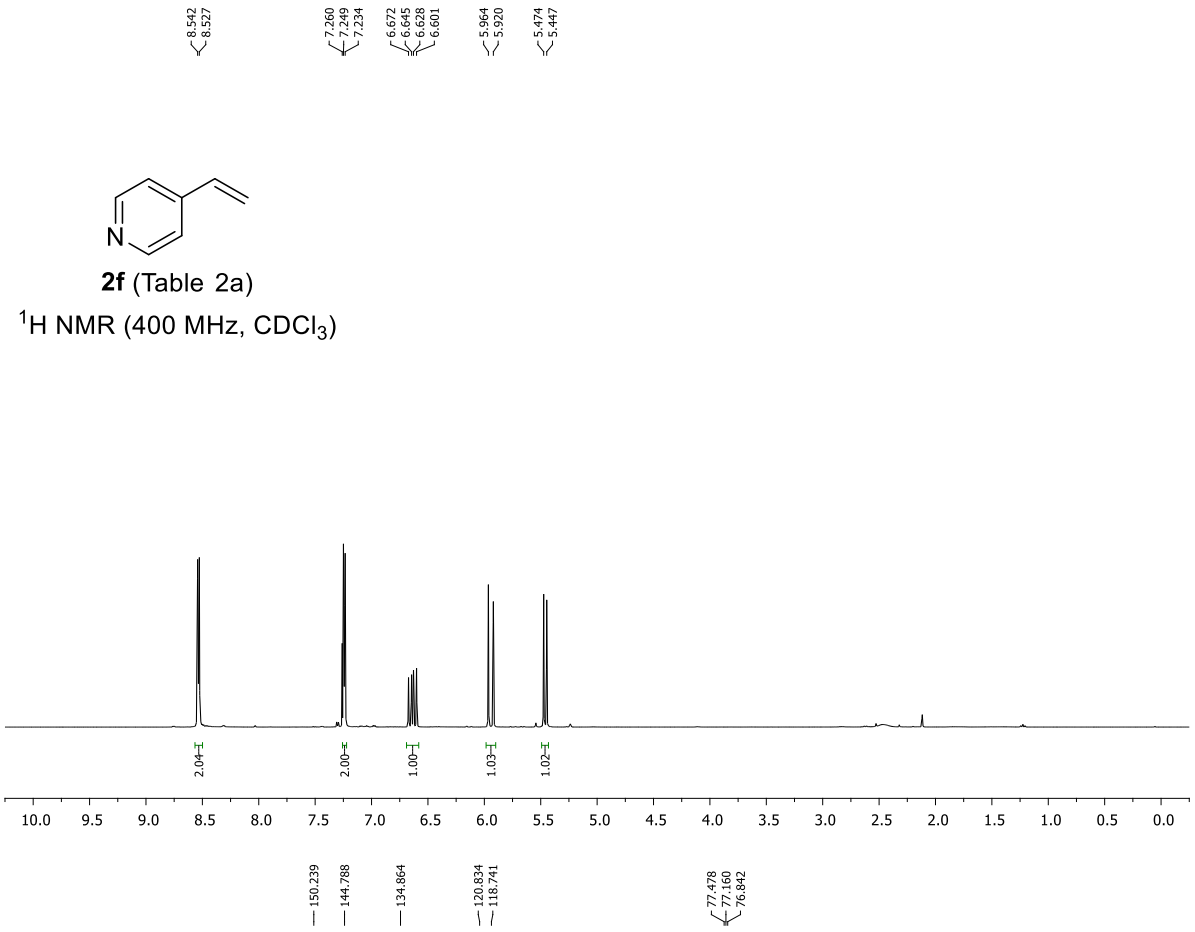


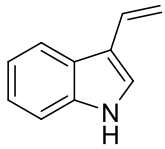


2e (Table 2a)

^{13}C NMR (101 MHz, $CDCl_3$)

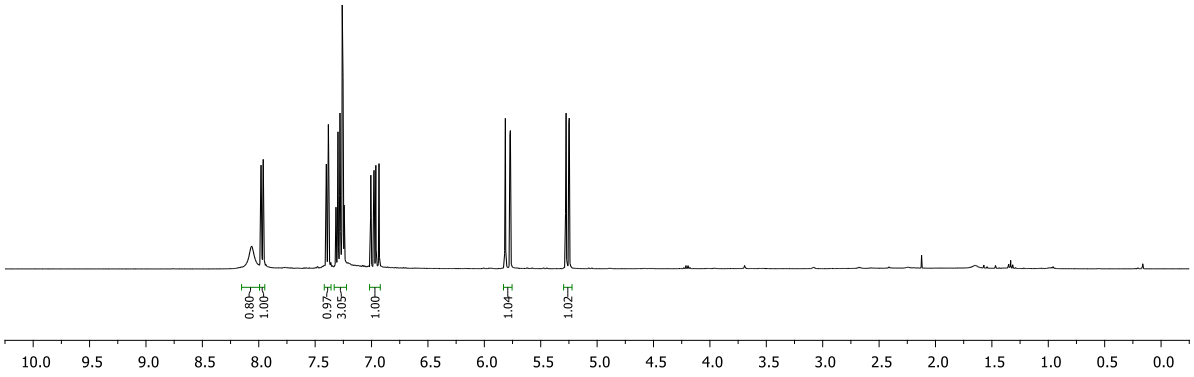


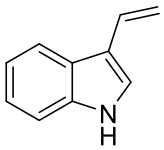

8.542
8.527
7.260
7.249
7.234
6.672
6.645
6.628
6.601
5.964
5.920
5.474
5.447
N
2f (Table 2a)
1H NMR (400 MHz, CDCl3)
2.04
2.00
1.00
1.03
1.02
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
150.239
144.788
134.864
120.834
118.741
77.478
77.160
76.842
N
2f (Table 2a)
13C NMR (101 MHz, CDCl3)
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0



2g (Table 2a)

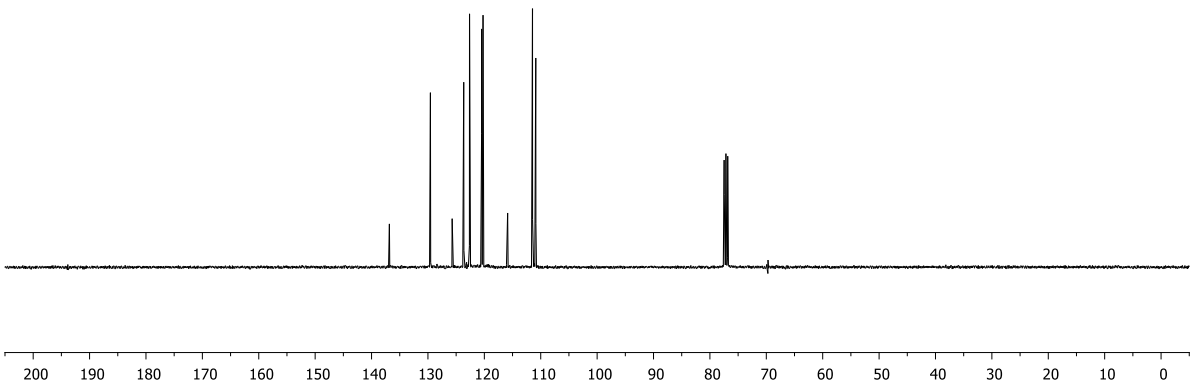
^{1}H NMR (400 MHz, $CDCl_3$)

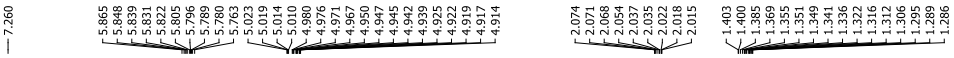


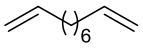


2g (Table 2a)

^{13}C NMR (101 MHz, $CDCl_3$)

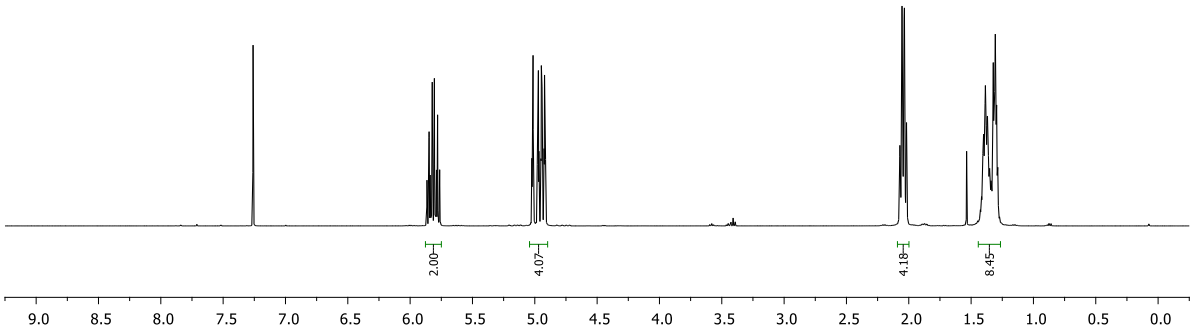


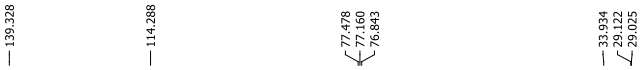


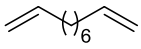


2h (Table 2a)

^{1}H NMR (400 MHz, $CDCl_3$)

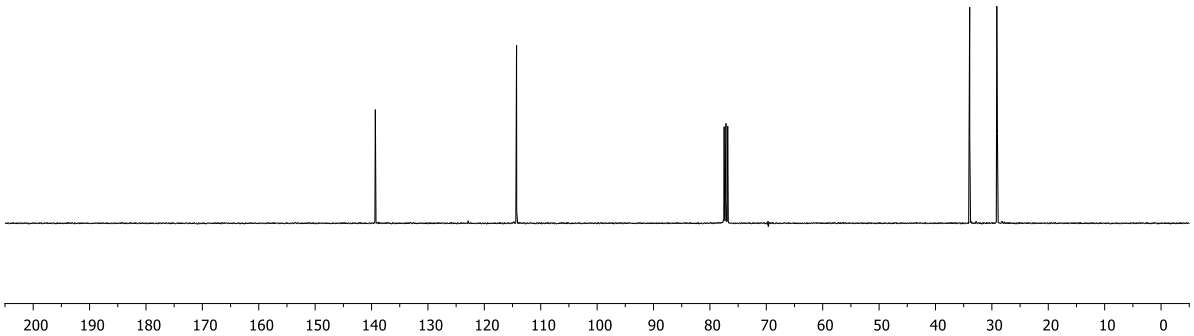


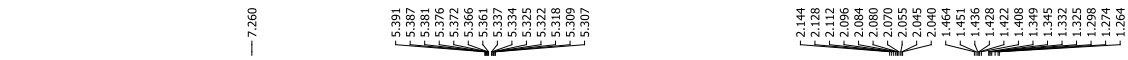


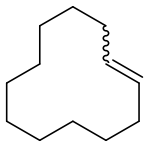


2h (Table 2a)

^{13}C NMR (101 MHz, $CDCl_3$)

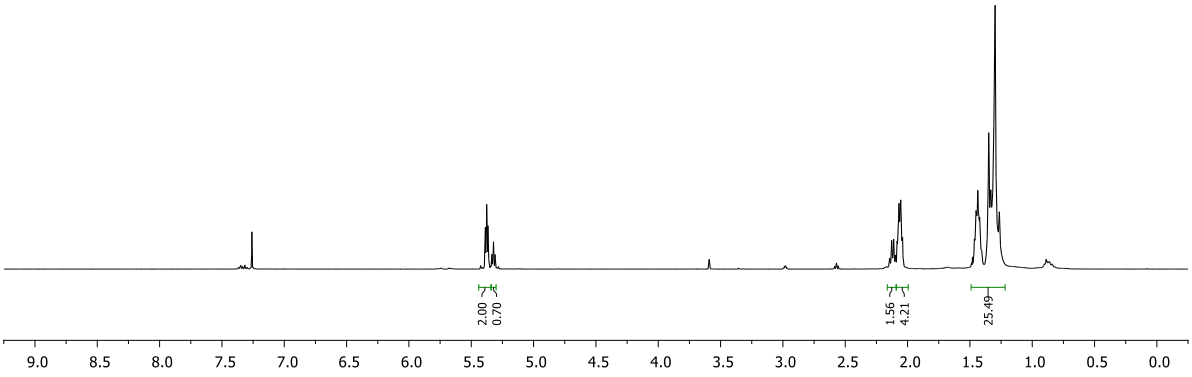


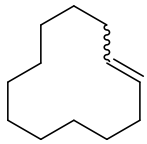




2i (Table 2a)

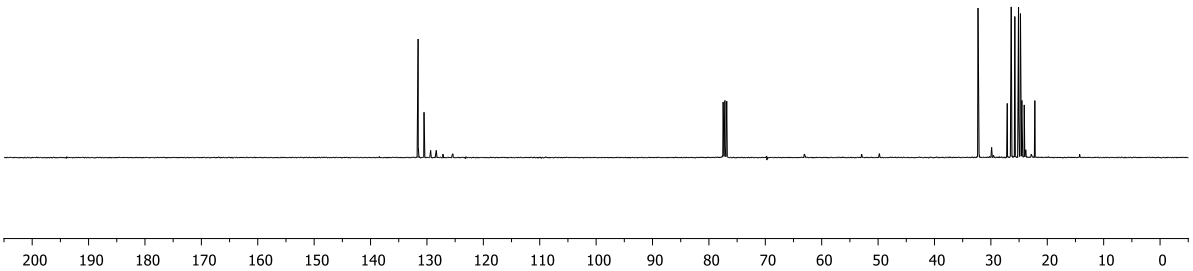
^{1}H NMR (400 MHz, $CDCl_3$)

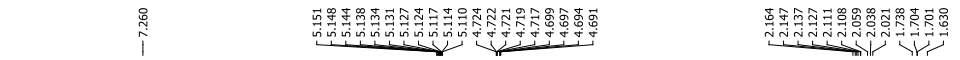


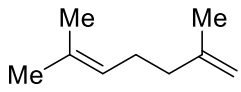


2i (Table 2a)

^{13}C NMR (101 MHz, $CDCl_3$)

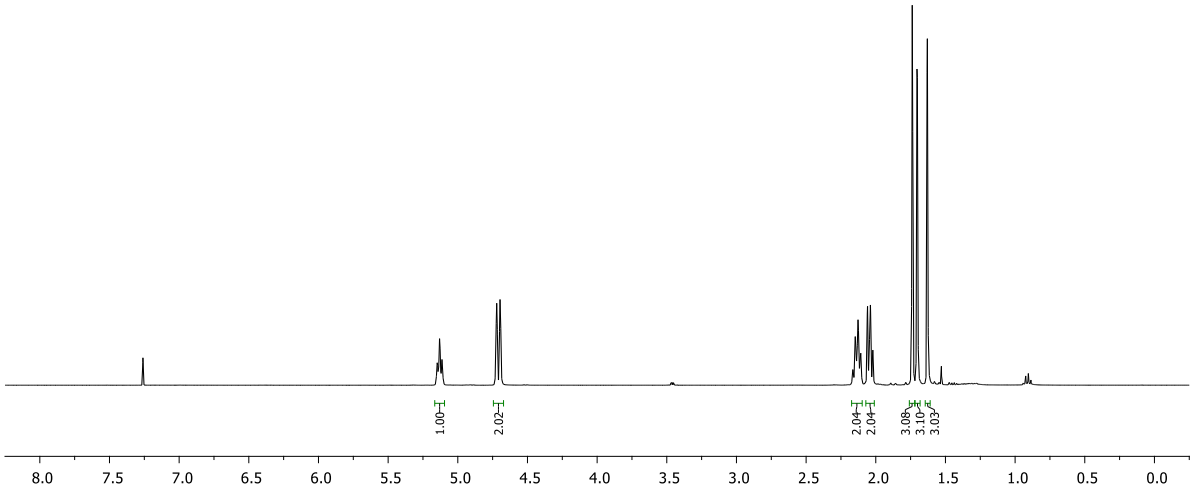


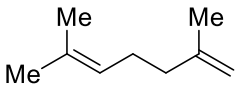




2j (Table 2a)

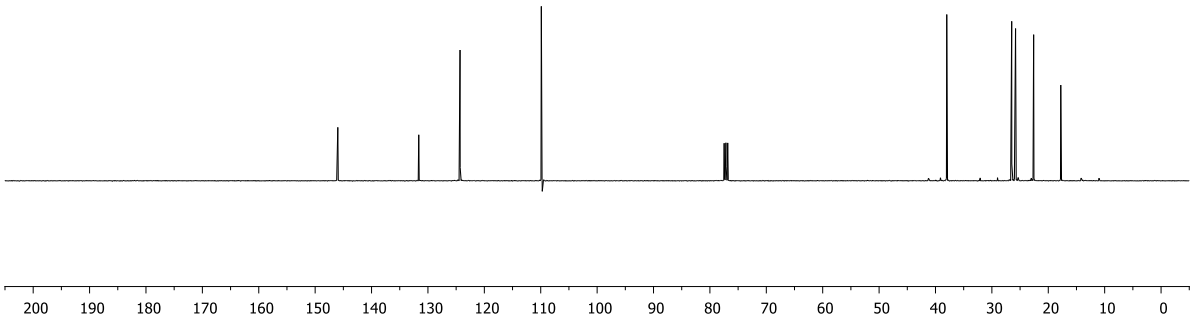
^{1}H NMR (400 MHz, $CDCl_3$)

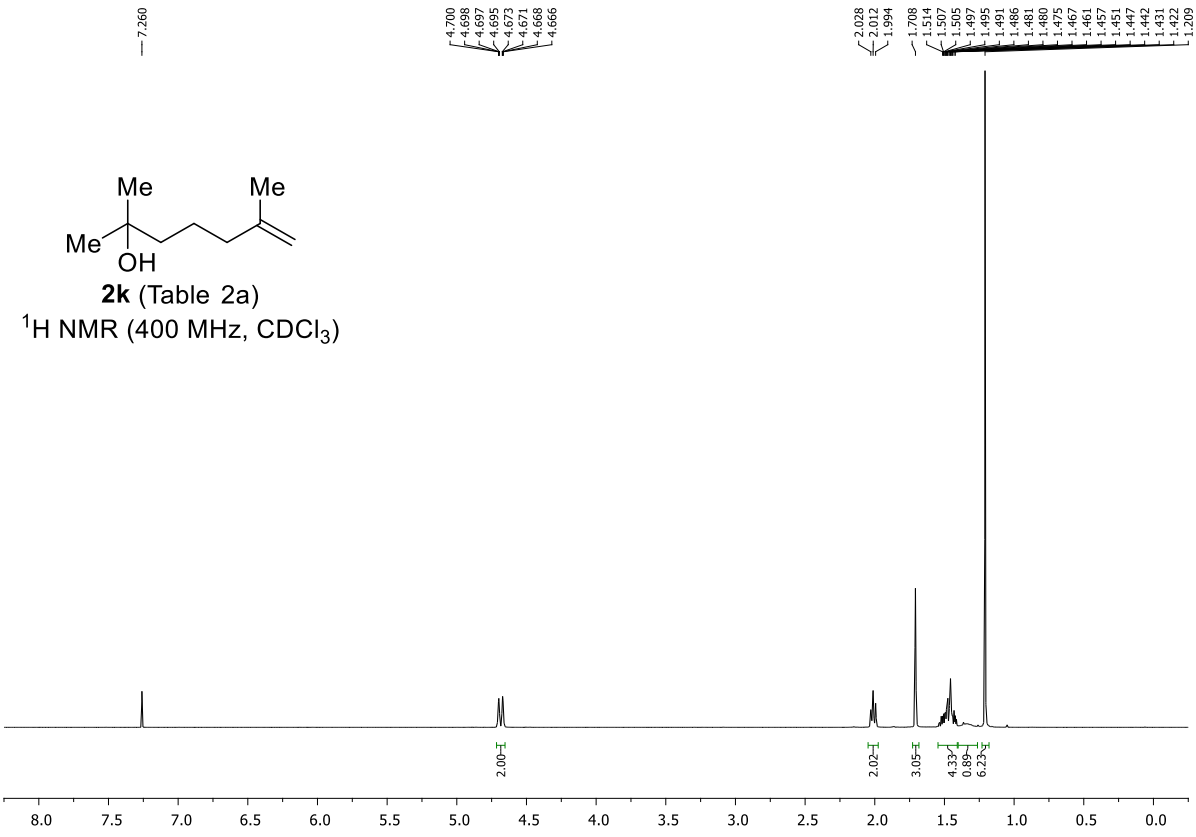




2j (Table 2a)

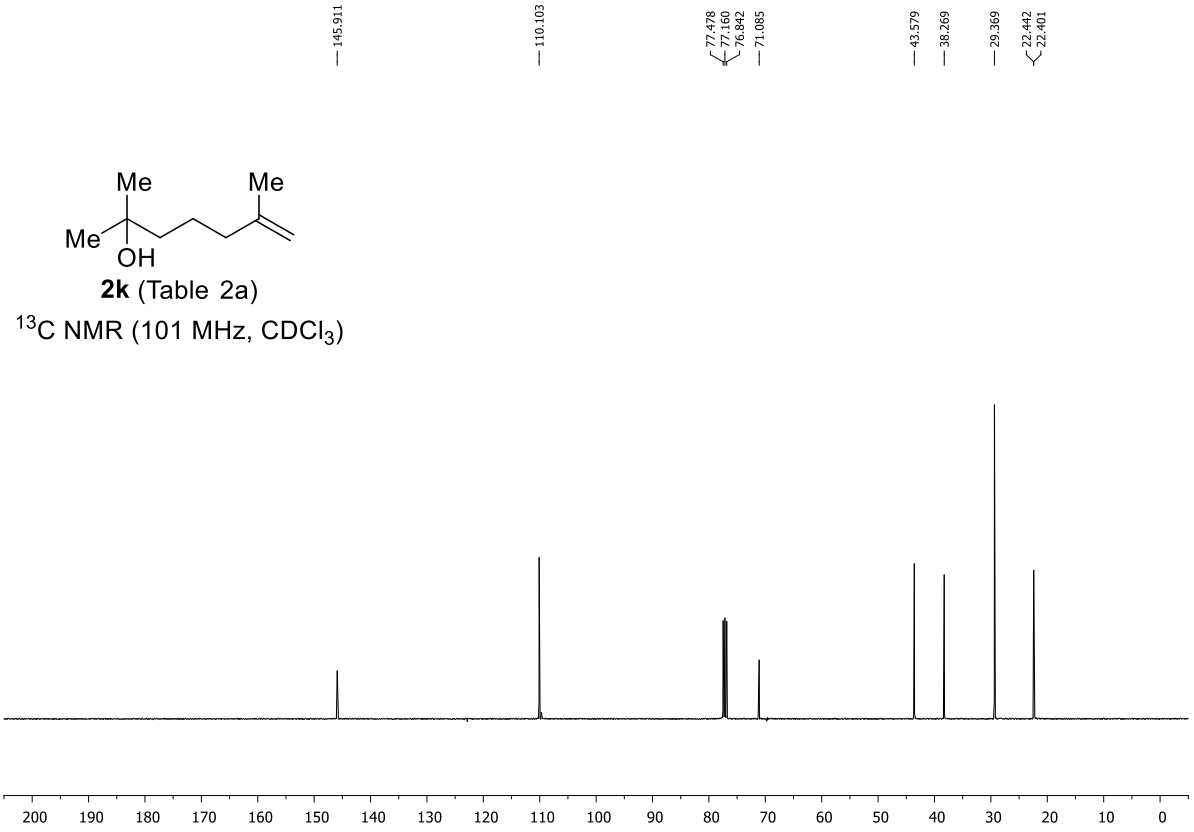
^{13}C NMR (101 MHz, $CDCl_3$)





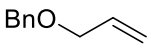
2k (Table 2a)

^{1}H NMR (400 MHz, $CDCl_3$)



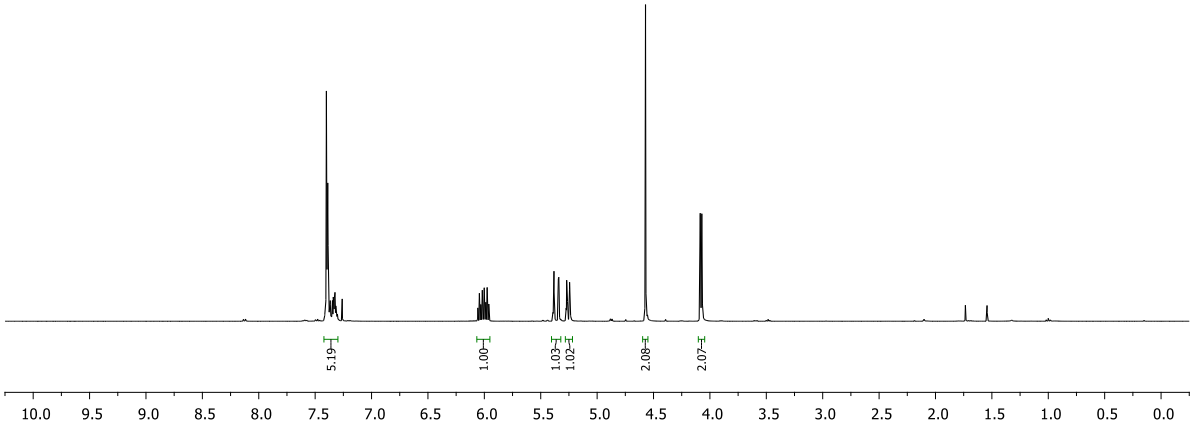
2k (Table 2a)

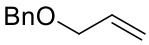
^{13}C NMR (101 MHz, $CDCl_3$)



2l (Table 2a)

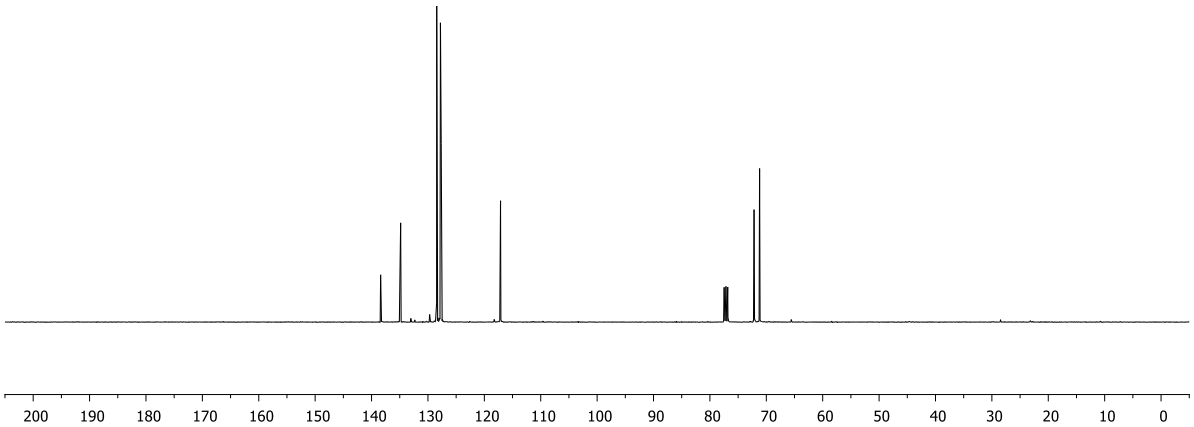
^{1}H NMR (400 MHz, $CDCl_3$)

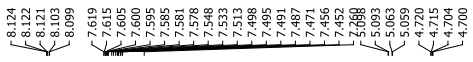


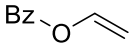


2l (Table 2a)

^{13}C NMR (101 MHz, $CDCl_3$)

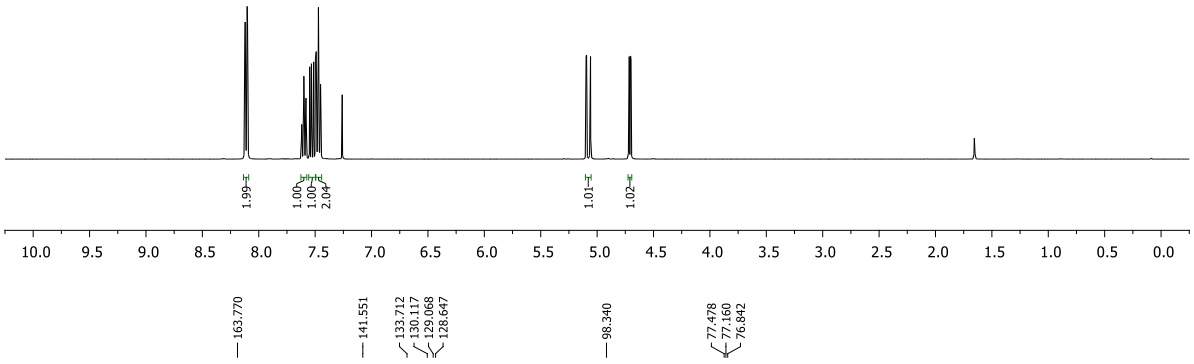


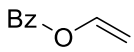




2m (Table 2a)

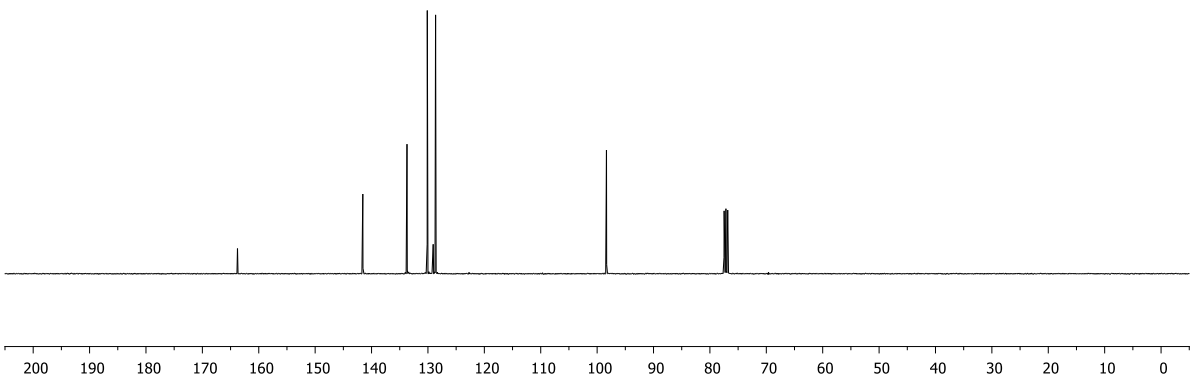
^{1}H NMR (400 MHz, $CDCl_3$)

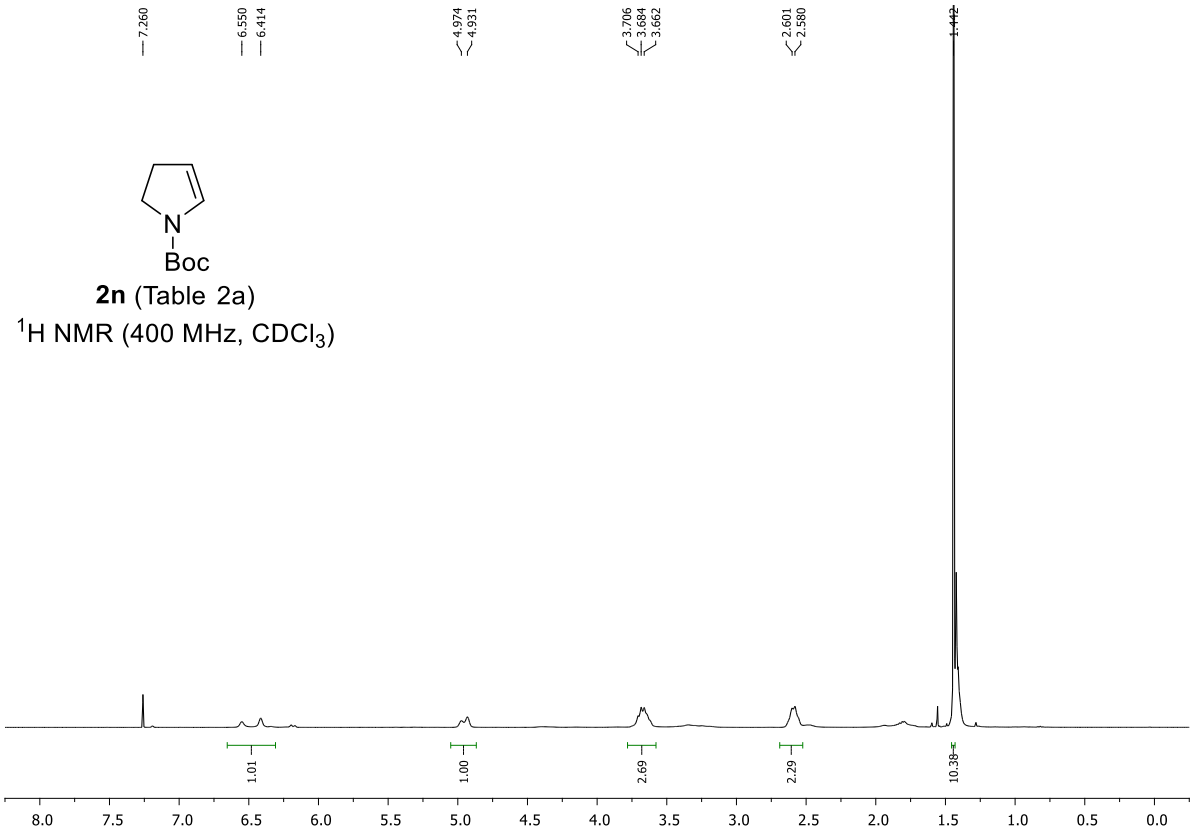




2m (Table 2a)

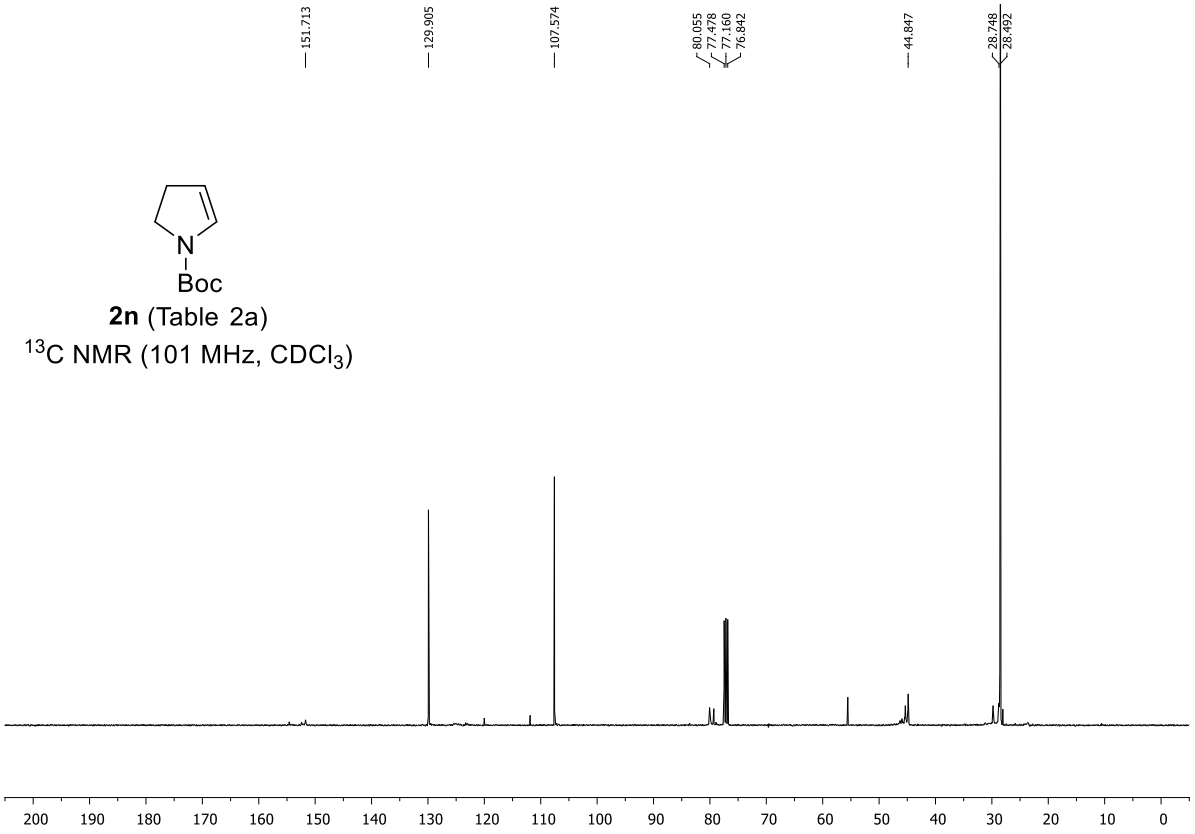
^{13}C NMR (101 MHz, $CDCl_3$)





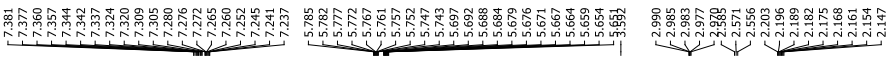
2n (Table 2a)

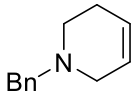
^{1}H NMR (400 MHz, $CDCl_3$)



2n (Table 2a)

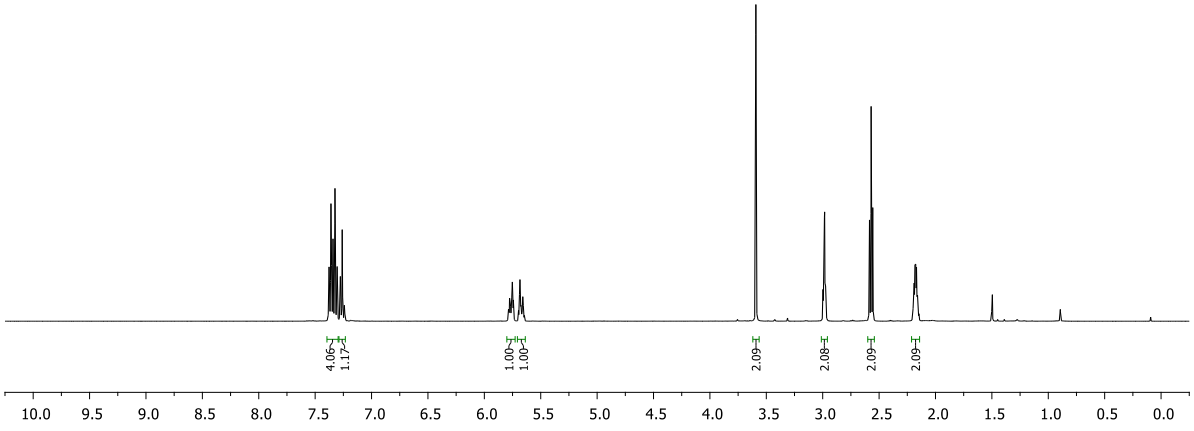
^{13}C NMR (101 MHz, $CDCl_3$)

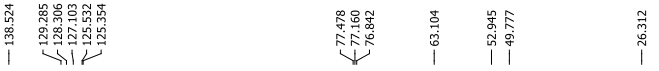


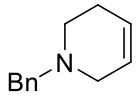


2o (Table 2a)

^{1}H NMR (400 MHz, $CDCl_3$)

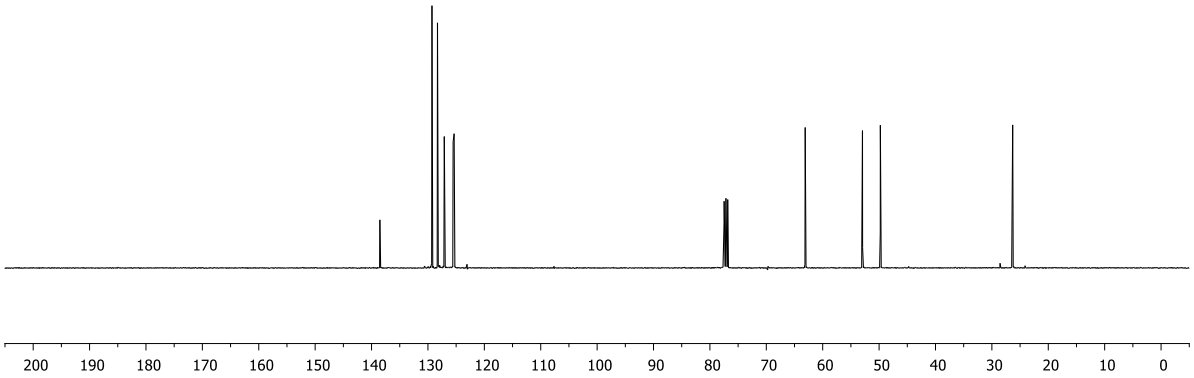


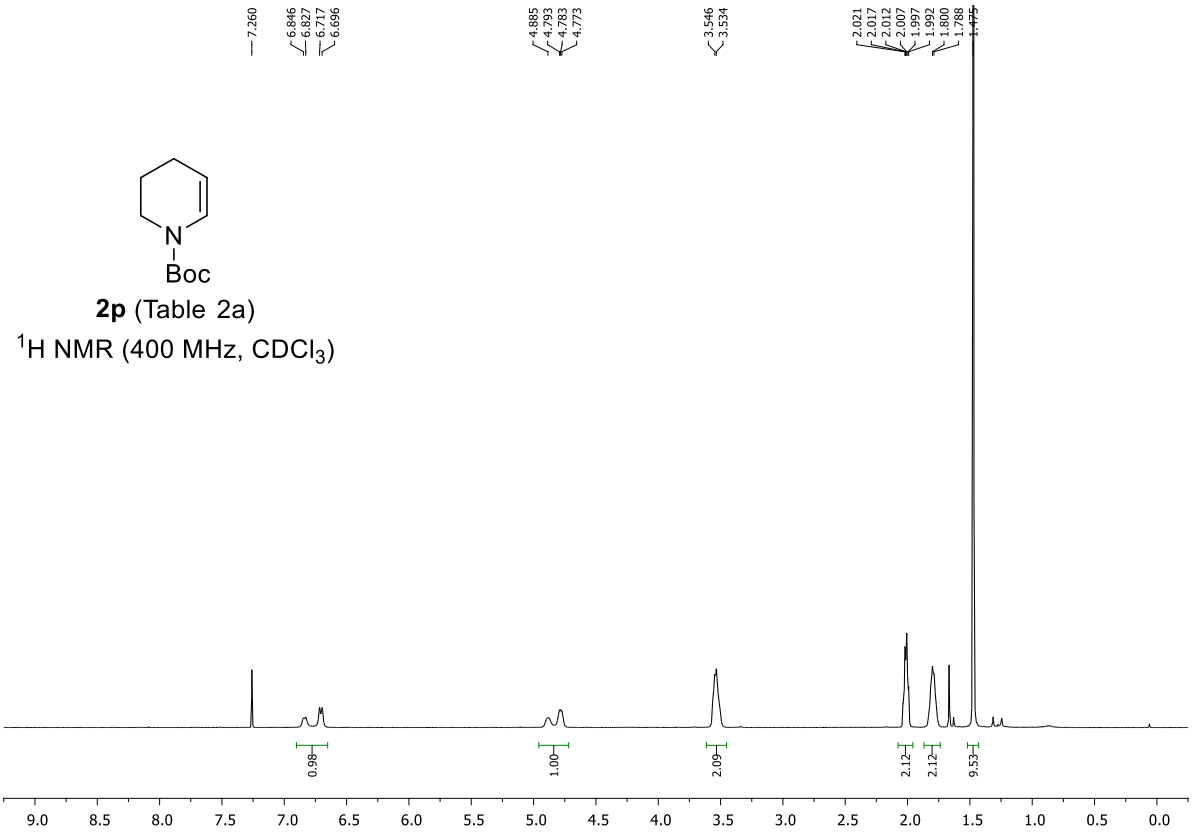




2o (Table 2a)

^{13}C NMR (101 MHz, $CDCl_3$)

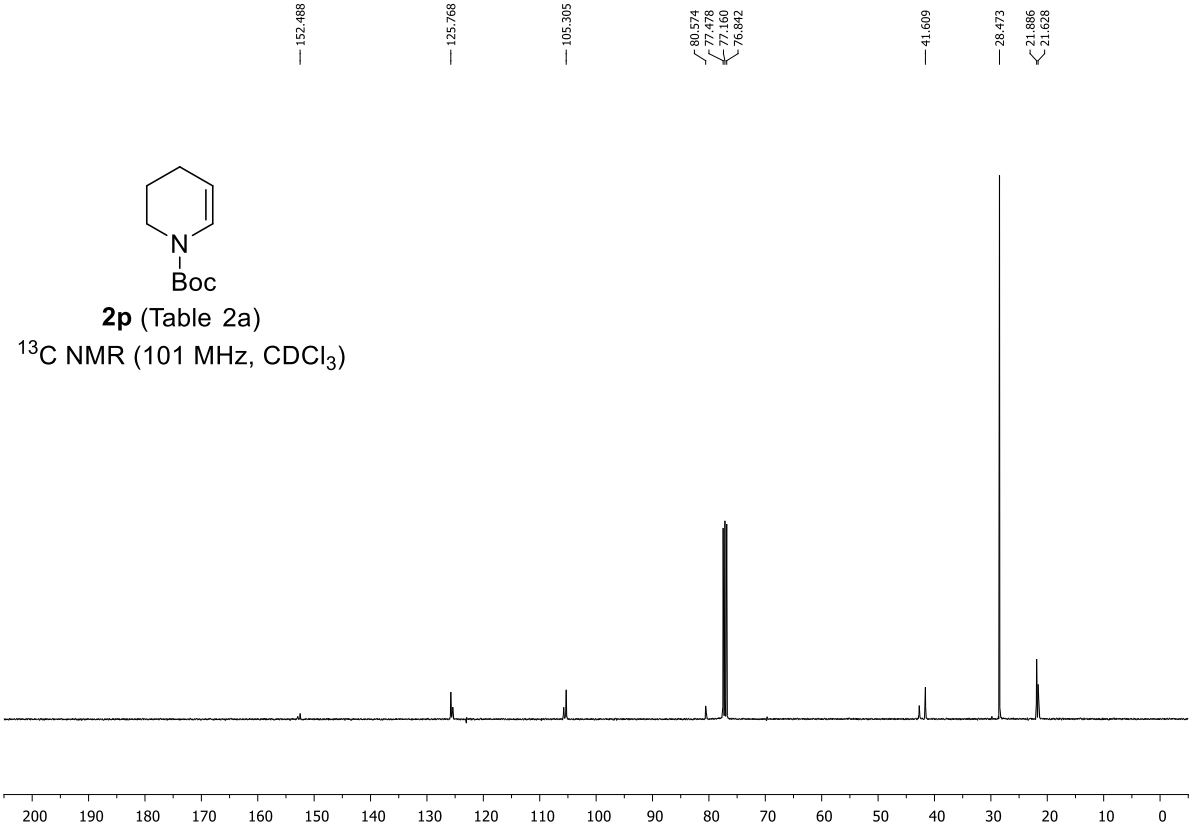




N
Boc

2p (Table 2a)

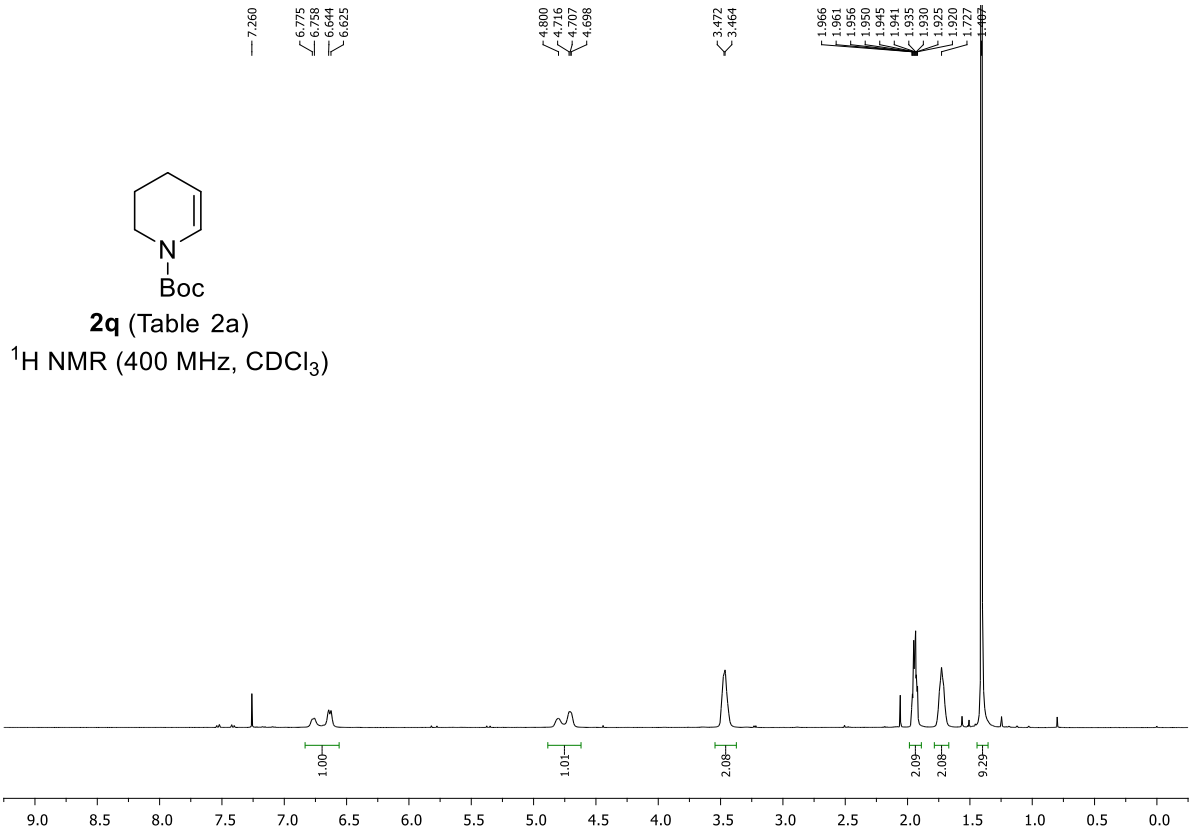
^{1}H NMR (400 MHz, $CDCl_3$)

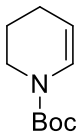


N
Boc

2p (Table 2a)

^{13}C NMR (101 MHz, $CDCl_3$)



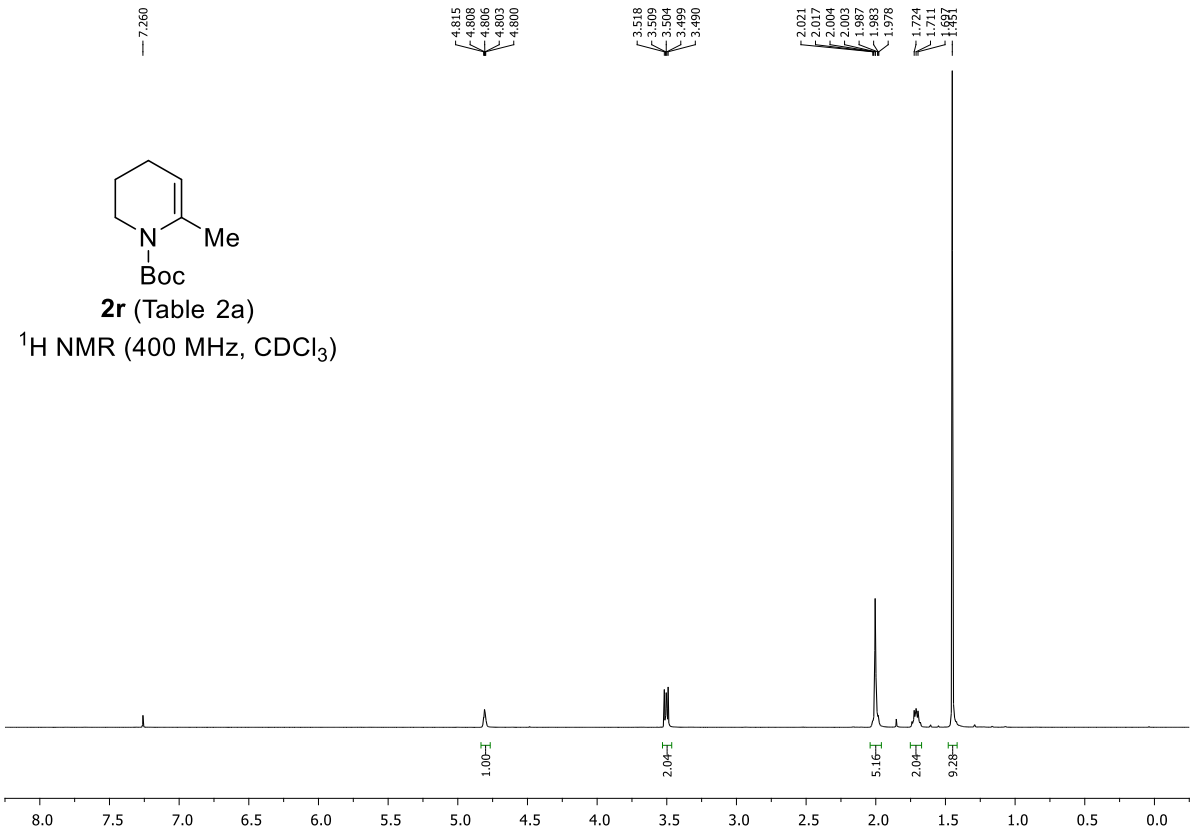


2q (Table 2a)

^{1}H NMR (400 MHz, $CDCl_3$)

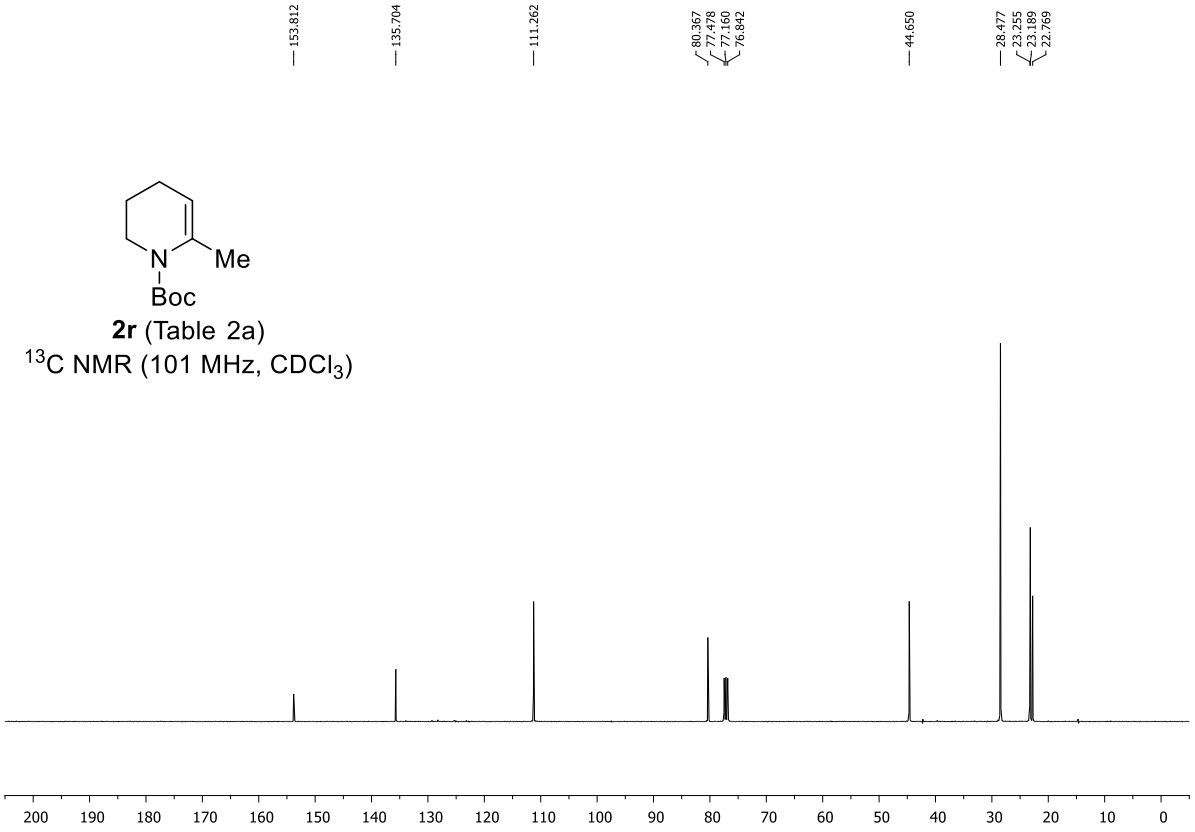
2q (Table 2a)

^{13}C NMR (101 MHz, $CDCl_3$)



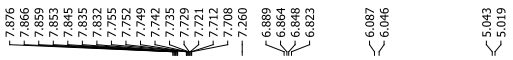
2r (Table 2a)

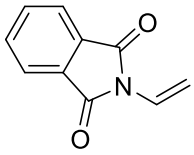
^{1}H NMR (400 MHz, $CDCl_3$)



2r (Table 2a)

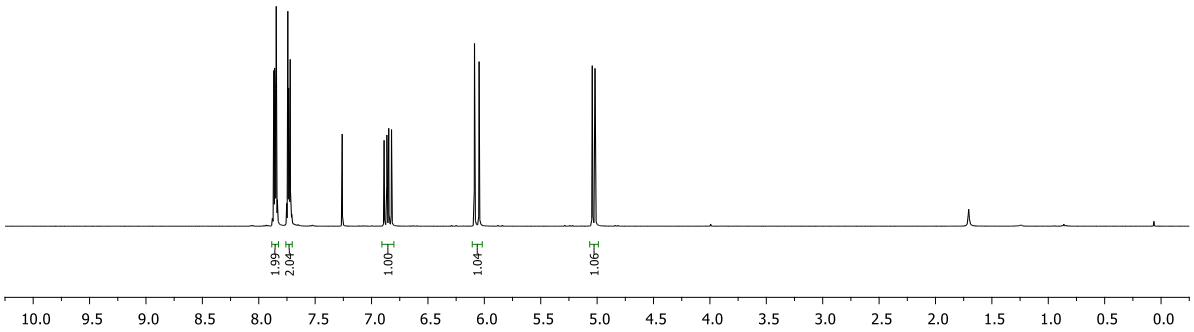
^{13}C NMR (101 MHz, $CDCl_3$)

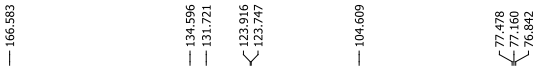


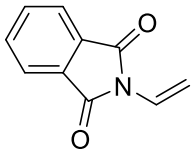


2s (Table 2a)

^{1}H NMR (400 MHz, $CDCl_3$)

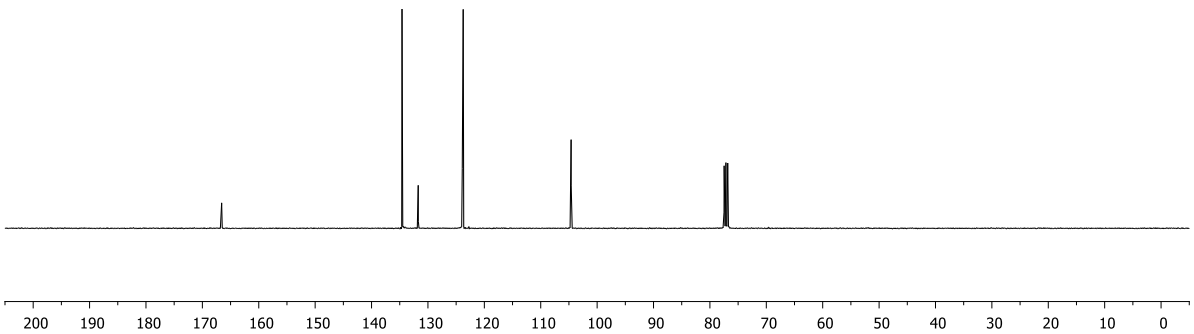


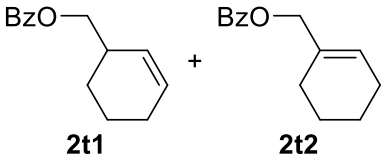




2s (Table 2a)

^{13}C NMR (101 MHz, $CDCl_3$)

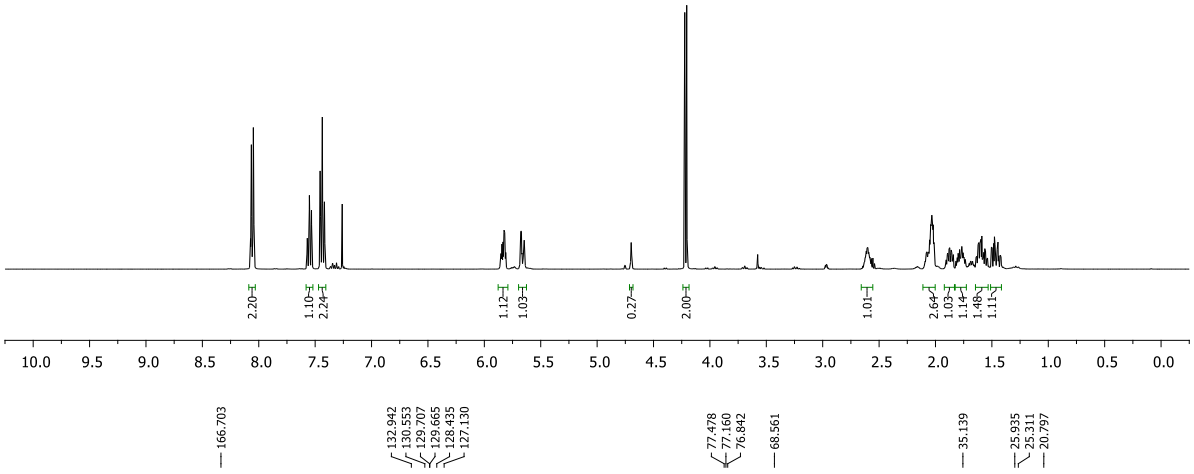


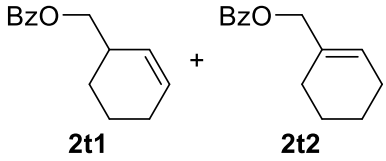


2t1 **2t2**

(Table 2a)

^{1}H NMR (400 MHz, $CDCl_3$)

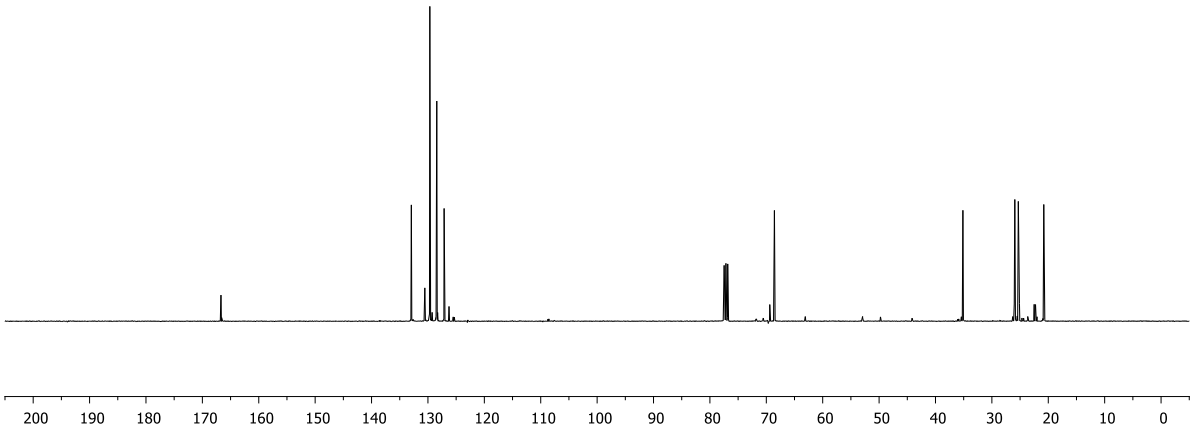


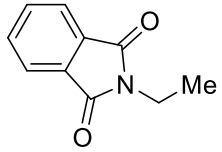


2t1 **2t2**

(Table 2a)

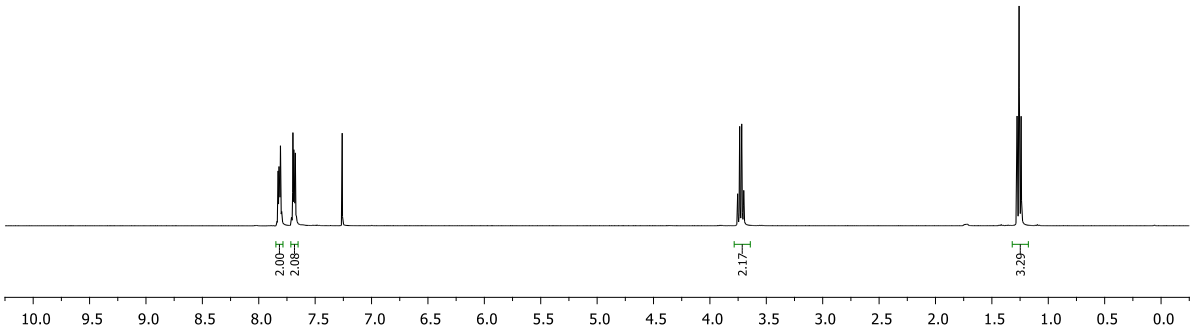
^{13}C NMR (101 MHz, $CDCl_3$)

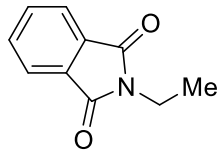




3s (Table 2a)

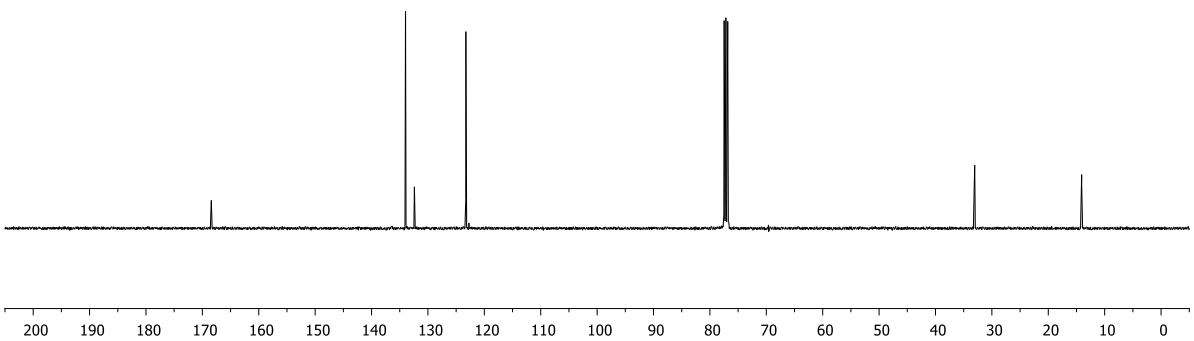
^{1}H NMR (400 MHz, $CDCl_3$)

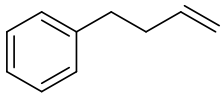




3s (Table 2a)

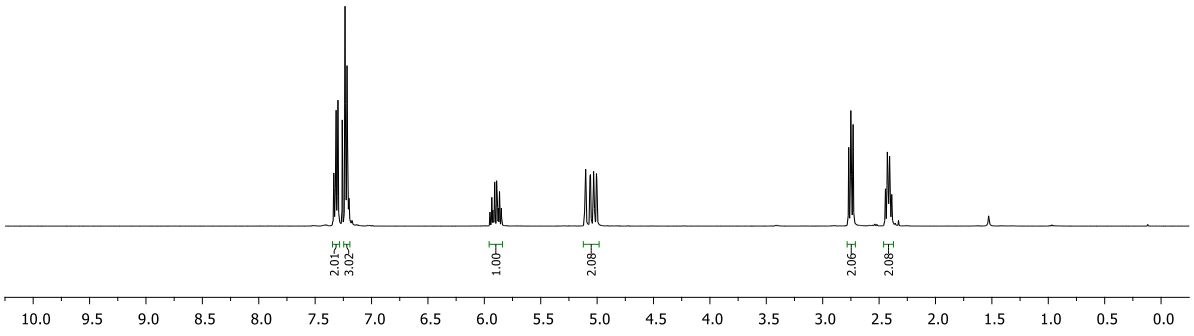
^{13}C NMR (101 MHz, $CDCl_3$)

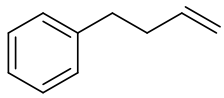




2u (Table 2b)

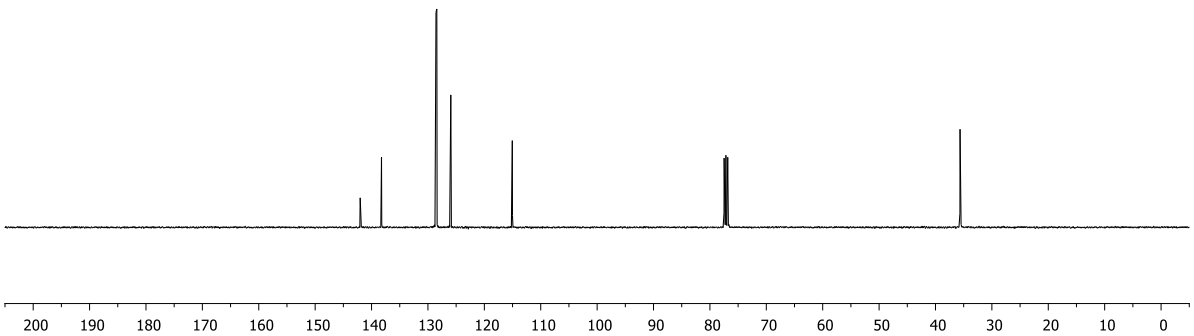
^{1}H NMR (400 MHz, $CDCl_3$)

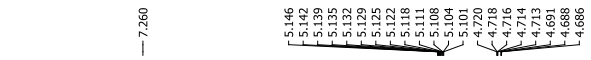


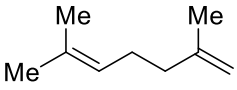


2u (Table 2b)

^{13}C NMR (101 MHz, $CDCl_3$)

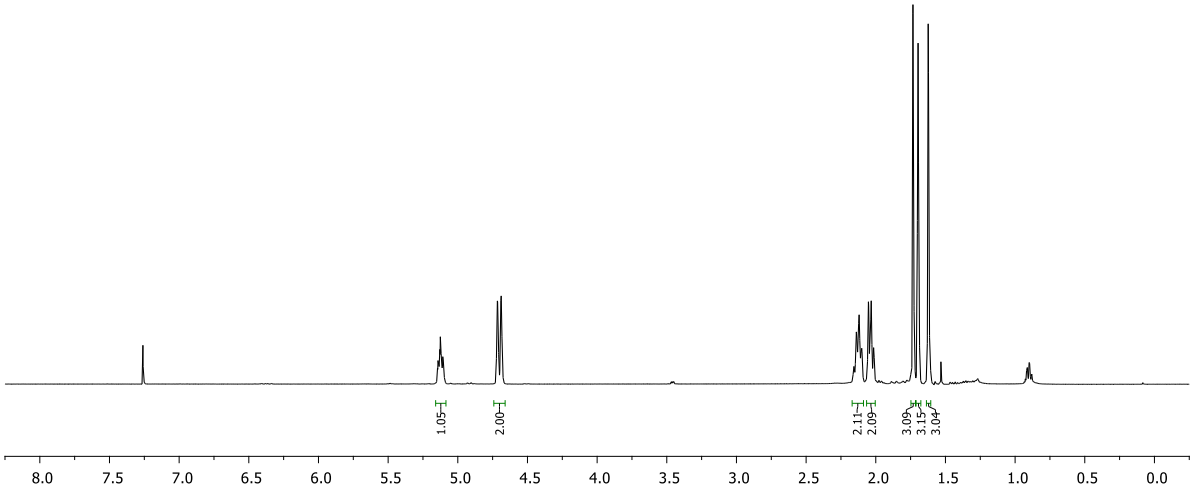


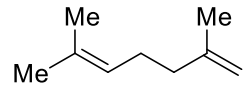




2j (Table 2b)

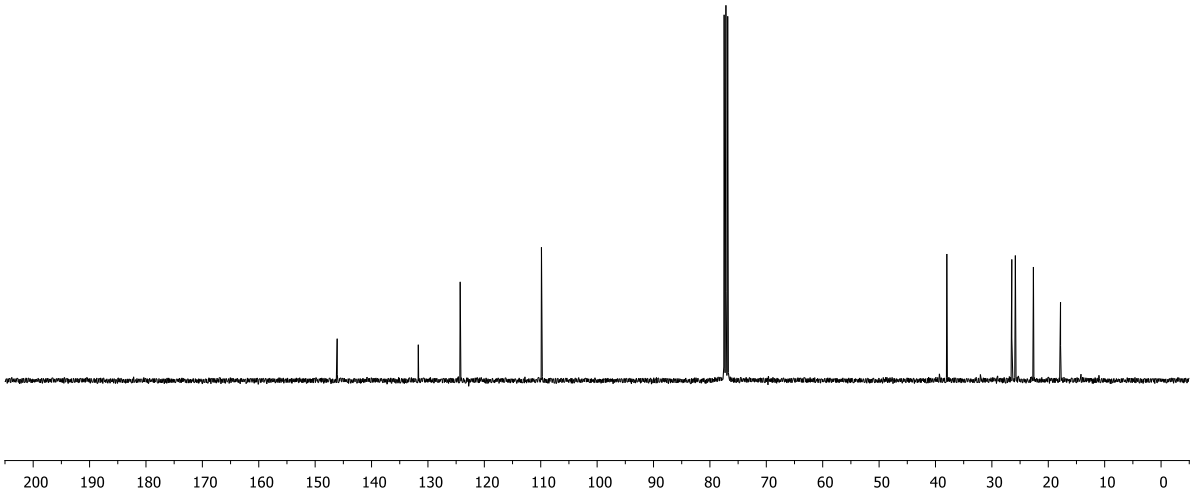
^{1}H NMR (400 MHz, $CDCl_3$)

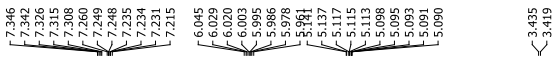


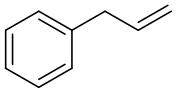


2j (Table 2b)

^{13}C NMR (101 MHz, $CDCl_3$)

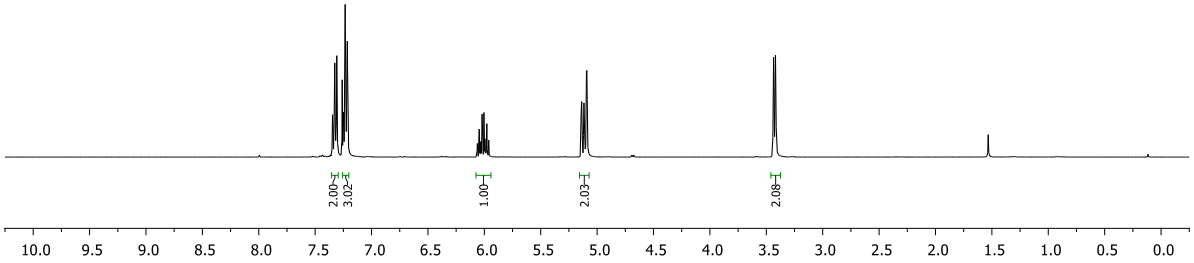


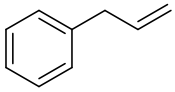




2b (Table 2c)

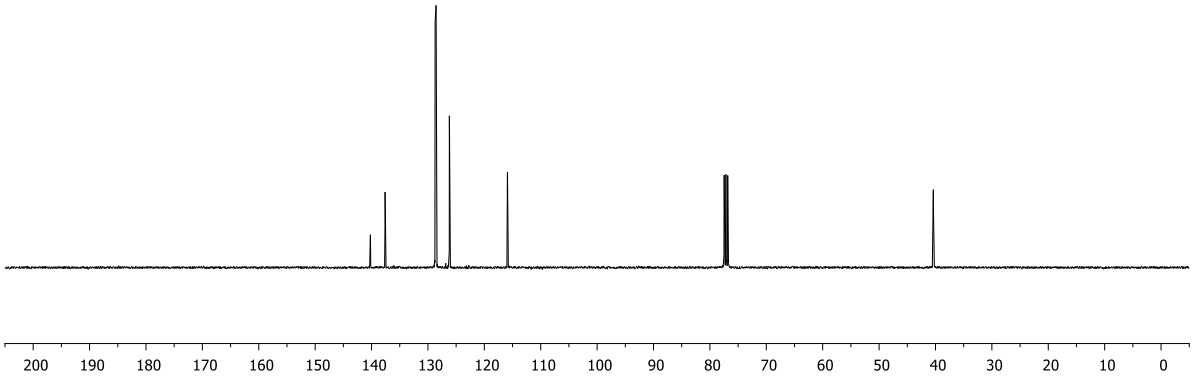
^{1}H NMR (400 MHz, $CDCl_3$)

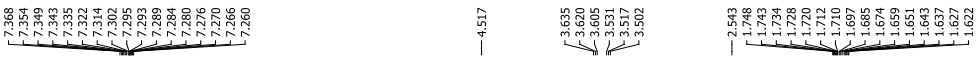


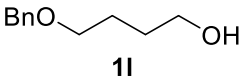


2b (Table 2c)

^{13}C NMR (101 MHz, $CDCl_3$)

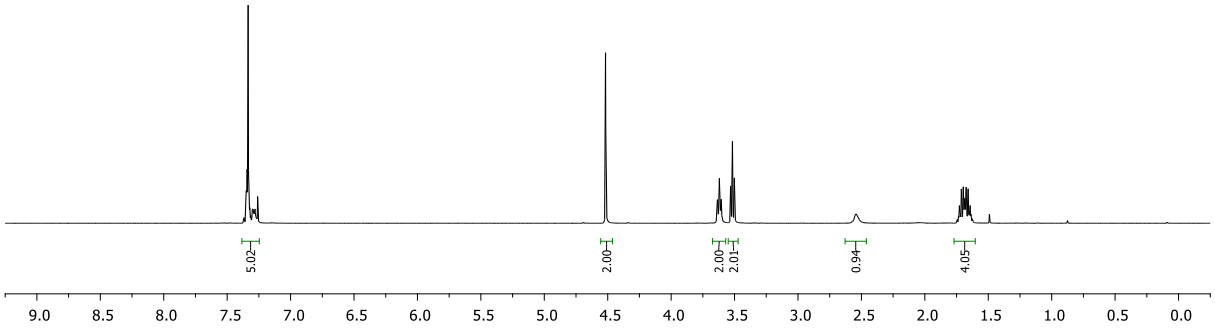


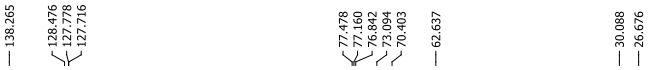


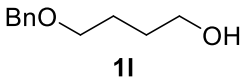


1l

^{1}H NMR (400 MHz, $CDCl_3$)

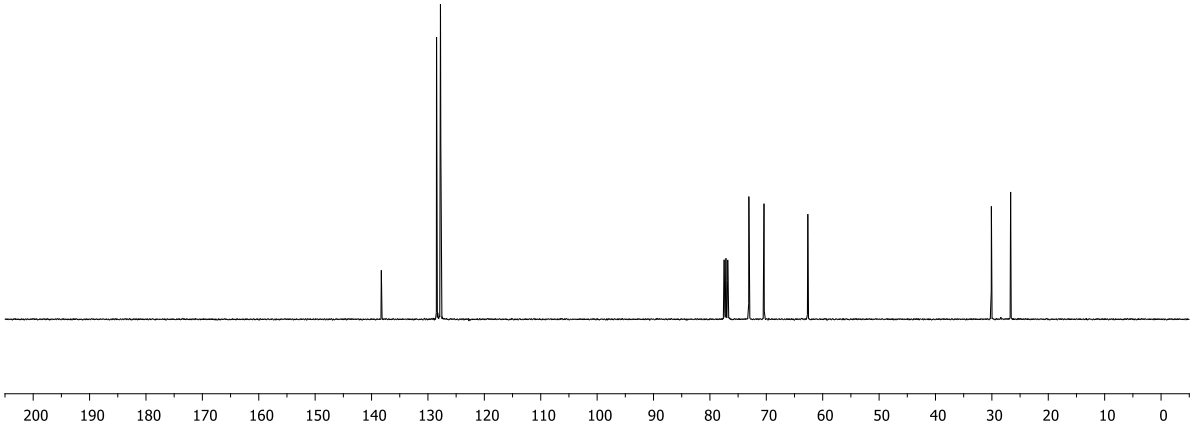


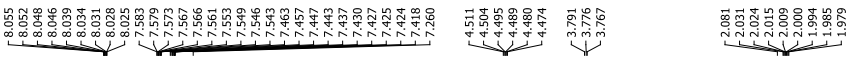


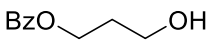


1l

^{13}C NMR (101 MHz, $CDCl_3$)

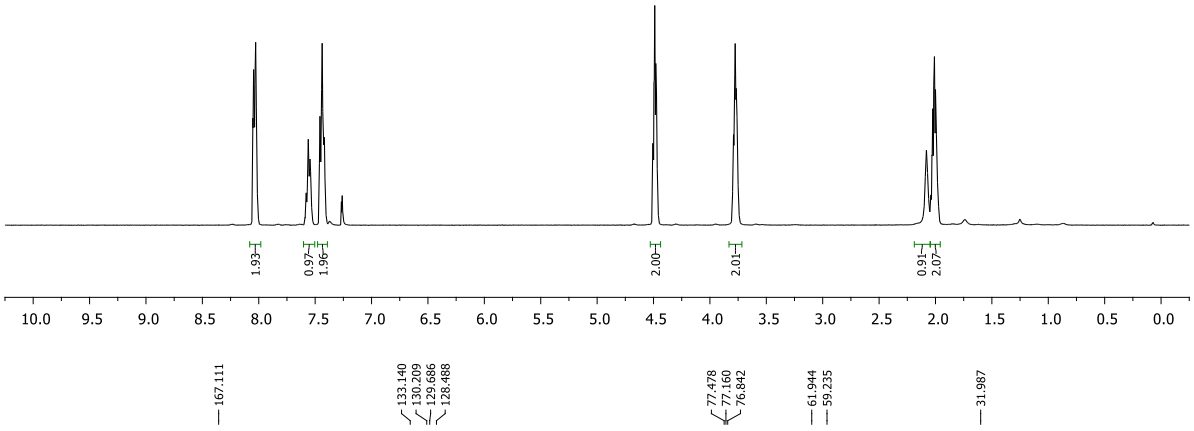


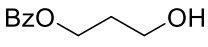




1m

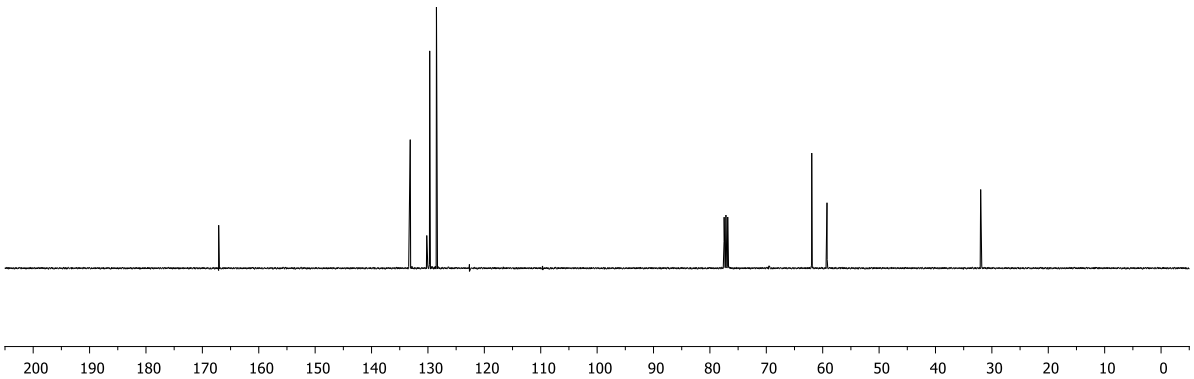
^{1}H NMR (400 MHz, $CDCl_3$)

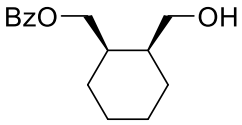




1m

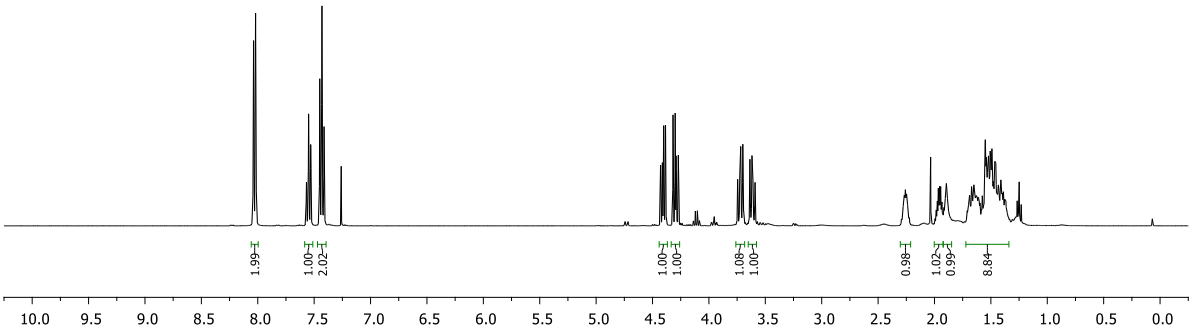
^{13}C NMR (101 MHz, $CDCl_3$)

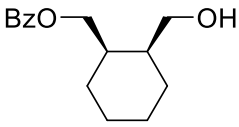




***cis*-1t**

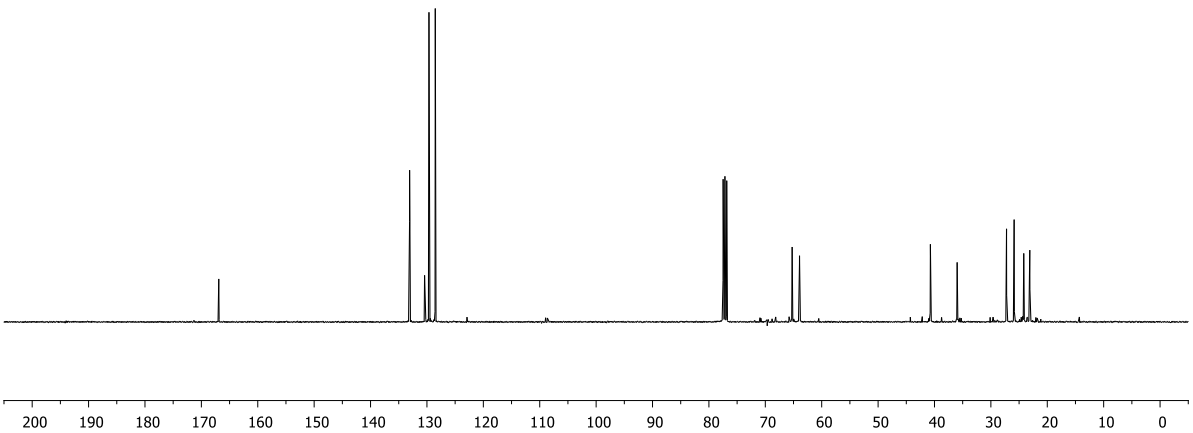
^{1}H NMR (400 MHz, $CDCl_3$)

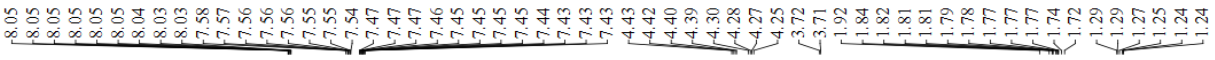


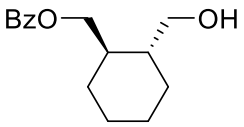


***cis*-1t**

^{13}C NMR (101 MHz, $CDCl_3$)

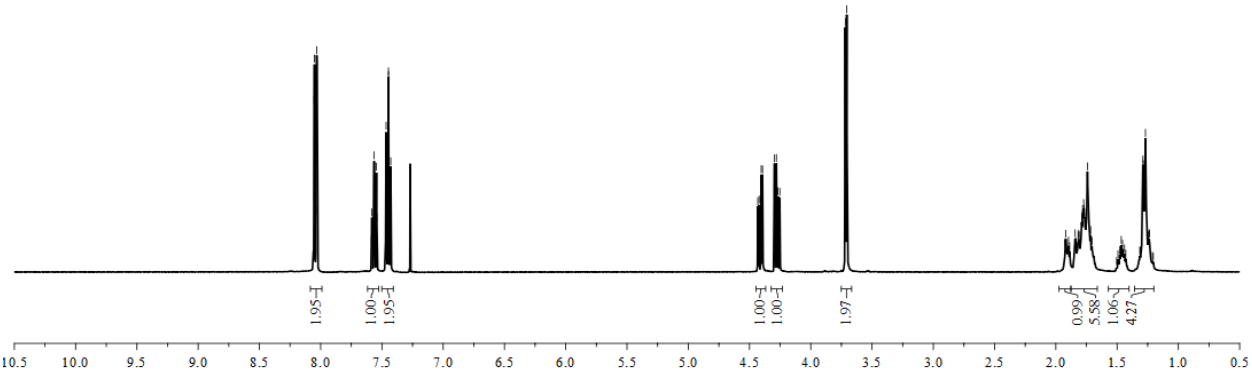


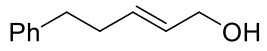




***trans*-1t**

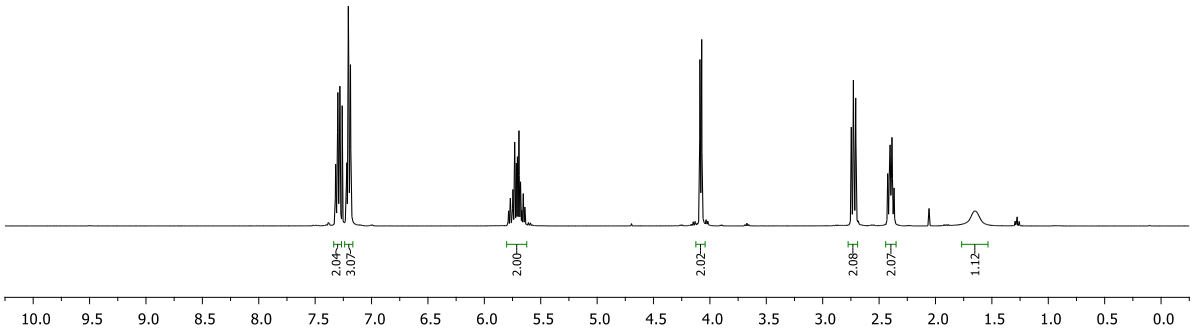
^{1}H NMR (400 MHz, $CDCl_3$)

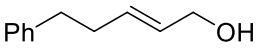




4b

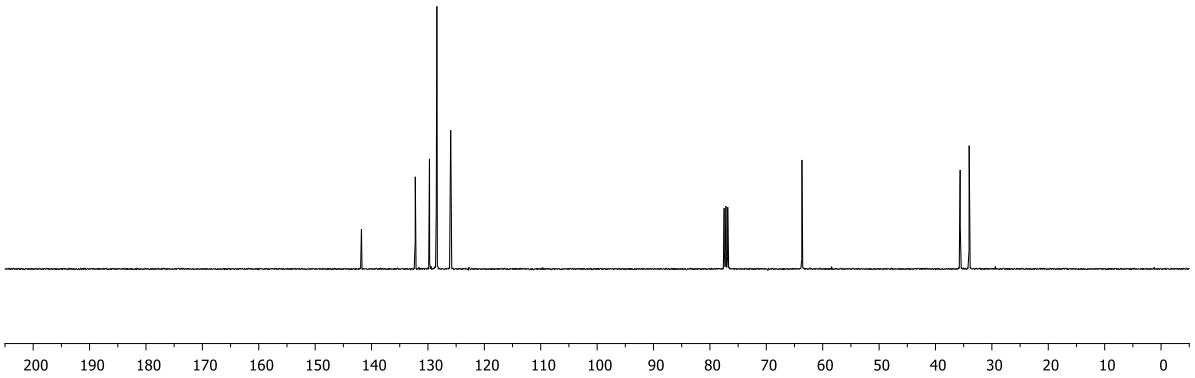
^{1}H NMR (400 MHz, $CDCl_3$)

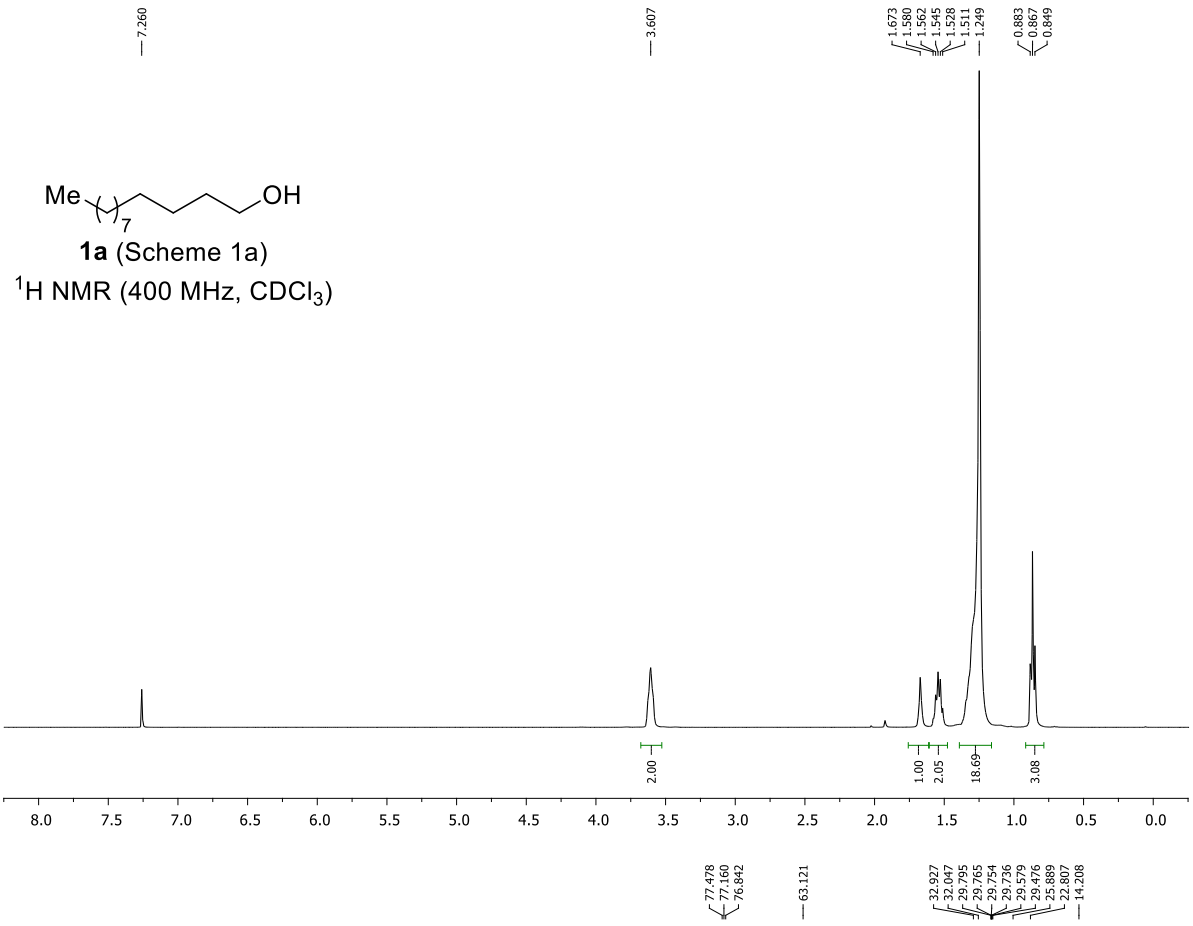




4b

^{13}C NMR (101 MHz, $CDCl_3$)





Me$_7$OH

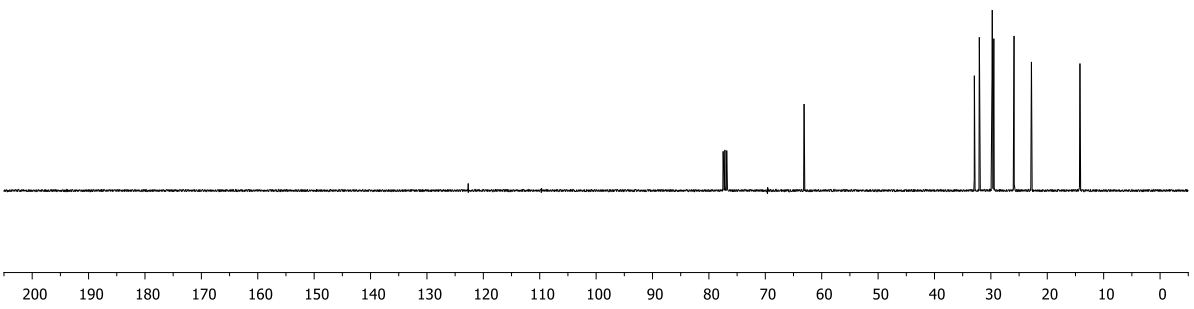
1a (Scheme 1a)

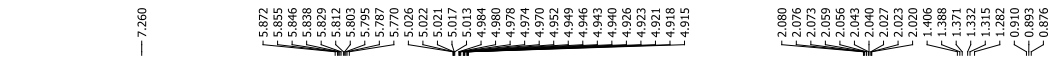
^{1}H NMR (400 MHz, $CDCl_3$)

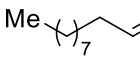
Me$_7$OH

1a (Scheme 1a)

^{13}C NMR (101 MHz, $CDCl_3$)

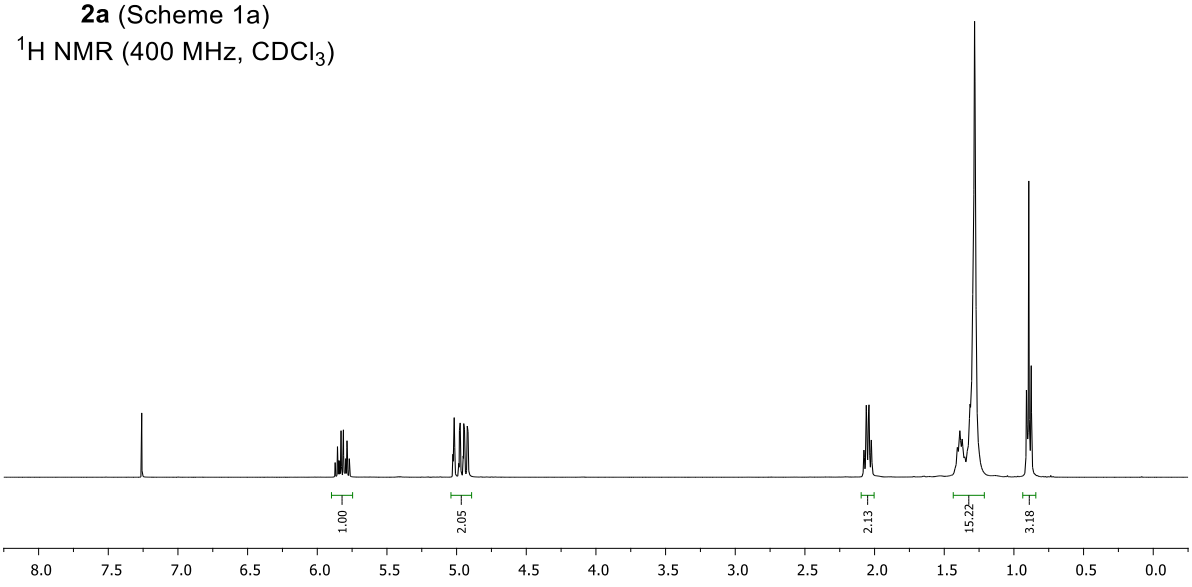


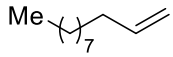




2a (Scheme 1a)

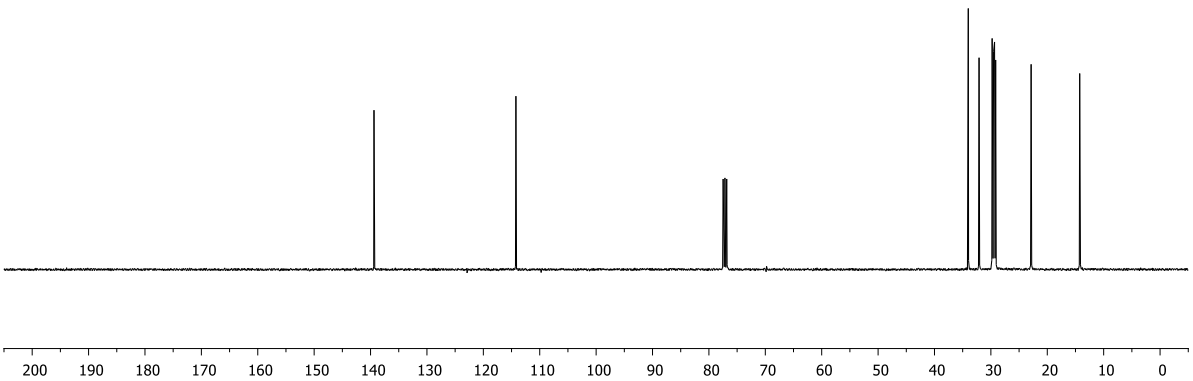
^{1}H NMR (400 MHz, $CDCl_3$)

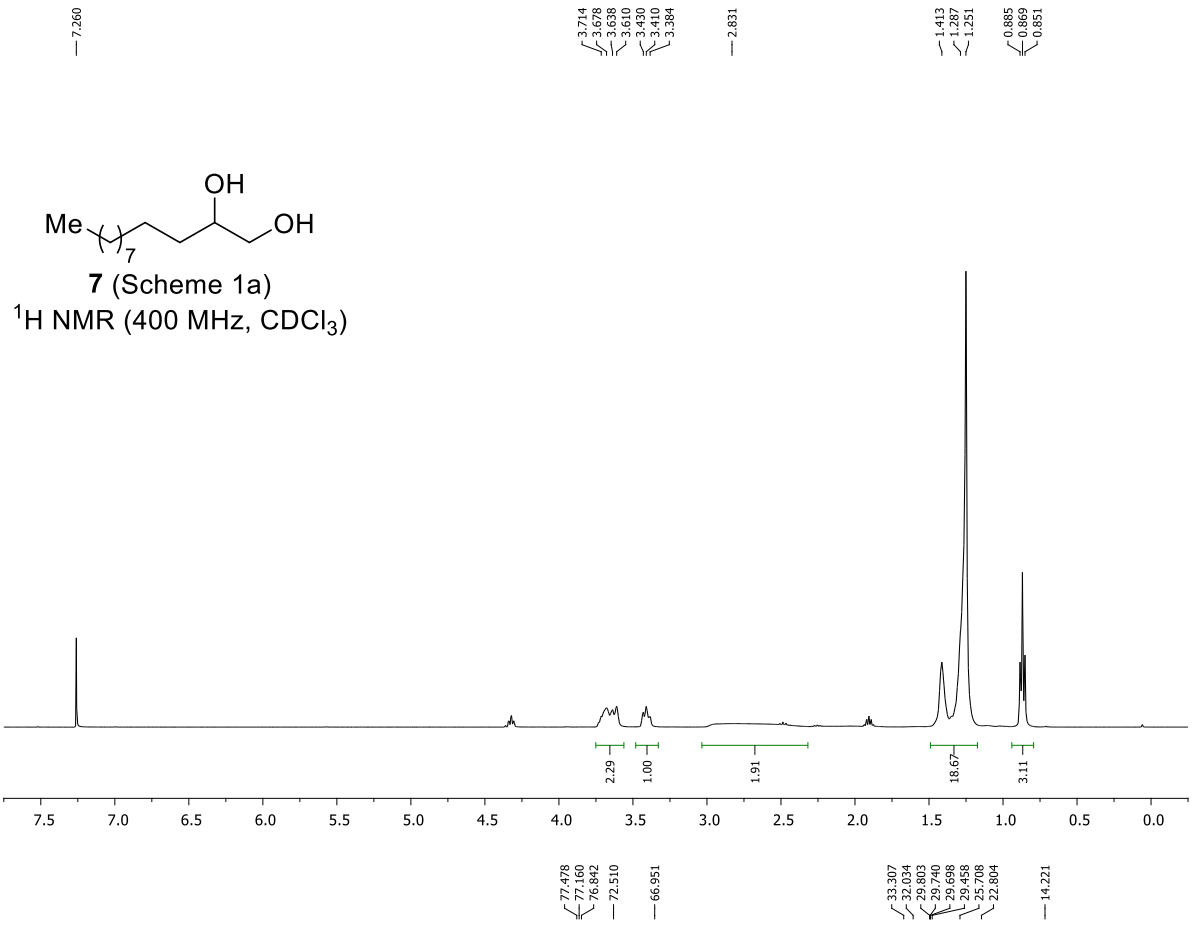




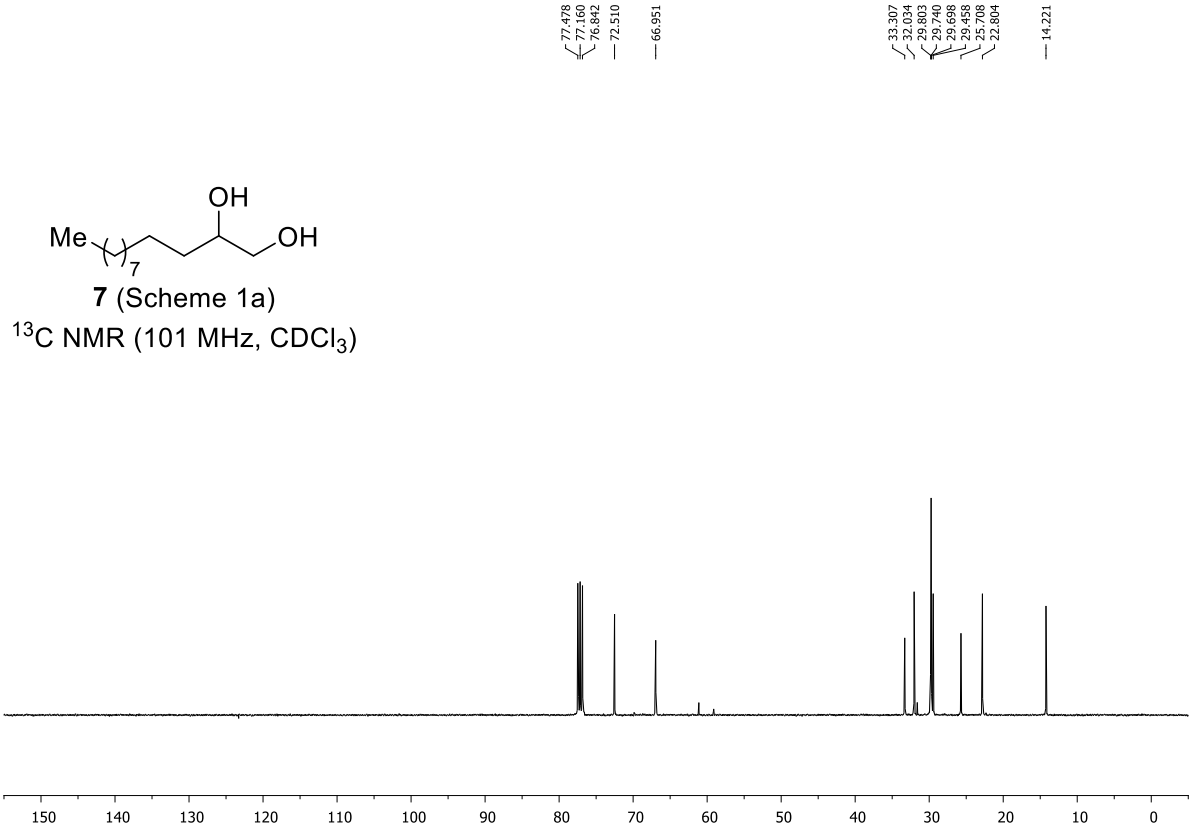
2a (Scheme 1a)

^{13}C NMR (101 MHz, $CDCl_3$)

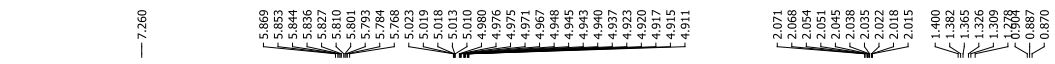


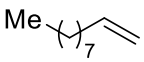


7 (Scheme 1a)
^{1}H NMR (400 MHz, $CDCl_3$)



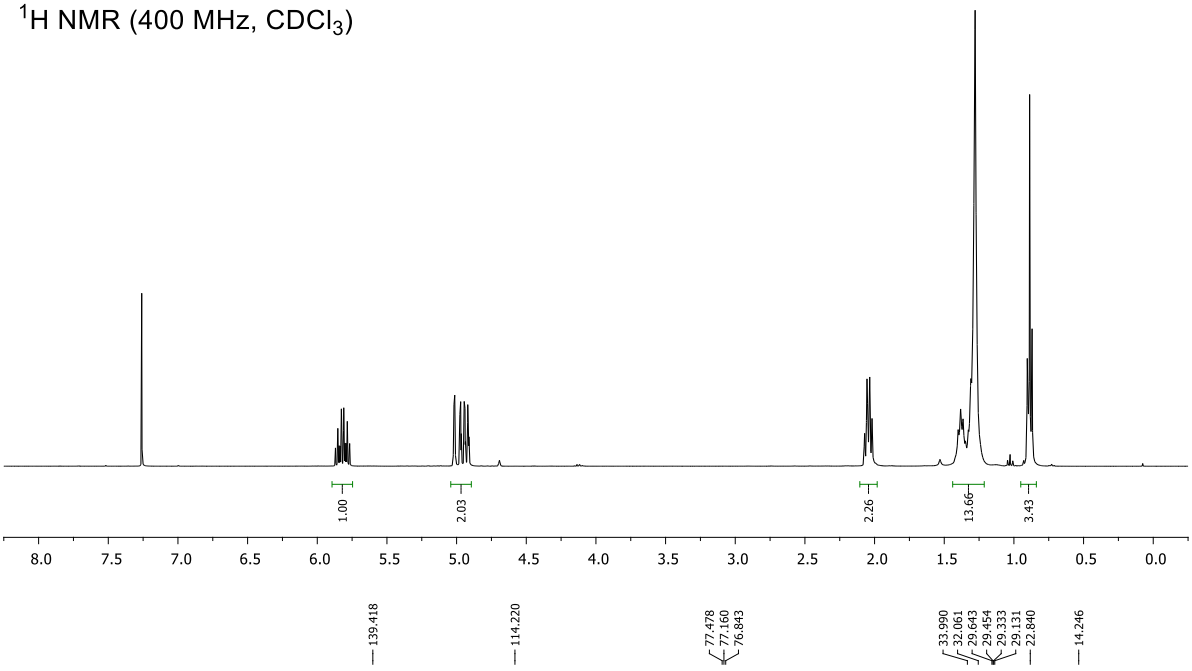
7 (Scheme 1a)
^{13}C NMR (101 MHz, $CDCl_3$)

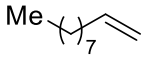




2v (Scheme 1a)

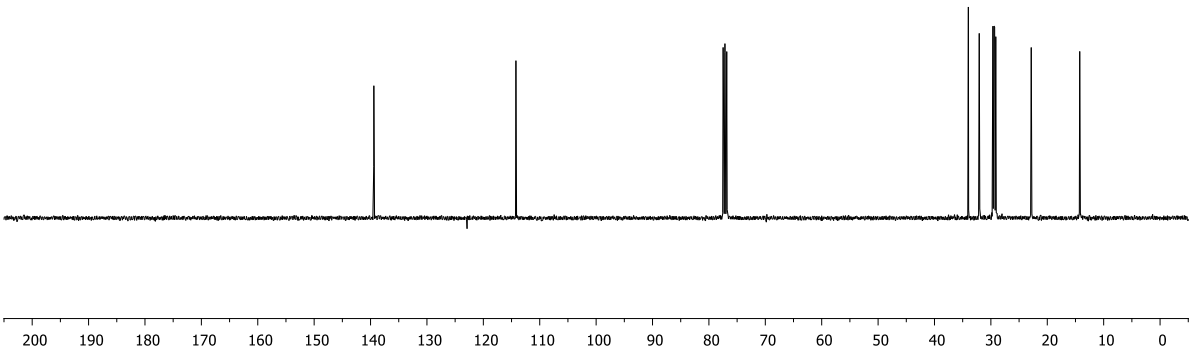
^{1}H NMR (400 MHz, $CDCl_3$)

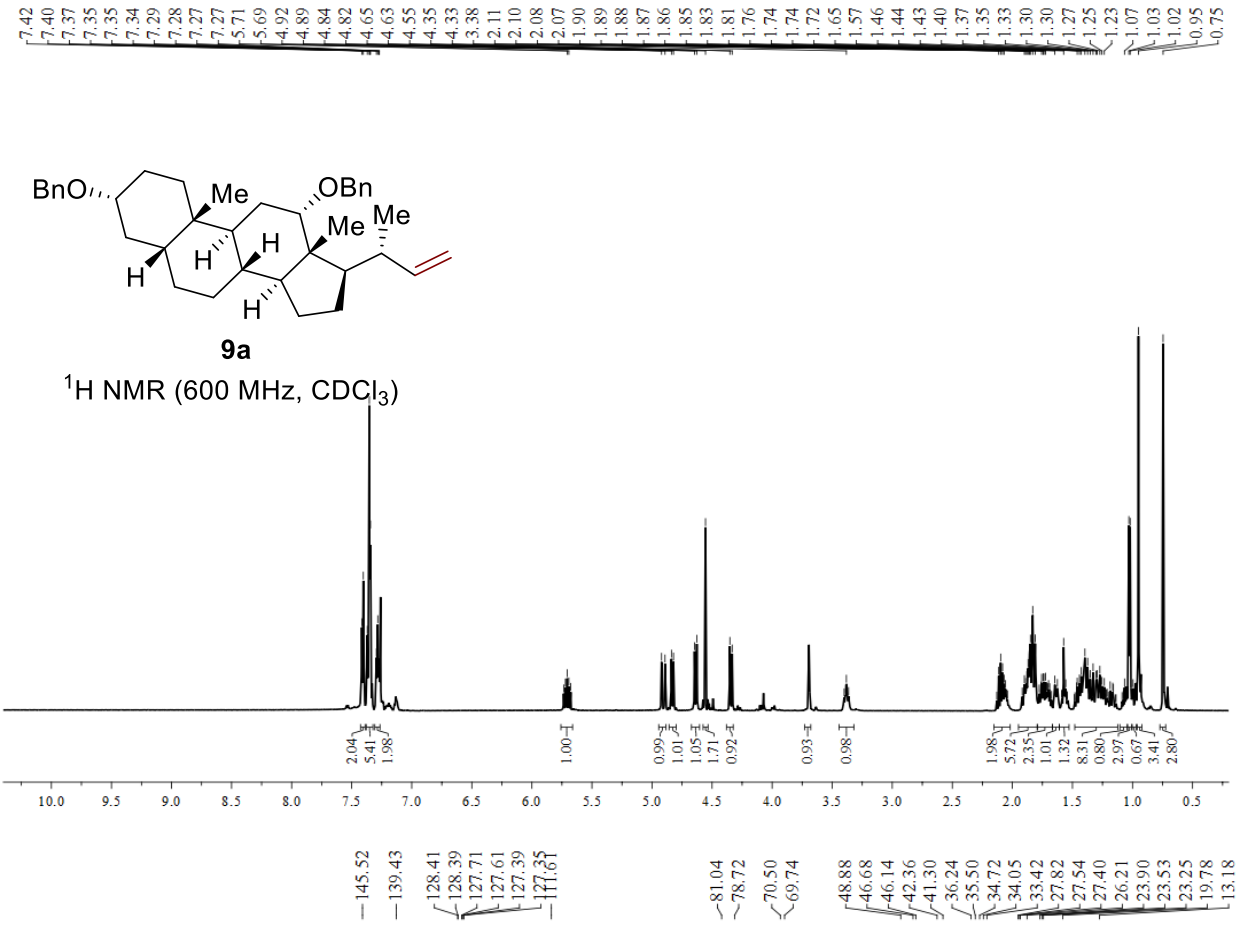


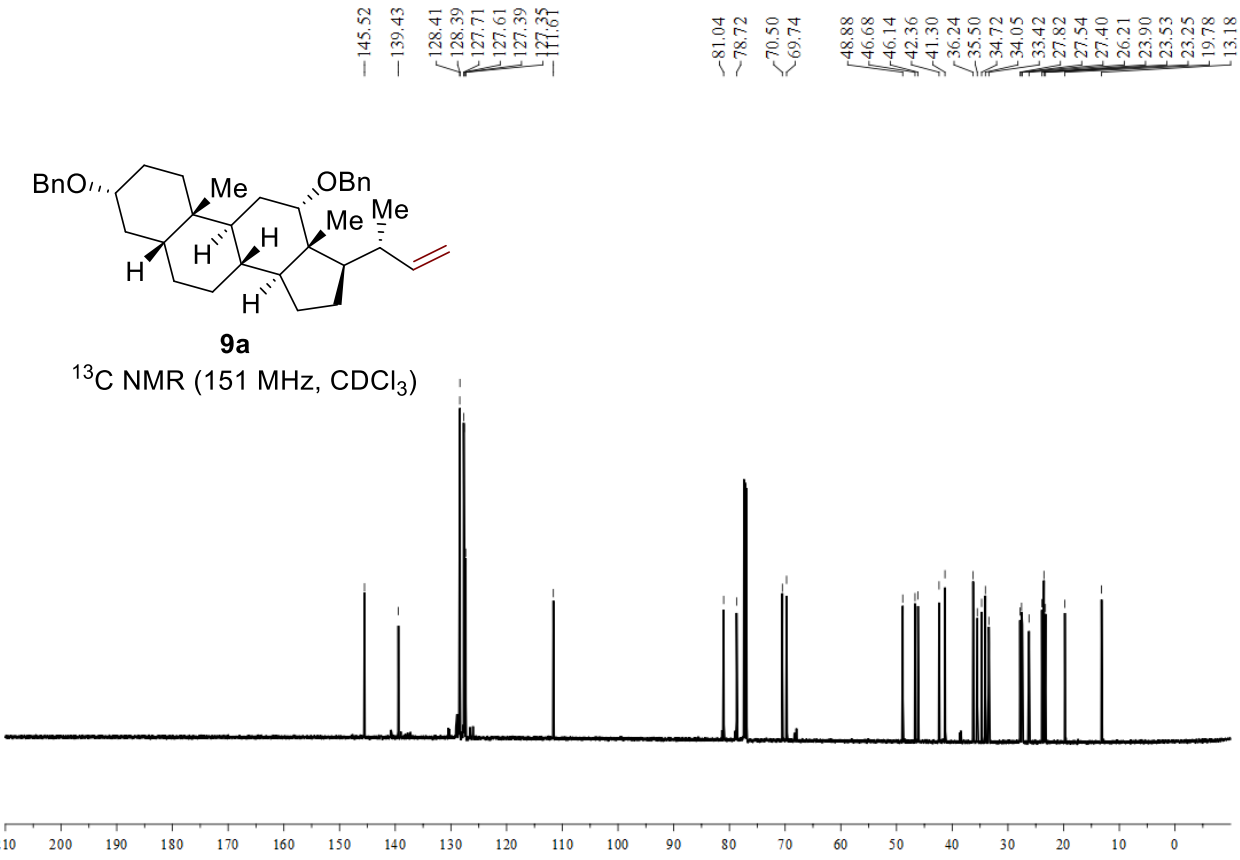


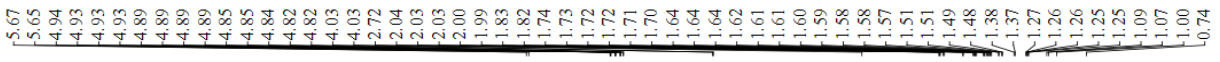
2v (Scheme 1a)

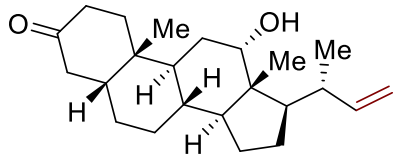
^{13}C NMR (101 MHz, $CDCl_3$)




BnO
Me
OBn
Me
Me
H
H
H
9a
1H NMR (600 MHz, CDCl3)

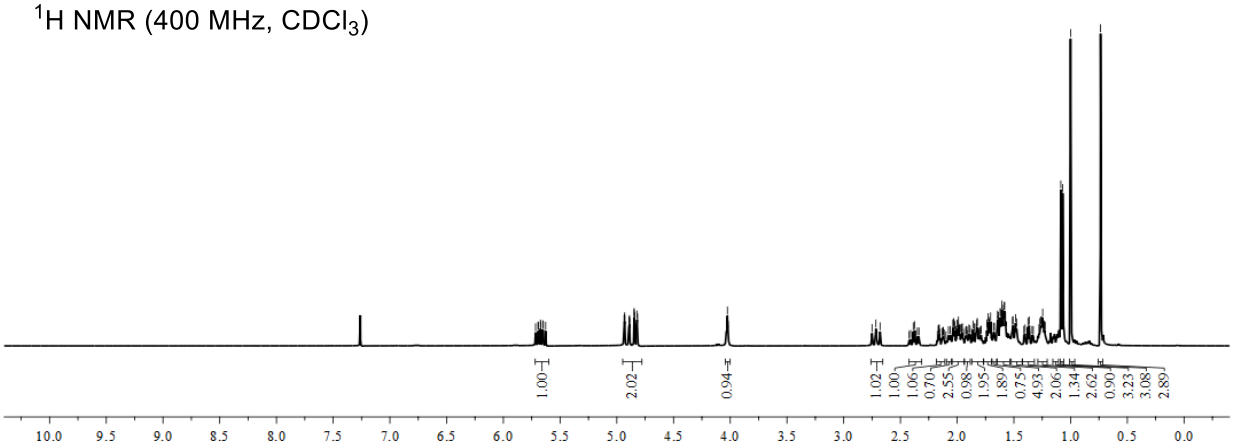

BnO
Me
OBn
Me
Me
H
H
H
9a
13C NMR (151 MHz, CDCl3)

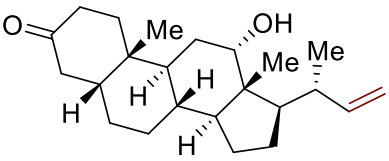




9b

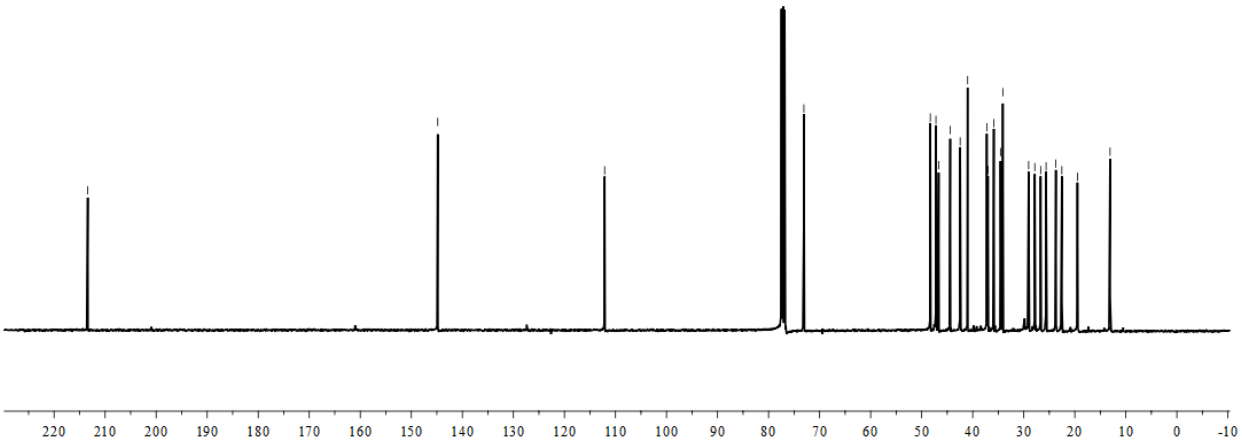
^{1}H NMR (400 MHz, $CDCl_3$)

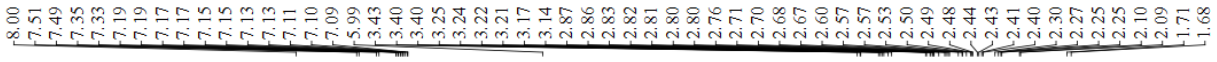


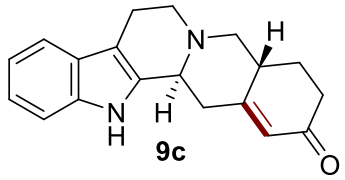


9b

^{13}C NMR (101 MHz, $CDCl_3$)



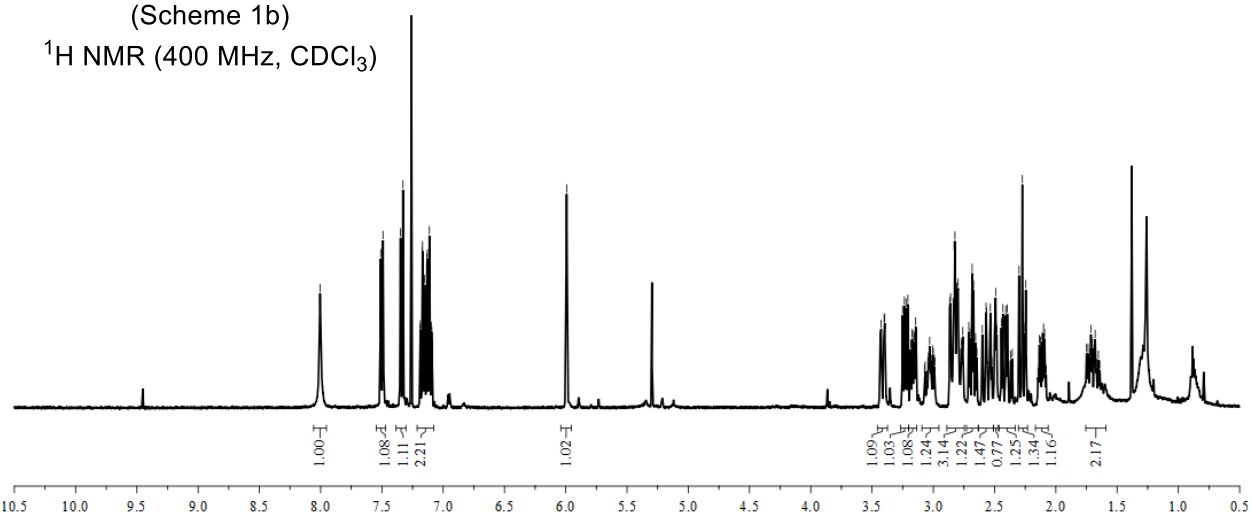


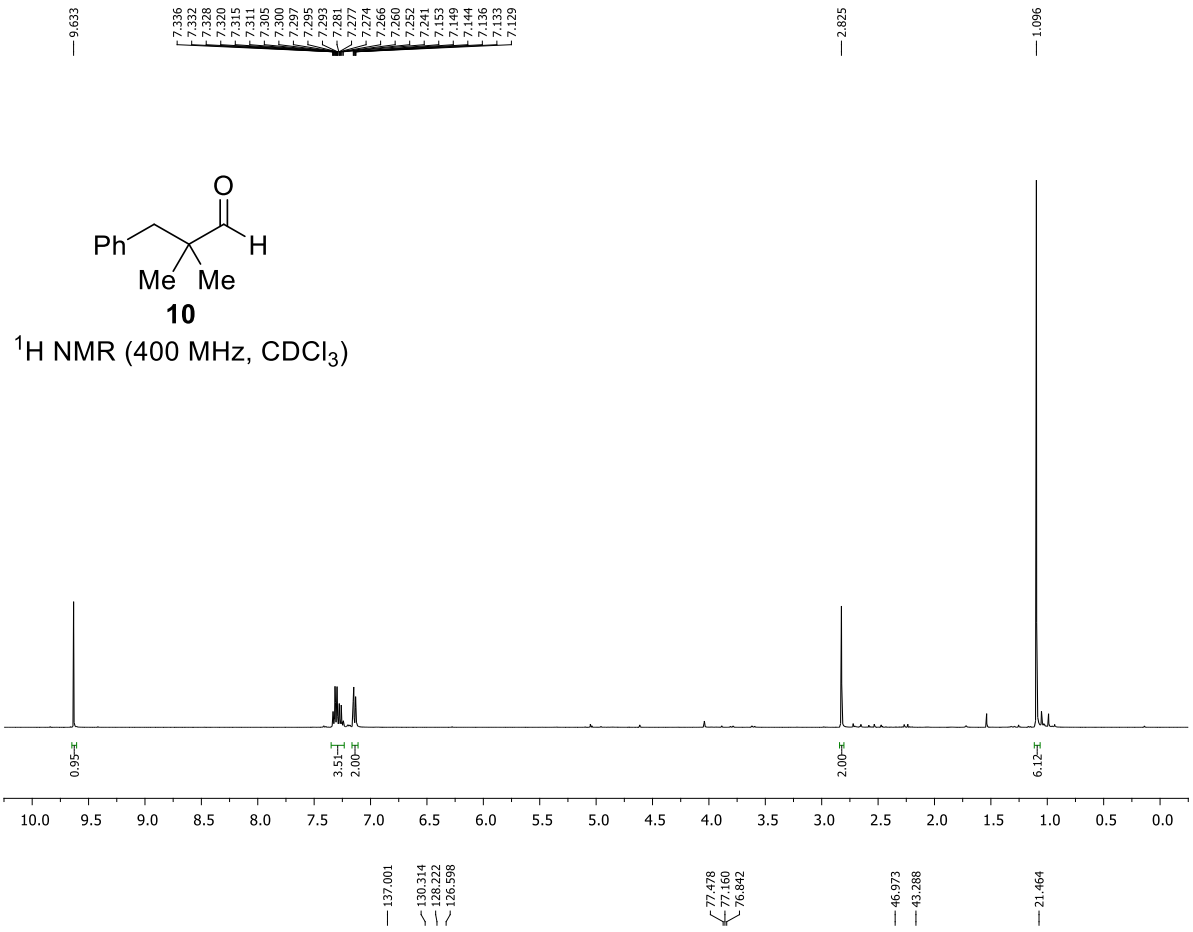


9c

(Scheme 1b)

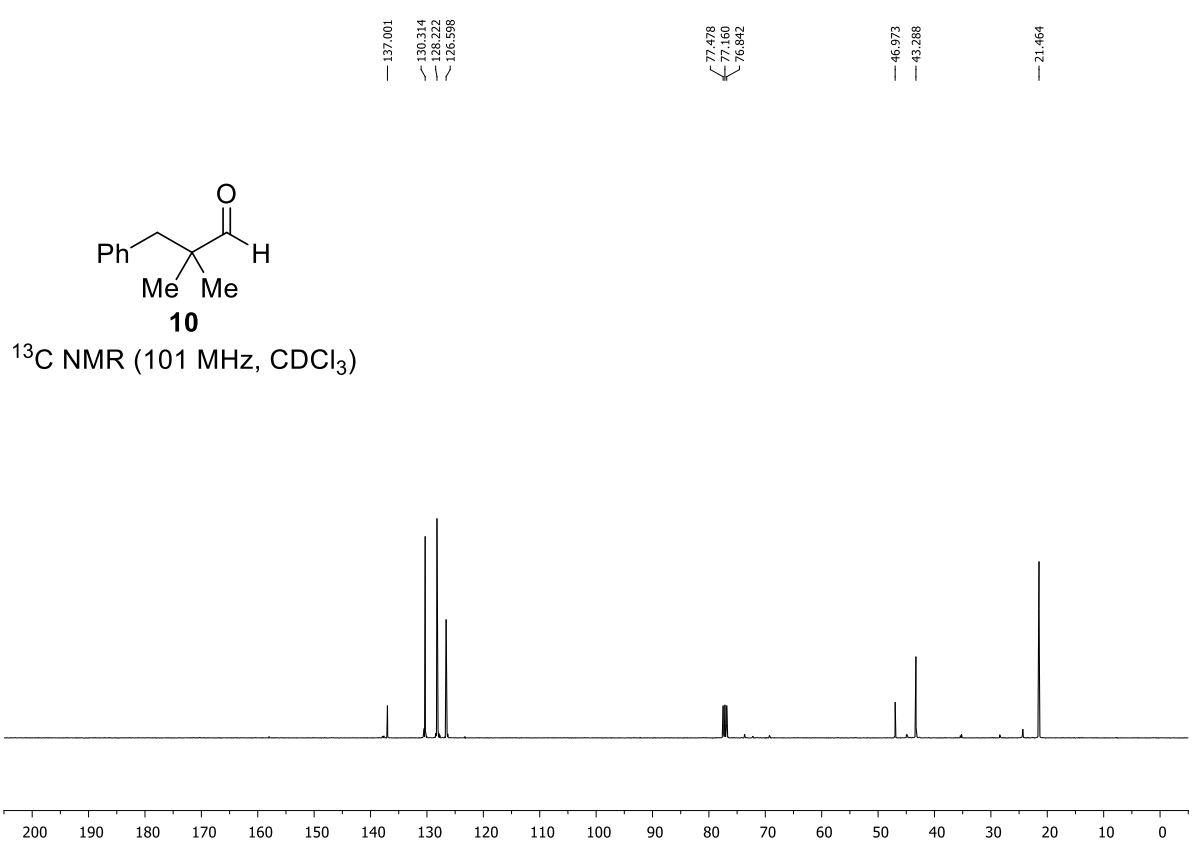
^{1}H NMR (400 MHz, $CDCl_3$)





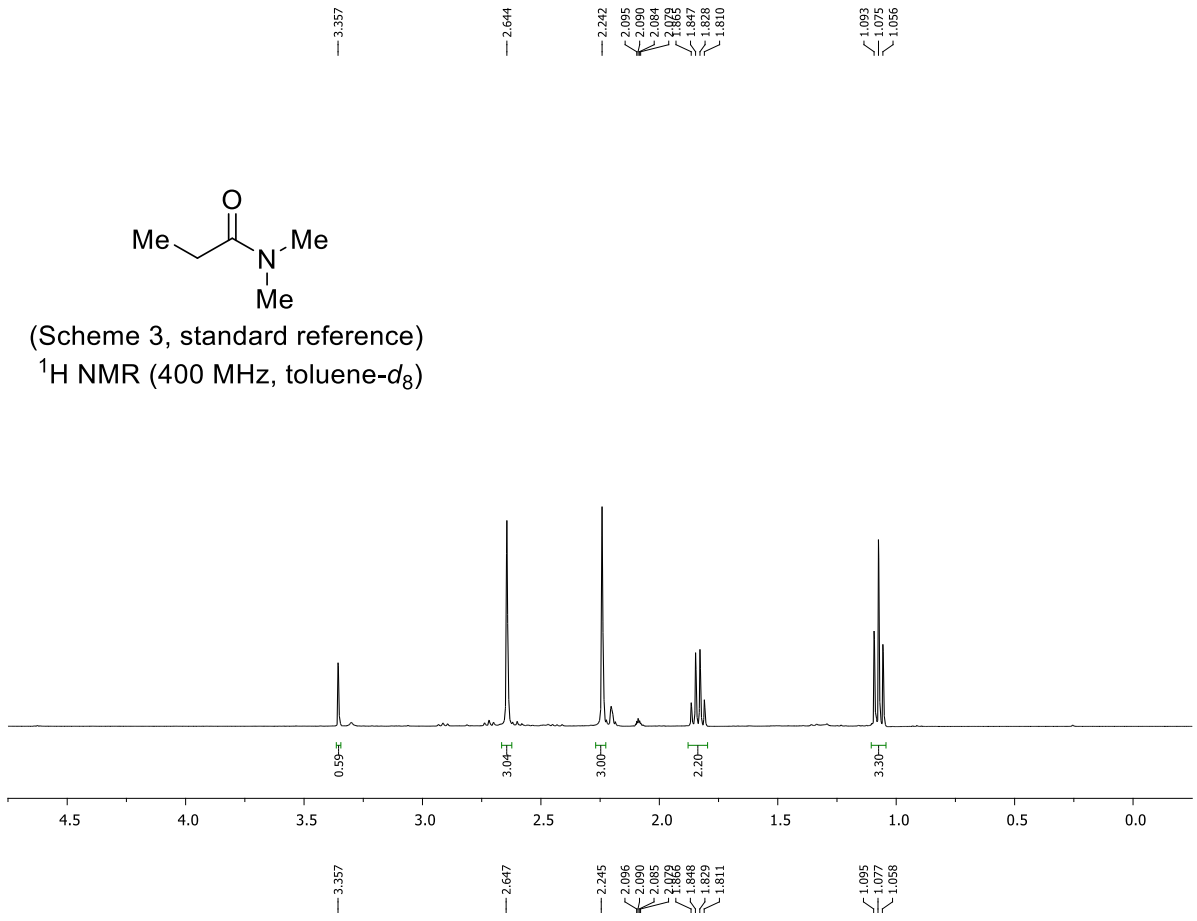
10

^{1}H NMR (400 MHz, $CDCl_3$)



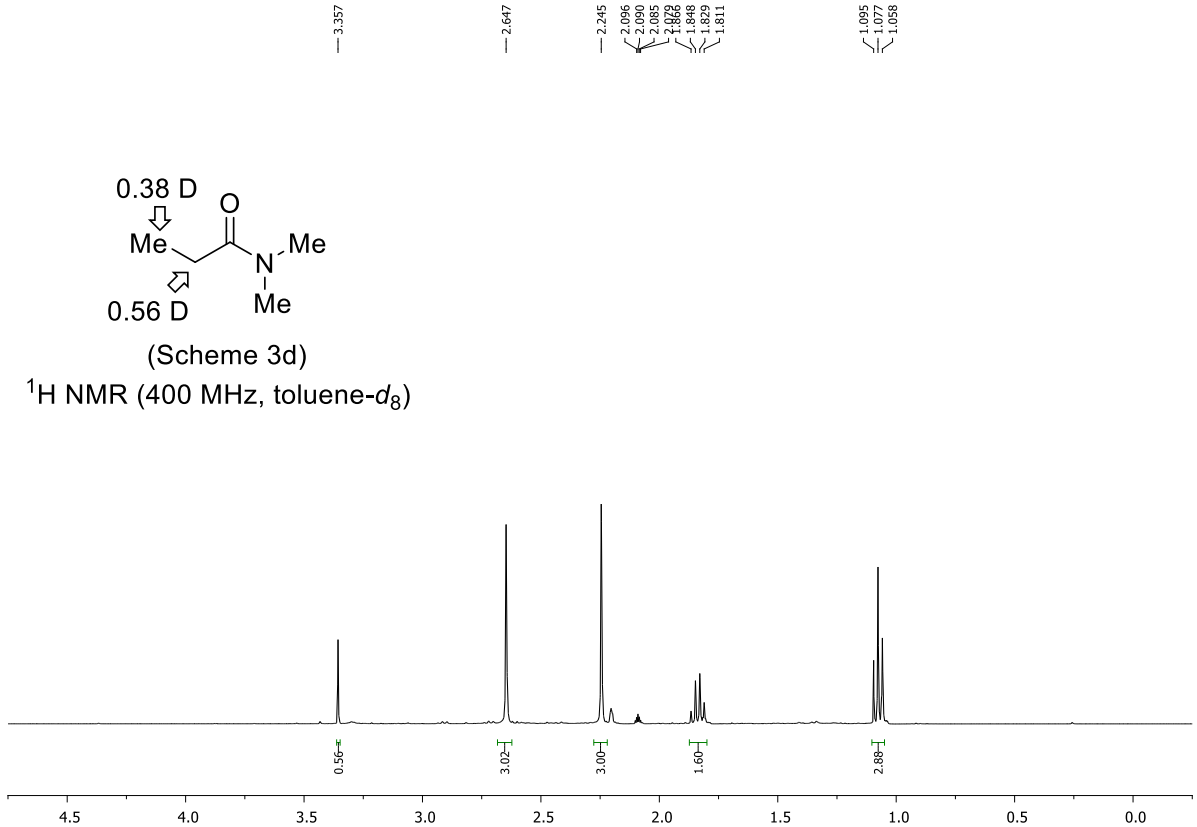
10

^{13}C NMR (101 MHz, $CDCl_3$)



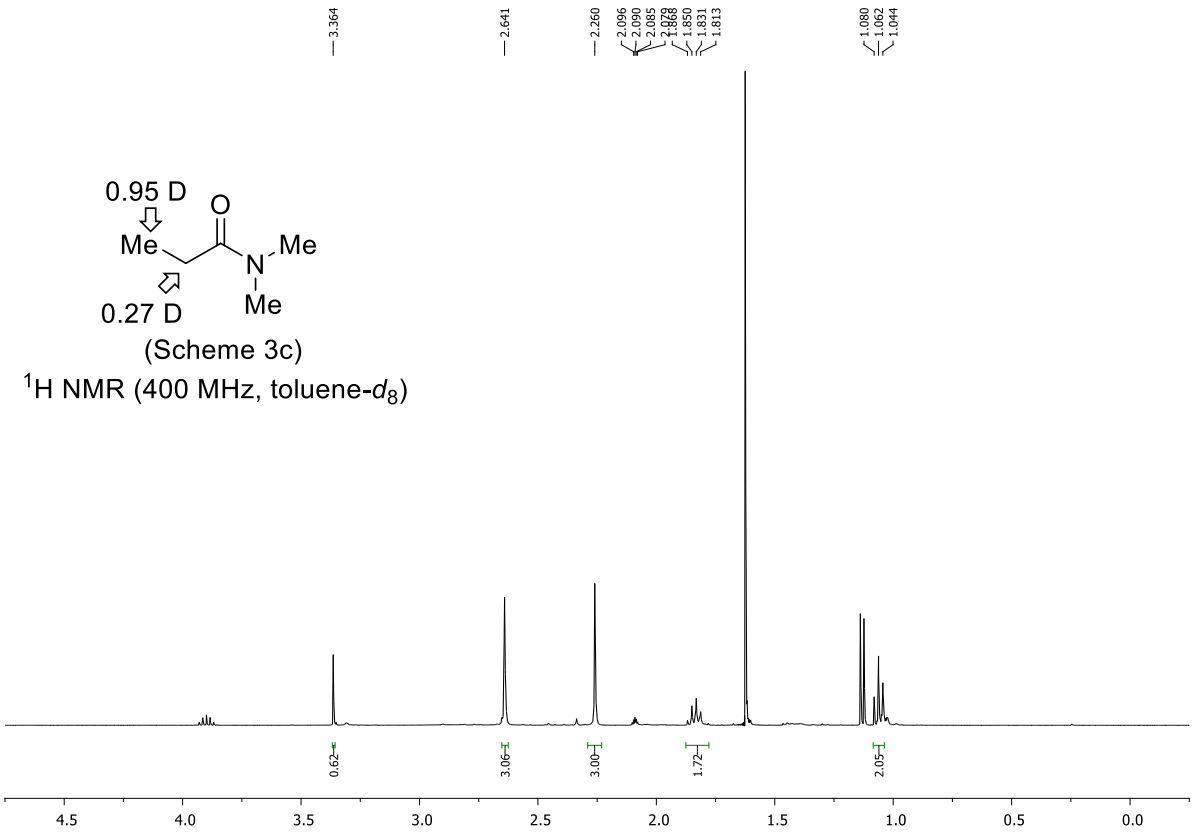
(Scheme 3, standard reference)

^{1}H NMR (400 MHz, toluene-d_8)



(Scheme 3d)

^{1}H NMR (400 MHz, toluene-d_8)



(Scheme 3c)

^{1}H NMR (400 MHz, toluene-d_8)

Appendix 2.1: Supporting Information for Chapter 2.1

Alkyne Hydroacylation: Switching Regioselectivity by Tandem Ru-Catalysis[11]

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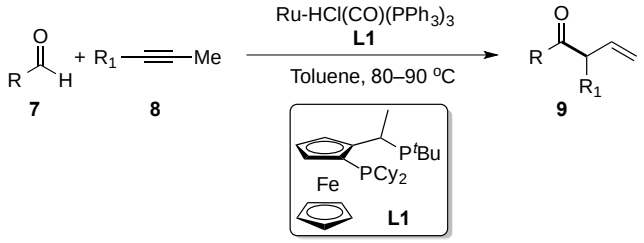
1. Materials and Methods

All syntheses were performed in oven-dried or flame-dried glassware under an atmosphere of N_2. Tetrahydrofuran, dichloromethane, toluene and diethyl ether were purified using an Innovative Technologies Pure Solv system, degassed by three freeze-pump-thaw cycles, and stored over 3 Å MS within an N_2 filled glove box. 1,4-Dioxane, 1,2-dimethoxyethane and dimethylsulfoxide were refluxed with CaH_2 and distilled prior to use. The molarity of organolithium reagents was determined by titration with *iso*-propanol/1,10-phenanthroline. Reactions were monitored either *via* gas chromatography using an Agilent Technologies 7890A GC system equipped with an Agilent Technologies 5975C inert XL EI/CI MSD or by analytical thin-layer chromatography on EMD Silica Gel 60 F_{254} plates. Visualization of the developed plates was performed under UV light (254 nm) or using either $KMnO_4$ or *p*-anisaldehyde stain. Column chromatography was performed with Silicycle Silia-P Flash Silica Gel using glass columns. Automated column chromatography was performed using either a Biotage SP1 or Teledyne Isco CombiFlash Rf 200 purification system. ^{1}H, ^{13}C, ^{19}F, and ^{31}P NMR spectra were recorded on a Bruker DRX-400 (400 MHz ^{1}H, 100 MHz ^{13}C, 376.5 MHz ^{19}F, 161.9 MHz ^{31}P), GN-500 (500 MHz ^{1}H, 125.7 MHz ^{13}C) or CRYO-500 (500 MHz ^{1}H, 125.7 MHz ^{13}C) spectrometer. ^{1}H NMR spectra were internally referenced to the residual solvent signal or TMS. ^{13}C NMR spectra were internally referenced to the residual solvent signal. Data for ^{1}H NMR are reported as follows: chemical shift (δ ppm), multiplicity (s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet, br = broad), coupling constant (Hz), integration. Data for ^{13}C NMR are reported in terms of chemical shift (□, ppm). Infrared spectra were obtained on a Thermo Scientific Nicolet iS5 FT-IR spectrometer equipped with an iD5 ATR accessory. High resolution mass spectra (HRMS) was performed by the University of California, Irvine Mass Spectrometry Center. All new compounds were characterized by ^{1}H NMR, ^{13}C NMR, HRMS, and optical rotation. For known compounds, we have cited the published characterization data that we used to compare to our synthesized compounds and we have included a ^{1}H NMR spectrum to establish purity of the isolated material.

[11] For additional details, see: Chen. Q.–A.; Cruz, F. A.; Dong, V. M. *J. Am. Chem. Soc.*, **2015,** *137*, 3157.

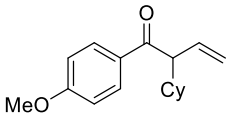
2. β,γ-Unsaturated Ketone Synthesis



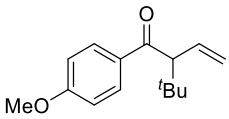
General Procedure for Alkyne Hydroacylation

Method A: In a N_2-filled glovebox, $RuHCl(CO)(PPh_3)_3$ (7.6 mg, 0.008 mmol), **L1** (4.4 mg, 0.008 mmol), aldehyde **7** (0.20 mmol), alkyne **8** (0.40 mmol), and toluene (0.5 mL) were added to a 1 dram vial equipped with a stir bar. The reaction mixture was cooled to room temperature after heating at 80 °C for 18 h. Selectivity was determined by ^1H NMR or GC–FID analysis of the reaction mixture. The reaction mixture was directly purified by column chromatography on silica gel using hexanes:EtOAc (20:1 – 10:1) to give **9**.

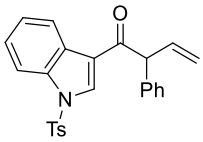
Method B: In a N_2-filled glovebox, $RuHCl(CO)(PPh_3)_3$ (7.6 mg, 0.008 mmol), **L1** (4.4 mg, 0.008 mmol), aldehyde **7** (0.20 mmol), alkyne **8** (0.24 mmol), and toluene (1.0 mL) were added into a 1 dram equipped with a stir bar. The reaction mixture was cooled to room temperature after heating at 90 °C for 18 h. Selectivity was determined by ^1H NMR or GC–FID analysis of the reaction mixture. The reaction mixture was directly purified by column chromatography on silica gel using hexanes:EtOAc (20:1 – 10:1) to give **9**.



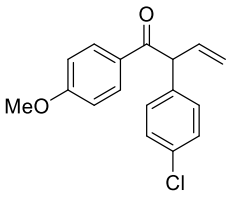
2-Cyclohexyl-1-(4-methoxyphenyl)-3-buten-1-one **9bb**: (Method **A**) colorless oil, ^1H NMR (500 MHz, $CDCl_3$) δ 7.99–7.95 (m, 2H), 6.96–6.92 (m, 2H), 5.87 (ddd, *J* = 17.0, 10.2, 9.5 Hz, 1H), 5.15–5.09 (m, 2H), 3.88 (s, 3H), 3.80 (t, *J* = 9.1 Hz, 1H), 1.96–1.71 (m, 3H), 1.66–1.61 (m, 3H), 1.29–1.11 (m, 3H), 1.01–0.89 (m, 2H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 200.4, 163.6, 136.9, 130.8, 130.7, 117.9, 113.9, 58.3, 55.6, 40.3, 32.0, 30.5, 26.5, 26.3; IR (ATR) 1598, 1170, 905, 720, 649 cm^{-1}; HRMS calculated for $C_{17}H_{23}O_2$ $[M + H]^+$ 259.1693, found 259.1691.



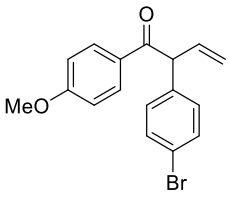
2-*tert*-Butyl-1-(4-methoxyphenyl)-3-buten-1-one **9bc**: (Method **A**) colorless oil, ^1H NMR (500 MHz, $CDCl_3$) δ 7.95 (d, *J* = 8.9 Hz, 2H), 6.93 (d, *J* = 8.8 Hz, 2H), 6.04 (dt, *J* = 17.1, 9.9 Hz, 1H), 5.16 (dd, *J* = 10.1, 1.2 Hz, 1H), 5.11 (d, *J* = 17.2 Hz, 1H), 3.89 (d, *J* = 9.6 Hz, 1H), 3.86 (s, 3H), 0.99 (s, 9H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 200.5, 163.4, 136.1, 131.7, 130.7, 118.4, 113.8, 60.1, 55.6, 34.9, 28.2; IR (ATR) 1667, 1598, 1261, 1217, 1171, 1030, 733, 641, 628, 605 cm^{-1}; HRMS calculated for $C_{15}H_{21}O_2$ $[M + H]^+$ 233.1536, found 233.1551.



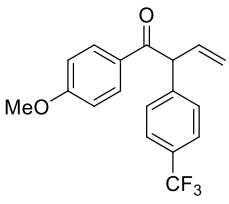
2-Phenyl-1-(1-tosyl-3-indolyl)-3-buten-1-one **9ld**: (Method **B**, 80 ºC) colorless oil, ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.37–8.33 (m, 1H), 8.14 (s, 1H), 7.89–7.85 (m, 1H), 7.63–7.61 (m, 2H), 7.36–7.27 (m, 7H), 7.19 (d, *J* = 8.1 Hz, 2H), 6.40 (ddd, *J* = 17.2, 10.2, 7.6 Hz, 1H), 5.28 (dt, *J* = 10.3, 1.1 Hz, 1H), 5.16 (dt, *J* = 17.2, 1.2 Hz, 1H), 5.08 (d, *J* = 7.7 Hz, 1H), 2.35 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 194.3, 145.9, 139.1, 136.7, 134.8, 134.3, 132.8, 130.2, 129.1, 128.3, 128.2, 127.3, 127.1, 125.9, 125.0, 123.3, 120.2, 117.7, 113.1, 60.1, 21.7; IR (ATR) 1666, 1534, 1445, 1375, 1190, 1174, 1137, 1103, 1086, 1018, 991, 961, 923, 811, 661, 601 cm^{-1}; HRMS calculated for $C_{25}H_{22}NO_3S$ $[M + H]^+$ 416.1315, found 416.1332.



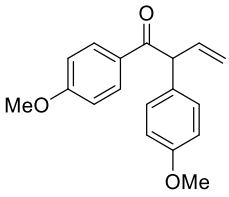
2-(4-Chlorophenyl)-1-(4-methoxyphenyl)-3-buten-1-one **9be**: (Method **B**) colorless oil, ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.96–7.92 (m, 2H), 7.30–7.22 (m, 4H), 6.91–6.87 (m, 2H), 6.35–6.26 (m, 1H), 5.25–5.21 (m, 2H), 5.11–5.06 (m, 1H), 3.84 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 196.8, 163.7, 137.4, 137.1, 133.2, 131.3, 129.9, 129.21, 129.15, 117.6, 114.0, 56.9, 55.6; IR (ATR) 1670, 1610, 1261, 1231, 1121, 1165, 1092, 1014, 925, 812, 786, 615 cm^{-1}; HRMS calculated for $C_{17}H_{16}ClO_2$ $[M + H]^+$ 287.0833, found 287.0835.



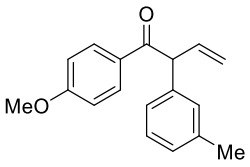
2-(4-Bromophenyl)-1-(4-methoxyphenyl)-3-buten-1-one **9bf**: (Method **B**) colorless oil, ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.94 (d, *J* = 9.0 Hz, 2H), 7.44 (d, *J* = 8.4 Hz, 2H), 7.18 (d, *J* = 8.4 Hz, 2H), 6.89 (d, *J* = 9.0 Hz, 2H), 6.30 (ddd, *J* = 17.6, 10.2, 7.6 Hz, 1H), 5.24–5.20 (m, 2H), 5.08 (d, *J* = 17.2 Hz, 1H), 3.84 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 196.7, 163.7, 137.9, 137.0, 132.2, 131.3, 130.2, 129.1, 121.3, 117.7, 114.0, 57.0, 55.6; IR (ATR) 1670, 1597, 1260, 1185, 1010, 811, 785, 612 cm^{-1}; HRMS calculated for $C_{17}H_{16}BrO_2$ $[M + H]^+$ 331.0328, found 331.0339.



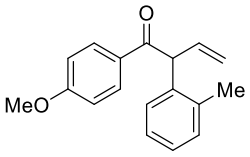
2-(4-Trifluoromethylphenyl)-1-(4-methoxyphenyl)-3-buten-1-one **9bg**: (Method **B**) colorless oil, ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.97–7.94 (m, 2H), 7.57 (d, *J* = 8.1 Hz, 2H), 7.43 (d, *J* = 8.2 Hz, 2H), 6.92–6.89 (m, 2H), 6.33 (ddd, *J* = 17.8, 10.2, 7.7 Hz, 1H), 5.33 (d, *J* = 7.7 Hz, 1H), 5.27 (d, *J* = 10.2 Hz, 1H), 5.12 (d, *J* = 17.2 Hz, 1H), 3.85 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 196.4, 163.9, 142.9, 136.7, 131.3, 129.1, 128.9, 126.0, 124.2, 118.1, 114.1, 57.3, 55.6; ^{19}F NMR (376 MHz, $CDCl_3$) δ –62.8; IR (ATR) 1672, 1598, 1301, 1262, 1212, 1118, 1102, 1067, 1018, 989, 926, 825, 789, 614 cm^{-1}; HRMS calculated for $C_{18}H_{15}F_3NaO_2$ $[M + Na]^+$ 343.0916, found 343.0913.



2-(4-Methoxyphenyl)-1-(4-methoxyphenyl)-3-buten-1-one **9bh**: (Method **B**) colorless oil, ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.97–7.94 (m, 2H), 7.23–7.20 (m, 2H), 6.89–6.84 (m, 4H), 6.34 (ddd, *J* = 17.2, 10.3, 7.5 Hz, 1H), 5.21–5.18 (m, 2H), 5.06 (d, *J* = 17.2 Hz, 1H), 3.83 (s, 3H), 3.76 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 197.4, 163.5, 158.8, 137.8, 131.3, 130.9, 129.5, 129.4, 116.8, 114.5, 113.9, 56.9, 55.6, 55.4; IR (ATR) 1669, 1597, 1509, 1249, 1164, 1028, 990, 924, 822, 641, 598 cm^{-1}; HRMS calculated for $C_{18}H_{18}NaO_3$ $[M + Na]^+$ 305.1148, found 305.1154.



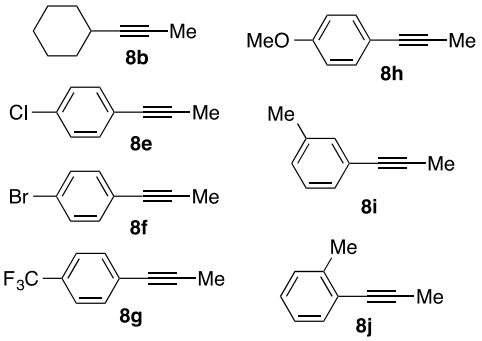
2-(3-Methylphenyl)-1-(4-methoxyphenyl)-3-buten-1-one **9bi**: (Method **B**) colorless oil, ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.98–7.94 (m, 2H), 7.20 (t, *J* = 7.9 Hz, 1H), 7.11–7.09 (m, 2H), 7.03 (d, *J* = 7.2 Hz, 1H), 6.90–6.86 (m, 2H), 6.42–6.29 (m, 1H), 5.21–5.17 (m, 2H), 5.08 (d, *J* = 17.1 Hz, 1H), 3.83 (s, 3H), 2.31 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 197.3, 163.5, 138.83, 138.79, 137.7, 131.3, 129.5, 129.0, 128.1, 125.5, 116.9, 113.9, 57.8, 55.6, 21.6; IR (ATR) 1669, 1597, 1259, 1230, 1168, 1026, 842, 773, 704, 612 cm^{-1}; HRMS calculated for $C_{18}H_{18}NaO_2$ $[M + Na]^+$ 289.1199, found 289.1210.

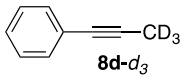


2-(2-Methylphenyl)-1-(4-methoxyphenyl)-3-buten-1-one **9bj**: (Method **B**) colorless oil, ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.86–7.83 (m, 2H), 7.21 (d, *J* = 6.9 Hz, 1H), 7.16–7.11 (m, 3H), 6.87–6.83 (m, 2H), 6.24 (ddd, *J* = 17.3, 10.2, 7.3 Hz, 1H), 5.34 (d, *J* = 7.2 Hz, 1H), 5.23 (d, *J* = 10.3 Hz, 1H), 4.98 (d, *J* = 17.2 Hz, 1H), 3.82 (s, 3H), 2.43 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 197.8, 163.3, 136.9, 136.4, 135.4, 131.0, 129.4, 128.1, 127.2, 126.7, 117.1, 113.8, 55.5, 54.4, 19.8; IR (ATR) 1671, 1596, 1258, 1197, 1026, 827, 756, 732, 610 cm^{-1}; HRMS calculated for $C_{18}H_{19}O_2$ $[M + H]^+$ 267.1380, found 267.1390.

3. Alkyne Synthesis

Alkyne **8b,**[12] **8d**-d_3,[11] **8e**,[13] **8f**,[14] **8g**,[15] **8h**,[14] **8i**,[14] **8j**,[11] were synthesized according to literature procedure



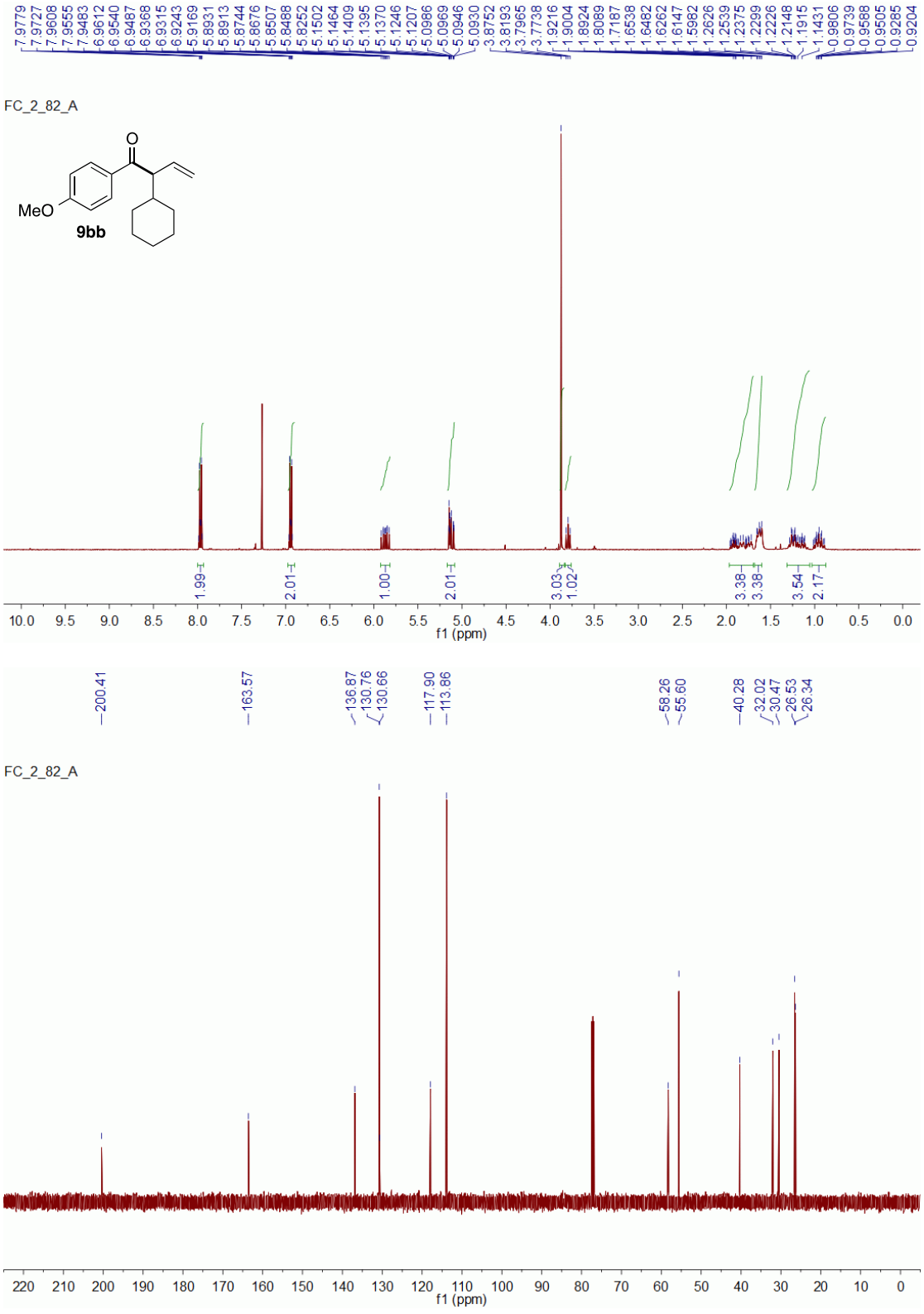


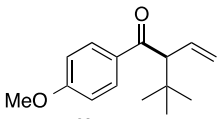
8d-d_3

Using a procedure similar to that for **8b**, alkyne **8d**-d_3 was obtained as a yellow oil (0.52 g, 60% yield). ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.40–7.37 (m, 2H), 7.29–7.25 (m, 3H); ^{2}H NMR (61 MHz, CDCl3) δ 2.0; ^{13}C NMR (126 MHz, CDCl3) δ 131.6, 128.3, 127.7, 124.1, 85.9, 79.9, 4.0, 3.9, 3.7; IR (ATR) 1489, 751, 689 cm^{-1}; HRMS (CI+) calculated for $C_9H_6D_3$ $[M + H]^+$, 119.0814, found 119.0819.

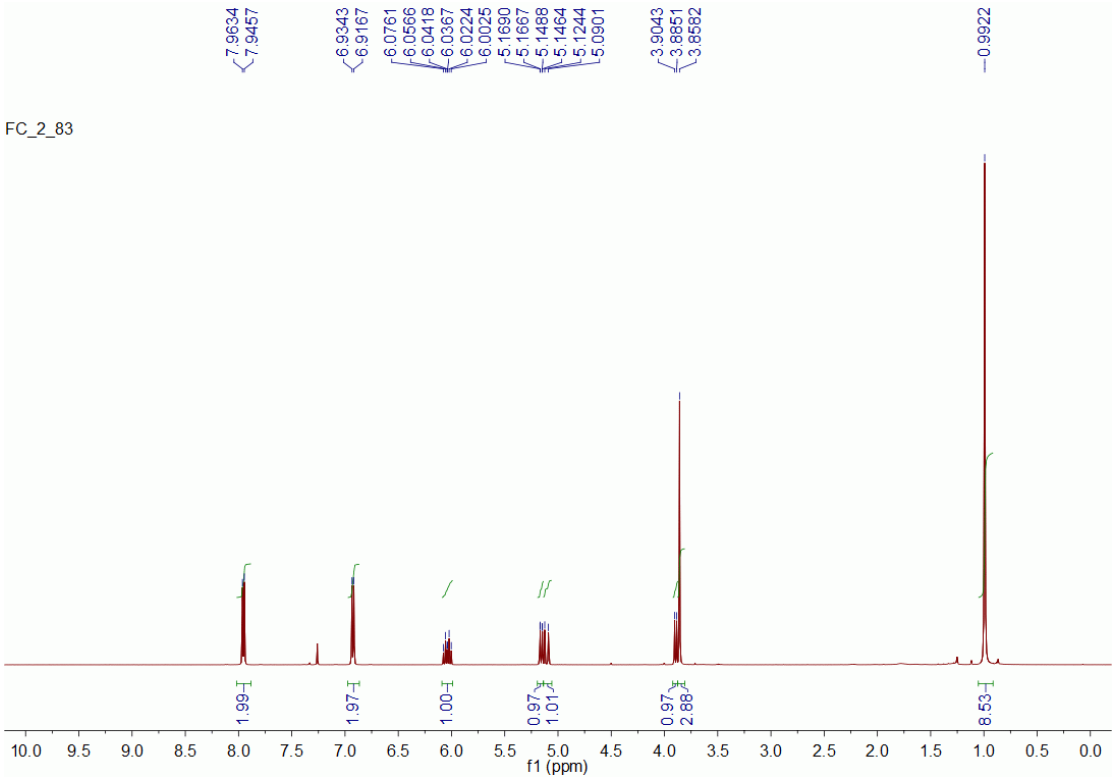
[12] *J. Am. Chem. Soc.*, **2010,** *132*, 14070.
[13] *Org. Biomol. Chem.*, **2003,** *1*, 2152.
[14] *Angew. Chem. Int. Ed.*, **2012,** *51*, 11487.
[15] *Org. Lett.*, **2012,** *14*, 3744.

4. NMR Spectra




O
MeO

9bc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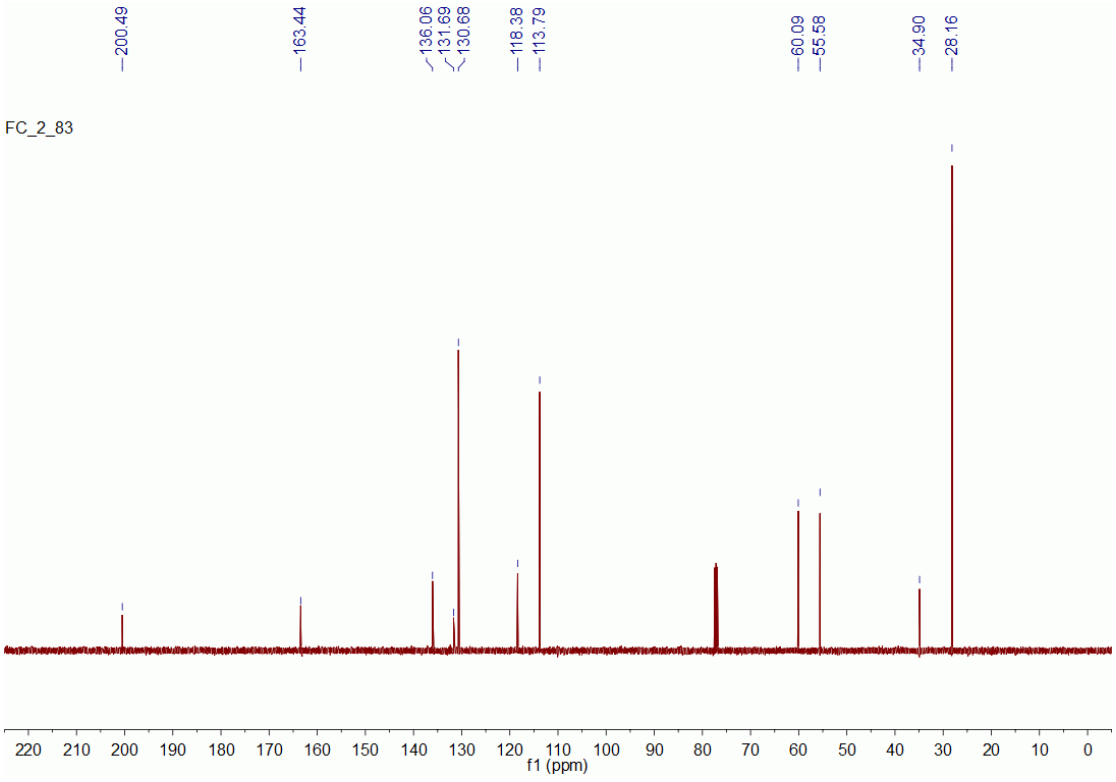
5.1667
5.1488
5.1464
5.1244
5.0901
3.9043
3.8851
3.8582
0.9922
FC_2_83
1.99
1.97
1.00
0.97
1.01
0.97
2.88
8.53
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
f1 (ppm)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163.44
136.06
131.69
130.68
118.38
113.79
60.09
55.58
34.90
28.16
FC_2_83
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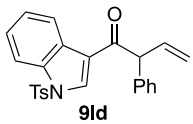
f1 (ppm)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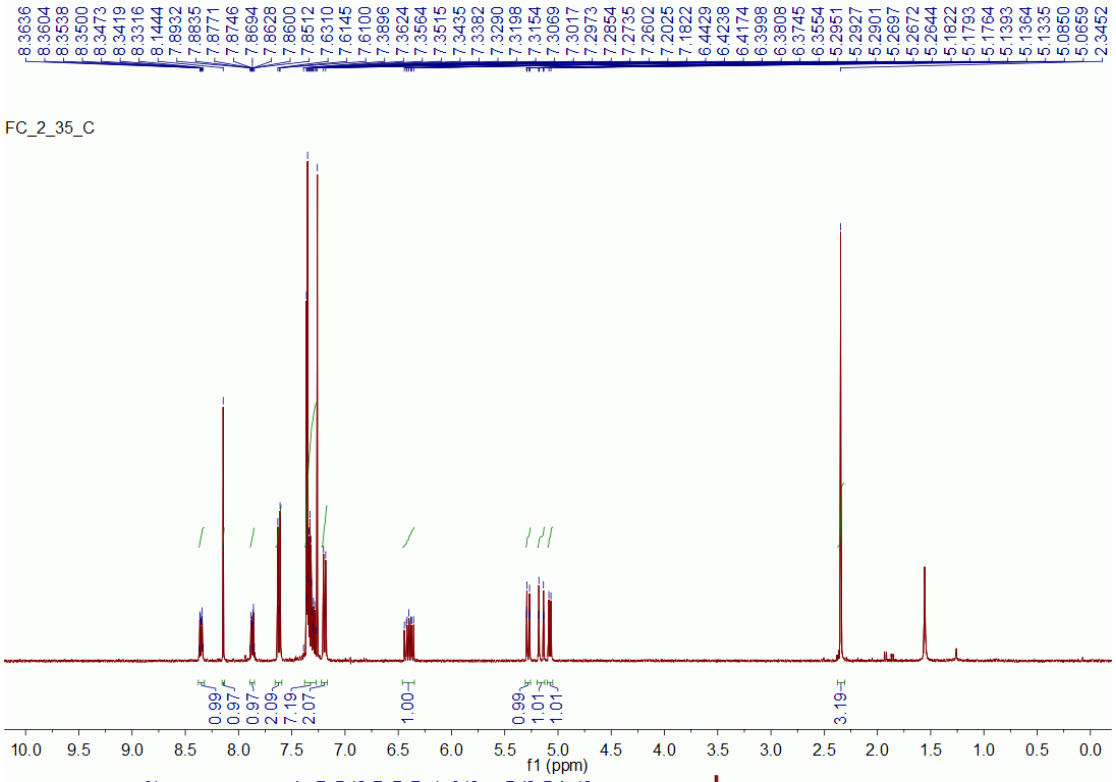
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1.01
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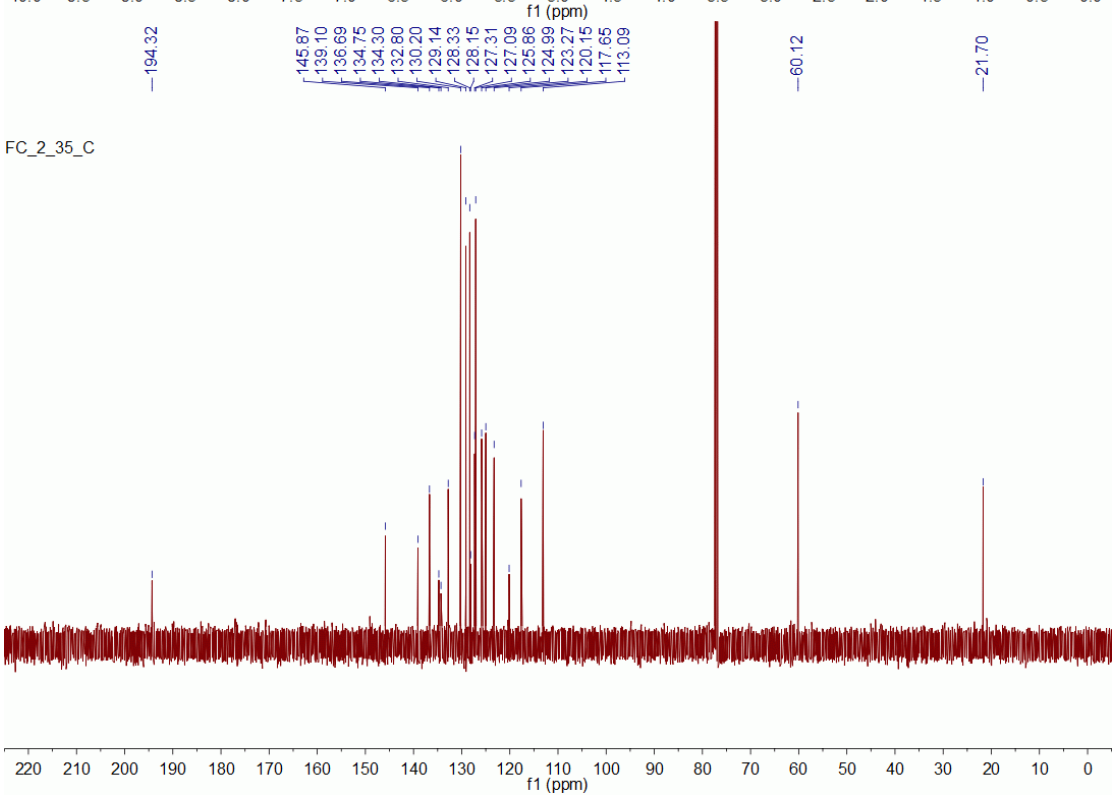
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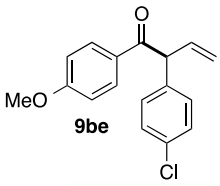
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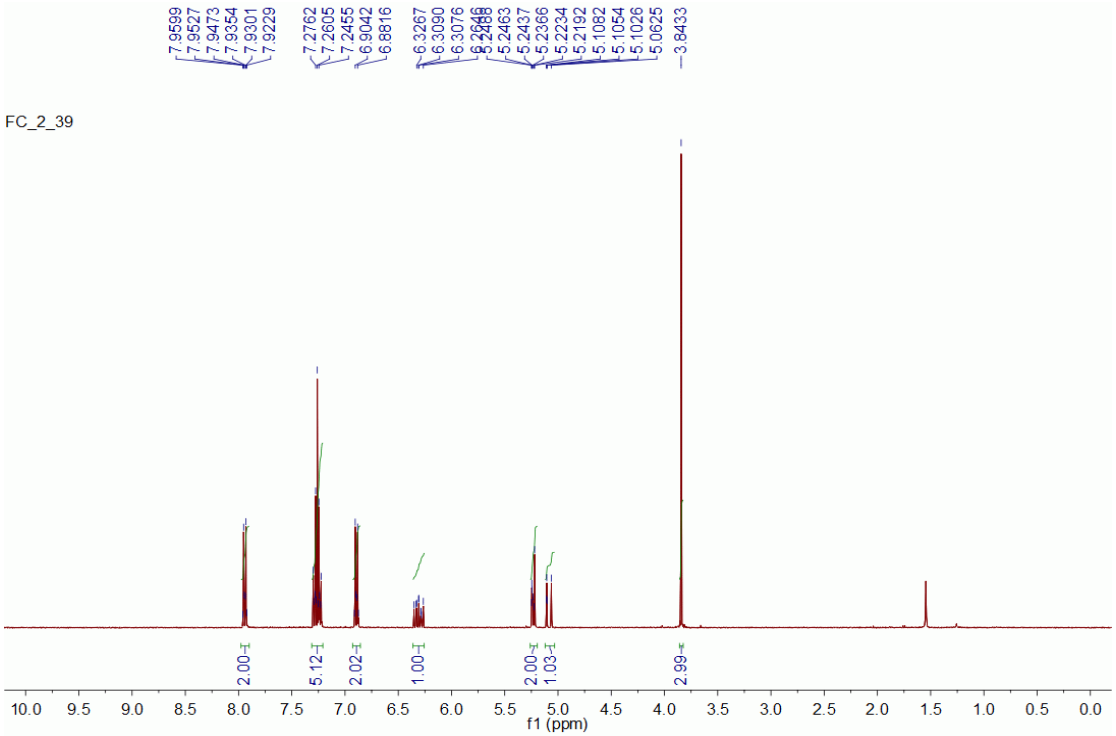
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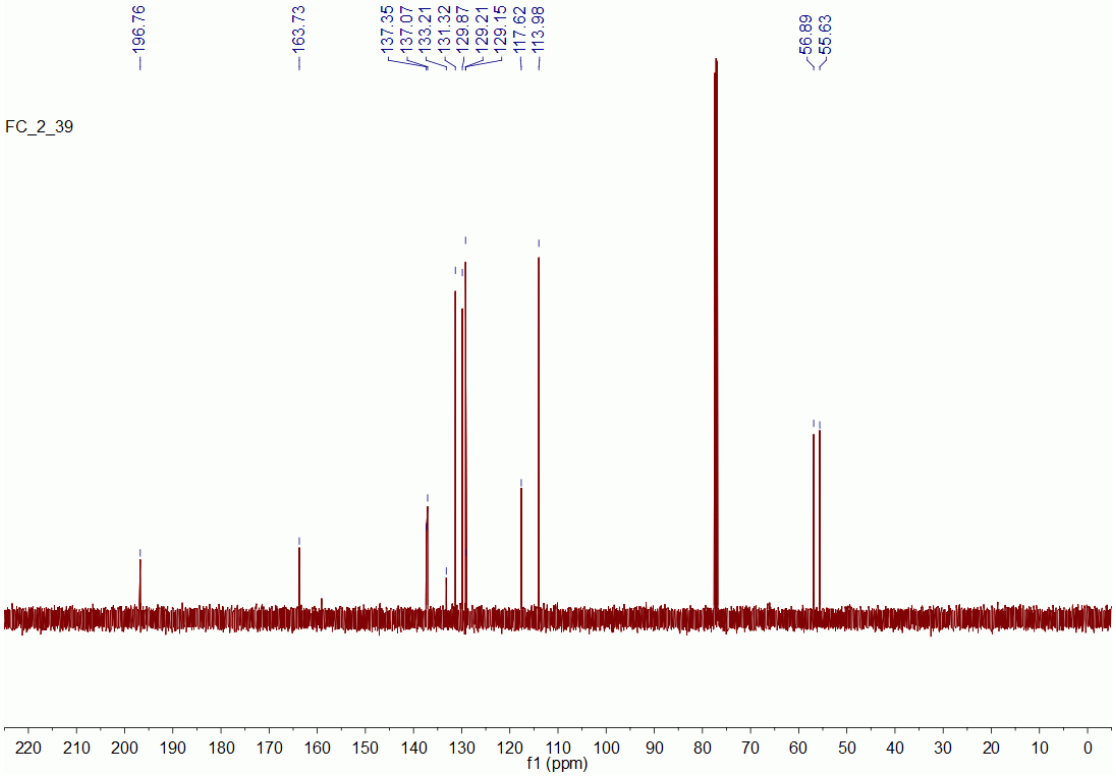
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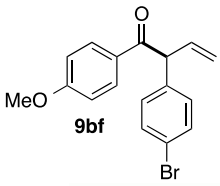
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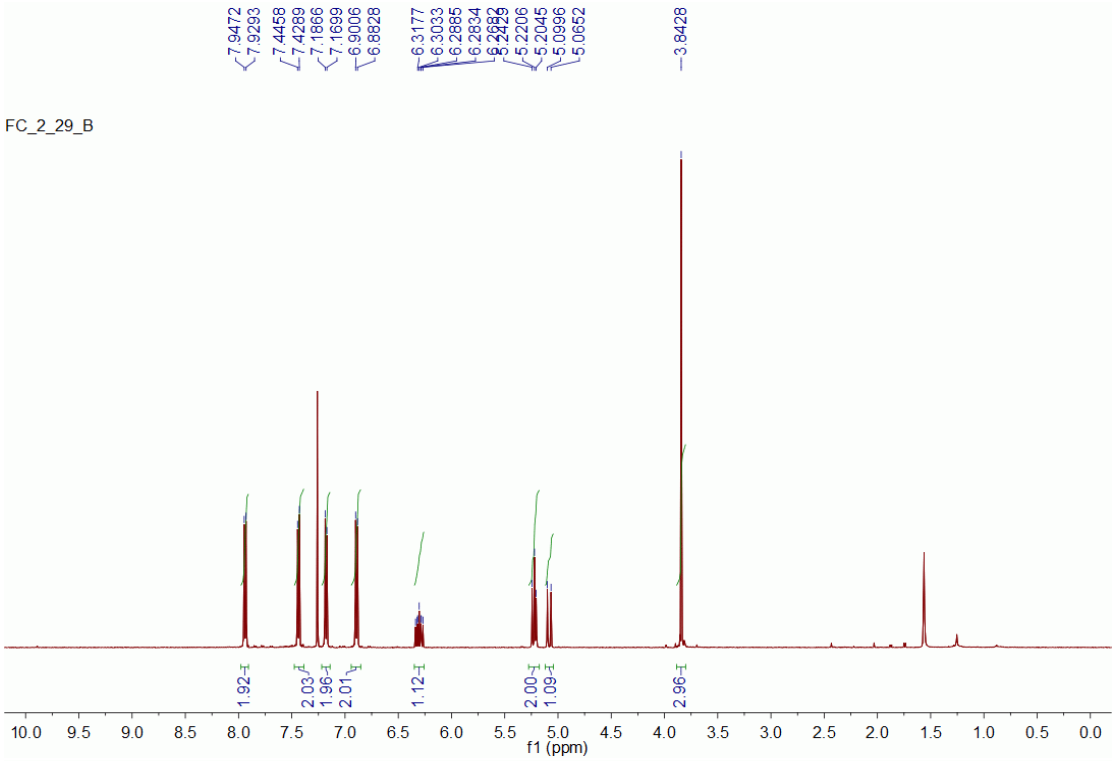
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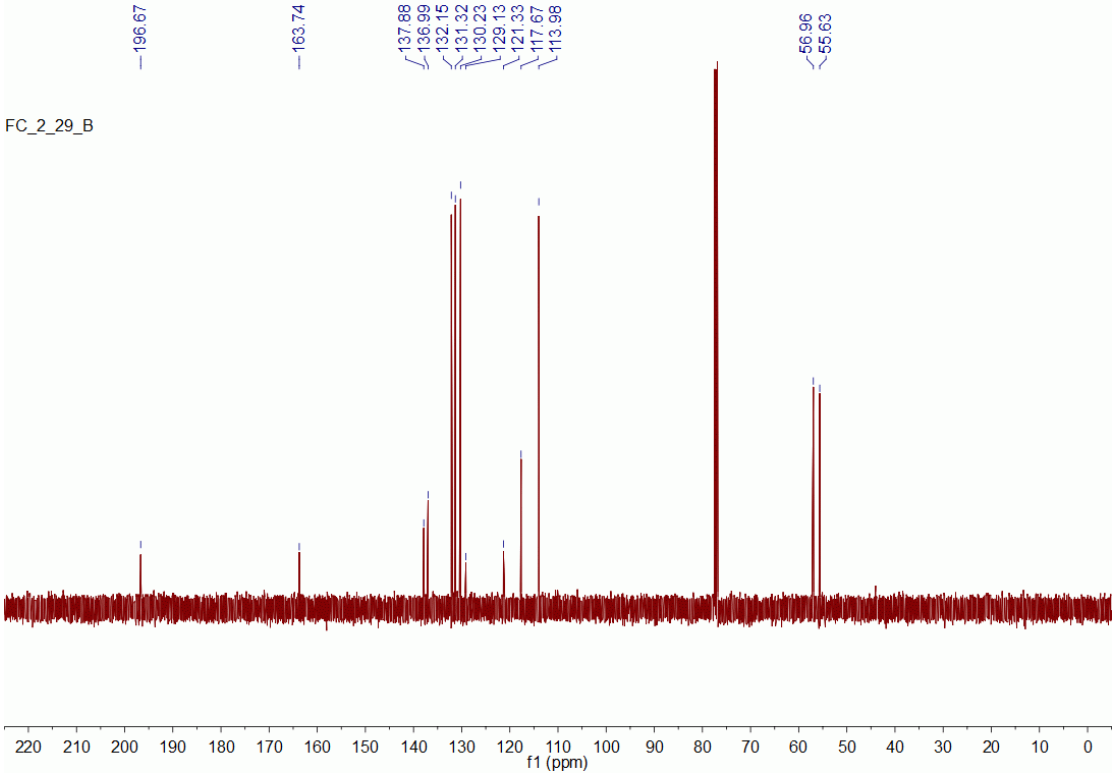
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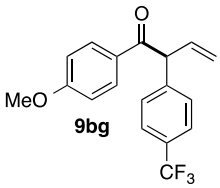
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CF3

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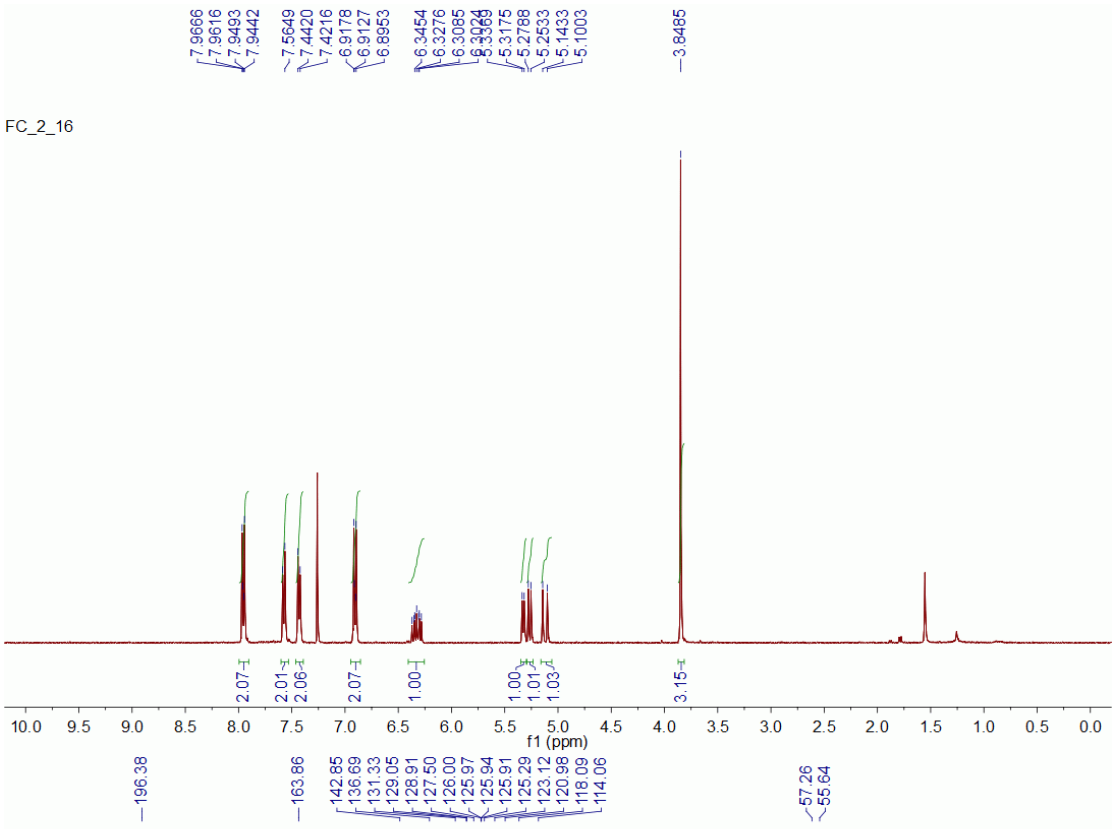
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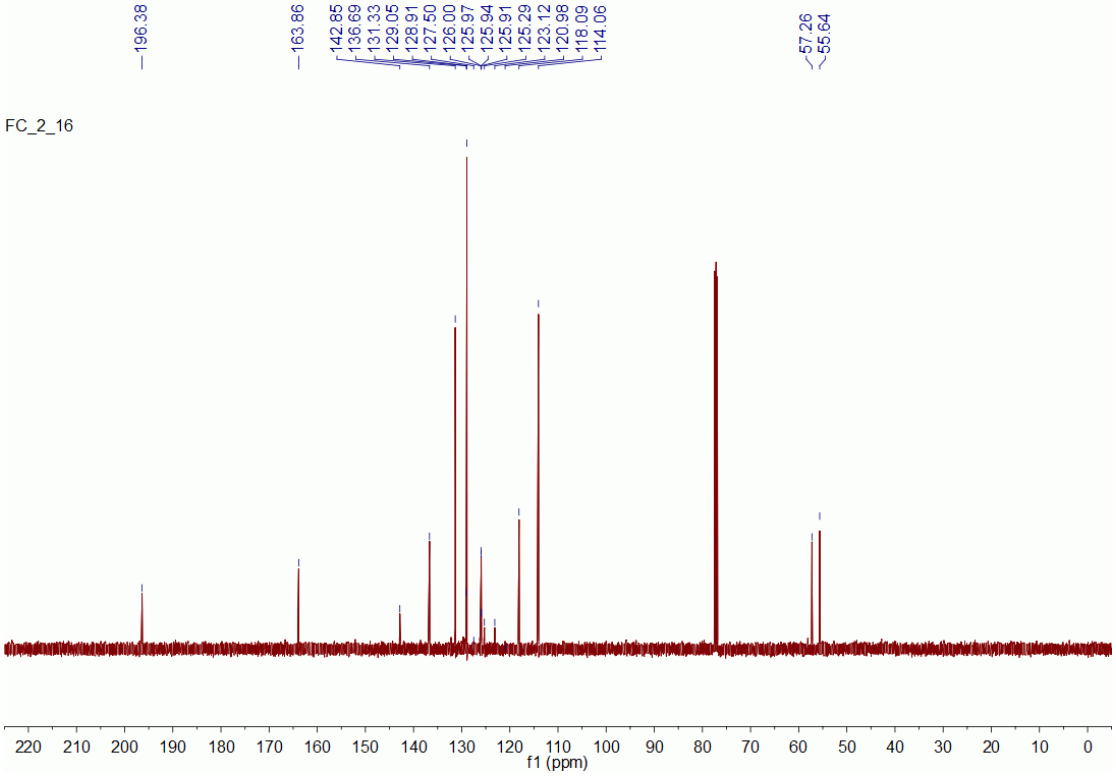
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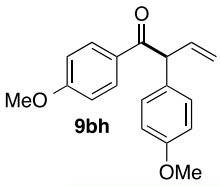
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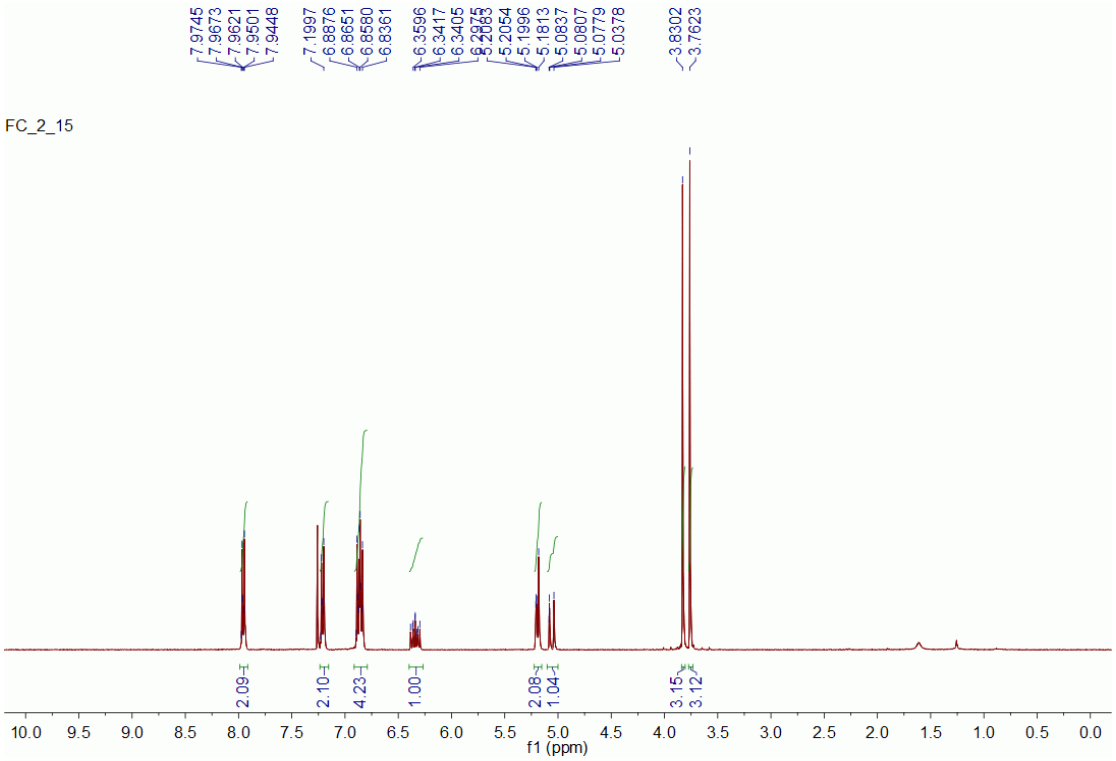
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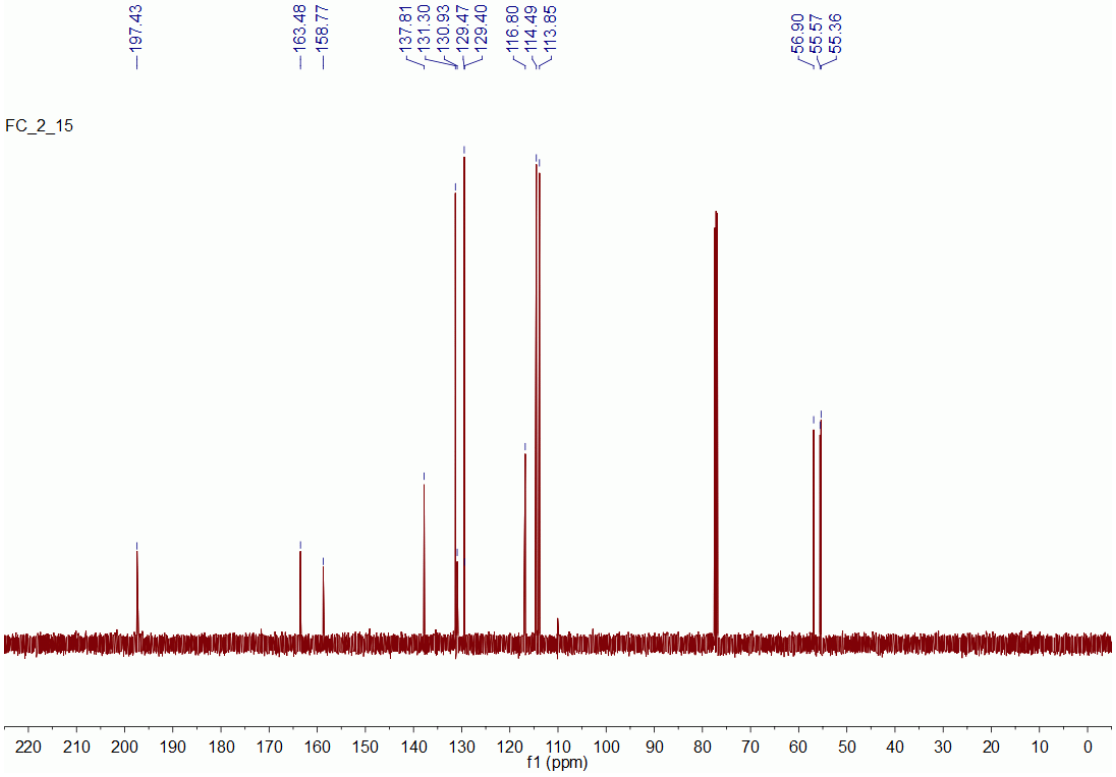
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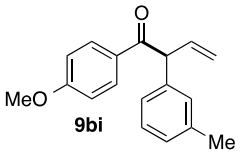
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Me

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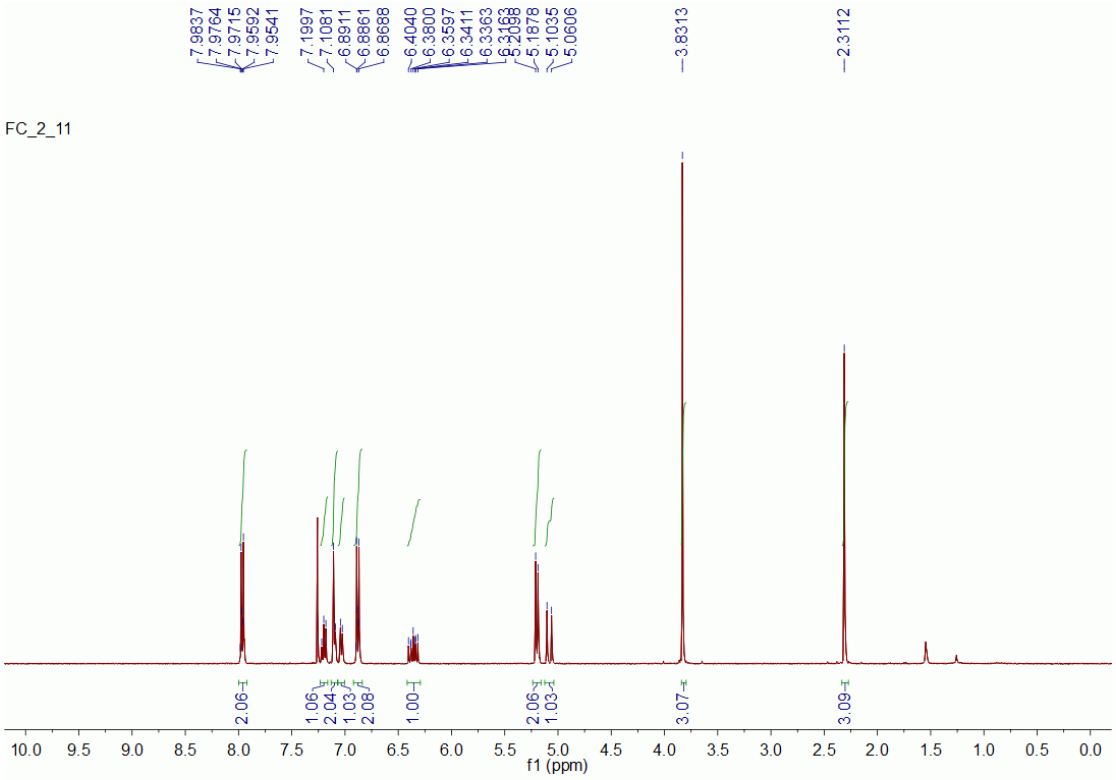
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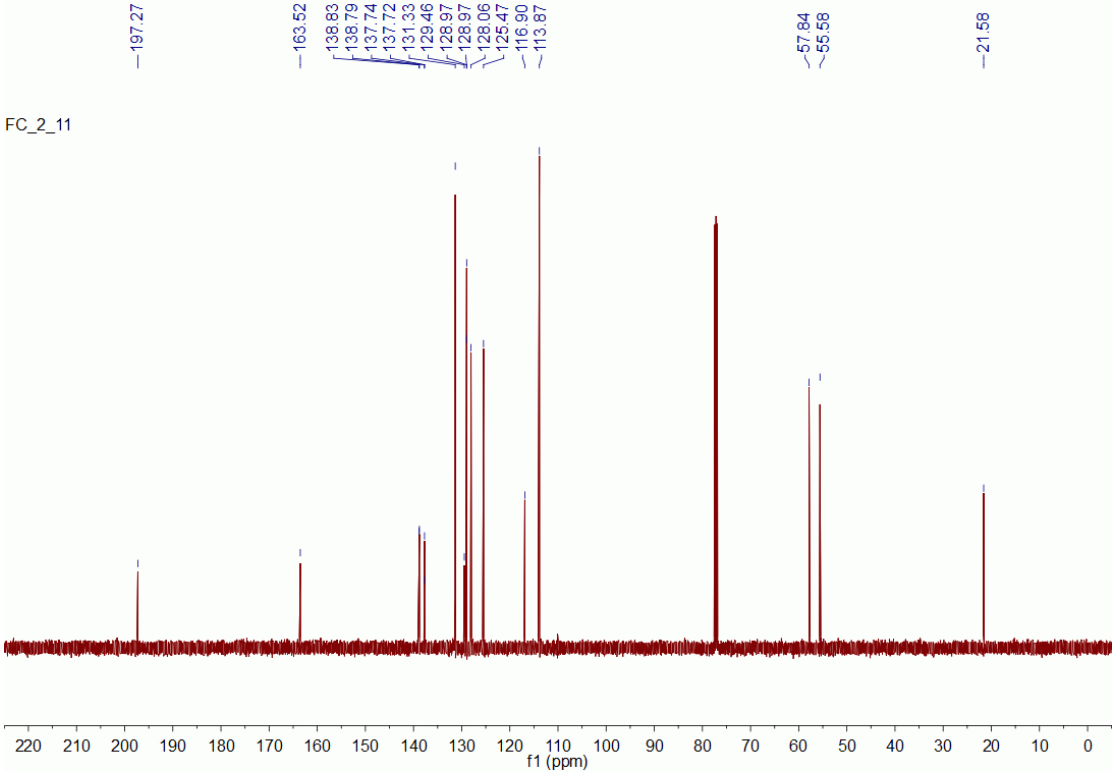
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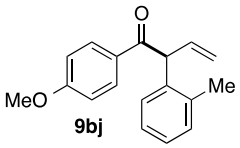
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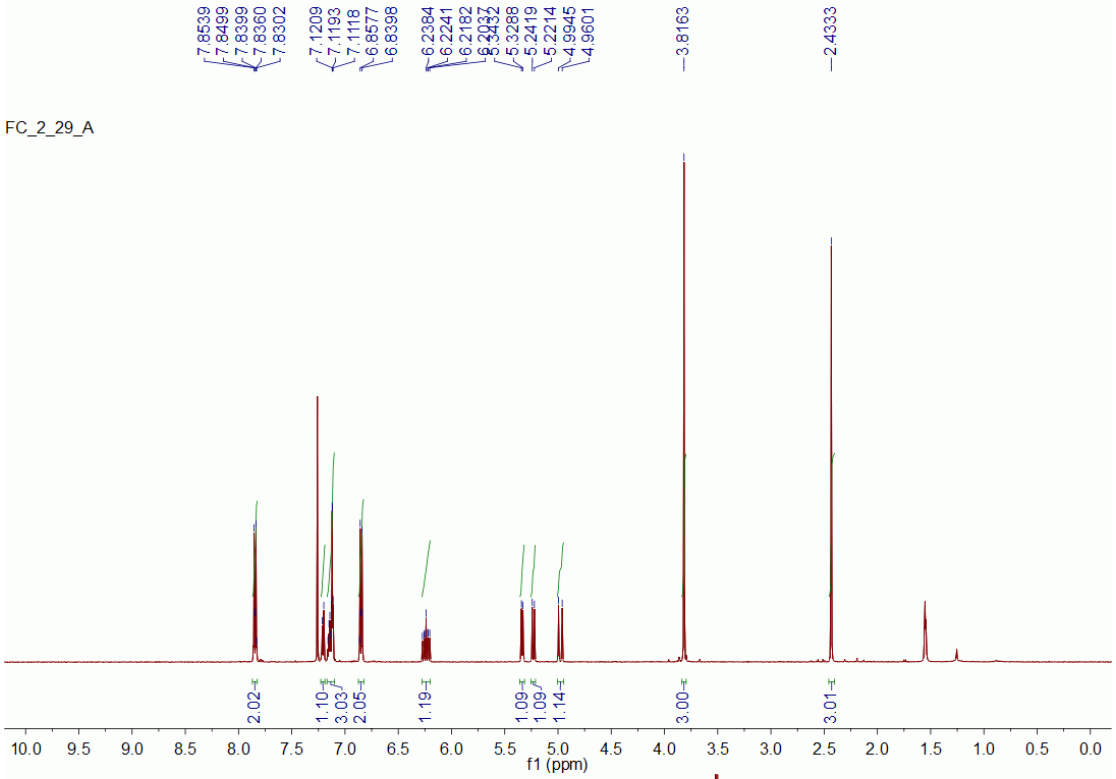
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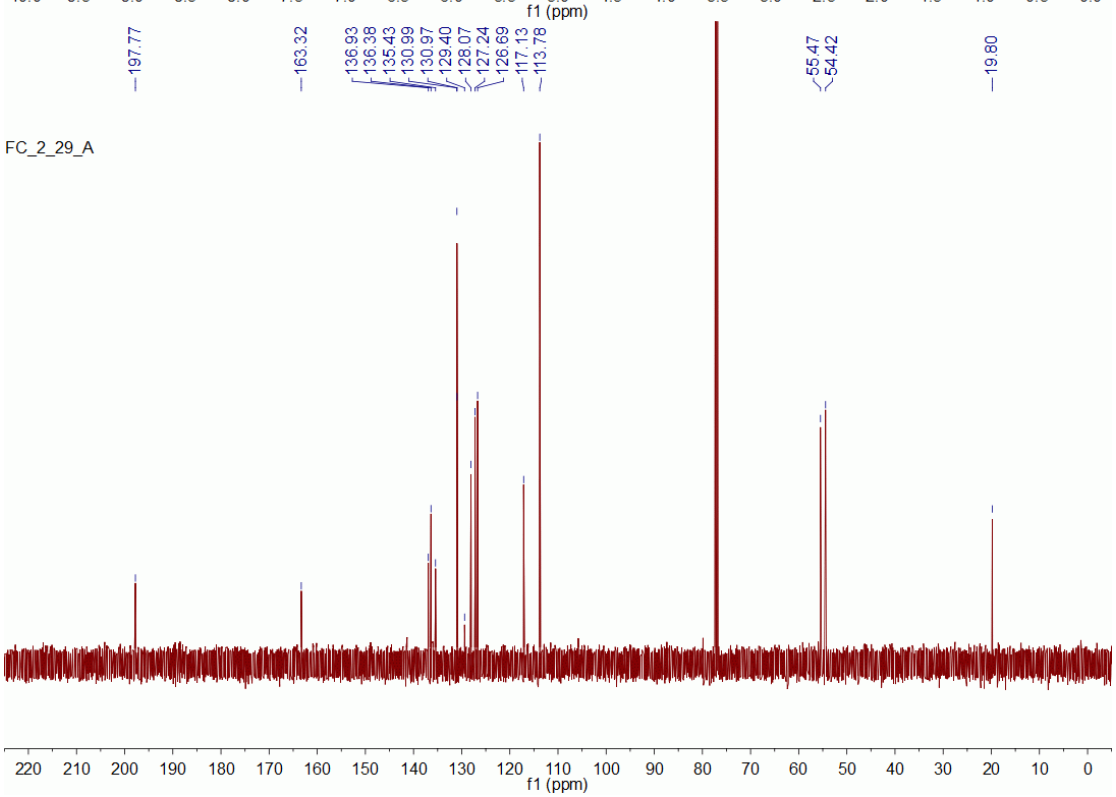
f1 (ppm)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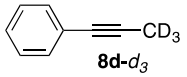
f1 (ppm)



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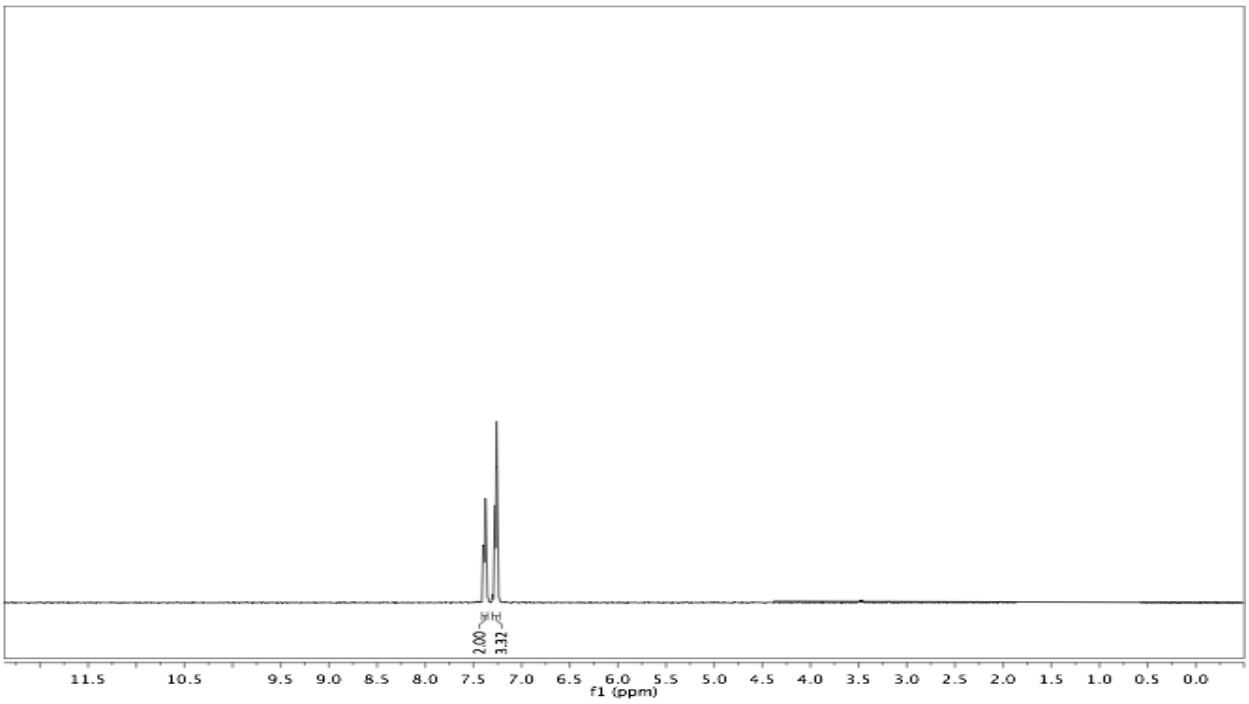

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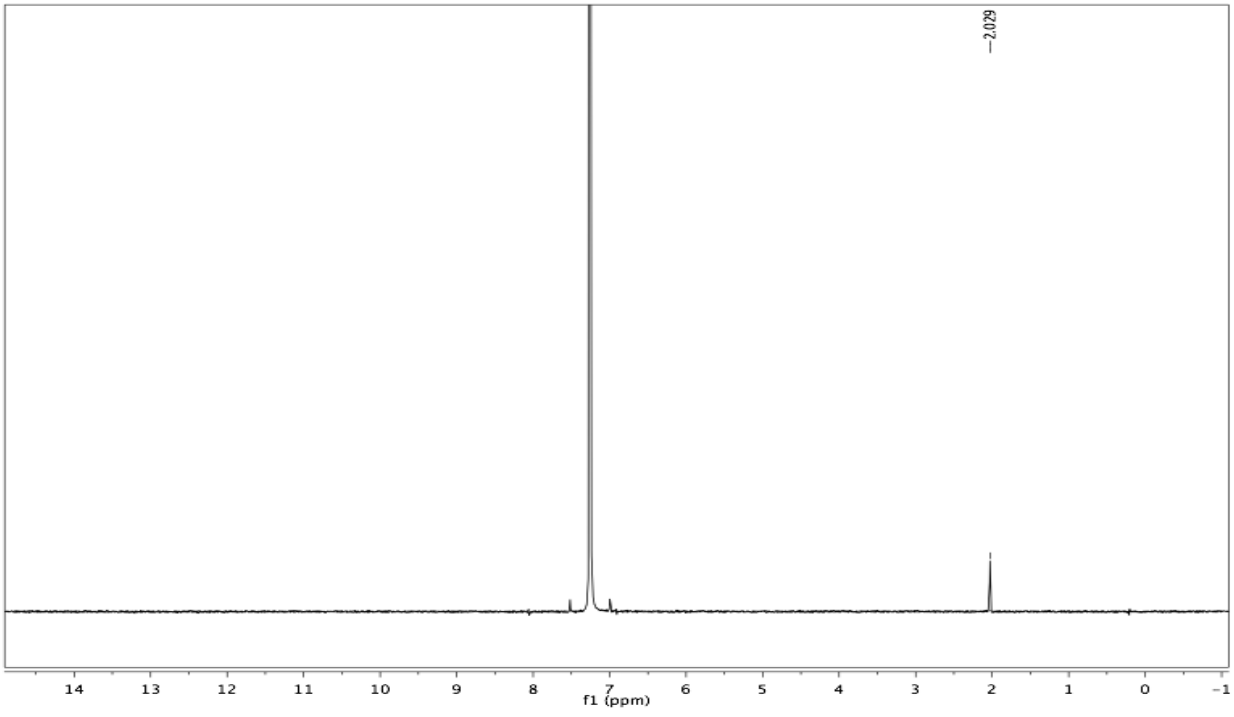

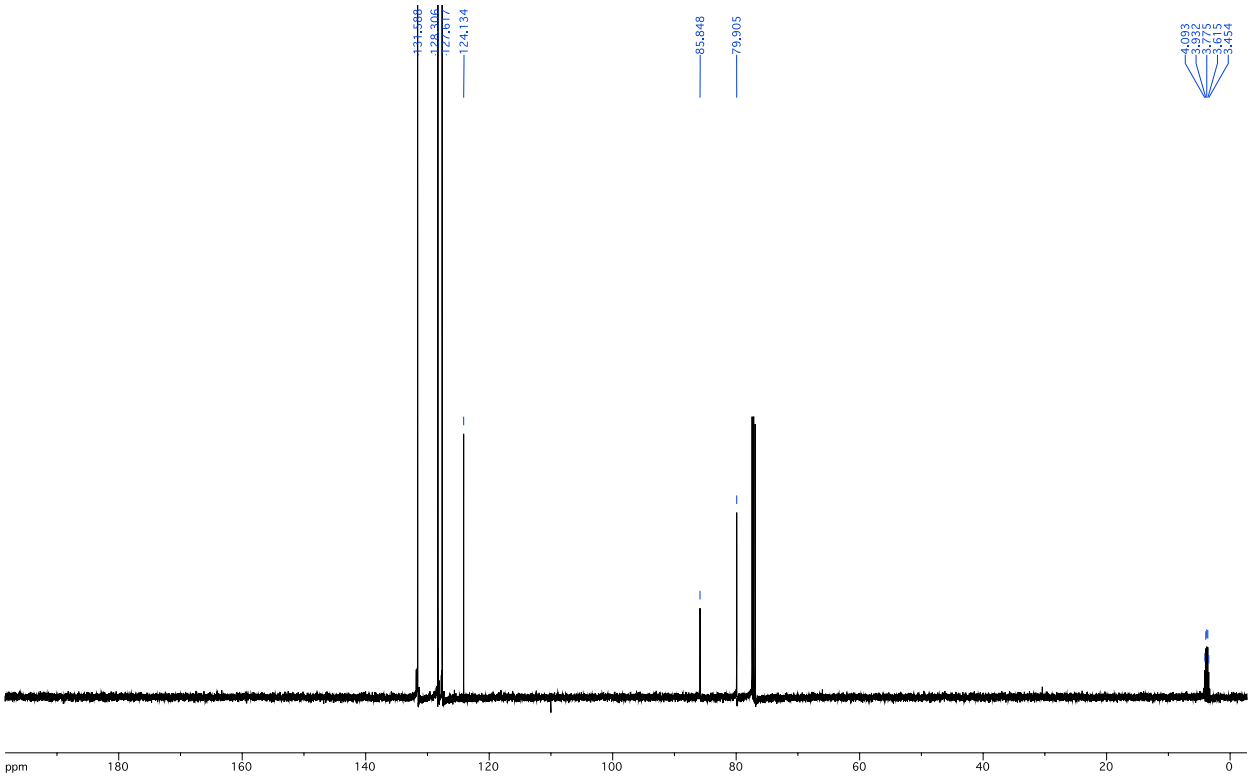
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ppm
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120
100
80
60
40
20
0

Appendix 2.2: Supporting Information for Chapter 2.2

Tandem Rh-Catalysis: Decarboxylative *β*-Keto Acid and Alkyne Cross-Coupling

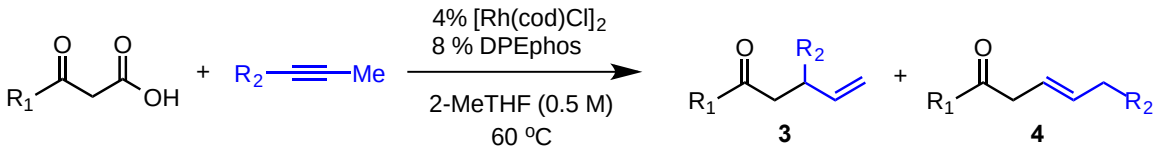
Table of Contents: **Page**

1. Materials and Methods

All reactions were run in oven-dried or flame-dried glassware under an atmosphere of N_2. Tetrahydrofuran, dichloromethane, toluene and diethyl ether were purified using an Innovative Technologies Pure Solv system, degassed by three freeze-pump-thaw cycles, and stored over 3A MS within an N_2 filled glove box. 1,4-Dioxane, 1,2-dimethoxyethane and dimethylsulfoxide were refluxed with CaH_2 and distilled prior to use. The molarity of organolithium reagents was determined by titration with *iso*-propanol/1,10-phenanthroline. Reactions were monitored either *via* gas chromatography using an Agilent Technologies 7890A GC system equipped with an Agilent Technologies 5975C inert XL EI/CI MSD or by analytical thin-layer chromatography on EMD Silica Gel 60 F_{254} plates. Visualization of the developed plates was performed under UV light (254 nm) or using either $KMnO_4$ or *p*-anisaldehyde stain. Column chromatography was performed with Silicycle Silia-P Flash Silica Gel using glass columns. Automated column chromatography was performed using either a Biotage SP1 or Teledyne Isco CombiFlash Rf 200 purification system. ^1H, ^{13}C, and ^{19}F NMR spectra were recorded on a Bruker DRX-400 (400 MHz ^1H, 100 MHz ^{13}C, 376.5 MHz ^{19}F), GN-500 (500 MHz ^1H, 125.7 MHz ^{13}C) or CRYO-500 (500 MHz ^1H, 125.7 MHz ^{13}C) spectrometer. ^1H NMR spectra were internally referenced to the residual solvent signal or TMS. ^{13}C NMR spectra were internally referenced to the residual solvent signal. Data for ^1H NMR are reported as follows: chemical shift (δ ppm), multiplicity (s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet, br = broad), coupling constant (Hz), integration. Data for ^{13}C NMR are reported in terms of chemical shift (δ, ppm). Infrared spectra were obtained on a Thermo Scientific Nicolet iS5 FT-IR spectrometer equipped with an iD5 ATR accessory. High resolution mass spectra (HRMS) was performed by the University of California, Irvine Mass Spectrometry Center.

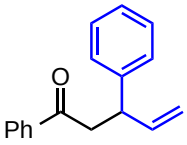
2. Ketone Synthesis

General Procedure for Alkyne and β-keto acid Coupling



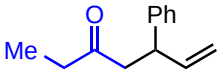
To a 1 dram vial equipped with a magnetic stir bar was added $[Rh(cod)Cl]_2$ (3.9 mg, 0.008 mmol), DPEphos (8.6 mg, 0.016 mmol), *β*-keto acid (0.40 mmol), alkyne (0.20 mmol), and 2-MeTHF (0.40 mL). In some cases, benzoic acid was added (12.2 mg, 0.10 mmol). The vial was then sealed with a Teflon-lined screw cap and heated to 60 °C for 24 hours. The resulting mixture was then cooled to room temperature. Chemo- and regioselectivities were determined by analysis of the crude reaction mixture by ^{1}H NMR spectroscopy. Ketone products were isolated by flash column chromatography or preparatory TLC.

1,3-diphenylpent-4-en-1-one (Figure 1, **3a**)



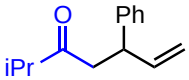
The title compound was synthesized according to the general procedure using $[Rh(cod)Cl]_2$ (2.0 mg, 0.004 mmol, 4 mol%), DPEphos (4.3 mg, 0.008 mmol, 8 mol%), benzoylacetic acid (32.8 mg, 0.2 mmol, 2 equiv), 1-phenyl-1-propyne (12.5 µL, 0.1 mmol, 1 equiv) and 2-MeTHF (200 µL, 0.5 M). After stirring at 60 °C for 7 hours, the yield was determined by GC-FID analysis using 1,3,5-trimethoxybenzene as an internal standard and branched to linear selectivity was determined by ^{1}H NMR analysis of the crude reaction mixture (97% yield, >20:1 branched:linear). **^{1}H NMR** (400 MHz, CDCl3) δ 8.03 – 7.91 (m, 2H), 7.64 – 7.56 (m, 1H), 7.53 – 7.44 (m, 2H), 7.41 – 7.30 (m, 4H), 7.30 – 7.19 (m, 1H), 6.12 (ddd, *J* = 17.1, 10.4, 6.8 Hz, 1H), 5.12 (tt, *J* = 17.2, 1.3 Hz, 2H), 4.21 (q, *J* = 6.7 Hz, 1H), 3.47 (qd, *J* = 16.6, 7.1 Hz, 2H).

5-phenylhept-6-en-3-one (Figure 2, **3b**)



The title compound was synthesized according to the general procedure with benzoic acid, ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (10% ethyl acetate in hexanes) as a yellow oil (33.8 mg, 90% yield). The ^{1}H NMR spectrum is in accordance with the literature.[16] **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.32–7.27 (m, 2H), 7.22–7.18 (m, 3H), 5.97 (ddd, *J* = 17.1, 10.3, 6.8 Hz, 1H), 5.07–4.99 (m, 2H), 3.93 (q, *J* = 7.2 Hz, 1H), 2.89–2.76 (m, 2H), 2.44–2.25 (m, 2H), 0.98 (d, *J* = 14.6 Hz, 3H).

2-methyl-5-phenylhept-6-en-3-one (Figure 2, **3c**)

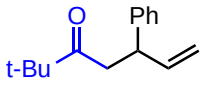


The title compound was synthesized according to the general procedure with benzoic acid, ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (10% ethyl acetate in hexanes) as a yellow oil

[16] E. C. Burger, J. A. Tunge, *Org. Lett.*, 2004**, 6**, 2603.

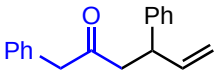
(32.4 mg, 80% yield). The ^{1}H NMR spectrum is in accordance with the literature.[17] **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.31–7.27 (m, 2H), 7.20 (t, *J* = 7.1 Hz, 3H), 5.98 (ddd, *J* = 17.1, 10.4, 6.8 Hz, 1H), 5.06–4.99 (m, 2H), 3.96 (q, *J* = 7.1 Hz, 1H), 2.93–2.81 (m, 2H), 2.50 (7, *J* = 6.9 Hz, 1H), 1.04 (d, *J* = 6.9 Hz, 3H), 0.98 (d, *J* = 6.9 Hz, 3H).

2,2-dimethyl-5-phenylhept-6-en-3-one (Figure 2, **3d**)



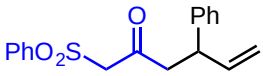
The title compound was synthesized according to the general procedure, ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (10% ethyl acetate in hexanes) as a yellow oil (36.5 mg, 85% yield). The ^{1}H NMR spectrum is in accordance with the literature.[18] **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.31–7.27 (m, 2H), 7.21–7.17 (m, 3H), 5.98 (ddd, *J* = 17.1, 10.4, 6.8 Hz, 1H), 5.06–4.99 (m, 2H), 3.99 (q, *J* = 7.0 Hz, 1H), 2.96–2.84 (m, 2H), 1.05 (s, 9H).

1,4-diphenylhex-5-en-2-one (Figure 2, **3e**)



The title compound was synthesized according to the general procedure, ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (5% ethyl acetate in hexanes) as a yellow oil (30.6 mg, 61% yield). The ^{1}H NMR spectrum is in accordance with the literature.[19] **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.33–7.26 (m, 5H), 7.25–7.18 (m, 1H), 7.16–7.13 (m, 2H), 7.11–7.09 (m, 2H), 5.93 (ddd, *J* = 17.1, 10.3, 6.8 Hz, 1H), 5.05–4.95 (m, 2H), 3.93 (q, *J* = 7.1 Hz, 1H), 3.60 (d, *J* = 1.3 Hz, 2H), 2.92–2.82 (m, 2H).

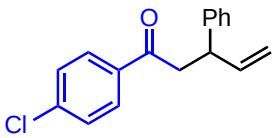
4-phenyl-1-(phenylsulfonyl)hex-5-en-2-one (Figure 2, **3f**)



The title compound was synthesized according to the general procedure, ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (5% ethyl acetate in hexanes) as a yellow oil (57.9 mg, 92% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.71–7.62 (m, 3H), 7.52–7.48 (m, 2H), 7.34–7.30 (m, 2H), 7.27–7.21 (m, 3H), 5.97 (ddd, *J* = 17.2, 10.4, 6.8 Hz, 1H), 5.10–5.03 (m, 2H), 4.06 (q, *J* = 13.4 Hz, 2H), 3.89 (q, *J* = 7.1 Hz, 1H), 3.20 (qd, *J* = 17.6, 7.4 Hz, 2H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 196.5, 142.2, 140.1, 138.3, 134.4, 129.4, 128.8, 128.4, 128.0, 127.0, 115.2, 67.4, 49.6, 44.2. **IR** (ATR): 3062, 1721, 1447, 1320, 1310, 1151, 1085, 912, 734, 686 cm^{-1}. **HRMS** calculated for $C_{18}H_{18}O_3SNa$ $[M+Na]^+$ 337.0874, found 337.0881.

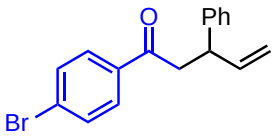
[17] G. W. Daub, M. A. McCoy, M. G. Sanchez, J. S. Carter, *J. Org. Chem.*, 1983**, 48**, 3876.
[18] T. Hirao, T. Fujii, Y. Oshiro, *Tetrahedron* 1994, **50**, 10207.
[19] E. C. Burger, J. A. Tunge, *Chem. Commun.*, 2005, **22**, 2835.

1-(4-chlorophenyl)-3-phenylpent-4-en-1-one (Figure 2, **3g**)



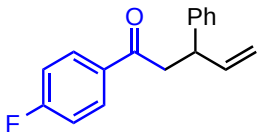
The title compound was synthesized according to the general procedure, ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (5% ethyl acetate in hexanes) as a yellow oil (38.1 mg, 70% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.87 (d, *J* = 8.6 Hz, 2H), 7.43 (d, *J* = 8.6 Hz, 2H), 7.34–7.30 (m, 2H), 7.28–7.20 (m, 3H), 6.06 (ddd, *J* = 17.2, 10.4, 6.8 Hz, 1H), 5.11–5.02 (m, 2H), 4.13 (q, *J* = 6.8 Hz, 1H), 3.38 (qd, *J* = 16.5, 7.7 Hz, 2H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 197.3, 143.1, 140.7, 139.7, 135.6, 129.7, 129.1, 128.8, 127.9, 126.9, 115.0, 44.8, 44.2. **IR** (ATR): 3028, 1684, 1588, 1488, 1399, 1202, 1090, 987, 815, 699 cm^{-1}. **HRMS** calculated for $C_{17}H_{19}ClNO$ $[M+NH_4]^+$ 288.1155, found 288.1154.

1-(4-bromophenyl)-3-phenylpent-4-en-1-one (Figure 2, **3h**)



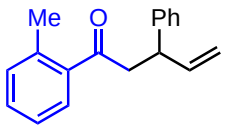
The title compound was synthesized according to the general procedure, ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (10% ethyl acetate in hexanes) as a colorless oil (47.6 mg, 76% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.84 (d, *J* = 8.7 Hz, 2H), 7.64 (d, *J* = 8.9 Hz, 2H), 7.38–7.35 (m, 2H), 7.32–7.25 (m, 3H), 6.10 (ddd, *J* = 17.2, 10.4, 6.7 Hz, 1H), 5.15–5.08 (m, 2H), 4.18 (q, *J* = 6.9 Hz, 1H), 3.42 (qd, *J* = 16.5, 7.6 Hz, 2H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 197.4, 143.1, 140.7, 136.0, 132.1, 130.0, 128.8, 128.4, 127.9, 126.8, 115.0, 44.7, 44.2. **IR** (ATR): 3028, 1685, 1568, 1484, 1396, 1201, 1070, 987, 811, 699 cm^{-1}. **HRMS** calculated for $C_{17}H_{15}BrONa$ $[M+Na]^+$ 337.0204, found 337.0211.

1-(4-fluorophenyl)-3-phenylpent-4-en-1-one (Figure 2, **3i**)



The title compound was synthesized according to the general procedure, ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (5% ethyl acetate in hexanes) as a colorless oil (46.4 mg, 91% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 8.03 (dd, *J* = 8.9, 5.4 Hz, 2H), 7.40–7.37 (m, 2H), 7.35–7.32 (m, 2H), 7.30–7.27 (m, 1H), 7.18 (t, *J* = 8.6 Hz, 2H), 6.13 (ddd, *J* = 17.2, 10.4, 6.9 Hz, 1H), 5.17–5.09 (m, 2H), 4.21 (q, *J* = 6.9 Hz, 1H), 3.45 (qd, *J* = 16.7, 7.6 Hz, 2H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 196.8, 165.9 (d, *J* = 253.9 Hz), 143.2, 140.8, 133.7 (d, *J* = 2.9 Hz), 130.9 (d, *J* = 9.0 Hz), 128.8, 127.9, 126.8, 115.8 (d, *J* = 21.6 Hz), 115.0, 44.8, 44.1. **^{19}F NMR** (376 MHz, $CDCl_3$) δ -105.7. **IR** (ATR): 3028, 1683, 1596, 1505, 1408, 1232, 1155, 989, 829, 699 cm^{-1}. **HRMS** calculated for $C_{17}H_{15}FONa$ $[M+Na]^+$ 277.1005, found 277.0999.

3-phenyl-1-(*o*-tolyl)pent-4-en-1-one (Figure 2, **3j**)

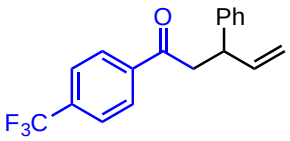


The title compound was synthesized according to the general, ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (5% ethyl acetate in hexanes) as a yellow oil (35.1 mg, 70% yield). The ^{1}H NMR spectrum is in accordance with the literature.[20] **^{1}H NMR** (400

[20] S. Chen, G. Lu, C. Cai, *Chem. Commun.*, 2015, **51**,11512.

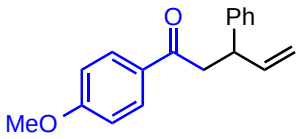
MHz, $CDCl_3$): δ 7.56–7.54 (m, 1H), 7.34 (dd, *J* = 7.5, 1.3 Hz, 1H), 7.32–7.28 (m, 2H), 7.24–7.19 (m, 5H), 6.04 (ddd, *J* = 17.1, 10.3, 6.8 Hz, 1H), 5.09–5.02 (m, 2H), 4.08 (q, *J* = 7.1 Hz, 1H), 3.39–3.27 (m, 2H), 2.35 (s, 3H).

3-phenyl-1-(4-(trifluoromethyl)phenyl)pent-4-en-1-one (Figure 2, **3k**)



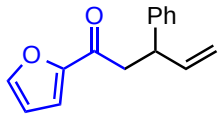
The title compound was synthesized according to the general, ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (10% ethyl acetate in hexanes) as a colorless oil (38.2 mg, 63% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ・8.02 (d, *J* = 8.2 Hz, 2H), 7.72 (d, *J* = 8.2 Hz, 2H), 7.34–7.30 (m, 2H), 7.28–7.20 (m, 3H), 6.06 (ddd, *J* = 17.2, 10.4, 6.7 Hz, 1H), 5.12–5.03 (m, 2H), 4.14 (q, *J* = 6.8 Hz, 1H), 3.43 (qd, *J* = 16.7, 7.5 Hz, 2H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 197.6, 143.0, 140.54, 140.53, 139.9 (q, *J* = 0.9 Hz), 134.5 (q, *J* = 32.6 Hz), 128.9, 128.6, 127.9, 126.9, 125.9 (q, *J* = 3.8 Hz), 115.2, 44.7, 44.5. **^{19}F NMR** (376 MHz, $CDCl_3$) δ –63.5. **IR** (ATR): 3029, 1692, 1511, 1410, 1322, 1167, 1126, 1065, 846, 700 cm^{-1}. **HRMS** calculated for $C_{18}H_{16}F_3O$ $[M+H]^+$ 305.1153, found 305.1153.

1-(4-methoxyphenyl)-3-phenylpent-4-en-1-one (Figure 2, **3l**)



The title compound was synthesized according to the general procedure, ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (10% ethyl acetate in hexanes) as a yellow oil (32.4 mg, 61% yield). The ^{1}H NMR spectrum is in accordance with the literature.[21] **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.94–7.91 (m, 2H), 7.32–7.25 (m, 4H), 7.22–7.18 (m, 1H), 6.94–6.90 (m, 2H), 6.05 (ddd, *J* = 17.1, 10.4, 6.8 Hz, 1H), 5.08–5.00 (m, 2H), 4.13 (q, *J* = 7.1 Hz, 1H), 3.86 (s, 3H), 3.35 (qd, *J* = 16.3, 7.1 Hz, 2H).

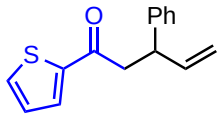
1-(furan-2-yl)-3-phenylpent-4-en-1-one (Figure 2, **3m**)



The title compound was synthesized according to the general procedure with benzoic acid, ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (10% ethyl acetate in hexanes) as a colorless oil (40.7 mg, 90% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.56 (s, 1H), 7.31–7.25 (m, 4H), 7.20 (t, *J* = 7.0 Hz, 1H), 7.15 (d, *J* = 3.2 Hz, 1H), 6.04 (ddd, *J* = 17.0, 10.2, 7.0 Hz, 1H), 5.08–5.04 (m, 2H), 4.11 (q, *J* = 6.8 Hz, 1H), 3.29 (dd, *J* = 15.7, 7.9 Hz, 1H), 3.21 (dd, *J* = 15.7, 6.6 Hz, 1H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 187.7, 153.1, 146.5, 143.0, 140.6, 128.7, 127.9, 126.8, 117.3, 115.0, 112.4, 44.7, 44.0. **IR** (ATR): 3028, 1671, 1567, 1466, 1393, 1268, 1156, 915, 759, 699 cm^{-1}. **HRMS** calculated for $C_{15}H_{14}O_2Na$ $[M+Na]^+$ 249.0892, found 249.0895.

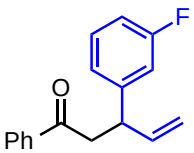
[21] H. He, X.-J. Zheng, Y. Li, L.-X. Dai, S.-L. You, *Org. Lett.*, 2007, **9**, 4339.

3-phenyl-1-(thiophen-2-yl)pent-4-en-1-one (Figure 2, **3n**)



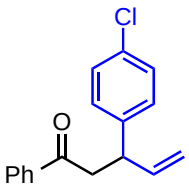
The title compound was synthesized according to the general procedure, ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (10% ethyl acetate in hexanes) as a colorless oil (43.2 mg, 89% yield). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.69 (d, *J* = 3.9 Hz, 1H), 7.60 (d, *J* = 5.4 Hz, 1H), 7.32–7.25 (m, 4H), 7.20 (t, *J* = 6.9 Hz, 1H), 7.09 (t, *J* = 3.7 Hz, 1H), 6.05 (ddd, *J* = 17.0, 10.3, 6.8 Hz, 1H), 5.09–5.04 (m, 2H), 4.13 (q, *J* = 6.9 Hz, 1H), 3.36 (dd, *J* = 15.9, 7.8 Hz, 1H), 3.28 (dd, *J* = 15.9, 6.6 Hz, 1H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 191.3, 144.7, 143.0, 140.5, 133.9, 132.0, 128.8, 128.3, 127.9, 126.8, 115.1, 45.0. **IR** (ATR): 3081, 3027, 1657, 1413, 1258, 1061, 916, 857, 723, 699 cm^{-1}. **HRMS** calculated for $C_{15}H_{14}OSNa$ $[M+Na]^+$ 265.0663, found 265.0667.

3-(3-fluorophenyl)-1-phenylpent-4-en-1-one (Figure 3, **3o**)



The title compound was synthesized according to the general, ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (10% ethyl acetate in hexanes) as a colorless oil (15.8 mg, 68% yield). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.95–7.92 (m, 2H), 7.58–7.54 (m, 1H), 7.48–7.43 (m, 2H), 7.29–7.23 (m, 1H), 7.05 (dddd, *J* = 7.7, 1.6, 1.0, 0.5 Hz, 1H), 6.99–6.95 (m, 1H), 6.89 (tdd, *J* = 8.4, 2.5, 0.9 Hz, 1H), 6.02 (ddd, *J* = 17.1, 10.4, 6.8 Hz, 1H), 5.11–5.03 (m, 2H), 4.15 (q, *J* = 6.9 Hz, 1H), 3.39 (qd, *J* = 14.5, 7.1 Hz, 2H). **^{19}F NMR** (376 MHz, $CDCl_3$): δ -113.5. **^{13}C NMR** (101 MHz, $CDCl_3$): δ 198.0, 164.3, 161.9, 145.92, 145.85, 140.2, 137.1, 133.3, 130.19, 130.11, 128.8, 128.2, 123.61, 123.58, 115.4, 114.9, 114.7, 113.7, 113.5, 77.2, 44.3, 43.9. **HRMS** calculated for C17H19FON $[M+NH_4]^+$ 272.1451, found 272.1449. **IR** (ATR): 3061, 2927, 1684, 1588, 1447, 1260, 1239, 988, 912, 784, 756, 732, 688 cm^{-1}.

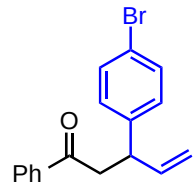
3-(4-chlorophenyl)-1-phenylpent-4-en-1-one (Figure 3, **3p**)



The title compound was synthesized according to the general procedure, ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (5% ethyl acetate in hexanes) as a colorless oil (40.6 mg, 75% yield). The ^{1}H NMR spectrum is in accordance with the literature.[22] **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.91–7.89 (m, 2H), 7.56–7.52 (m, 1H), 7.46–7.41 (m, 2H), 7.27–7.23 (m, 3H), 7.19–7.16 (m, 2H), 6.00 (ddd, *J* = 17.1, 10.4, 6.7 Hz, 1H), 5.09–4.99 (m, 2H), 4.11 (q, *J* = 6.9 Hz, 1H), 3.36 (qd, *J* = 15.3, 7.1 Hz, 2H).

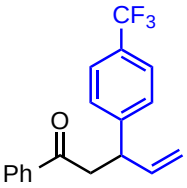
[22] S. Chen, G. Lu, C. Cai, *Chem. Commun.*, 2015, **51**,11512.

3-(4-bromophenyl)-1-phenypent-4-en-1-one (Figure 3, **3q**)



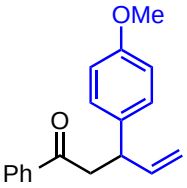
The title compound was synthesized according to the general procedure, ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (5% ethyl acetate in hexanes) as a colorless oil (38.5 mg, 57% yield). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.93–7.91 (m, 2H), 7.58–7.54 (m, 1H), 7.47–7.40 (m, 4H), 7.16–7.12 (m, 2H), 6.01 (ddd, *J* = 17.1, 10.4, 6.7 Hz, 1H), 5.11–5.01 (m, 2H), 4.11 (q, *J* = 6.9 Hz, 1H), 3.38 (qd, *J* = 15.3, 7.1 Hz, 2H). **^{13}C NMR** (101 MHz, $CDCl_3$): δ 198.0, 142.3, 140.3, 137.1, 133.3, 131.8, 129.7, 128.8, 128.2, 120.5, 115.3, 77.2, 43.99, 43.90. **HRMS** calculated for $C_{17}H_{16}BrO$ $[M+H]^+$ 315.0396, found 315.0385. **IR** (ATR): 1683, 1487, 1010, 989, 908, 823, 750, 729, 688, 648 cm^{-1}.

1-phenyl-3-(4-trifluoromethyl-phenyl)pent-4-en-1-one (Figure 3, **3r**)



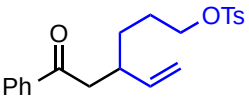
The title compound was synthesized according to the general procedure, ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (5% ethyl acetate in hexanes) as a colorless oil (49.4 mg, 81% yield). The ^{1}H NMR spectrum is in accordance with the literature.[23] **^{1}H NMR** (400 MHz; $CDCl_3$): δ 7.95–7.92 (m, 2H), 7.58–7.54 (m, 3H), 7.48–7.38 (m, 4H), 6.04 (ddd, *J* = 17.1, 10.4, 6.7 Hz, 1H), 5.14–5.04 (m, 2H), 4.25–4.20 (m, 1H), 3.50–3.37 (m, 2H).

3-(4-methoxyphenyl)-1-phenylpent-4-en-1-one (Figure 3, **3s**)



The title compound was synthesized according to the general, ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (5% ethyl acetate in hexanes) as a colorless oil (29.0 mg, 55% yield). The ^{1}H NMR spectrum is in accordance with the literature.[24] **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.94–7.92 (m, 2H), 7.57–7.53 (m, 1H), 7.46–7.43 (m, 2H), 7.19–7.16 (m, 2H), 6.87–6.83 (m, 2H), 6.04 (ddd, *J* = 17.1, 10.4, 6.7 Hz, 1H), 5.07–4.99 (m, 2H), 4.10 (q, *J* = 7.0 Hz, 1H), 3.78 (s, 3H), 3.37 (qd, *J* = 14.9, 7.2 Hz, 2H).

4-(2-oxo-2-phenylethyl_hex-5-en-1-yl 4-methylbenzenesulfonate (Figure 3, **3t**)

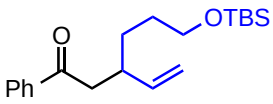


The title compound was synthesized according to the general procedure, ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (20% ethyl acetate in hexanes) as a yellow oil (60.4 mg, 85% yield). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.93–7.90 (m, 2H), 7.79–7.76 (m, 2H), 7.58–7.54 (m, 1H), 7.48–7.43 (m, 2H), 7.33 (dd, *J* = 8.6, 0.6 Hz, 2H), 5.64–5.55 (m, 1H), 4.99 (s, 1H), 4.96 (ddd, *J* = 6.5, 1.6, 0.8 Hz, 1H), 4.06–3.97 (m, 2H), 2.94 (qd, *J* = 14.6, 6.8 Hz, 2H), 2.73–2.64 (m, 1H), 2.43 (s, 3H), 1.78–1.66 (m, 1H), 1.65–1.59 (m, 1H), 1.57–1.44 (m, 1H), 1.41–1.30 (m, 2H). **^{13}C NMR** (101 MHz, $CDCl_3$): δ 198.9, 144.8, 140.7, 137.3,

[23] T. Graening, J. F. Hartwig, *J. Am. Chem. Soc.*, 2005, **127**, 17192.
[24] T. Graening, J. F. Hartwig, *J. Am. Chem. Soc.*, 2005, **127**, 17192.

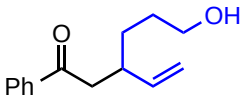
133.3, 133.2, 130.0, 128.8, 128.2, 128.03, 115.8, 70.7, 43.9, 39.3, 30.4, 26.8, 21.8. **HRMS** calculated for $C_{21}H_{24}O_4SNa$ $[M+Na]^+$ 395.1293, found 395.1282. **IR** (ATR): 1682, 1355, 1174, 913, 813, 689, 661 cm^{-1}.

6-((*tert*-butyldimethylsilyl)oxy)-1-phenyl-3-vinylhexan-1-one (Figure 3, **3u**)



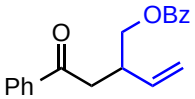
The title compound was synthesized according to the general procedure, ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (2% ethyl acetate in hexanes) as a yellow oil (38.5 mg, 58% yield). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.93 (dd, *J* = 7.2, 1.1 Hz, 2H), 7.57–7.53 (m, 1H), 7.47–7.43 (m, 2H), 5.72–5.63 (m, 1H), 5.02–4.97 (m, 2H), 3.61–3.58 (m, 2H), 2.99–2.97 (m, 2H), 2.79–2.72 (m, 1H), 1.61–1.47 (m, 3H), 1.43–1.37 (m, 1H), 0.88 (s, 9H), 0.03 (s, 6H). **^{13}C NMR** (101 MHz, $CDCl_3$): δ 199.5, 141.5, 137.5, 133.0, 128.7, 128.2, 115.1, 63.2, 44.1, 39.7, 31.0, 30.5, 26.1, 18.5, -5.1. **HRMS** calculated for $C_{20}H_{33}O_2Si$ $[M+H]^+$ 333.2250, found 333.2257. **IR** (ATR): 2928, 2856, 1683, 1448, 1250, 1095, 914, 833, 774, 688 cm^{-1}.

6-hydroxy-1-phenyl-3-vinylhexan-1-one (Figure 3, **3v**)



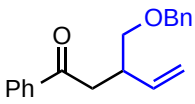
The title compound was synthesized according to the general procedure, ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (40% ethyl acetate in hexanes) as a yellow oil (22.1 mg, 53% yield). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.95–7.92 (m, 2H), 7.58–7.54 (m, 1H), 7.46 (tt, *J* = 7.5, 1.4 Hz, 2H), 5.69 (ddd, *J* = 17.1, 10.3, 8.3 Hz, 1H), 5.05–4.99 (m, 2H), 3.66 (t, *J* = 6.1 Hz, 2H), 3.01 (dd, *J* = 6.8, 1.8 Hz, 2H), 2.78 (s, 1H), 1.72 (d, *J* = 17.3 Hz, 1H), 1.68–1.52 (m, 3H), 1.45–1.38 (m, 1H). **^{13}C NMR** (101 MHz, $CDCl_3$): δ 199.5, 141.3, 137.4, 133.2, 128.7, 128.2, 115.3, 62.8, 44.0, 39.2, 30.7, 30.2. **HRMS** calculated for $C_{14}H_{18}O_2Na$ $[M+Na]^+$ 241.1205, found 241.1197. **IR** (ATR): 3367, 2927, 1681, 1596, 1448, 1211, 1055, 1000, 914, 751, 688, 657 cm^{-1}.

2-(2-oxo-2-phenylethyl)but-3-en-1-yl benzoate (Figure 3, **3w**)



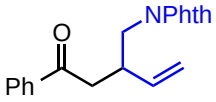
The title compound was synthesized according to the general procedure, ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (5% ethyl acetate in hexanes) as a yellow oil (30.1 mg, 51% yield). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 8.01–7.94 (m, 4H), 7.58–7.53 (m, 2H), 7.47–7.40 (m, 4H), 5.89 (ddd, *J* = 17.3, 10.4, 7.5 Hz, 1H), 5.23–5.13 (m, 2H), 4.45–4.34 (m, 2H), 3.40–3.32 (m, 1H), 3.19 (qd, *J* = 18.5, 6.7 Hz, 2H). **^{13}C NMR** (101 MHz, $CDCl_3$): δ 198.3, 166.5, 137.6, 137.1, 133.3, 133.1, 130.2, 129.7, 128.8, 128.5, 128.2, 117.0, 67.1, 40.2, 38.6. **HRMS** calculated for $C_{19}H_{19}O_3$ $[M+H]^+$ 295.1334, found 295.1324. **IR** (ATR): 1716, 1683, 1268, 1112, 752, 733, 710, 687 cm^{-1}.

3-((benzyloxy)methyl)-1-phenylpent-4-en-1-one (Figure 3, **3x**)



The title compound was synthesized according to the general procedure with benzoic acid, ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (5% ethyl acetate in hexanes) as a colorless oil (50.5 mg, 90% yield). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.96–7.94 (m, 2H), 7.57–7.53 (m, 1H), 7.47–7.43 (m, 2H), 7.34–7.25 (m, 5H), 5.85 (ddd, *J* = 17.4, 10.4, 7.4 Hz, 1H), 5.14–5.06 (m, 2H), 4.51 (s, 2H), 3.57–3.46 (m, 2H), 3.28 (dd, *J* = 16.2, 5.8 Hz, 1H), 3.20–3.11 (m, 1H), 3.00 (dd, *J* = 16.2, 7.3 Hz, 1H). **^{13}C NMR** (101 MHz, $CDCl_3$): δ 199.3, 138.7, 138.5, 137.4, 133.1, 128.7, 128.5, 128.3, 127.7, 123.0, 116.0, 73.2, 73.0, 40.4, 39.7. **HRMS** calculated for $C_{19}H_{21}O_2$ $[M+H]^+$ 281.1541, found 281.1537. **IR** (ATR): 1682, 1448, 1359, 1208, 1099, 1001, 915, 750, 689, 655 cm^{-1}.

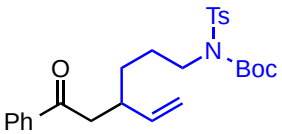
2-(2-(2-oxo-2-phenylethyl)but-3-en-1-yl)isoindoline-1,3-dione (Figure 3, **3y**)



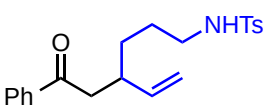
The title compound was synthesized according to the general procedure with benzoic acid, ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (20% ethyl acetate in hexanes) as a white solid (33.0 mg, 52% yield). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.91–7.89 (m, 2H), 7.82–7.79 (m, 2H), 7.72–7.67 (m, 2H), 7.56–7.52 (m, 1H), 7.43 (t, *J* = 7.7 Hz, 2H), 5.81–5.72 (m, 1H), 5.08–5.00 (m, 2H), 3.85–3.76 (m, 2H), 3.41–3.32 (m, 1H), 3.11 (d, *J* = 6.7 Hz, 2H). **^{13}C NMR** (101 MHz, $CDCl_3$): δ 198.1, 168.5, 138.1, 137.1, 134.1, 133.2, 132.1, 128.7, 128.2, 123.4, 117.4, 41.8, 41.3, 39.0. **HRMS** calculated for $C_{20}H_{17}NO_3Na$ $[M+Na]^+$ 342.1106, found 342.1107. **IR** (ATR): 1771, 1707, 1392, 1357, 753, 723, 713, 689 cm^{-1}.

***Tert*-butyl (4-(2-oxo-2-phenylethyl)hex-5-en-1-yl)(tosyl)carbamate** (Figure 3, **3z**)

The title compound was synthesized according to the general procedure, ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (10% ethyl acetate in hexanes) as a colorless oil (55.0 mg, 59% yield). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.95–7.93 (m, 2H), 7.76 (d, *J* = 8.3 Hz, 2H), 7.57–7.53 (m, 1H), 7.47–7.43 (m, 2H), 7.29–7.27 (m, 2H), 5.69 (ddd, *J* = 17.1, 10.3, 8.3 Hz, 1H), 5.05–5.00 (m, 2H), 3.84–3.79 (m, 2H), 3.00 (d, *J* = 6.8 Hz, 2H), 2.84–2.77 (m, 1H), 2.42 (s, 3H), 1.87–1.70 (m, 2H), 1.58–1.50 (m, 1H), 1.47–1.38 (m, 1H), 1.32 (s, 9H). **^{13}C NMR** (101 MHz, $CDCl_3$): δ 199.3, 151.1, 144.1, 141.0, 137.6, 137.4, 133.1, 129.3, 128.7, 128.2, 127.9, 115.6, 84.2, 47.2, 44.0, 39.5, 31.7, 28.0, 27.9, 21.7. **HRMS** calculated for $C_{26}H_{33}NO_5SNa$ $[M+Na]^+$ 494.1977, found 494.1985. **IR** (ATR): 1720, 1683, 1352, 1283, 1255, 1153, 1087, 914, 813, 753, 722, 689, 671, 597 cm^{-1}.



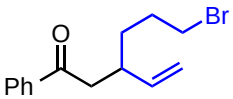
4-methyl-*N*-(4-(2-oxo-2-phenylethyl_hex-5-en-1-yl)benzenesulfonamide (Figure 3, **3aa**)



The title compound was synthesized according to the general procedure, ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (20% ethyl acetate in

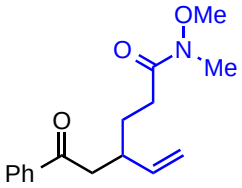
hexanes) as a yellow oil (60.6 mg, 82% yield). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.92–7.89 (m, 2H), 7.75–7.73 (m, 2H), 7.57–7.53 (m, 1H), 7.47–7.43 (m, 2H), 7.29–7.26 (m, 2H), 5.63–5.54 (m, 1H), 4.96–4.92 (m, 2H), 2.99–2.87 (m, 4H), 2.69–2.61 (m, 1H), 2.39 (s, 3H), 1.56–1.39 (m, 3H), 1.33–1.25 (m, 1H). **^{13}C NMR** (101 MHz, $CDCl_3$): δ 199.3, 143.4, 140.8, 137.19, 137.16, 133.2, 129.8, 128.7, 128.2, 127.2, 115.5, 43.9, 43.0, 38.8, 31.2, 27.1, 21.6. **HRMS** calculated for $C_{21}H_{25}NO_3SNa$ $[M+Na]^+$ 394.1453, found 394.1449 **IR** (ATR): 1679, 1324, 1155, 1092, 911, 813, 730, 689, 660 cm^{-1}.

6-bromo-1-phenyl-3-vinylhexan-1-one (Figure 3, **3ab**)



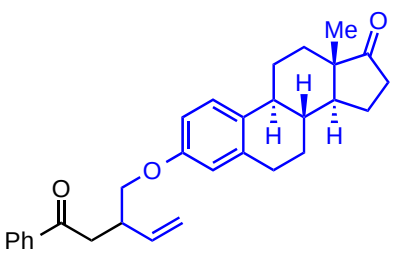
The title compound was synthesized according to the general procedure, ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (20% ethyl acetate in hexanes) as a colorless oil (34.5 mg, 61% yield). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.95–7.92 (m, 2H), 7.58–7.54 (m, 1H), 7.49–7.44 (m, 2H), 5.67 (ddd, *J* = 17.1, 10.3, 8.4 Hz, 1H), 5.06–5.01 (m, 2H), 3.45–3.35 (m, 2H), 3.07–2.94 (m, 2H), 2.83–2.74 (m, 1H), 1.97–1.80 (m, 2H), 1.69–1.60 (m, 1H), 1.53–1.43 (m, 1H). **^{13}C NMR** (101 MHz, $CDCl_3$): δ 199.1, 140.9, 137.3, 133.2, 128.8, 128.2, 115.7, 44.0, 39.2, 33.9, 33.2, 30.6. **HRMS** calculated for $C_{14}H_{18}BrO$ $[M+H]^+$ 281.0541, found 281.0537. **IR** (ATR): 1682, 1447, 1210, 1000, 914, 751, 734, 688, 657 cm^{-1}.

***N*-methoxy-*N*-methyl-4-(2-oxo-2-phenylethyl)hex-5-enamide** (Figure 3, **3ac**)



The title compound was synthesized according to the general procedure with benzoic acid, ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (30% ethyl acetate in hexanes) as a yellow oil (43.5 mg, 79% yield). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.94–7.91 (m, 2H), 7.57–7.52 (m, 1H), 7.47–7.42 (m, 2H), 5.67 (ddd, *J* = 17.1, 10.3, 8.5 Hz, 1H), 5.06–5.00 (m, 2H), 3.66 (s, 3H), 3.15 (s, 3H), 3.02 (d, *J* = 6.7 Hz, 2H), 2.84–2.76 (m, 1H), 2.48–2.42 (m, 2H), 1.86 (dddd, *J* = 13.7, 9.6, 6.4, 4.3 Hz, 1H), 1.74-1.64 (m, 1H). **^{13}C NMR** (101 MHz, $CDCl_3$): δ 199.1, 140.8, 137.4, 133.1, 128.7, 128.2, 123.1, 115.9, 61.4, 44.1, 39.7, 29.9, 29.4. **HRMS** calculated for $C_{16}H_{21}NO_3Na$ $[M+Na]^+$ 298.1419, found 298.1417. **IR** (ATR): 1682, 1659, 1447, 1179, 994, 916, 752, 732, 690 cm^{-1}.

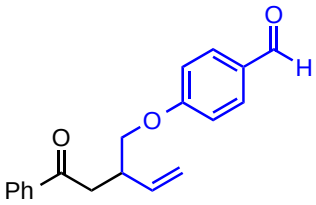
(8*R*,9*S*,13*S*,14*S*)-13-methyl-3-((2-(2-oxo-2-phenylethyl)but-3-en-1-yl)oxy)-6,7,8,9,11,12,13,14,15,16-decahydro-17*H*-cyclopenta[*a*]phenanthren-17-one (Figure 3, **3ad**)



The title compound was synthesized according to the general procedure, ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (10% ethyl acetate in hexanes) as a colorless oil (40.4 mg, 46% yield). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.99–7.96 (m, 2H), 7.58–7.54 (m, 1H), 7.48–7.44 (m, 2H), 7.19–7.17 (m, 1H), 6.70 (dd, *J* = 8.6, 2.8 Hz, 1H), 6.63 (d, *J* = 2.6 Hz, 1H), 5.93 (ddd, *J* = 17.4, 10.3, 7.2 Hz, 1H), 5.20–5.11 (m, 2H), 4.06–4.02 (m, 1H), 3.95 (ddd, *J* = 9.3, 6.3, 3.2 Hz,

1H), 3.37 (dd, *J* = 16.0, 5.9 Hz, 1H), 3.33–3.28 (m, 1H), 3.10 (dd, *J* = 16.2, 6.7 Hz, 1H), 2.88–2.86 (m, 2H), 2.53–2.47 (m, 1H), 2.40–2.36 (m, 1H), 2.27–2.21 (m, 1H), 2.18–1.93 (m, 4H), 1.65–1.42 (m, 6H), 0.90 (s, 3H). ^{13}C NMR (101 MHz, $CDCl_3$): δ 221.1, 198.9, 157.0, 138.1, 137.9, 137.3, 133.2, 132.3, 128.7, 128.3, 126.5, 116.5, 114.7, 112.3, 70.3, 50.6, 48.2, 44.1, 40.2, 39.1, 38.5, 36.0, 31.7, 29.8, 26.7, 26.1, 21.7, 14.0. **HRMS** calculated for $C_{30}H_{34}O_3Na$ $[M+Na]^+$ 465.2406, found 465.2416. **IR** (ATR): 2924, 1587, 2359, 1736, 1683, 1608, 1233, 1002, 917, 753, 689 cm^{-1}.

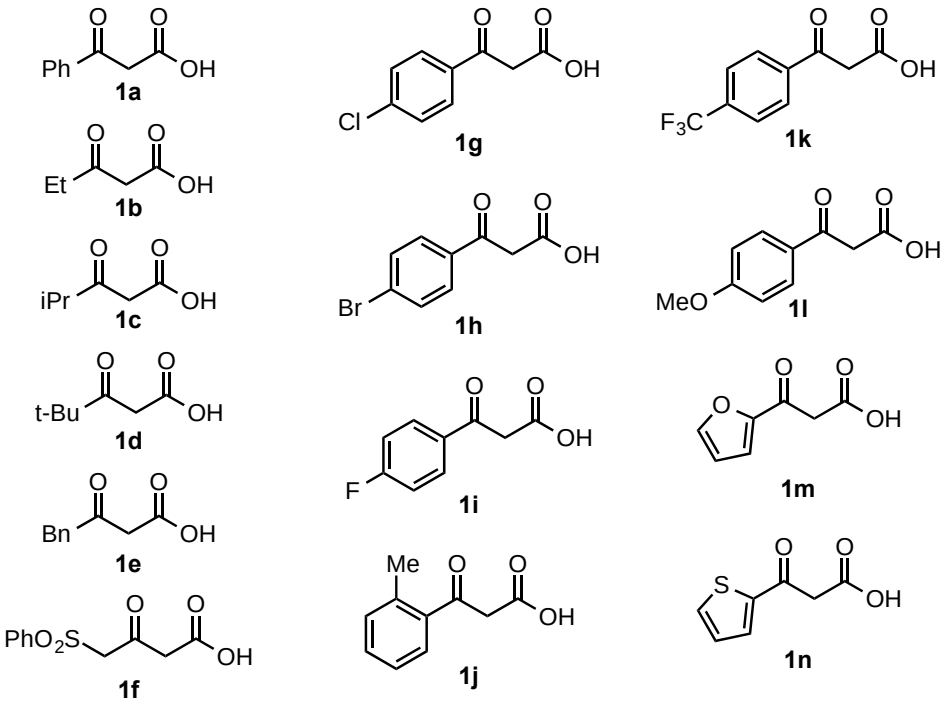
4-((2-(2-oxo-2-phenylethyl)but-3-en-1-yl)oxy)benzaldehyde (Figure 3, **3ae**)



The title compound was synthesized according to the general procedure with benzoic acid, ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (20% ethyl acetate in hexanes) as a colorless oil (35.8 mg, 61% yield). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 9.88 (s, 1H), 7.99–7.96 (m, 2H), 7.83–7.80 (m, 2H), 7.59–7.55 (m, 1H), 7.49–7.45 (m, 2H), 7.01–6.97 (m, 2H), 5.94 (ddd, *J* = 17.4, 10.4, 7.0 Hz, 1H), 5.23–5.15 (m, 2H), 4.16–4.08 (m, 2H), 3.38–3.32 (m, 2H), 3.16 (q, *J* = 9.4 Hz, 1H). **^{13}C NMR** (101 MHz, $CDCl_3$): δ 198.6, 190.9, 163.9, 137.6, 137.1, 133.4, 132.1, 130.2, 128.8, 128.2, 123.0, 117.0, 115.0, 70.6, 39.9, 38.8. **HRMS** calculated for $C_{19}H_{18}O_3Na$ $[M+Na]^+$ 317.1154, found 317.1161. **IR** (ATR): 2926, 1682, 1597, 1576, 1500, 1252, 1213, 1157, 1001, 831, 752, 689, 648, 615 cm^{-1}.

3. Substrate Preparation

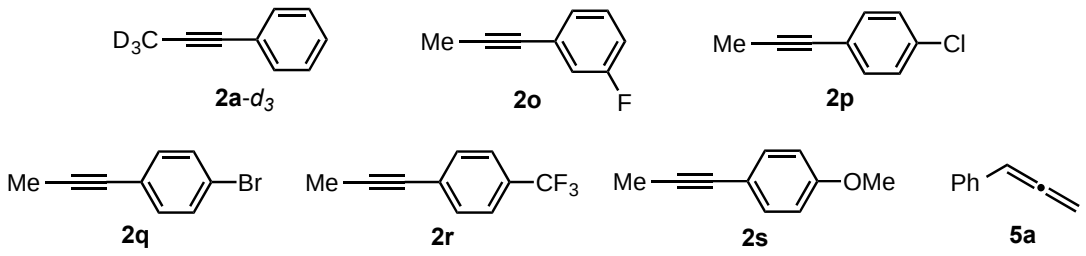
Preparation of β-Keto Acids



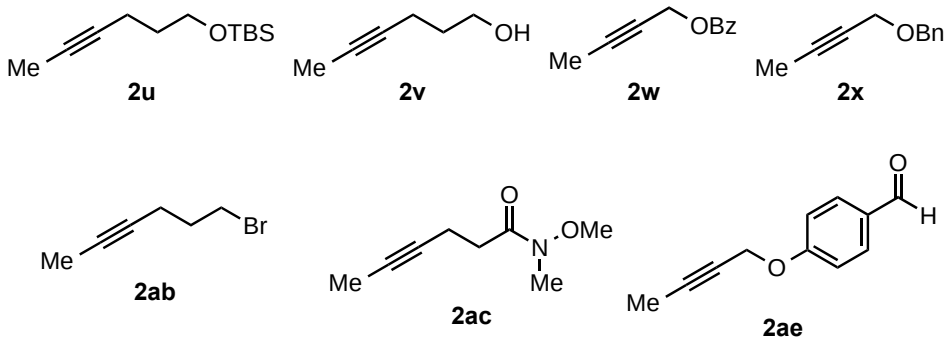
β-Keto acids **1a**-**1n** were prepared from the corresponding *β*-Keto esters according to literature procedure.[25]

Preparation of Alkynes and 1-Phenylallene

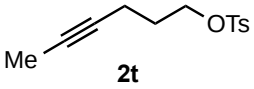
Alkynes **2a**-d_3 and **2o**-**2s** were prepared from the corresponding terminal alkyne according to literature procedure.[26] 1-Phenylallene was prepared from styrene according to literature procedure.[27]



[25] D. A. Evans, S. Mito, D. Seidel, *J. Am. Chem. Soc*. 2007, **129**, 11583.
[26] T. Fujihara, Y. Tani, K. Semba, J. Terao,Y. Tsuji, *Angew. Chem. Int. Ed.*, **2012,** *51*, 11487.
[27] T. Kippo, T. Fukuyama, I. Ryu, *Org. Lett.*, **2011,** *13*, 11487.

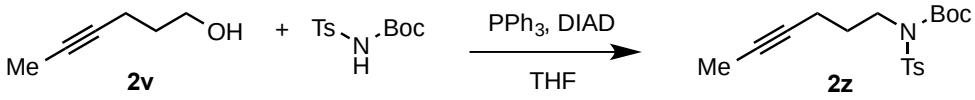


Alkyne **2u**[28] and **2ab**[29] were prepared according to literature procedure from **2v**. Alkyne **2v** was prepared according to literature procedure from 5-hexyn-1-ol.[30] Alkyne **2w**[31] and **2x**[32] were prepared according to literature procedure from 2-butyn-1-ol. Alkyne **2ac** was prepared according to literature procedure from hex-4-ynoic acid.[33] Alkyne **2ae** was prepared according to literature procedure from 4-hydroxy benzaldehyde.[34]



Prepared according to literature procedure from alcohol **2v** in 69% yield as a colorless oil.[35]

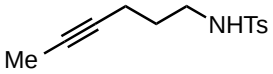
^{1}H NMR (400 MHz, $CDCl_3$): δ 7.81–7.79 (m, 2H), 7.35–7.33 (m, 2H), 4.13 (t, *J* = 6.2 Hz, 2H), 2.45 (s, 3H), 2.18 (tq, *J* = 6.9, 2.4 Hz, 2H), 1.79 (quintet, *J* = 6.5 Hz, 2H), 1.68 (t, *J* = 2.6 Hz, 3H). **^{13}C NMR** (101 MHz, $CDCl_3$): δ 144.8, 133.2, 129.9, 128.1, 123.1, 76.9, 69.3, 28.3, 21.8, 15.1, 3.5. **HRMS** calculated for $C_{13}H_{16}O_3SNa$ $[M+Na]^+$ 275.0718, found 275.0713. **IR** (ATR): 1597, 1439, 1357,1173, 1096, 970, 927, 813, 661, 574 cm^{-1}.



To a solution of alcohol **2v** (500 mg, 5.1 mmol, 1.0 equiv.) in THF (20 mL, 0.3 M) at room temperature under nitrogen was added N-[(tert-butoxy)carbonyl]-4-methylbenzenesulfonamide (1.52 g, 5.6 mmol, 1.1 equiv.) and triphenyl phosphine (1.47 g, 5.6 mmol, 1.1 equiv.). The resulting mixture was cooled to 0° C. Diisopropyl azodicarboxylate was added at 0° C, then the reaction mixture was allowed to warm to room temperature. After stirring for 24 hours at room temperature, the crude reaction mixture was concentrated *in vacuo*. The resulting residue was purified by column chromatography using 30% ethyl acetate in hexanes to yield 2z as a white solid (1.5 g, 4.3 mmol, 84% yield). **^{1}H**

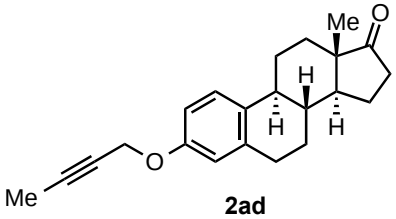
[28] H. Guo, G. A. O'Doherty, *Org. Lett.*, 2005, **7**, 3921.
[29] G. Zheng, S. P. Sumithran, A. G. Deaciuc, L. P. Dwoskin, P. A. Crooks, *Bioorg. Med. Chem. Lett.*, 2007, **24**, 6701.
[30] S. Hoetline, B. Haberlag, M. Tamm, J. Collatz, P. Mack, J. L. M. Steidle, M. Venes, S. Schulz, *Chem. Eur. J.*, 2014, **11**, 3183.
[31] F. R. Wuest, M. Berndt, *J. Label Compd. Radiopharm.*, 2006, **49**, 91.
[32] K. Semba, T. Fujihara, J. Terao, Y. Tsuji, *Chem. Eur. J.*, 2012, **14**, 4179.
[33] H. Kusama, K. Ishida, H. Funami, N. Iwasawa, *Angew. Chem. Int. Ed.*, 2008, **26**, 4903.
[34] K. Bera, S. Sarkar, S. Biswas, S. Maiti, U. Jana, *J. Org. Chem.*, 2011, **9**, 3539.
[35] F. Fang, M. Vogel, J. V. Hines, S. C. Bergmeier, *Org. Biomol. Chem.*, 2012, **10**, 3080.

NMR (400 MHz; $CDCl_3$): δ 7.78–7.75 (m, 2H), 7.29–7.27 (m, 2H), 3.88 (dd, *J* = 8.2, 6.8 Hz, 2H), 2.42 (s, 3H), 2.19 (tq, *J* = 7.1, 2.5 Hz, 2H), 1.91 (quintet, *J* = 7.4 Hz, 2H), 1.75 (t, *J* = 2.5 Hz, 3H), 1.33 (s, 9H). **^{13}C NMR** (101 MHz, $CDCl_3$): δ 151.0, 144.2, 137.5, 129.3, 127.9, 84.2, 77.9, 76.3, 46.6, 29.5, 28.0, 21.7, 16.4, 3.6. **HRMS** calculated for $C_{18}H_{25}NO_4SNa$ $[M+Na]^+$ 374.1402, found 374.1409. **IR** (ATR): 1716, 1355, 1288, 1157, 1085, 990, 670 cm^{-1}.



2aa

To a solution of alkyne **2z** (703 mg, 2 mmol, 1 equiv.) in DCM (10 mL, 0.2 M) at room temperature was added trifluoroacetic acid (3.1 mL, 40 mmol, 20 equiv.). After stirring for 45 minutes at room temperature, a saturated aqueous solution of $NaHCO_3$ was added. The aqueous layer was extracted with DCM. The combined organic layers were washed with brine, dried with anhydrous $MgSO_4$, filter, and concentrated *in vacuo*. The resulting residue was purified by column chromatography using 20% ethyl acetate in hexanes to yield **2aa** as a pale yellow solid (360 mg, 72% yield). Spectroscopic data were in accordance with the literature.[36]



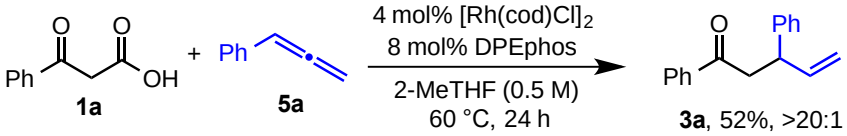
2ad

Prepared using a literature procedure from estrone and 1-bromo-2-butyne in 62% yield.[37] **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.21 (d, *J* = 8.2 Hz, 1H), 6.78 (dd, *J* = 8.6, 2.8 Hz, 1H), 6.70 (d, *J* = 2.8 Hz, 1H), 4.61 (q, *J* = 2.3 Hz, 2H), 2.92–2.88 (m, 2H), 2.50 (dd, *J* = 18.7, 8.4 Hz, 1H), 2.40 (ddd, *J* = 9.1, 7.0, 4.3 Hz, 1H), 2.29–2.22 (m, 1H), 2.19–1.93 (m, 4H), 1.86 (d, *J* = 4.7 Hz, 3H), 1.68–1.38 (m, 6H), 0.91 (s, 3H). **^{13}C NMR** (101 MHz, $CDCl_3$): δ 221.0, 156.0, 137.9, 132.7, 126.4, 115.0, 112.4, 83.6, 74.3, 56.4, 50.5, 48.1, 44.1, 38.4, 36.0, 31.7, 29.8, 26.6, 26.0, 21.7, 14.0, 3.9. **HRMS** calculated for $C_{22}H_{26}O_2Na$ $[M+Na]^+$ 345.1830, found 345.1836. **IR** (ATR): 2916, 1737, 1609, 1572, 1494, 1371, 1282, 1254, 1155, 1005, 869, 806, 776 cm^{-1}.

[36] F.-T. Luo, R.-T. Wang, *Tetrahedron Lett.*, 1992, **33**, 6835.
[37] P. Ramirez-Lopez, M. C. De La Torre, H. E. Montenegro, M. Asenjo, M. A. Sierra, *Org. Lett.*, 2008, **16**, 3555.

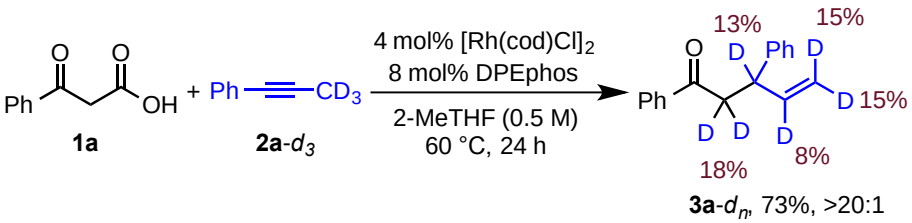
4. Mechanistic Experiments

Procedure for the Coupling of Benzoylacetic acid 1a and 1-Phenylallene 5a



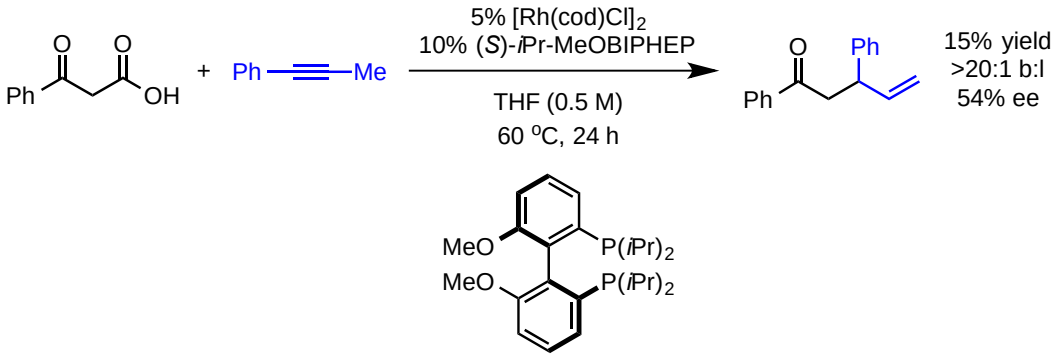
To a 1 dram vial equipped with a magnetic stir bar was added $[Rh(cod)Cl]_2$ (3.9 mg, 0.008 mmol), DPEphos (8.6 mg, 0.016 mmol), β-keto acid **1a** (0.40 mmol), 1-phenylallene **5a** (0.20 mmol), and 2-MeTHF (0.40 mL). The vial was then sealed with a Teflon-lined screw cap and heated to 60 °C for 24 hours. The resulting mixture was then cooled to room temperature. ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (10% ethyl acetate in hexanes) as a colorless oil (24.6 mg, 52% yield).

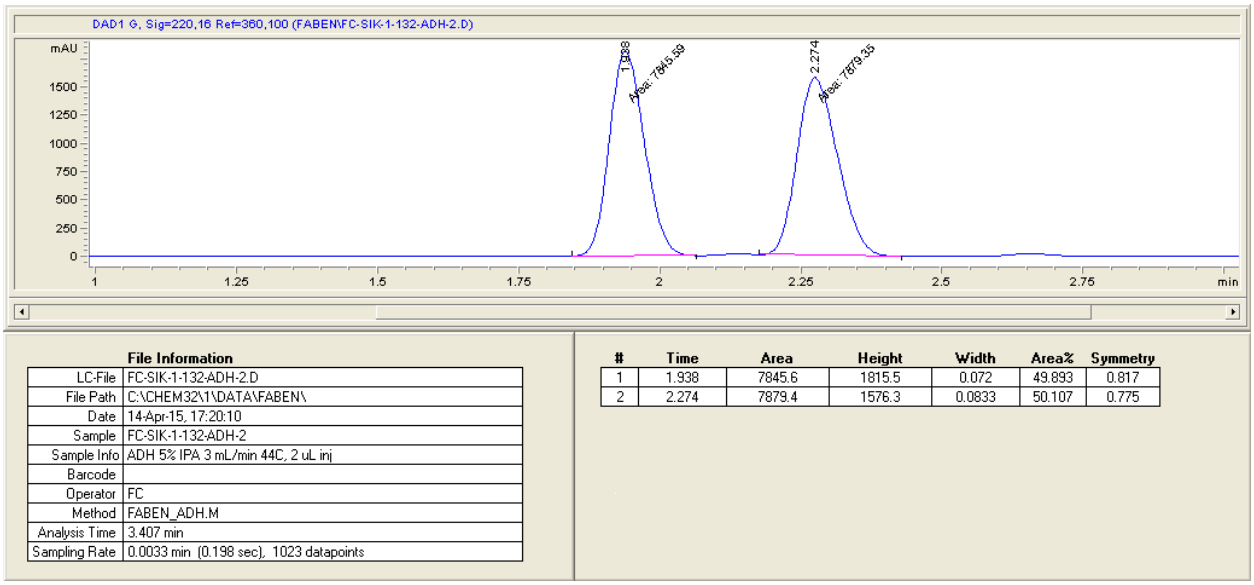
Procedure for the Coupling of Benzoylacetic acid 1a and Deuterated 1-Phenyl-1-propyne 2a-d_3



To a 1 dram vial equipped with a magnetic stir bar was added $[Rh(cod)Cl]_2$ (3.9 mg, 0.008 mmol), DPEphos (8.6 mg, 0.016 mmol), β-keto acid **1a** (0.40 mmol), deuterated 1-phenyl-1-propyne **2a**-d_3 (0.20 mmol), and 2-MeTHF (0.40 mL). The vial was then sealed with a Teflon-lined screw cap and heated to 60 °C for 24 hours. The resulting mixture was then cooled to room temperature. ^{1}H NMR analysis of the crude reaction mixture showed >20:1 regioselectivity in favor of the branched isomer. The title compound was isolated via preparatory TLC (10% ethyl acetate in hexanes) as a colorless oil (34.3 mg, 73% yield). **^{1}H NMR** (400 MHz, CDCl3) δ 8.03 – 7.96 (m, 2H), 7.61 (t, *J* = 7.4 Hz, 1H), 7.51 (t, *J* = 7.7 Hz, 2H), 7.41 – 7.30 (m, 4H), 7.30 – 7.22 (m, 1H), 6.13 (ddd, *J* = 22.4, 10.4, 6.7 Hz, 0.92H), 5.18 – 5.03 (m, 1.43H), 4.22 (q, *J* = 6.9 Hz, 0.87H), 3.47 (qd, *J* = 16.6, 7.1 Hz, 1.65H). **^{13}C NMR** (101 MHz, CDCl3) δ 198.5, 143.4, 140.9, 133.2, 128.78, 128.78, 128.3, 127.9, 126.8, 123.5, 114.9, 44.7, 44.2. **^{2}H NMR** (61 MHz, $CDCl_3$) δ 6.24, 5.24, 4.28, 3.57.

5. Enantioselective Alkyne and β-keto acid Coupling





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Sample	FC-SIK-1-132-ADH-2
Sample Info	ADH 5% IPA 3 mL/min 44C, 2 uL inj
Barcode	
Operator	FC
Method	FABEN_ADH.M
Analysis Time	3.407 min
Sampling Rate	0.0033 min (0.198 sec), 1023 datapoints

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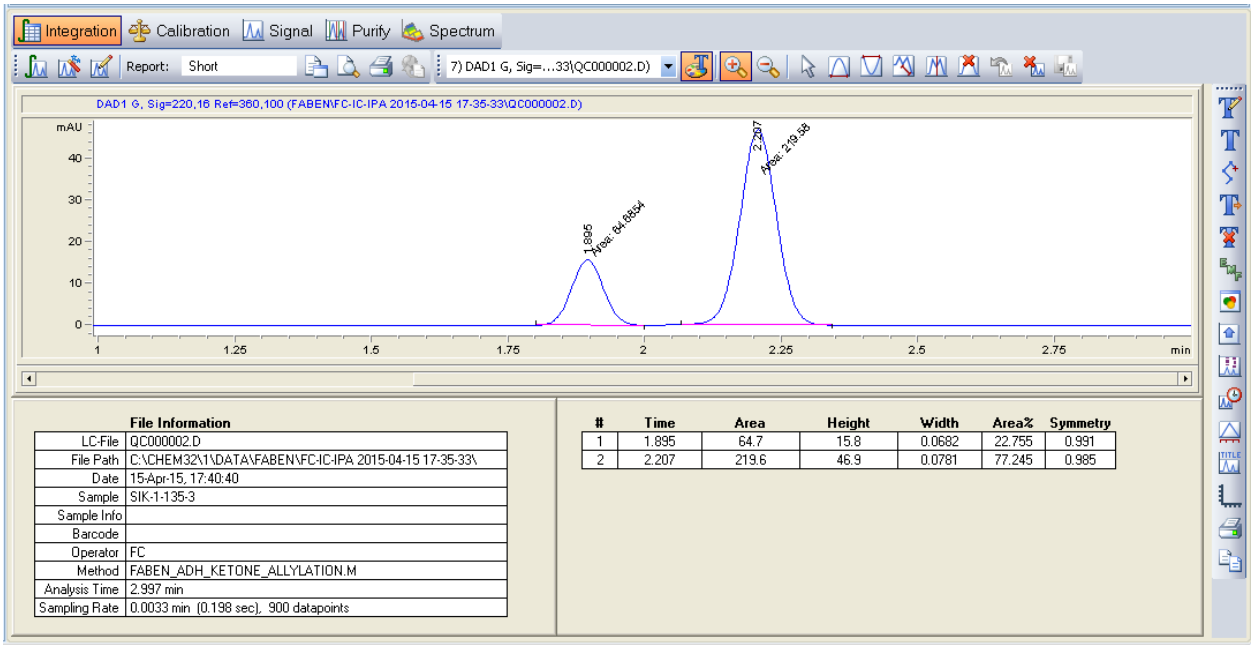

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Sample Info	
Barcode	
Operator	FC
Method	FABEN_ADH_KETONE_ALLYLATION.M
Analysis Time	2.997 min
Sampling Rate	0.0033 min (0.198 sec), 900 datapoints

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1	1.895	64.7	15.8	0.0682	22.755	0.991
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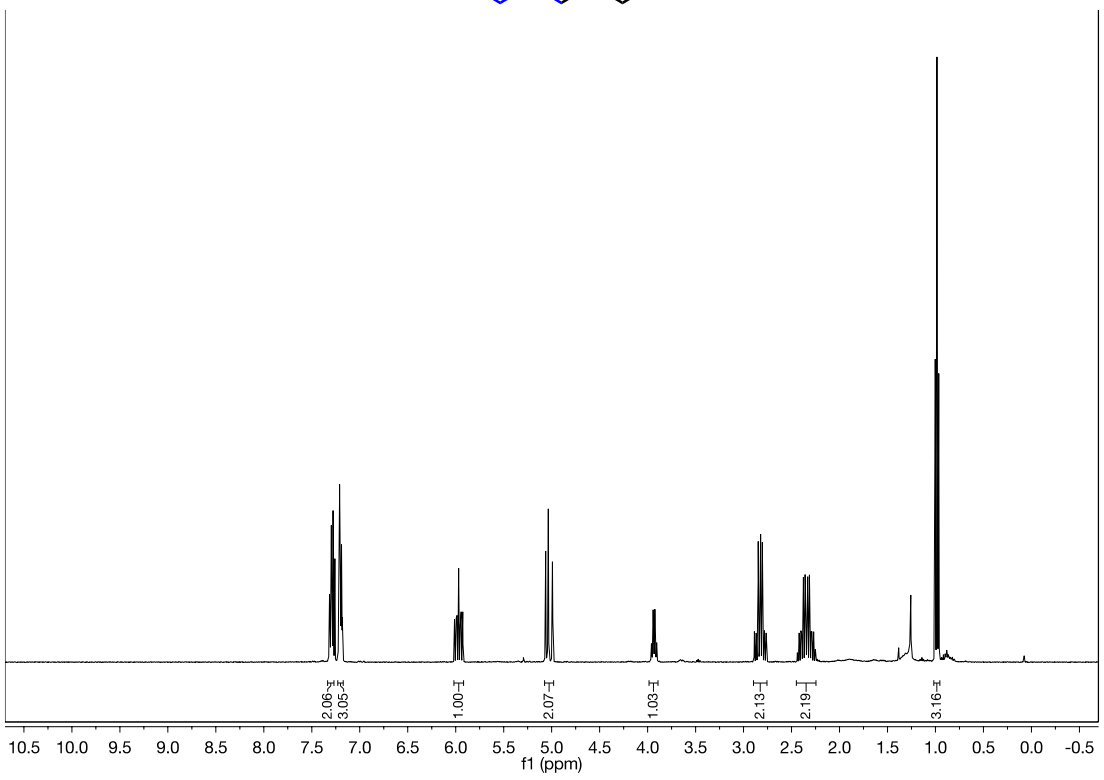
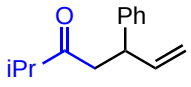
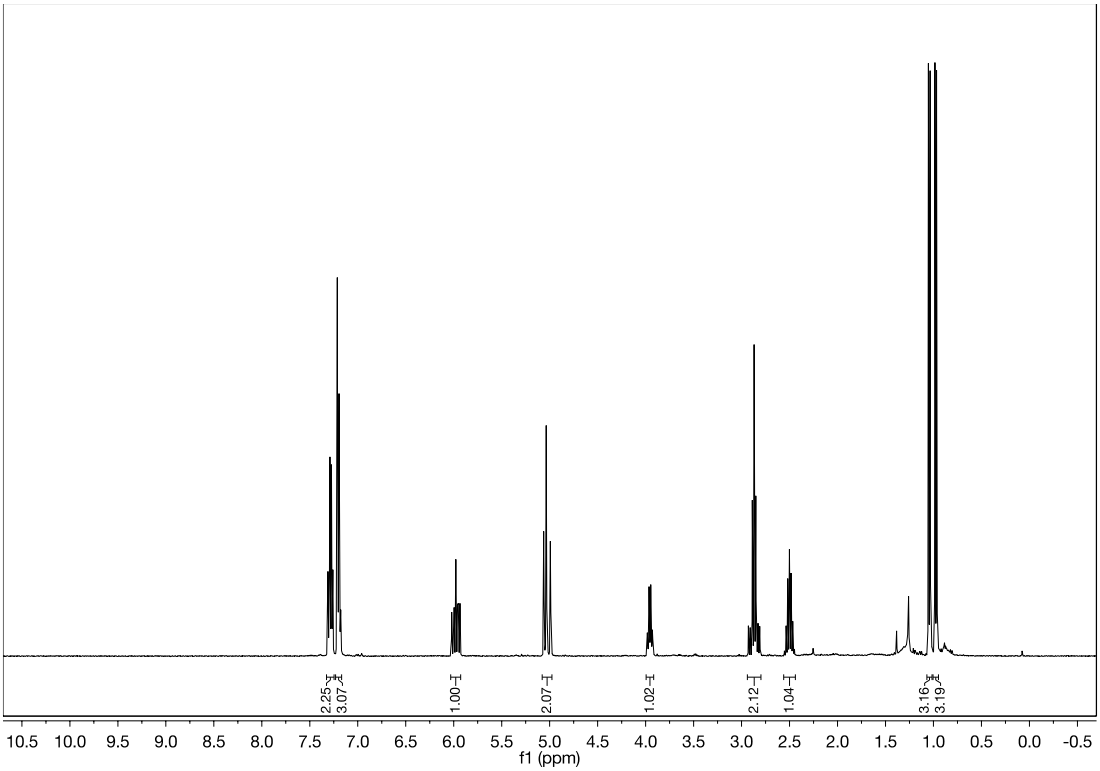
6. NMR Spectra

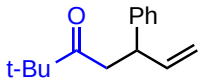
(3b)



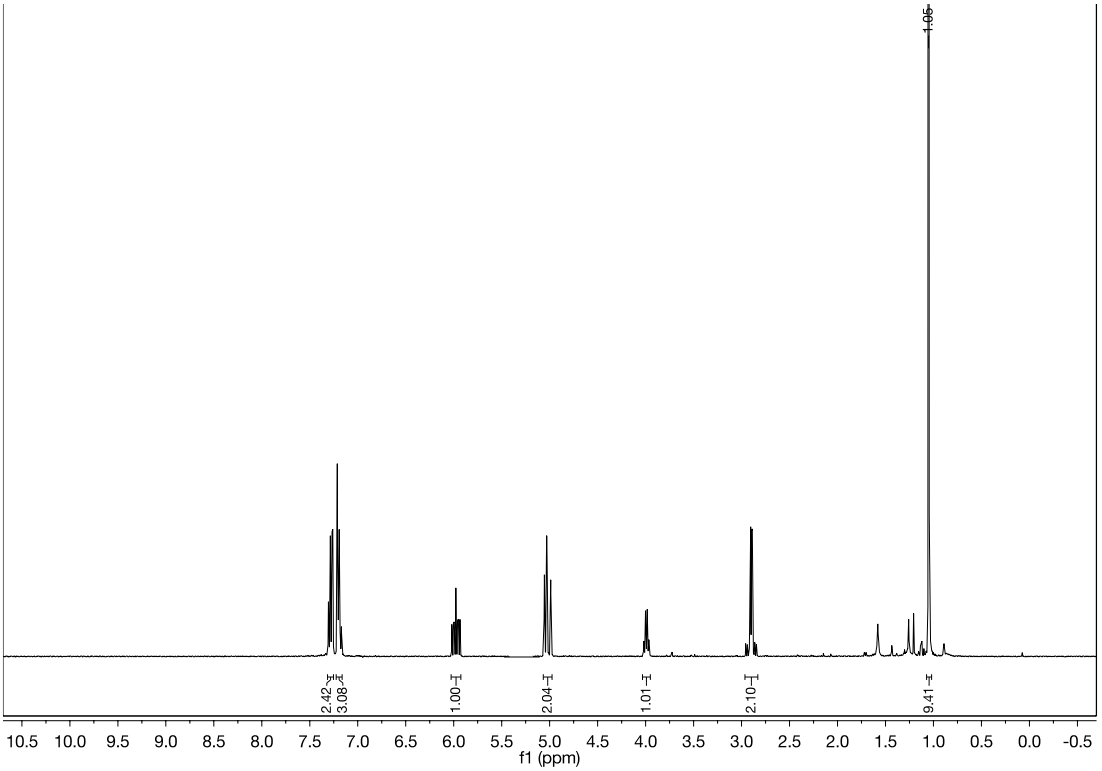

O
Ph
iPr

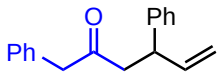
(**3c**)


2.25
3.07
1.00
2.07
1.02
2.12
1.04
3.16
3.19
10.5 10.0 9.5 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
f1 (ppm)

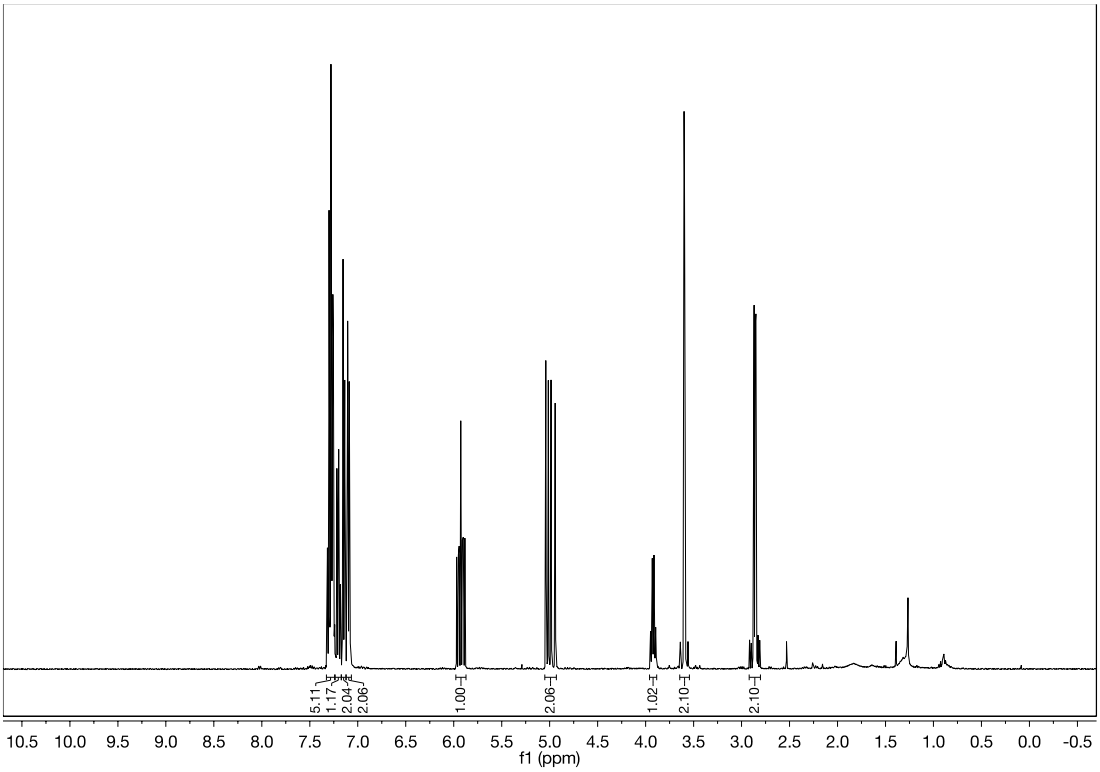

O
Ph
t-Bu

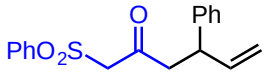
(3d)


1.06
2.42
3.08
1.00
2.04
1.01
2.10
9.41
10.5 10.0 9.5 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
f1 (ppm)

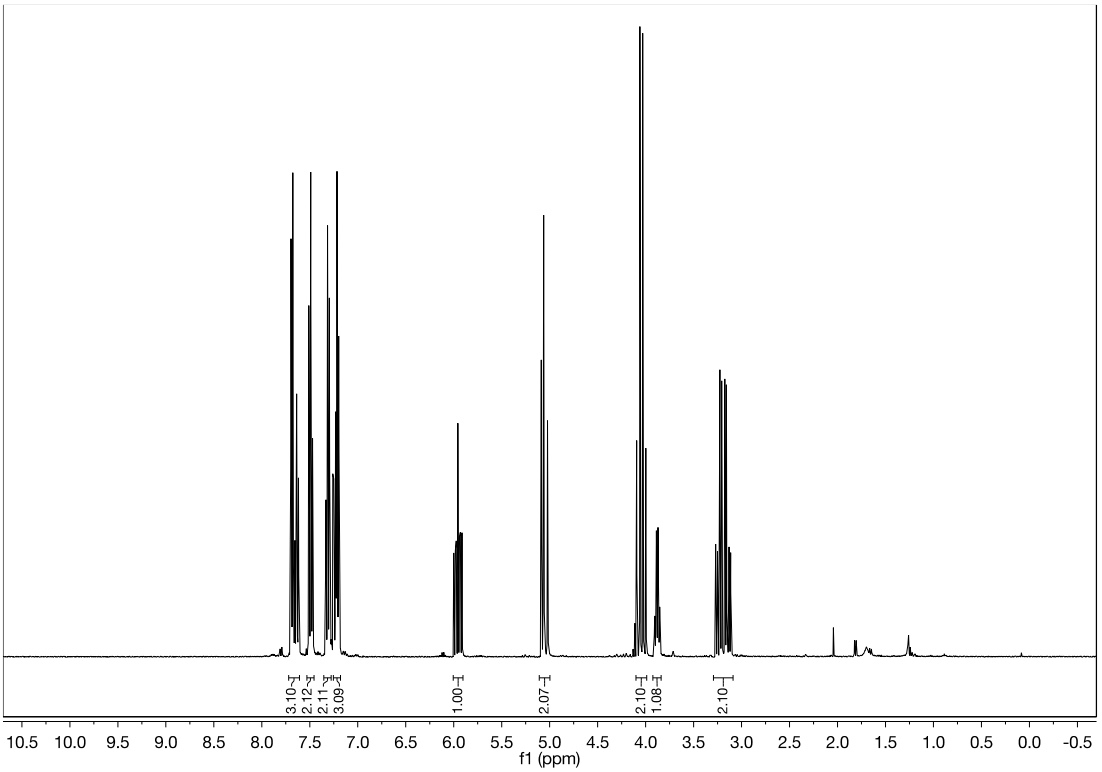

O
Ph
Ph

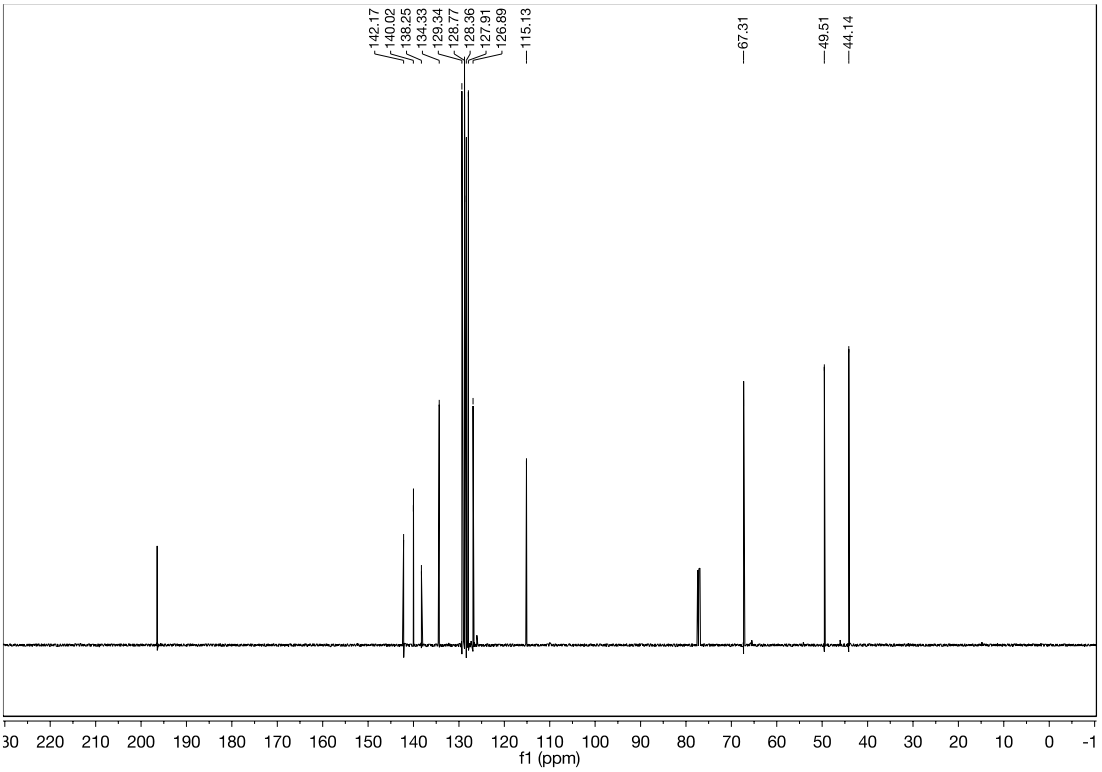
(**3e**)

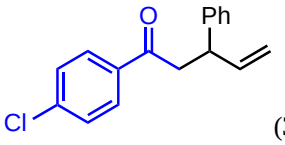

5.11
1.17
2.04
2.06
1.00
2.06
1.02
2.10
2.10
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)


O
Ph
PhO2S

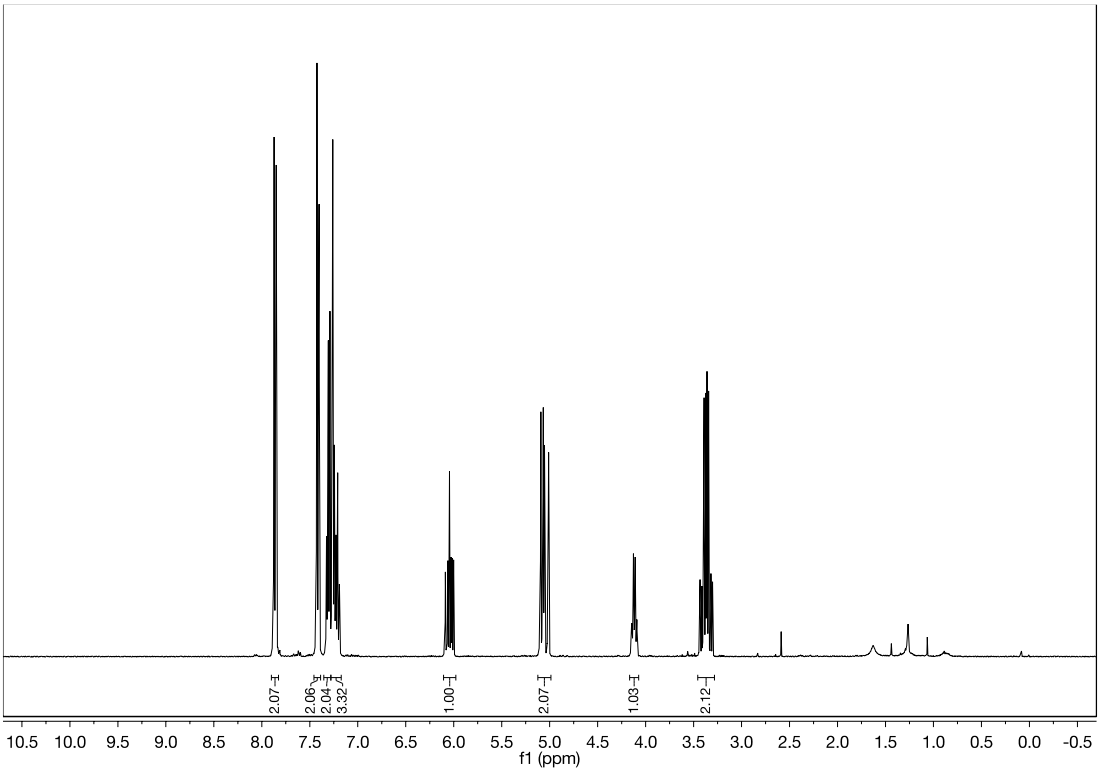
(3f)

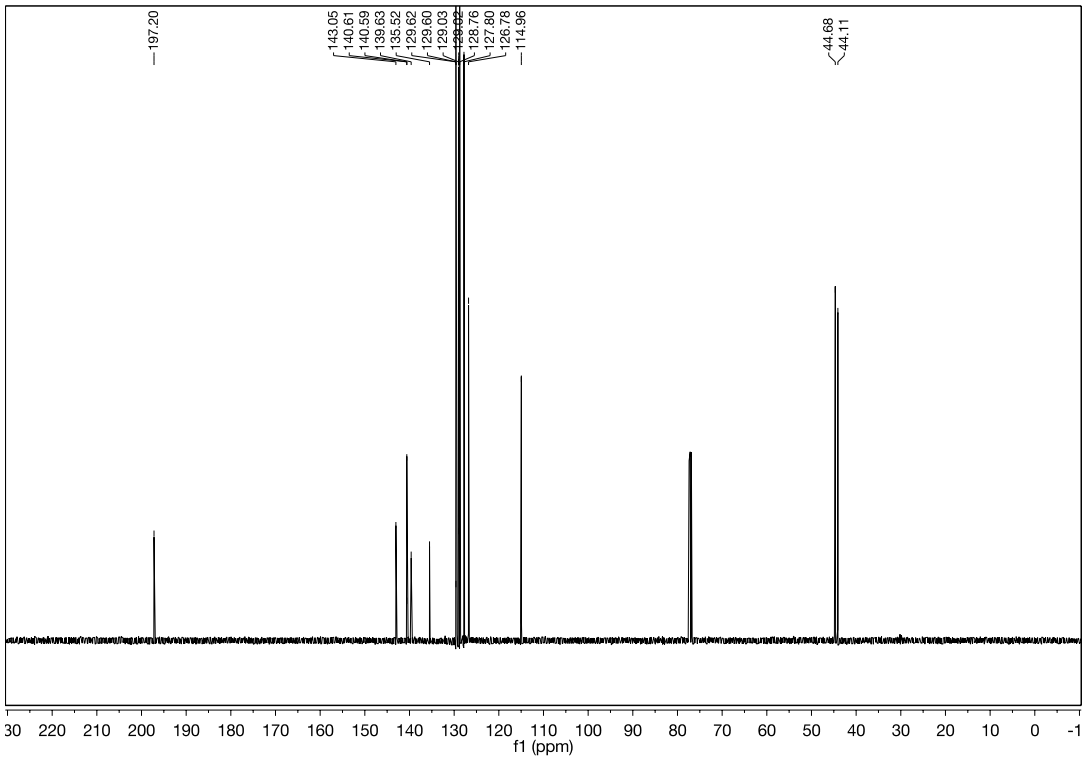

3.10
2.12
2.11
3.09
1.00
2.07
2.10
1.08
2.10
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)

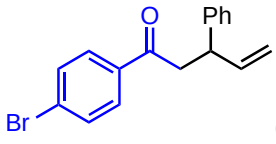

142.17
140.02
138.25
134.33
129.34
128.77
128.36
127.91
126.89
115.13
67.31
49.51
44.14
30 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -1
f1 (ppm)


O
Ph
Cl

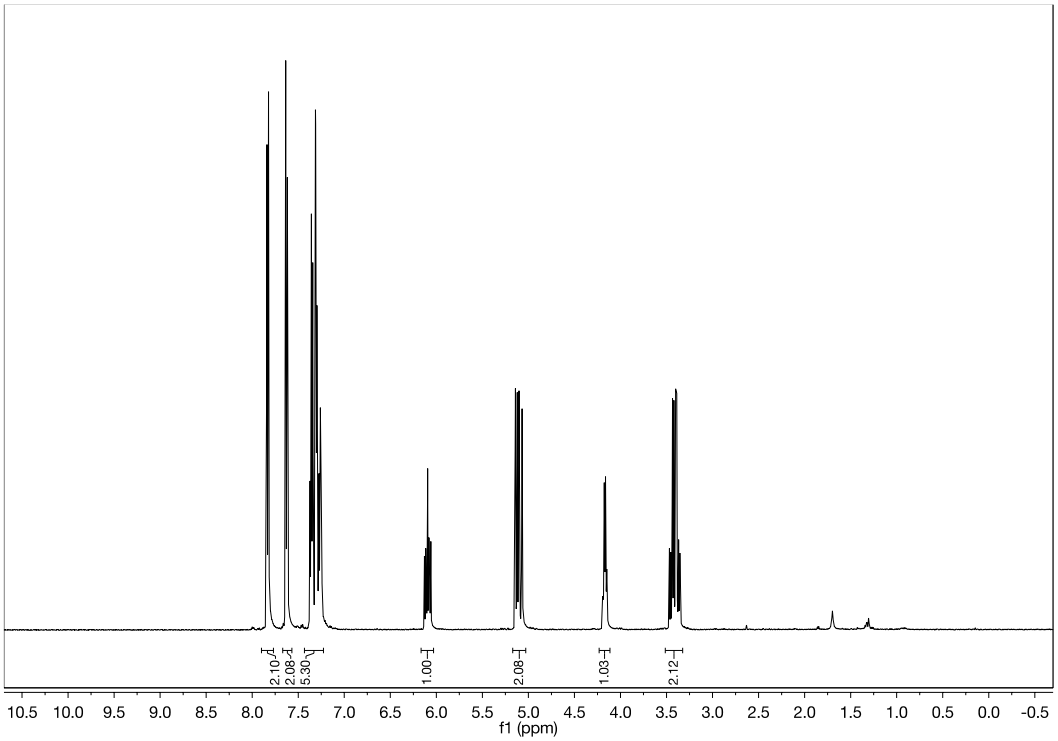
(3g)

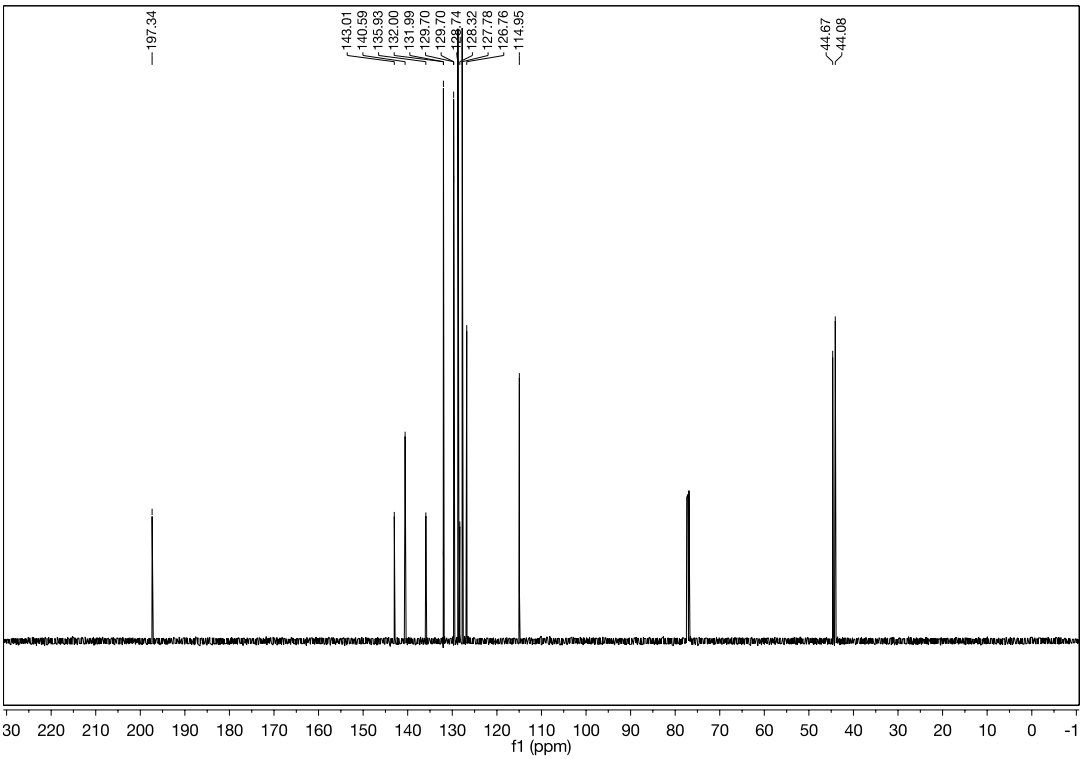

2.07
2.06
2.04
3.32
1.00
2.07
1.03
2.12
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)

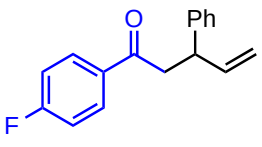

197.20
143.05
140.61
140.59
139.63
135.52
129.62
129.60
129.03
128.76
127.80
126.78
114.96
44.68
44.11
30 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -1
f1 (ppm)


O
Ph
Br

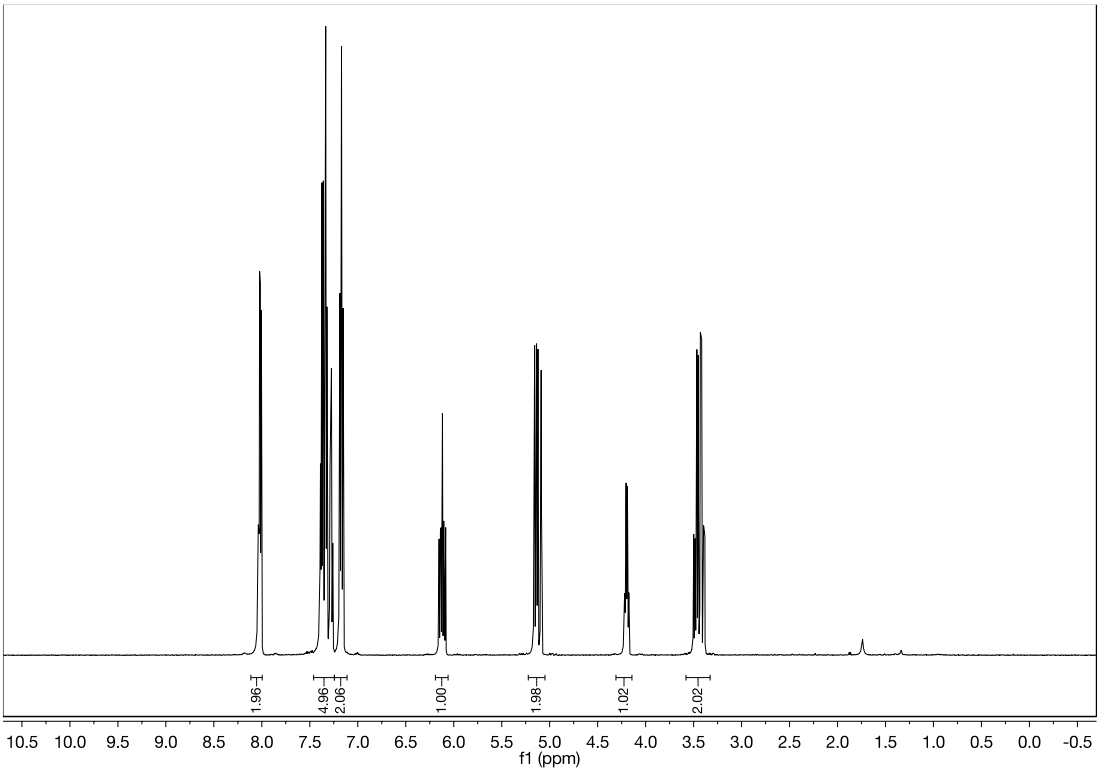
(**3h**)

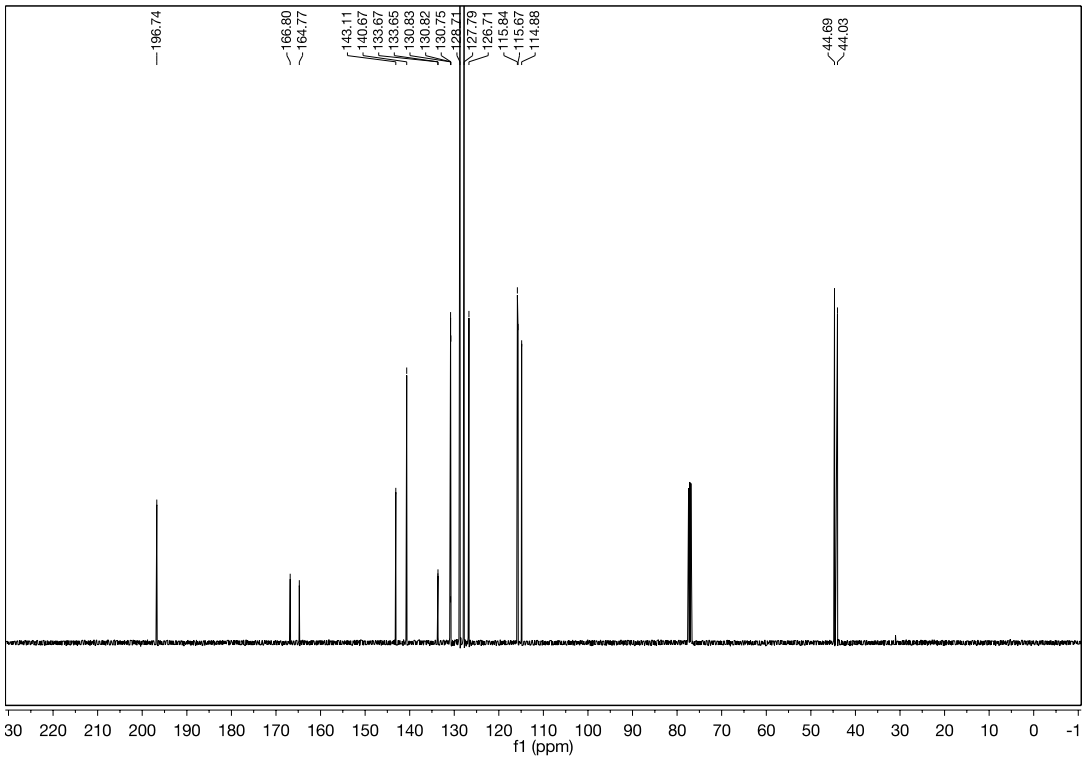

2.10
2.08
5.30
1.00
2.08
1.03
2.12
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)

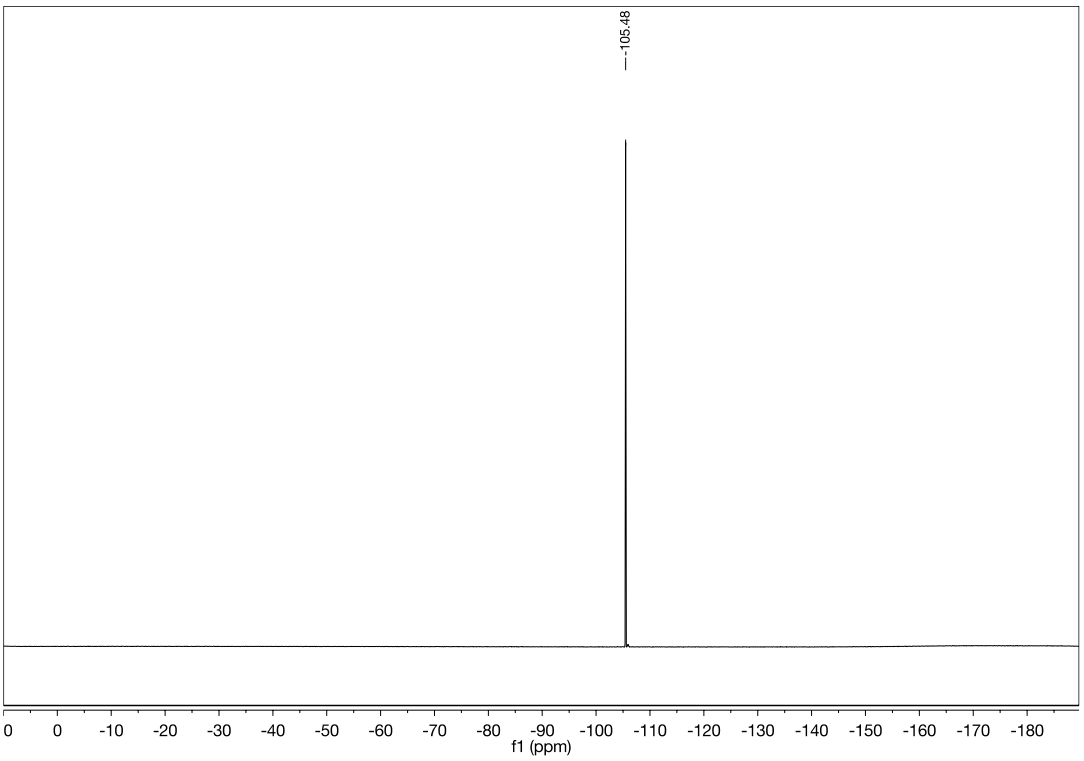

197.34
143.01
140.59
135.93
132.00
131.99
129.70
129.70
128.74
128.32
127.78
126.76
114.95
44.67
44.08
30 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -1
f1 (ppm)

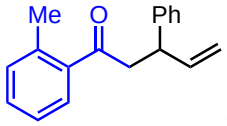

O
Ph
F

(3i)

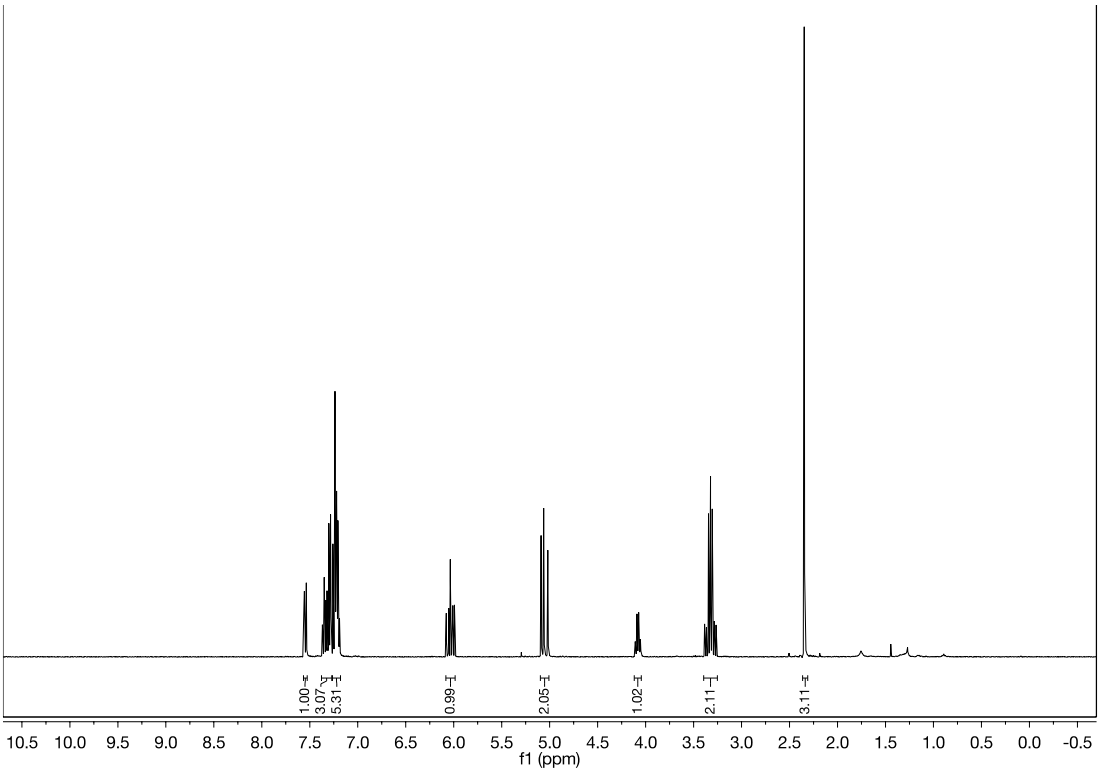

1.96
4.96
2.06
1.00
1.98
1.02
2.02
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)

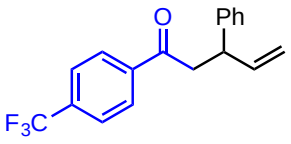

196.74
166.80
164.77
143.11
140.67
133.67
133.65
130.83
130.82
130.75
128.71
127.79
126.71
115.84
115.67
114.88
44.69
44.03
30 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -1
f1 (ppm)


-105.48
0
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
-120
-130
-140
-150
-160
-170
-180
f1 (ppm)

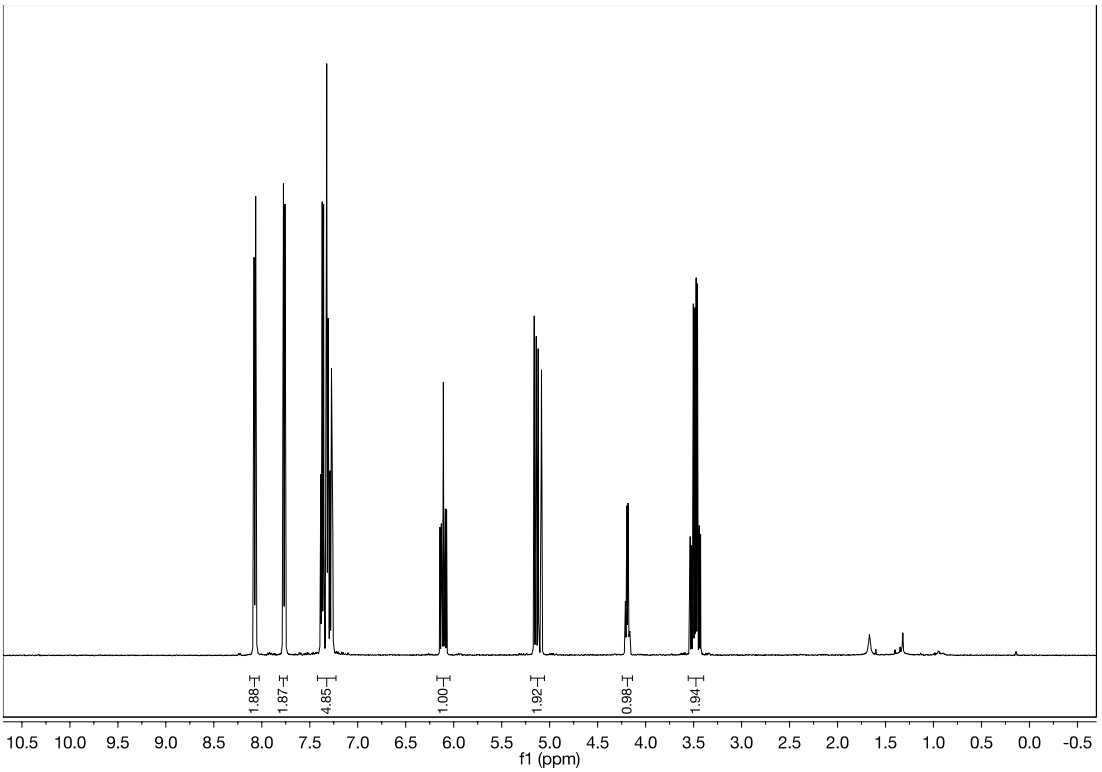

Me
O
Ph

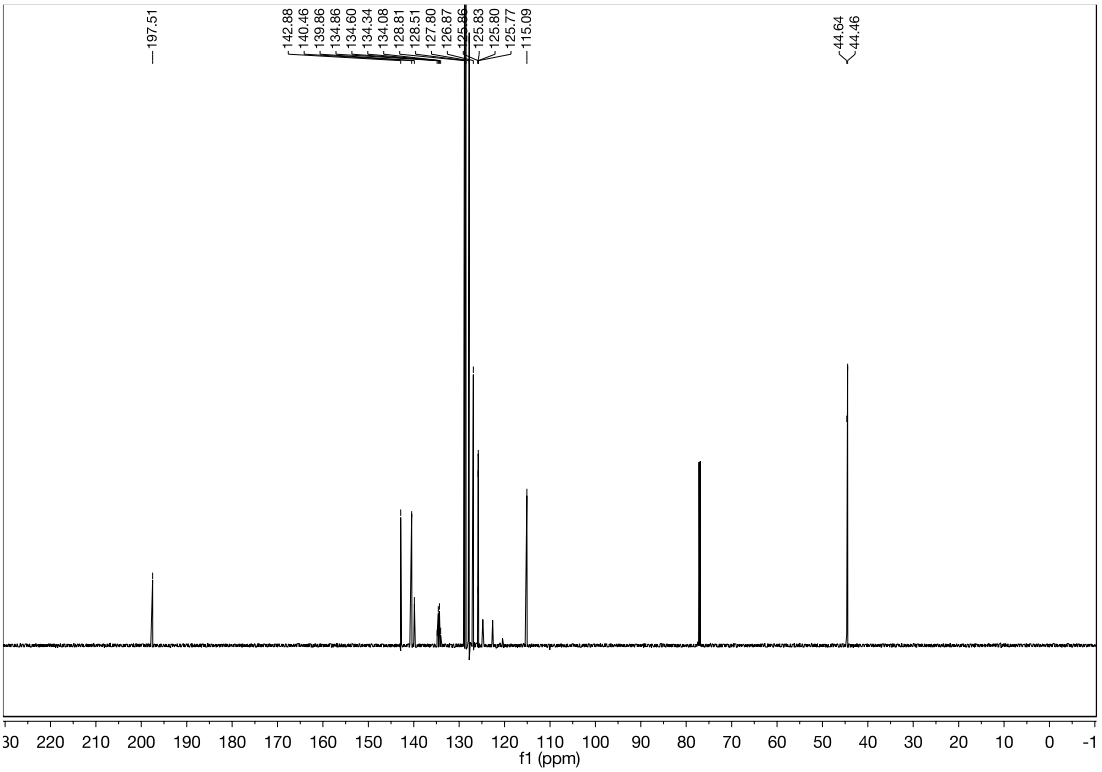
(**3j**)

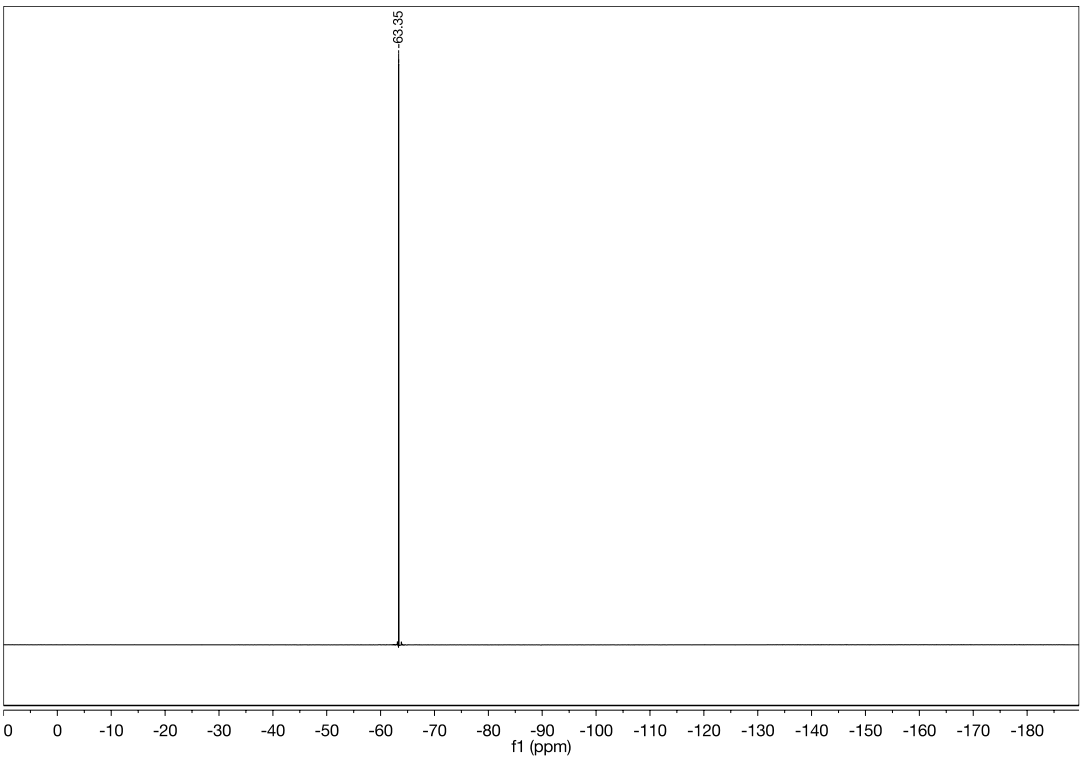

1.00
3.07
5.31
0.99
2.05
1.02
2.11
3.11
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)

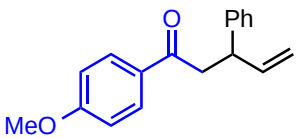

O
Ph
F3C

(**3k**)

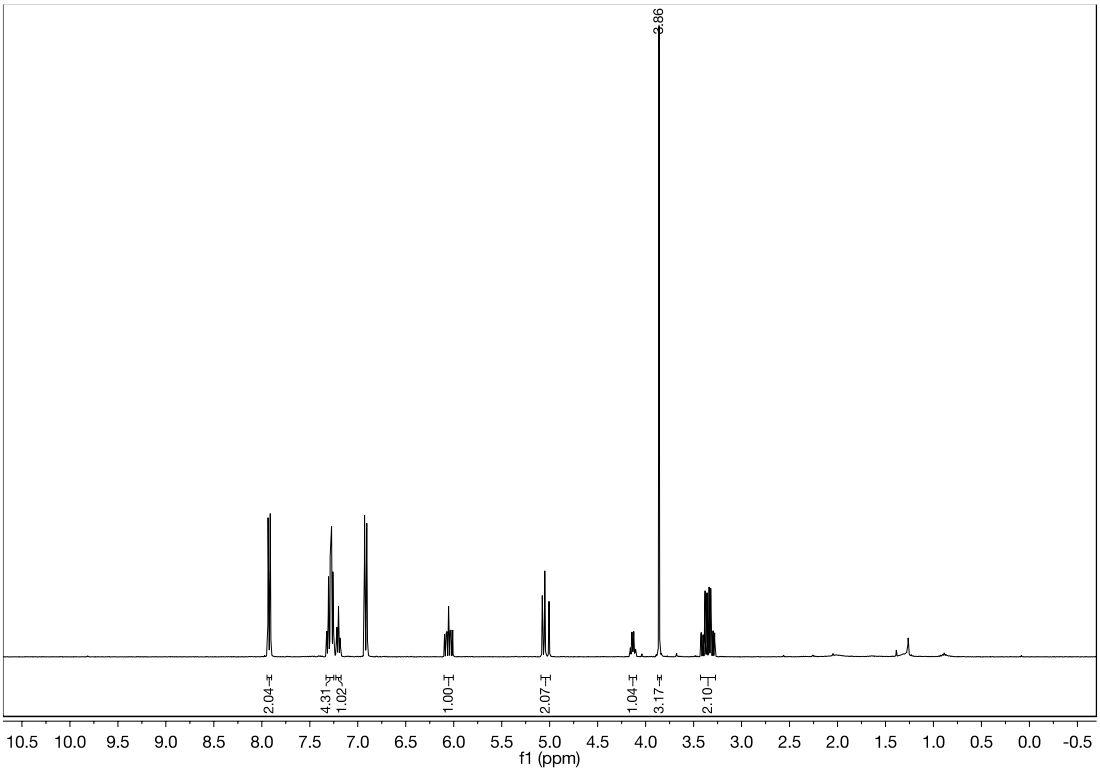

1.88
1.87
4.85
1.00
1.92
0.98
1.94
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)

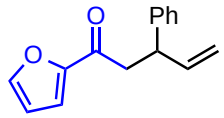

197.51
142.88
140.46
139.86
134.86
134.60
134.34
134.08
128.81
128.51
127.80
126.87
125.83
125.80
125.77
115.09
44.64
44.46
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10
f1 (ppm)


-63.35
0
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
-120
-130
-140
-150
-160
-170
-180
f1 (ppm)

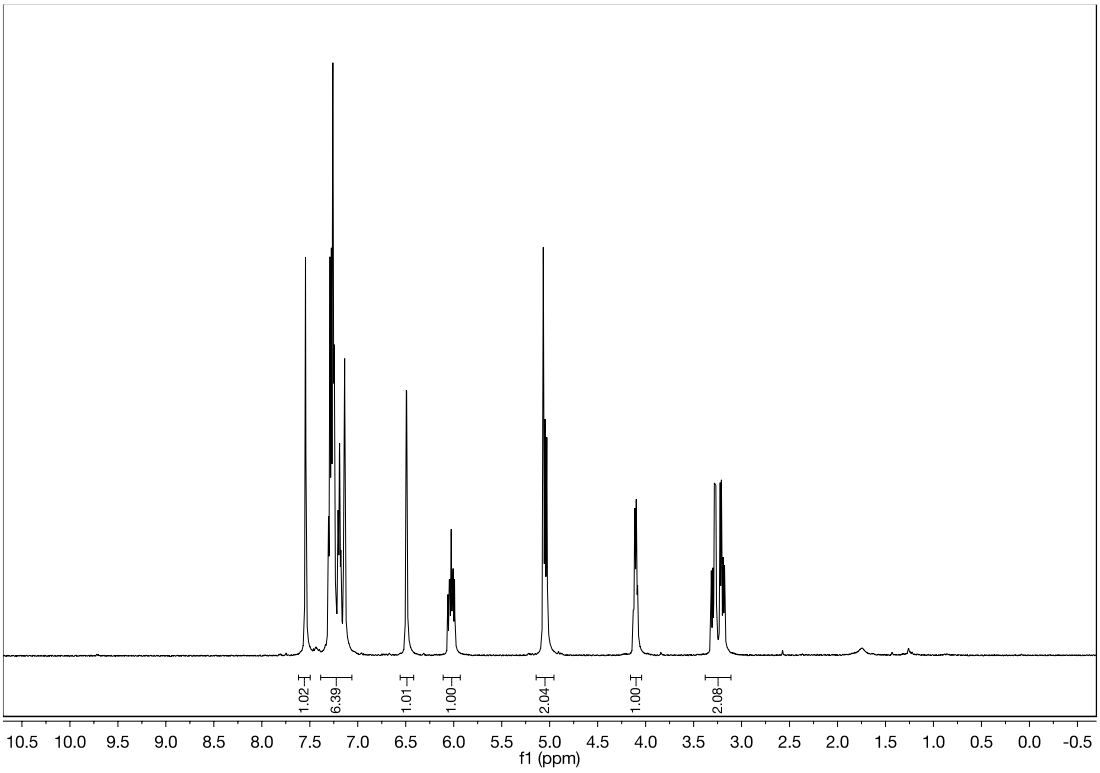

O
Ph
MeO

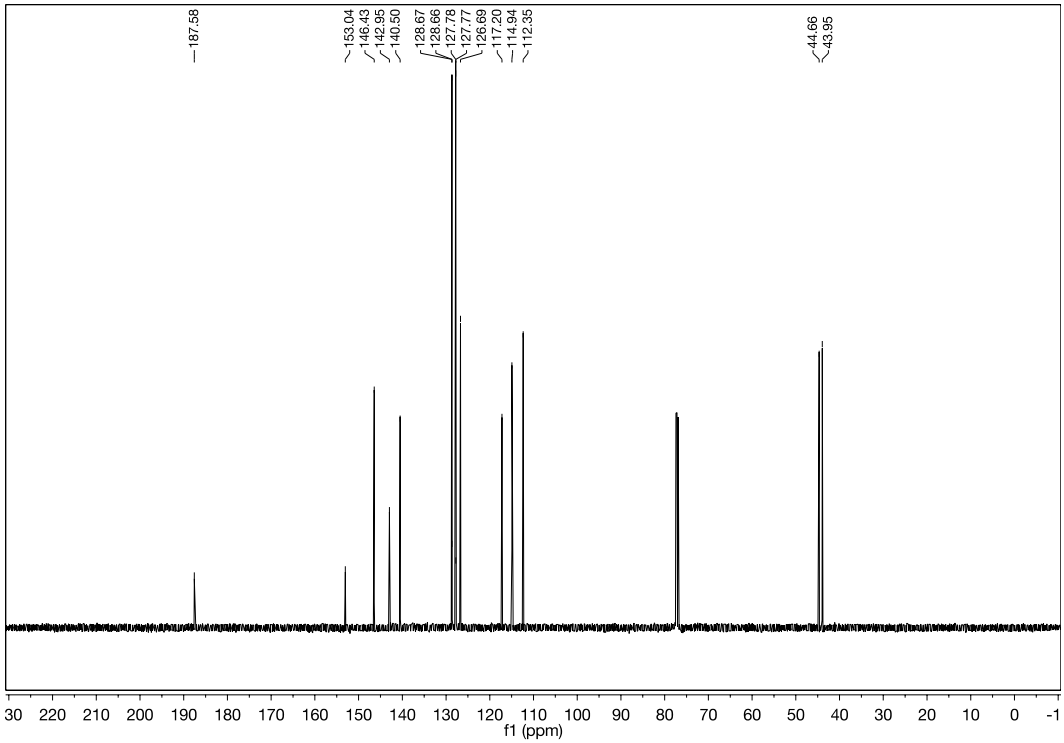
(3l)

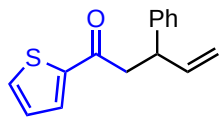

3.86
2.04
4.31
1.02
1.00
2.07
1.04
3.17
2.10
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)


O
Ph
O

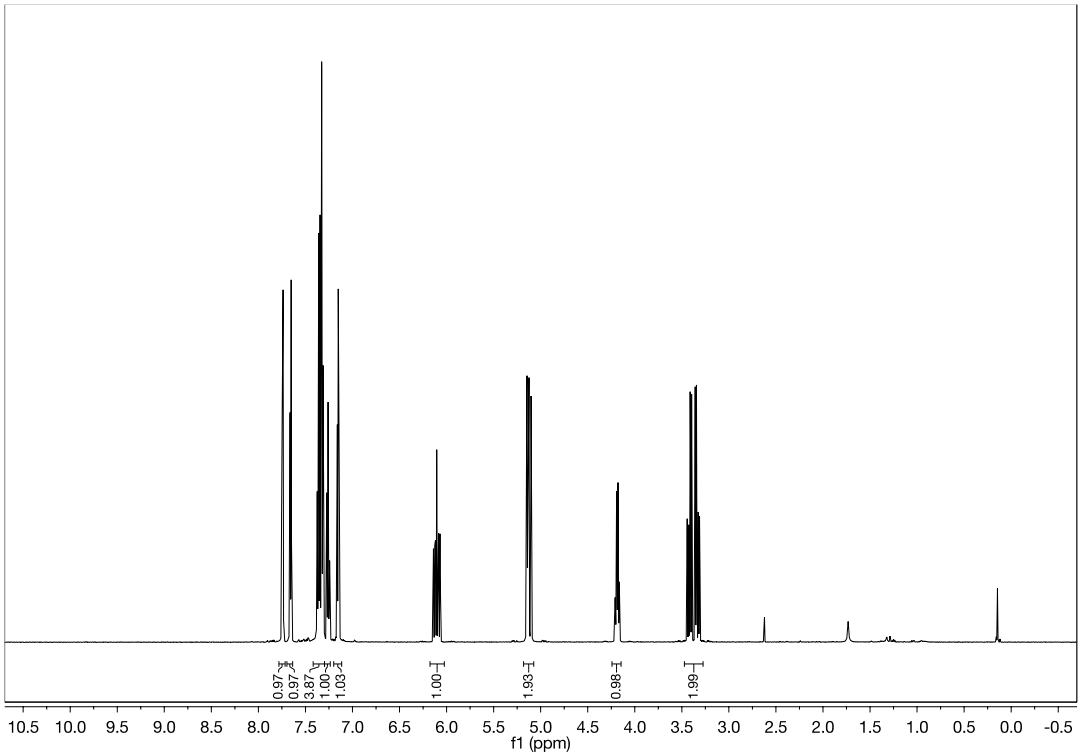
(**3m**)

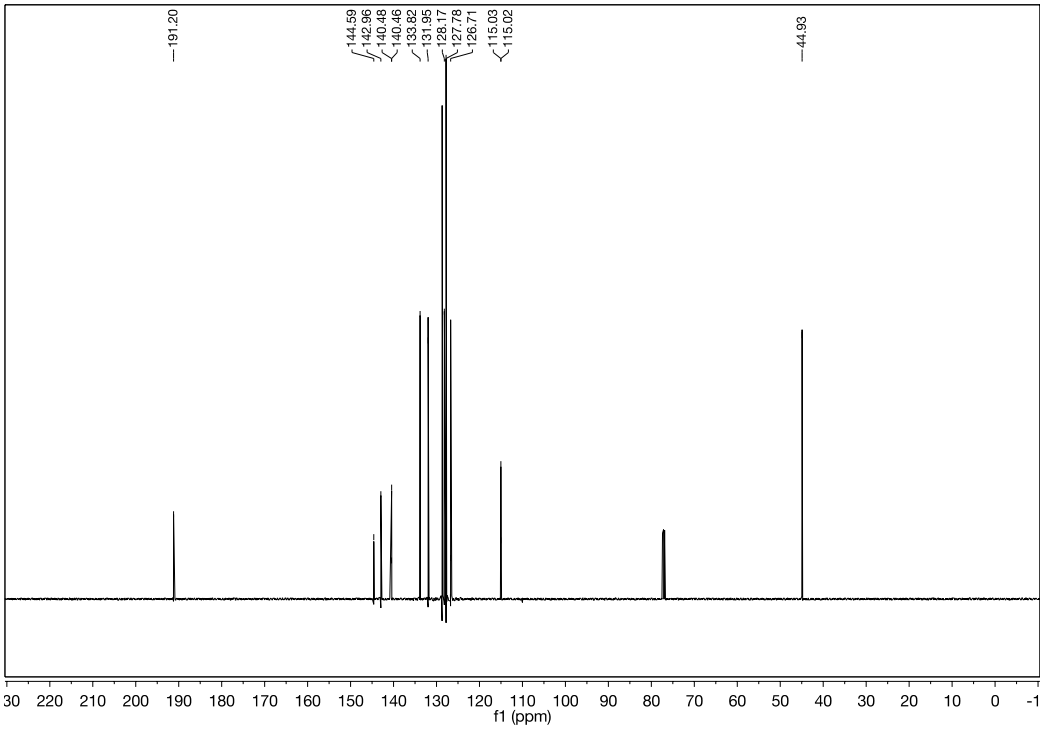

1.02
6.39
1.01
1.00
2.04
1.00
2.08
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)

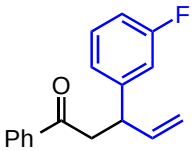

187.58
153.04
146.43
142.95
140.50
128.67
128.66
127.78
127.77
126.69
117.20
114.94
112.35
44.66
43.95
30 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -1
f1 (ppm)


O
Ph
S

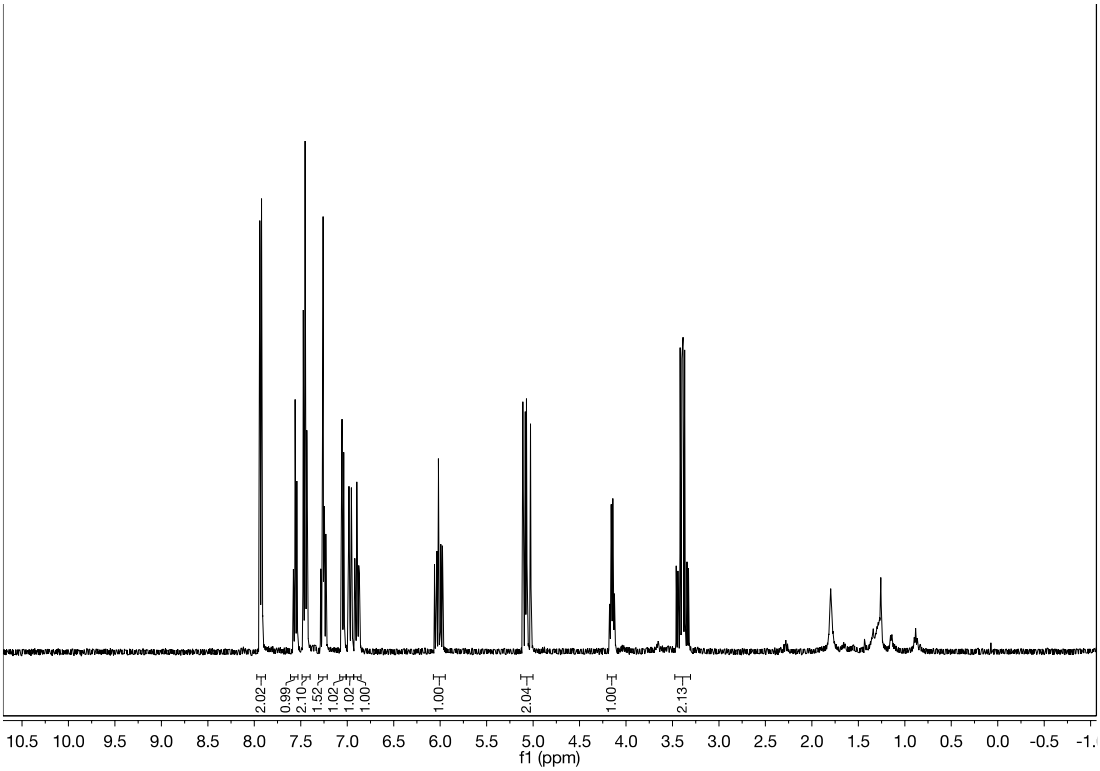
(3n)

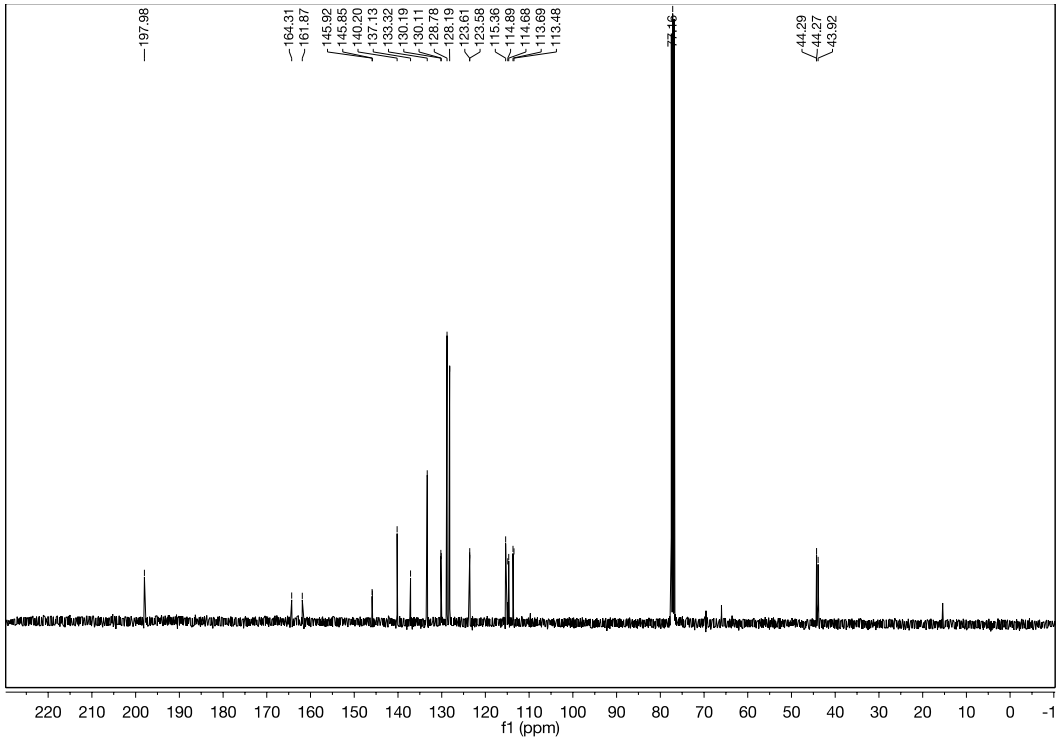

0.97
0.97
3.87
1.00
1.03
1.00
1.93
0.98
1.99
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)

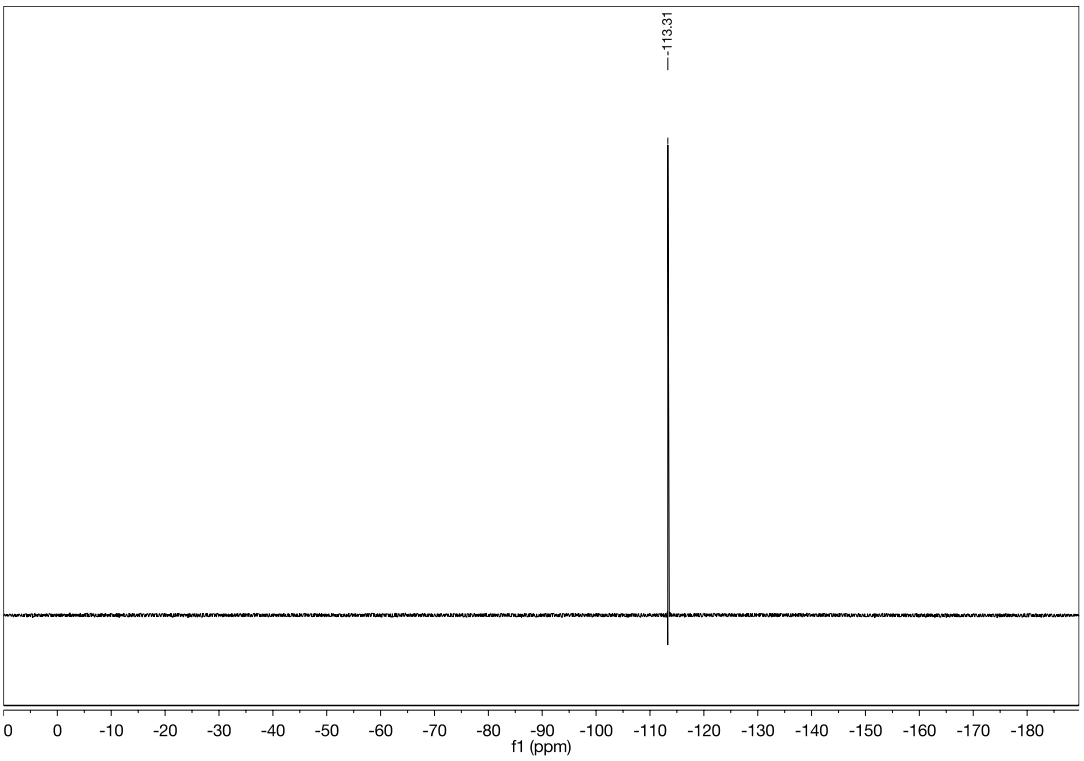

191.20
144.59
142.96
140.48
140.46
133.82
131.95
128.17
127.78
126.71
115.03
115.02
44.93
30 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -1
f1 (ppm)

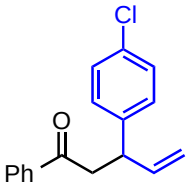

F
O
Ph

(**3o**)

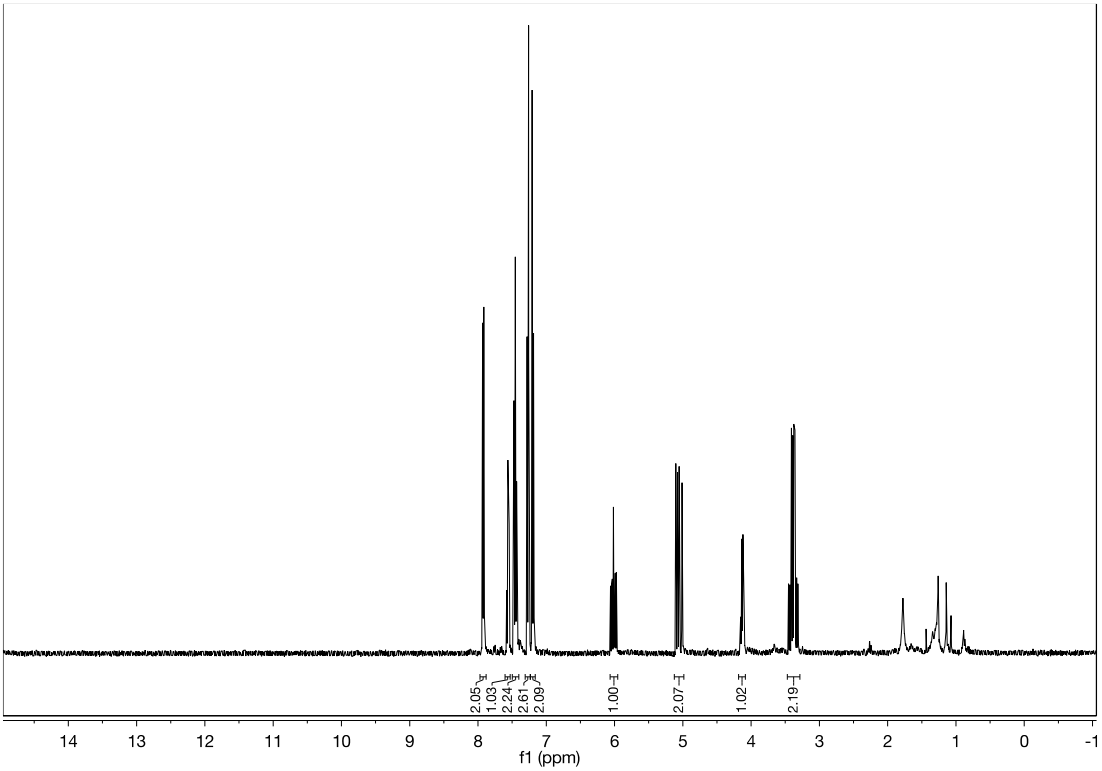

2.02
0.99
2.10
1.52
1.02
1.02
1.00
1.00
2.04
1.00
2.13
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)

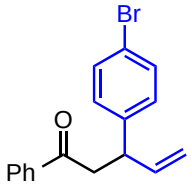

197.98
164.31
161.87
145.92
145.85
140.20
137.13
133.32
130.19
130.11
128.78
128.19
123.61
123.58
115.36
114.89
114.68
113.69
113.48
77.16
44.29
44.27
43.92
220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)


-113.31
0
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
-120
-130
-140
-150
-160
-170
-180
f1 (ppm)

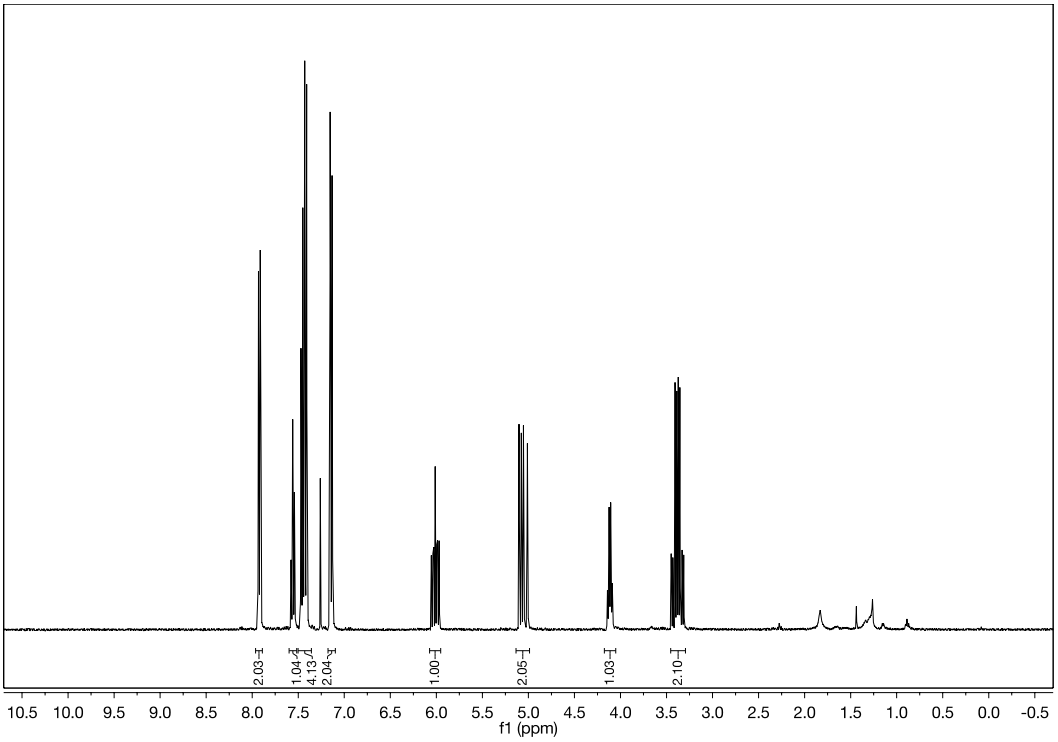

Cl
O
Ph

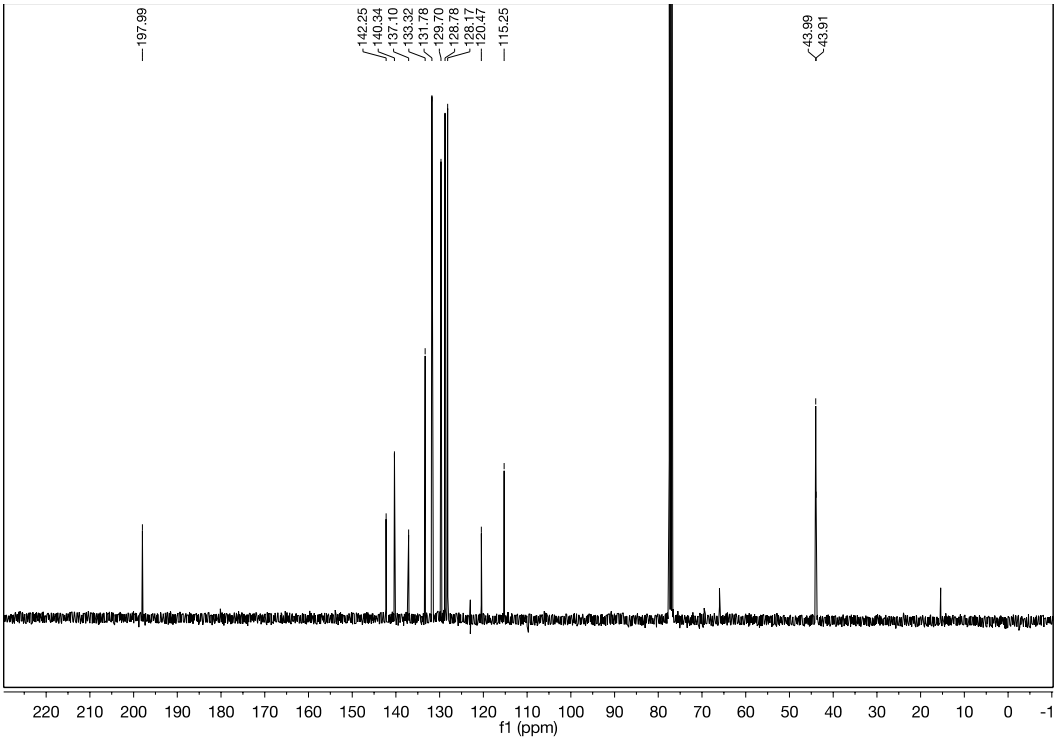
(3p)

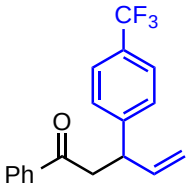

2.05
1.03
2.24
2.61
2.09
1.00
2.07
1.02
2.19
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
f1 (ppm)


Br
O
Ph

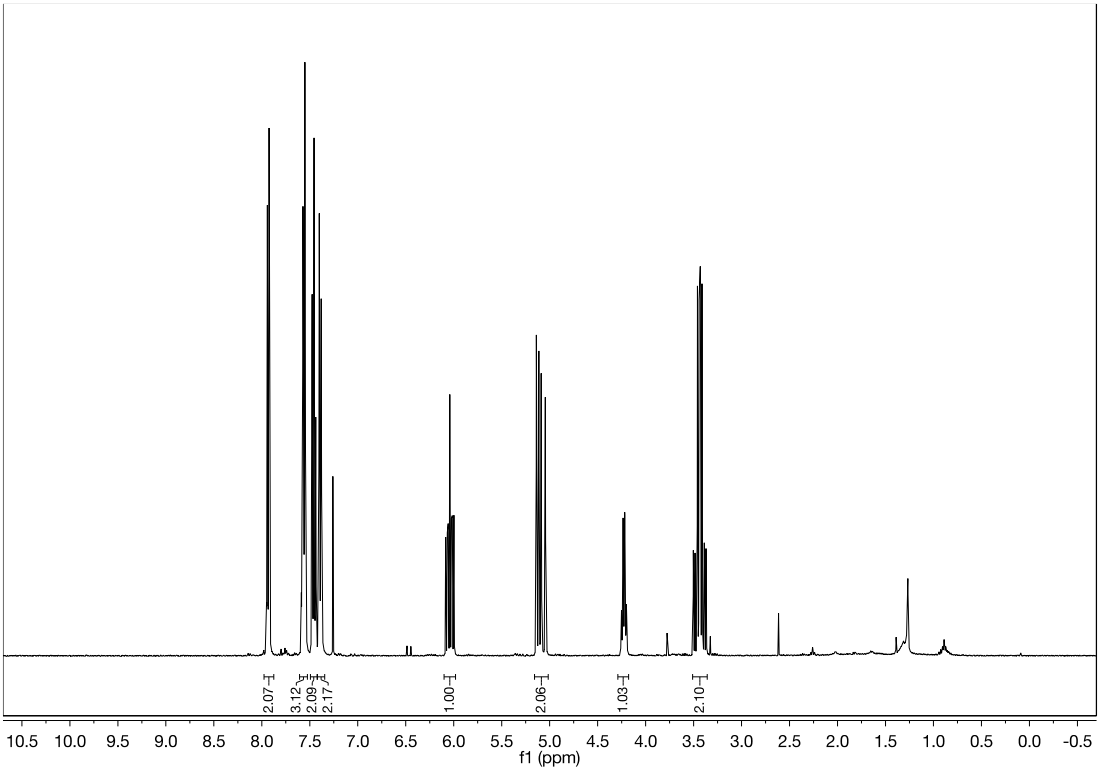
(3q)

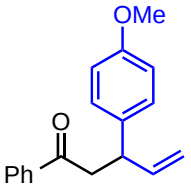

2.03
1.04
4.13
2.04
1.00
2.05
1.03
2.10
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)


197.99
142.25
140.34
137.10
133.32
131.78
129.70
128.78
128.17
120.47
115.25
43.99
43.91
220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -1
f1 (ppm)

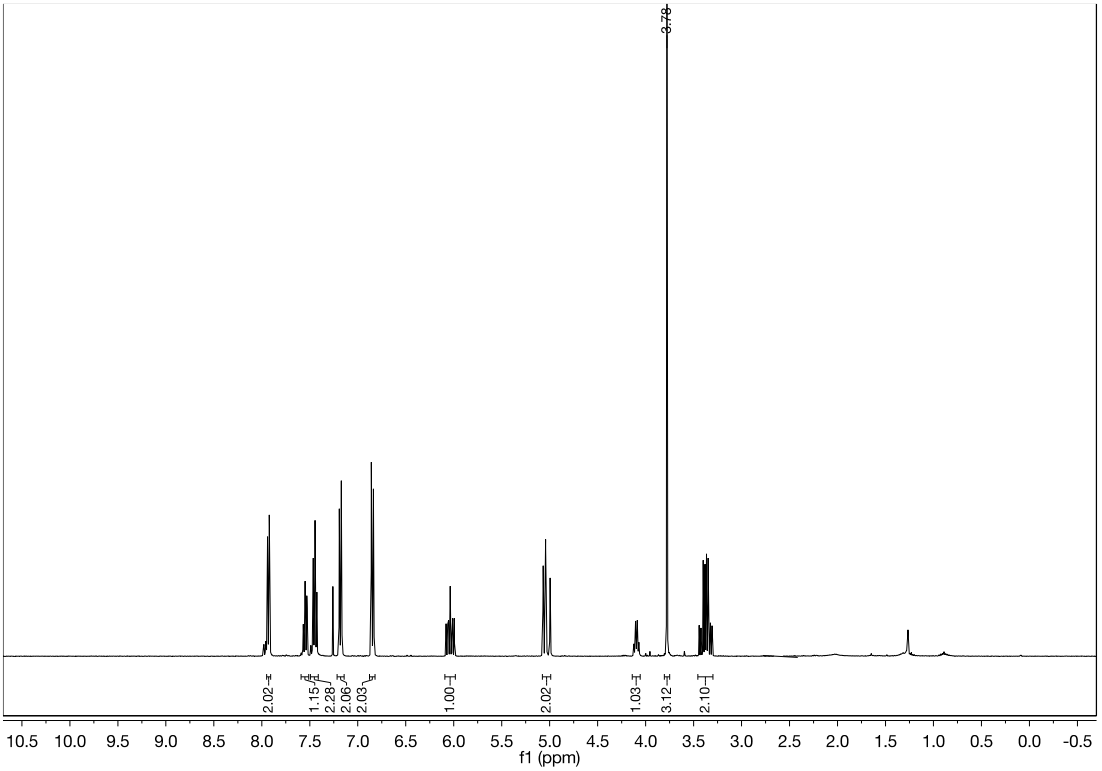

CF3
O
Ph

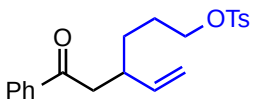
(**3r**)


2.07
3.12
2.09
2.17
1.00
2.06
1.03
2.10
10.5 10.0 9.5 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
f1 (ppm)

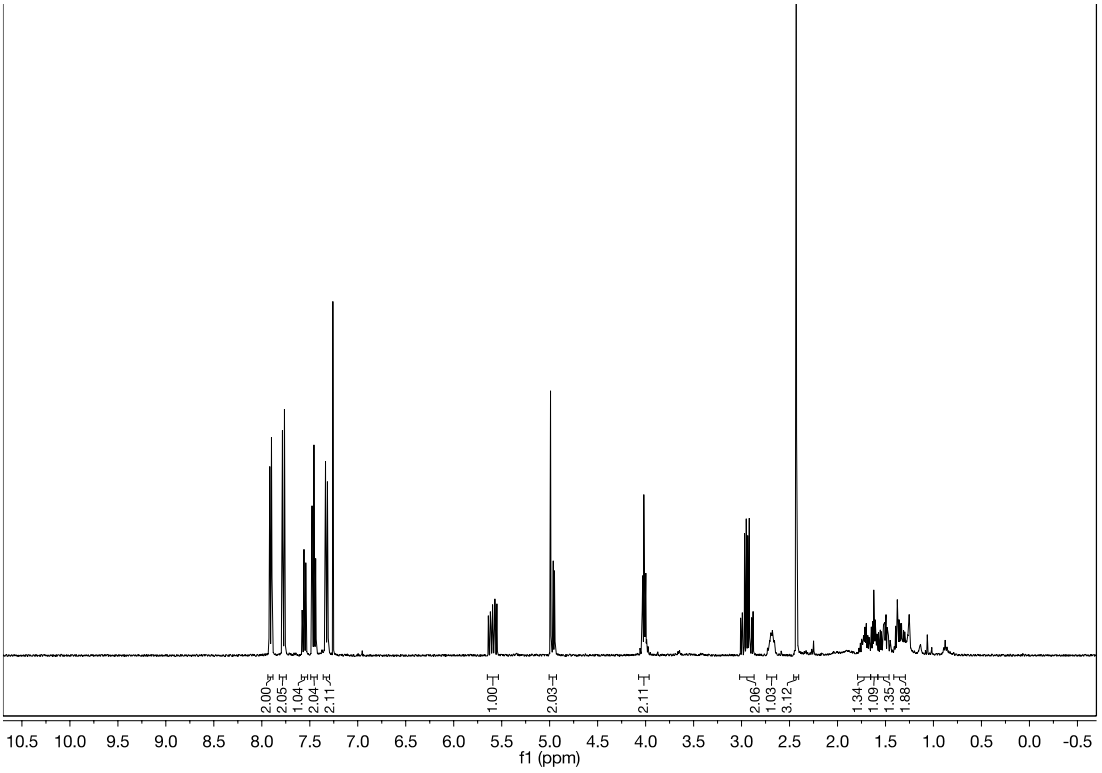

OMe
O
Ph

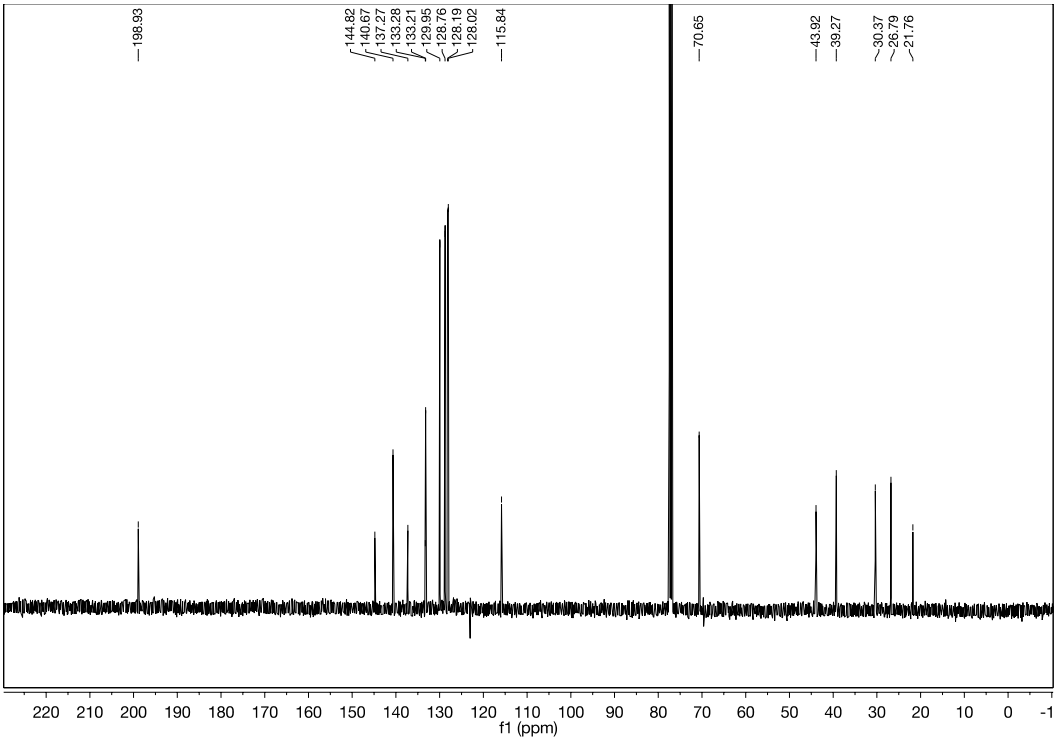
(**3s**)

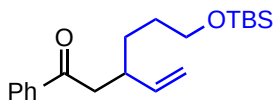

3.78
2.02
1.15
2.28
2.06
2.03
1.00
2.02
1.03
3.12
2.10
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)


OTs
O
Ph

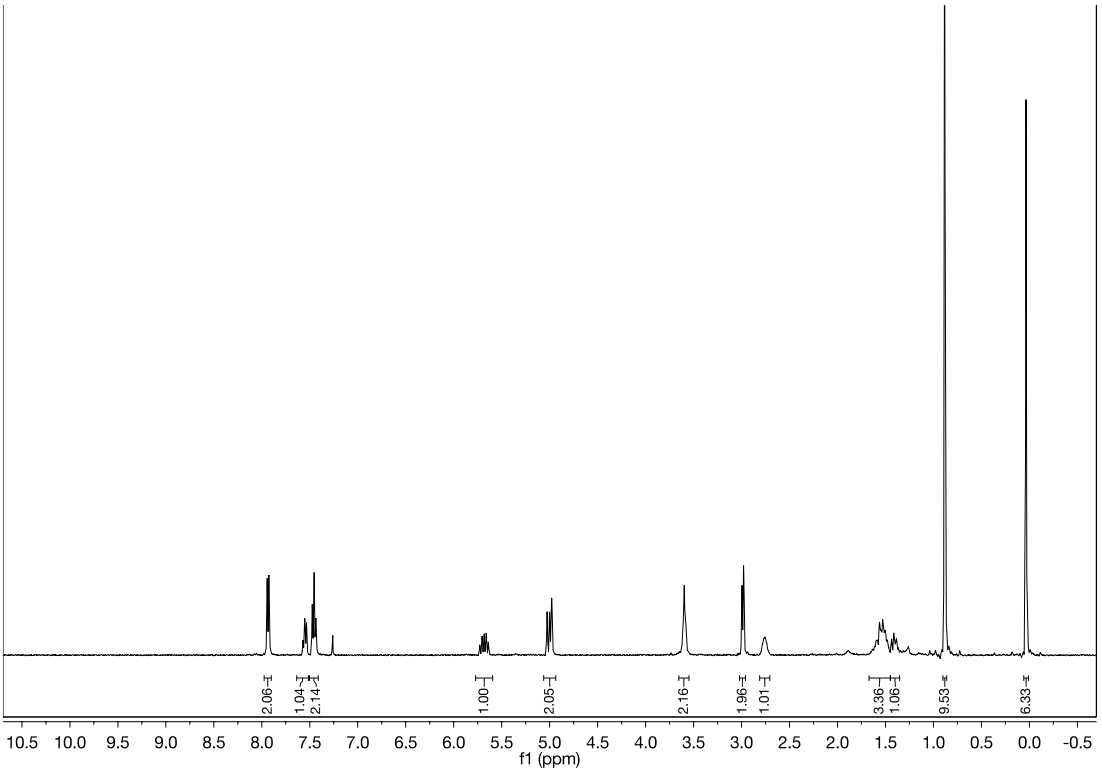
(3t)

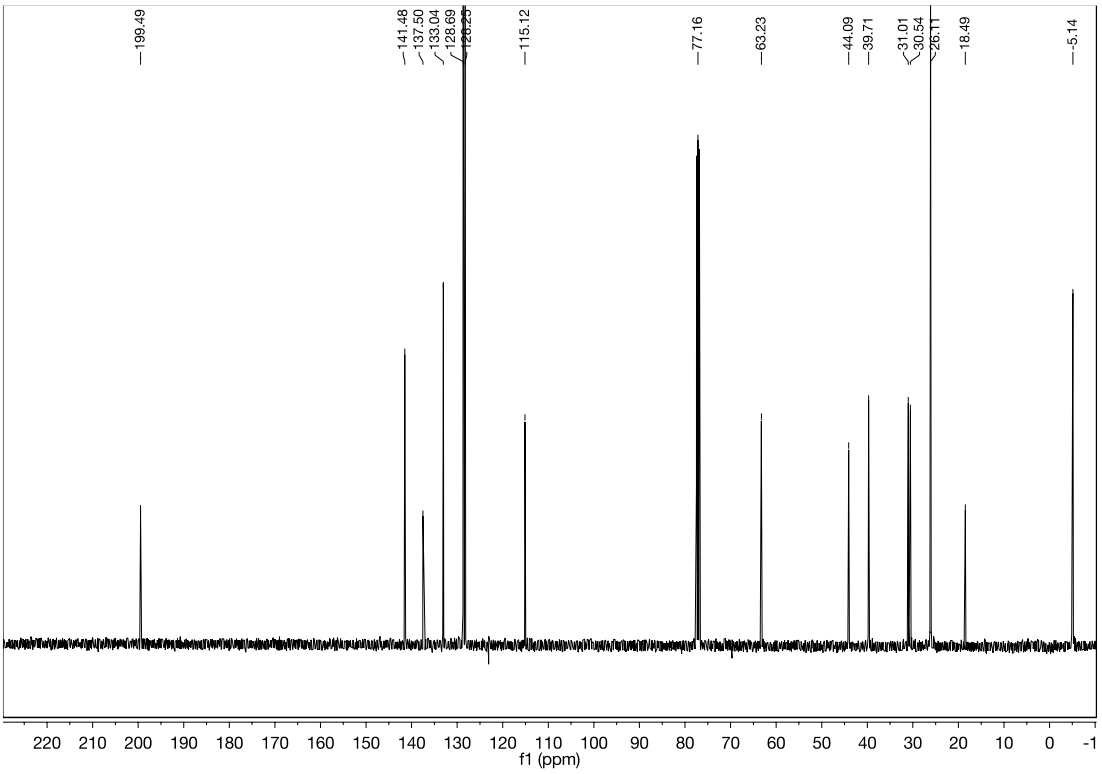

2.00
2.05
1.04
2.04
2.11
1.00
2.03
2.11
2.06
1.03
3.12
1.34
1.09
1.35
1.88
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)

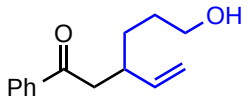

198.93
144.82
140.67
137.27
133.28
133.21
129.95
128.76
128.19
128.02
115.84
70.65
43.92
39.27
30.37
26.79
21.76
220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -1
f1 (ppm)


OTBS
O
Ph

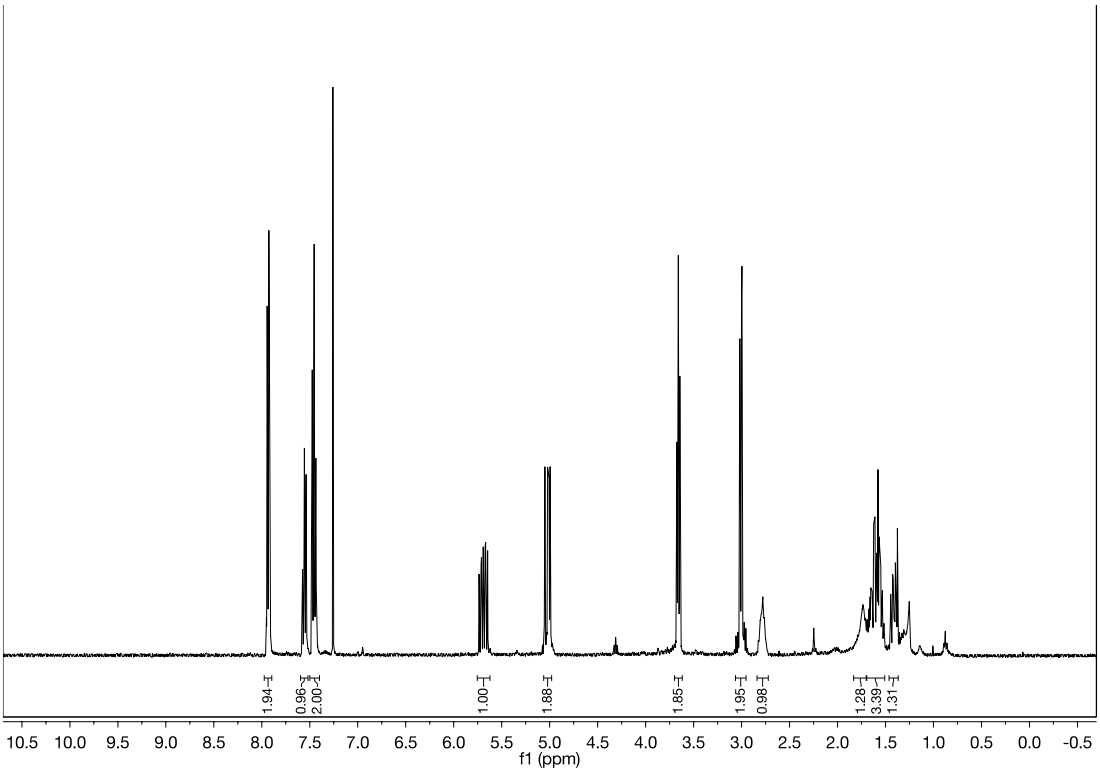
(**3u**)

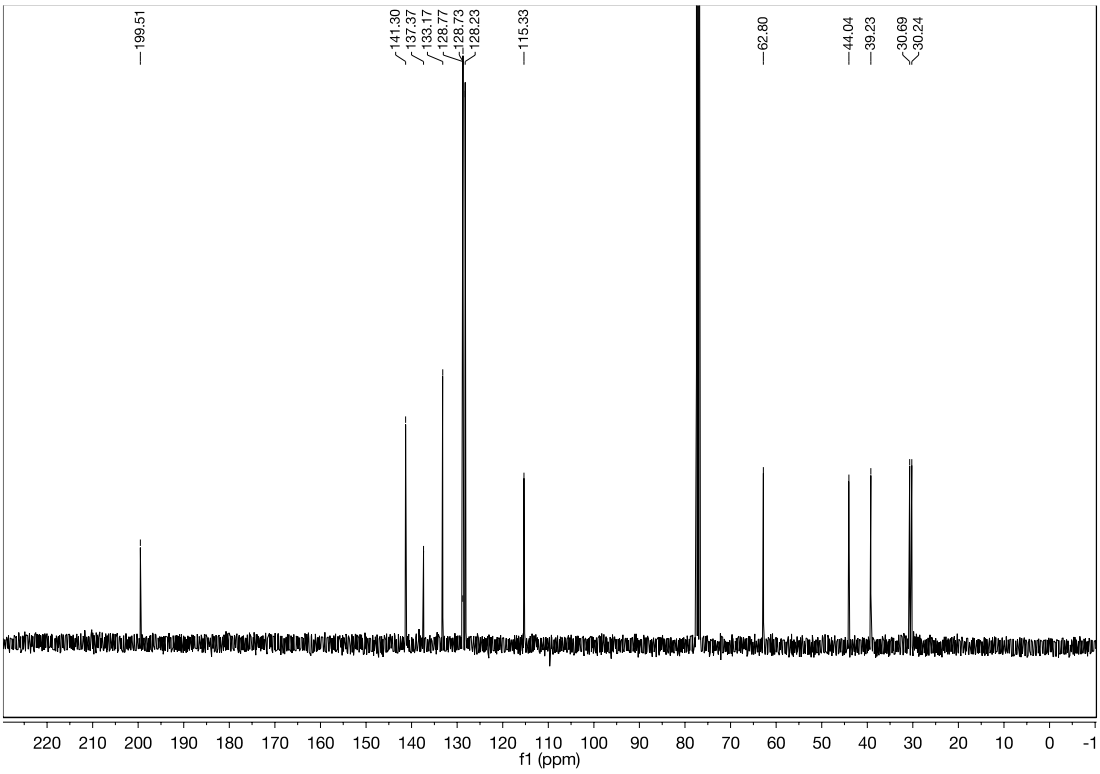

2.06
1.04
2.14
1.00
2.05
2.16
1.96
1.01
3.36
1.06
9.53
6.33
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)

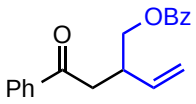

199.49
141.48
137.50
133.04
128.69
128.20
115.12
77.16
63.23
44.09
39.71
31.01
30.54
26.11
18.49
-5.14
220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -1
f1 (ppm)


O
OH
Ph

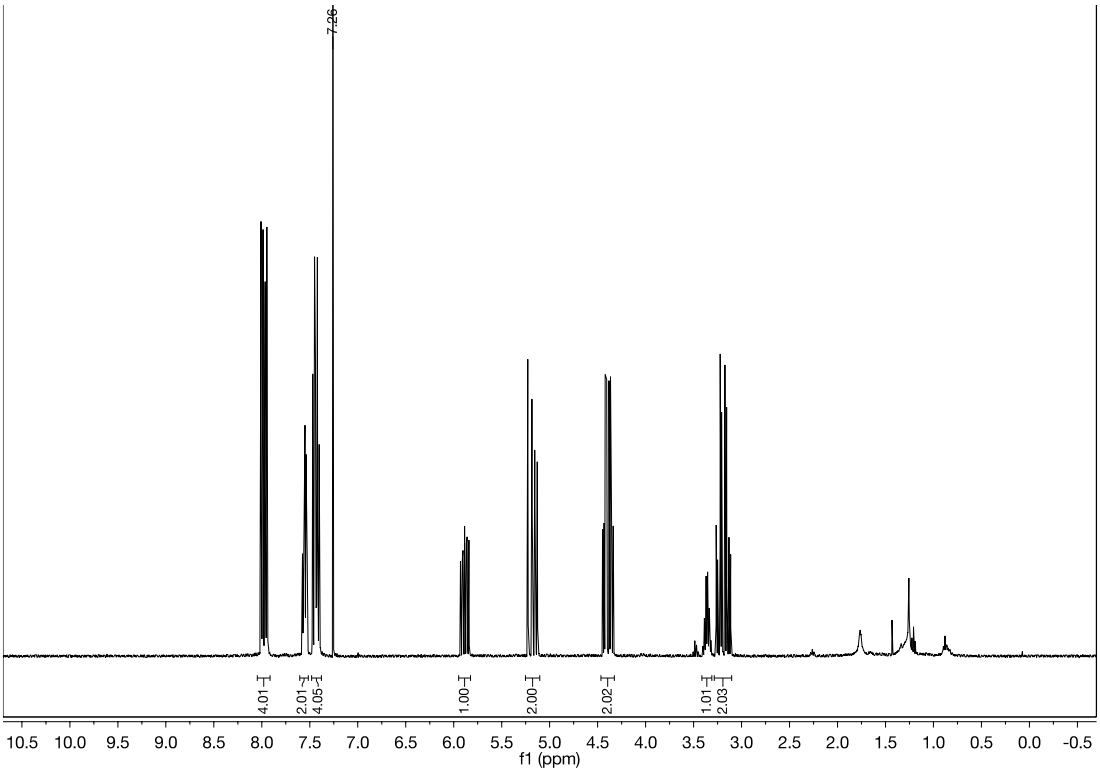
(3v)

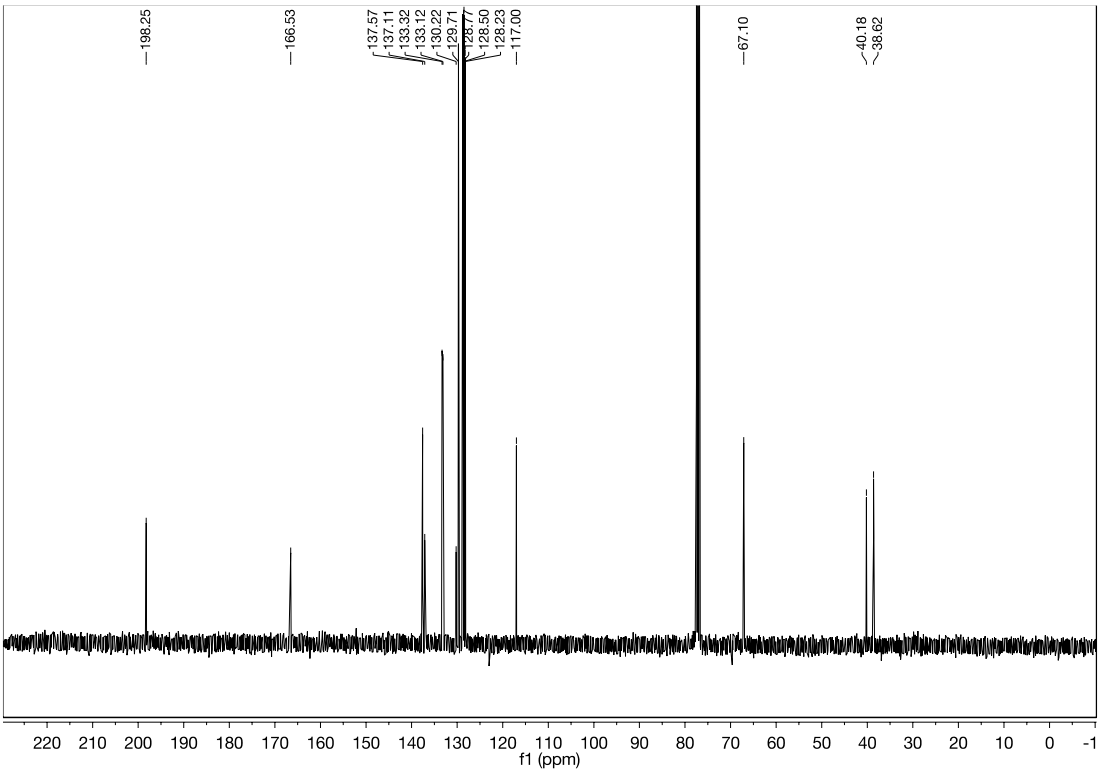

1.94
0.96
2.00
1.00
1.88
1.85
1.95
0.98
1.28
3.39
1.31
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)

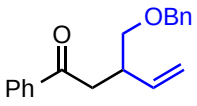

199.51
141.30
137.37
133.17
128.77
128.73
128.23
115.33
62.80
44.04
39.23
30.69
30.24
220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -1
f1 (ppm)


OBz
O
Ph

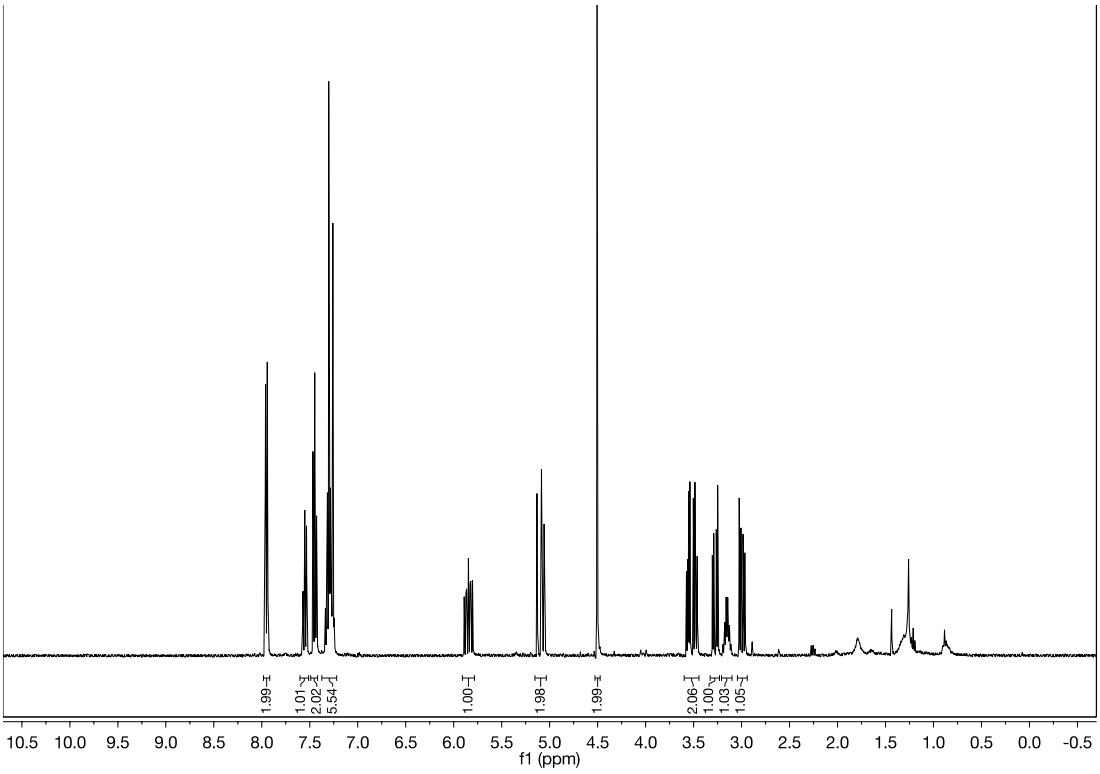
(3w)

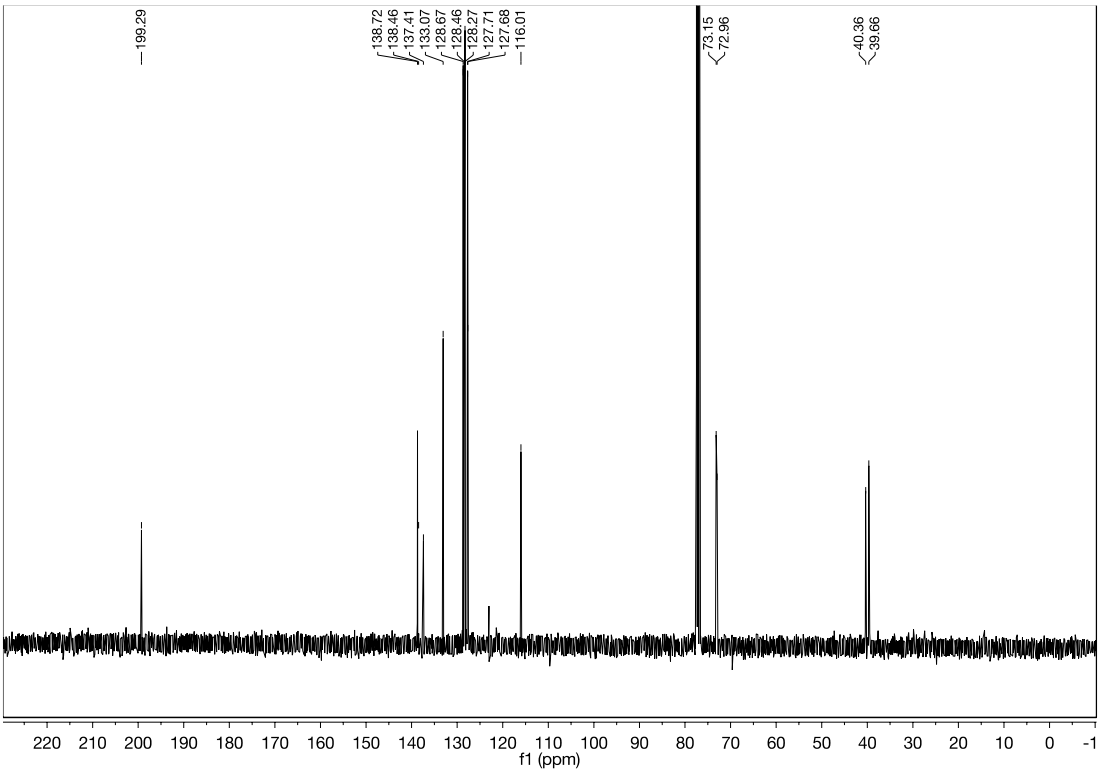

7.26
4.01
2.01
4.05
1.00
2.00
2.02
1.01
2.03
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)

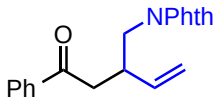

198.25
166.53
137.57
137.11
133.32
133.12
130.22
129.71
128.77
128.50
128.23
117.00
67.10
40.18
38.62
220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -1
f1 (ppm)


OBn
O
Ph

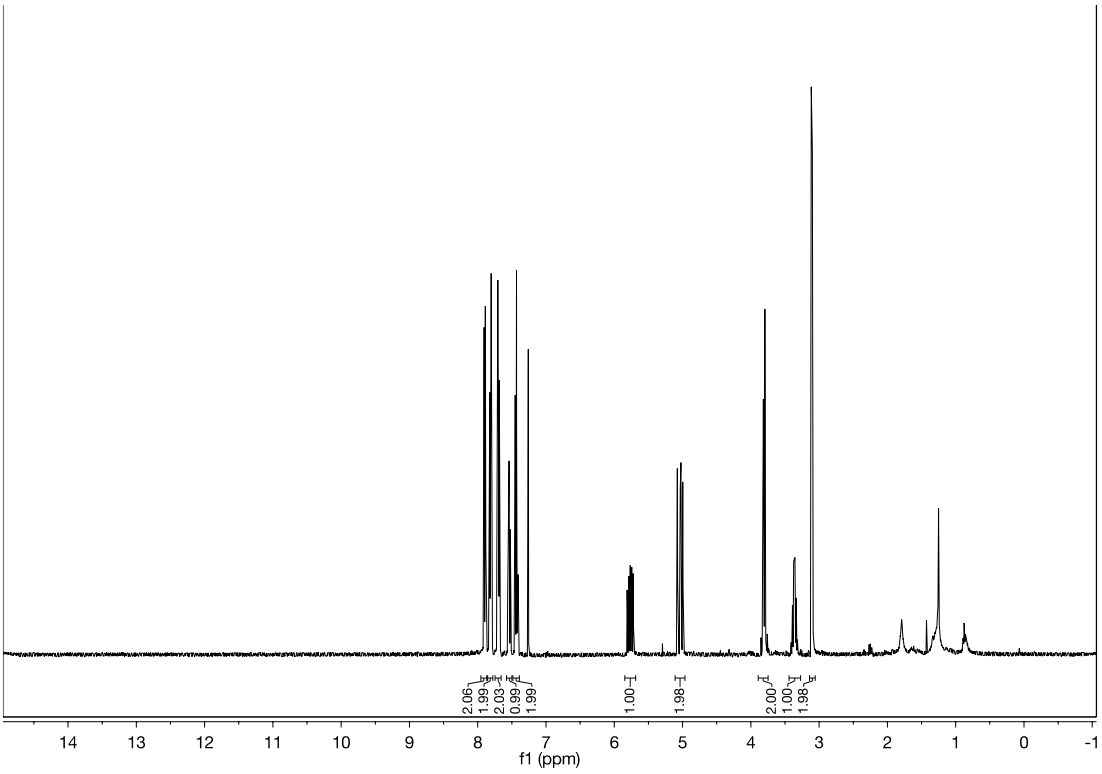
(3x)

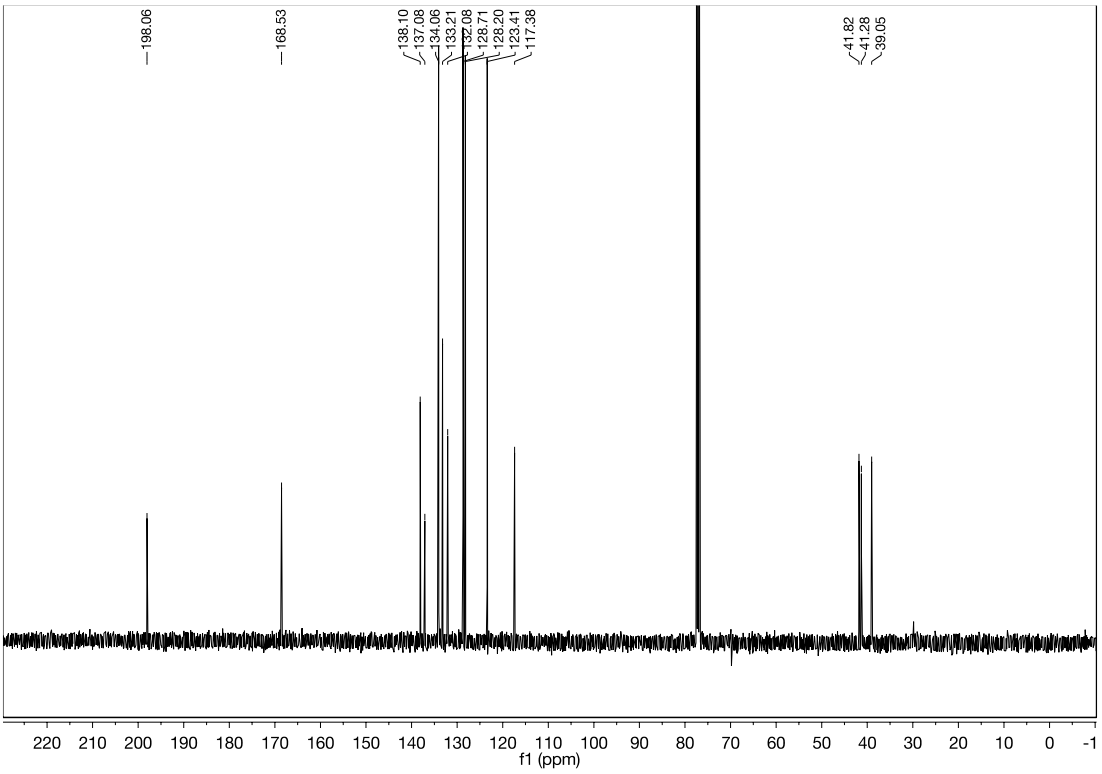

1.99
1.01
2.02
5.54
1.00
1.98
1.99
2.06
1.00
1.03
1.05
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)


199.29
138.72
138.46
137.41
133.07
128.67
128.46
128.27
127.71
127.68
116.01
73.15
72.96
40.36
39.66
220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -1
f1 (ppm)

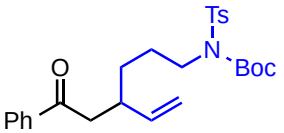

NPhth
O
Ph

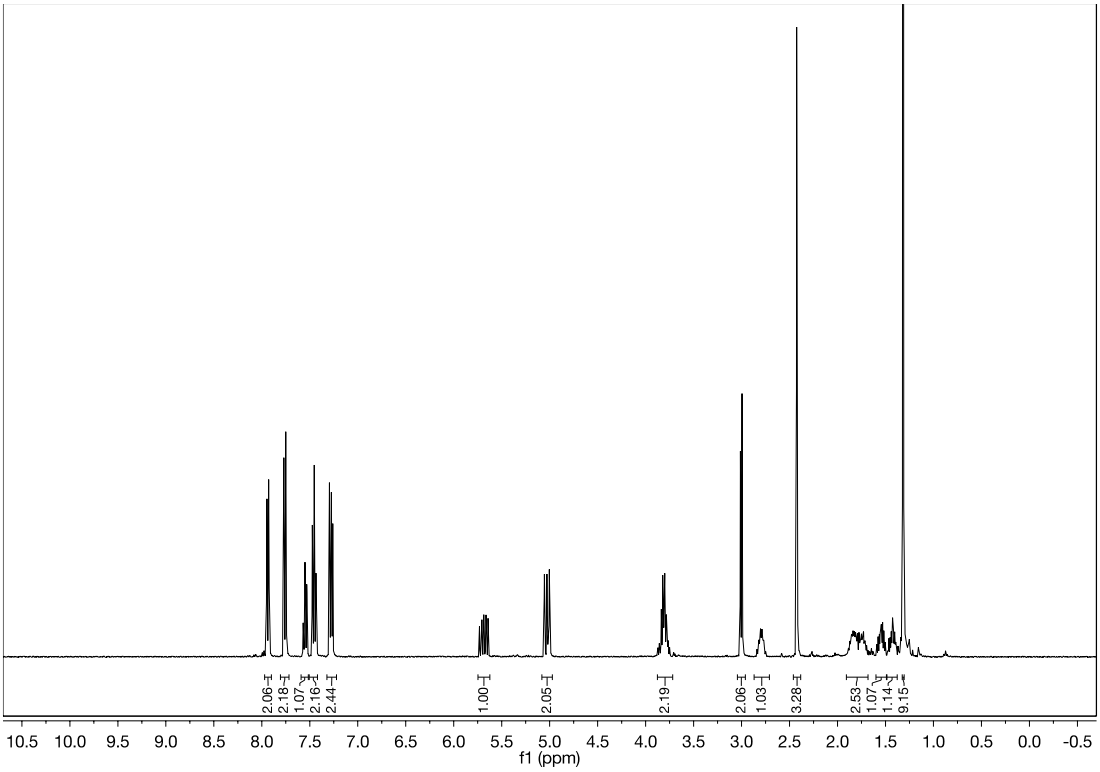
(**3y**)

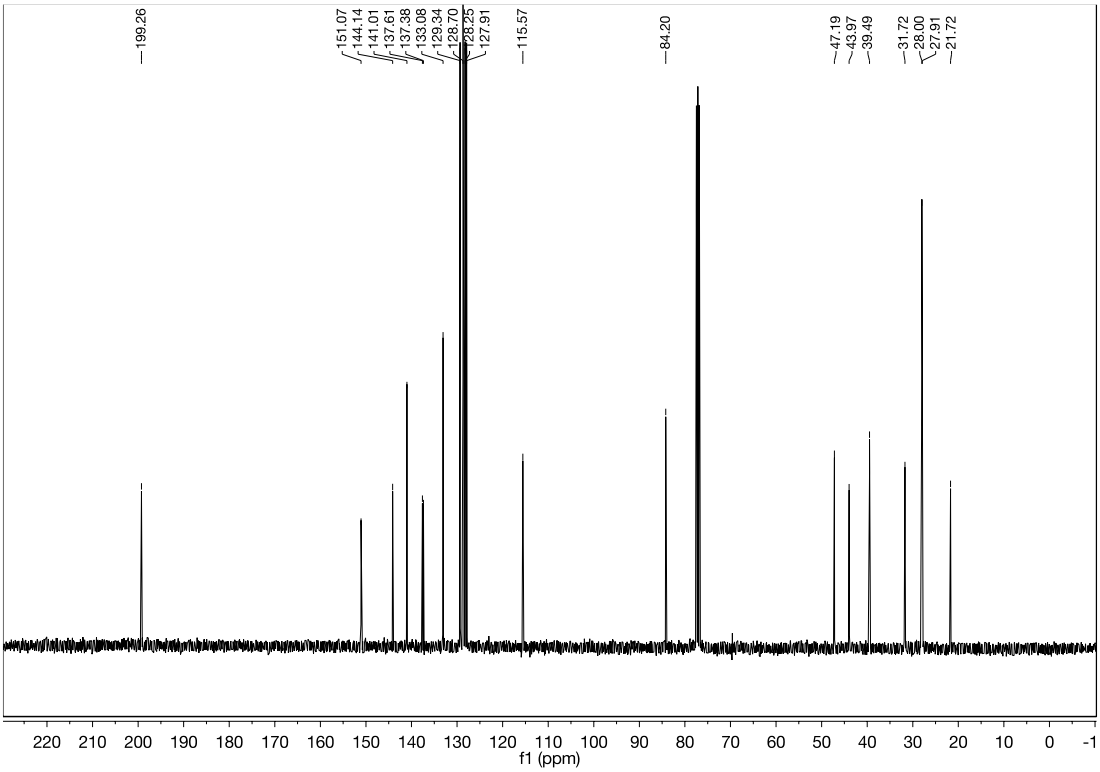

2.06
1.99
2.03
0.99
1.99
1.00
1.98
2.00
1.00
1.98
14 13 12 11 10 9 8 7 6 5 4 3 2 1 0 -1
f1 (ppm)

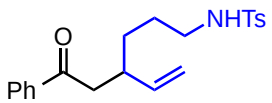

198.06
168.53
138.10
137.08
134.06
133.21
132.08
128.71
128.20
123.41
117.38
41.82
41.28
39.05
220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -1
f1 (ppm)

(3z)

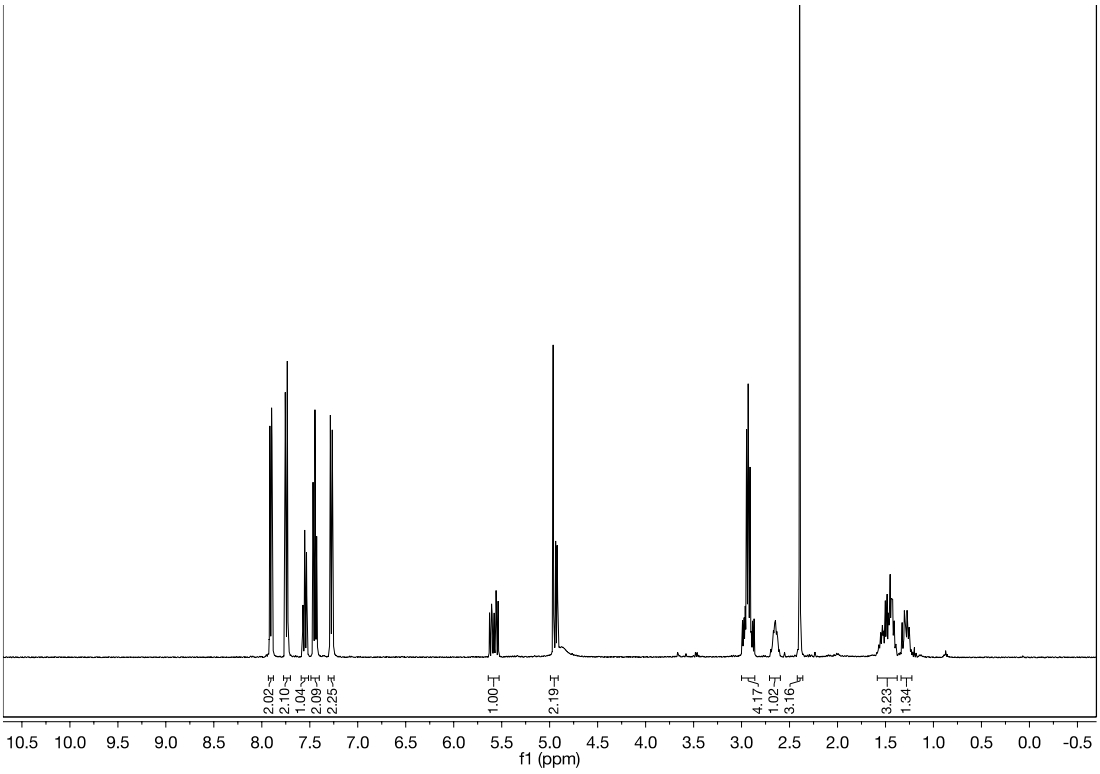

Ts
N
Boc
O
Ph

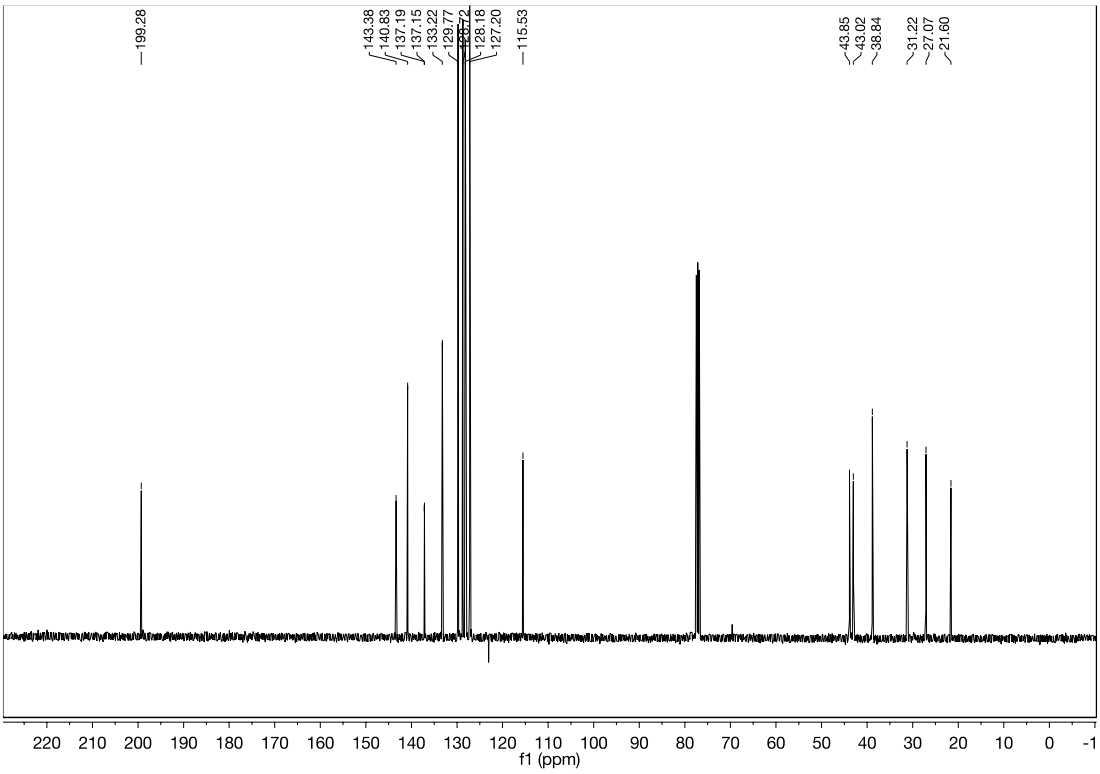

2.06
2.18
1.07
2.16
2.44
1.00
2.05
2.19
2.06
1.03
3.28
2.53
1.07
1.14
9.15
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)

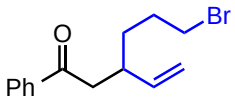

199.26
151.07
144.14
141.01
137.61
137.38
133.08
129.34
128.70
128.25
127.91
115.57
84.20
47.19
43.97
39.49
31.72
28.00
27.91
21.72
220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -1
f1 (ppm)


NHTs
O
Ph

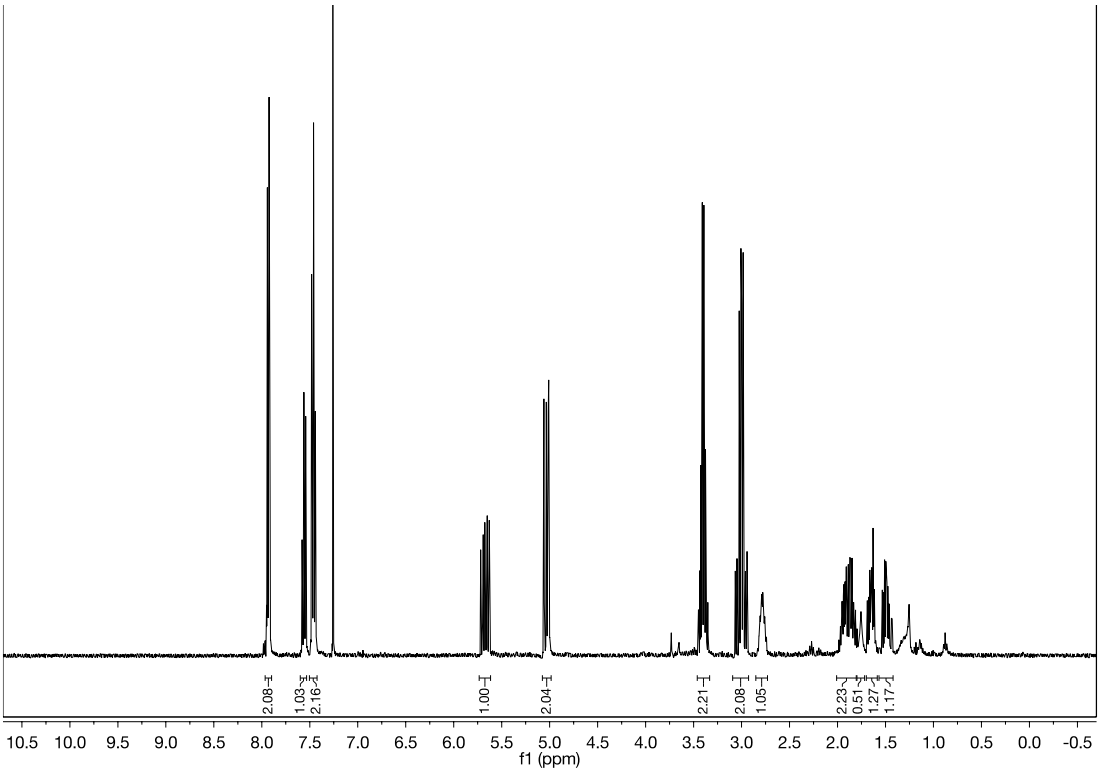
(**3aa**)

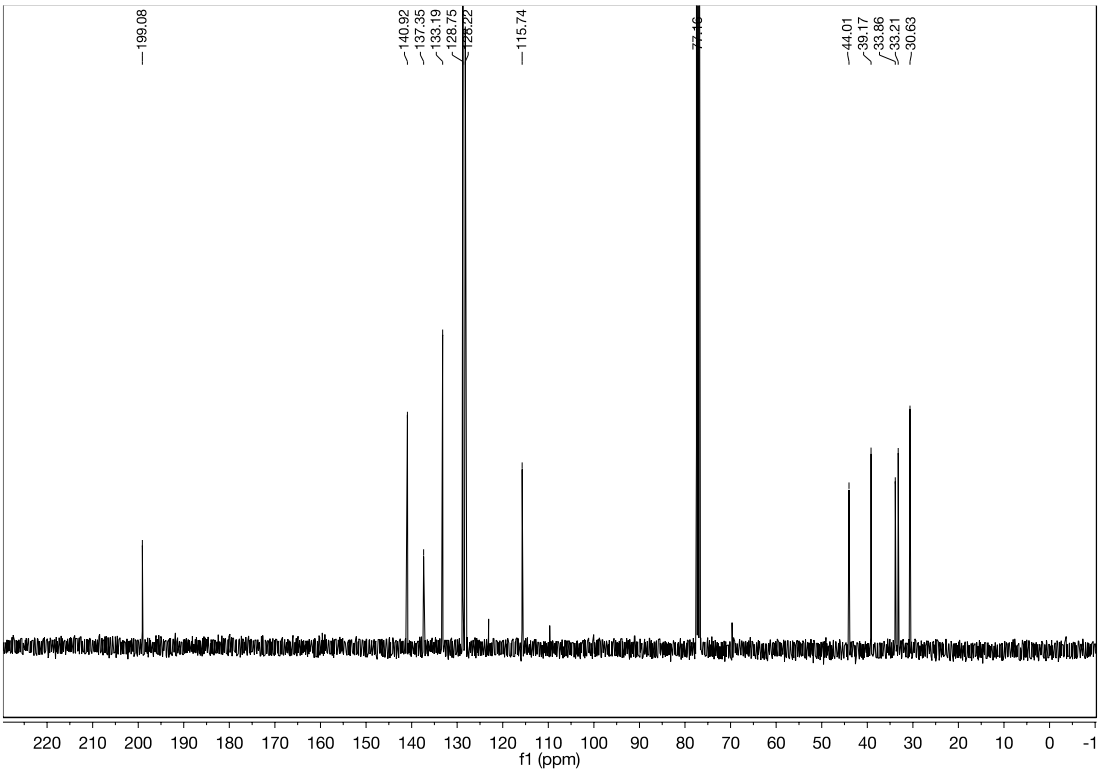

2.02
2.10
1.04
2.09
2.25
1.00
2.19
4.17
1.02
3.16
3.23
1.34
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)

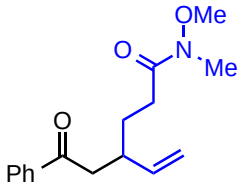

199.28
143.38
140.83
137.19
137.15
133.22
129.77
128.72
128.18
127.20
115.53
43.85
43.02
38.84
31.22
27.07
21.60
220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -1
f1 (ppm)


O
Br
Ph

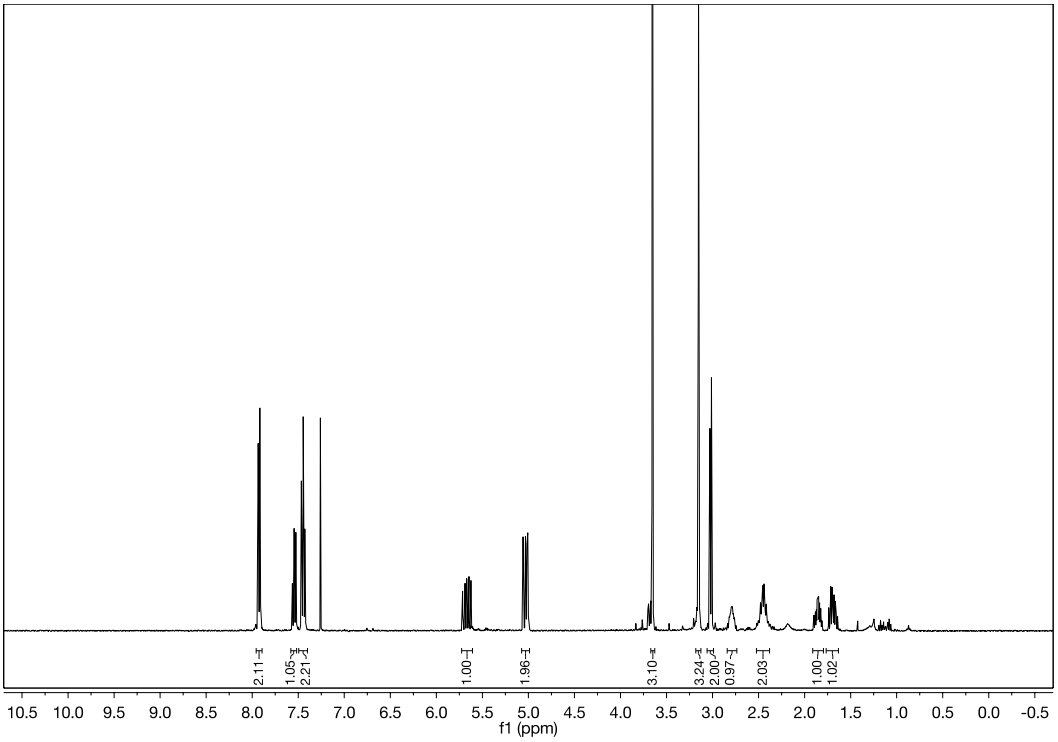
(**3ab**)


2.08
1.03
2.16
1.00
2.04
2.21
2.08
1.05
2.23
0.51
1.27
1.17
10.5 10.0 9.5 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
f1 (ppm)


199.08
140.92
137.35
133.19
128.75
128.22
115.74
77.16
44.01
39.17
33.86
33.21
30.63
220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -1
f1 (ppm)


OMe
O
N
Me
O
Ph

(**3ac**)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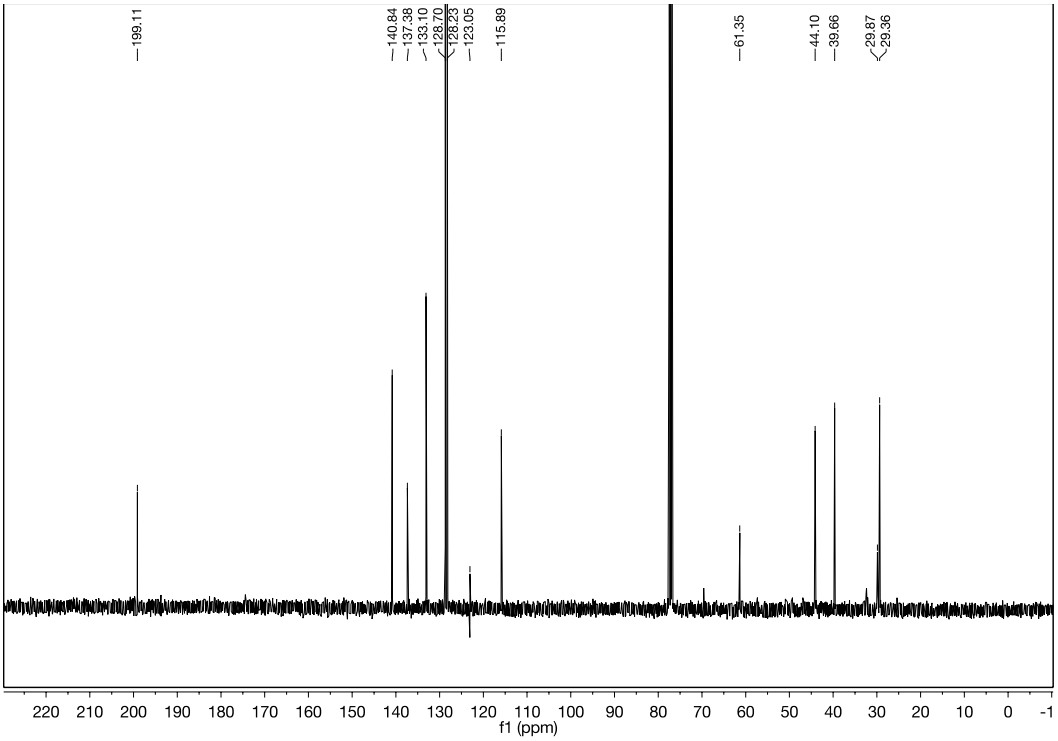
2.21
1.00
1.96
3.10
3.24
2.00
0.97
2.03
1.00
1.02
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)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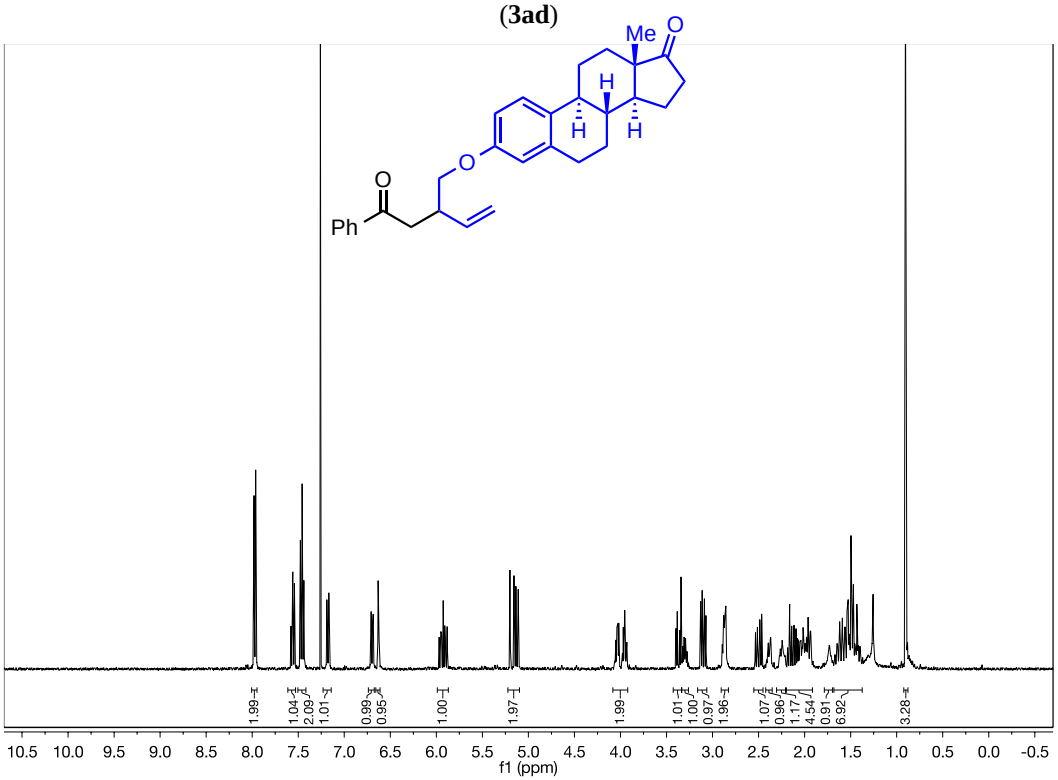
140.84
137.38
133.10
128.70
128.23
123.05
115.89
61.35
44.10
39.66
29.87
29.36
220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -1
f1 (ppm)

(**3ad**)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O
H
H
H
O
O
Ph
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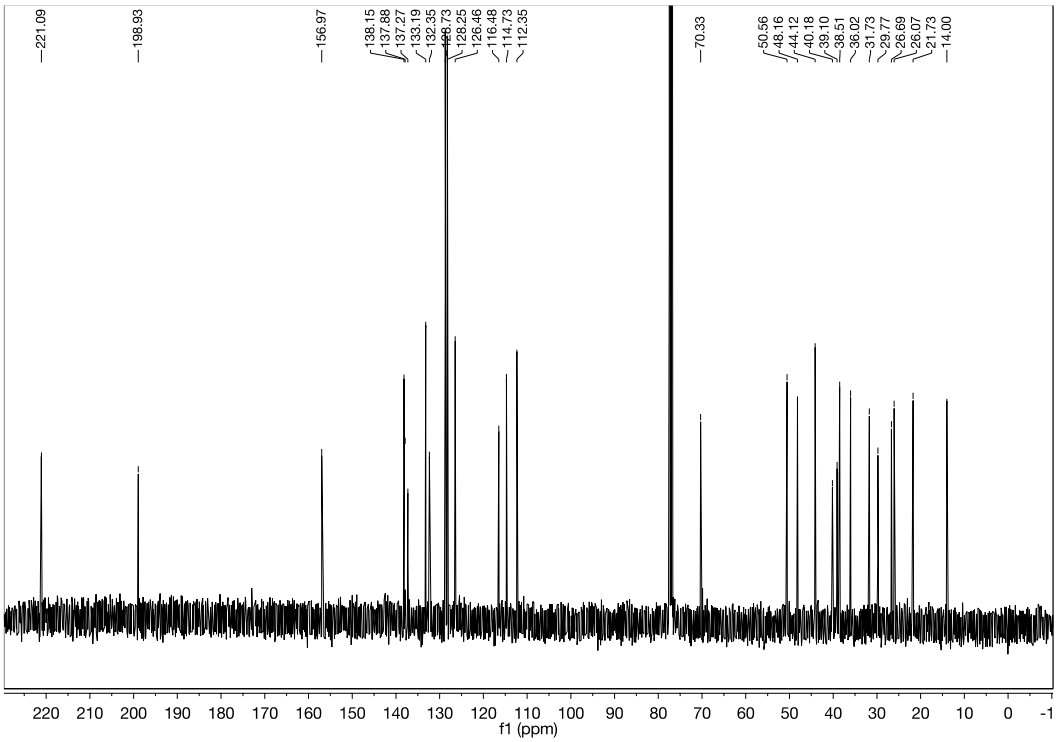
1.04
2.09
1.01
0.99
0.95
1.00
1.97
1.99
1.01
1.00
0.97
1.96
1.07
0.96
1.17
4.54
0.91
6.92
3.28
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)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137.88
137.27
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132.35
128.73
128.25
126.46
116.48
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112.35
70.33
50.56
48.16
44.12
40.18
39.10
38.51
36.02
31.73
29.77
26.69
26.07
21.73
14.00
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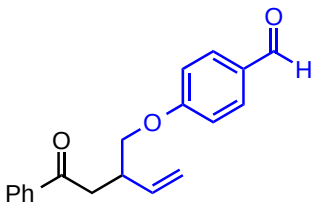
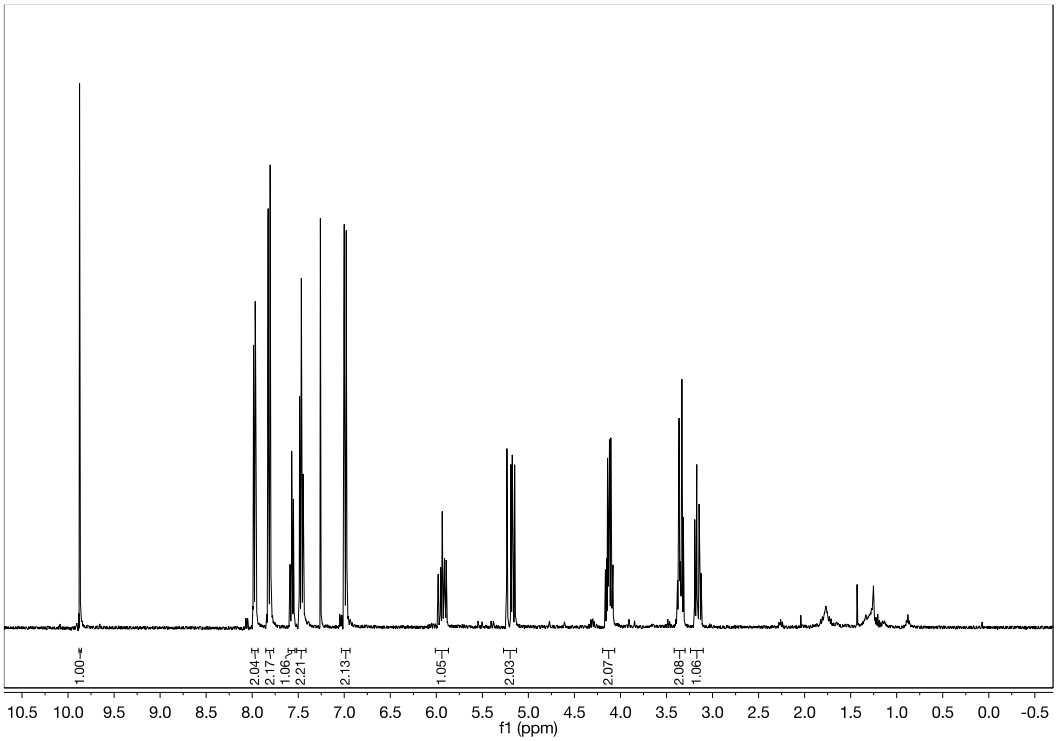
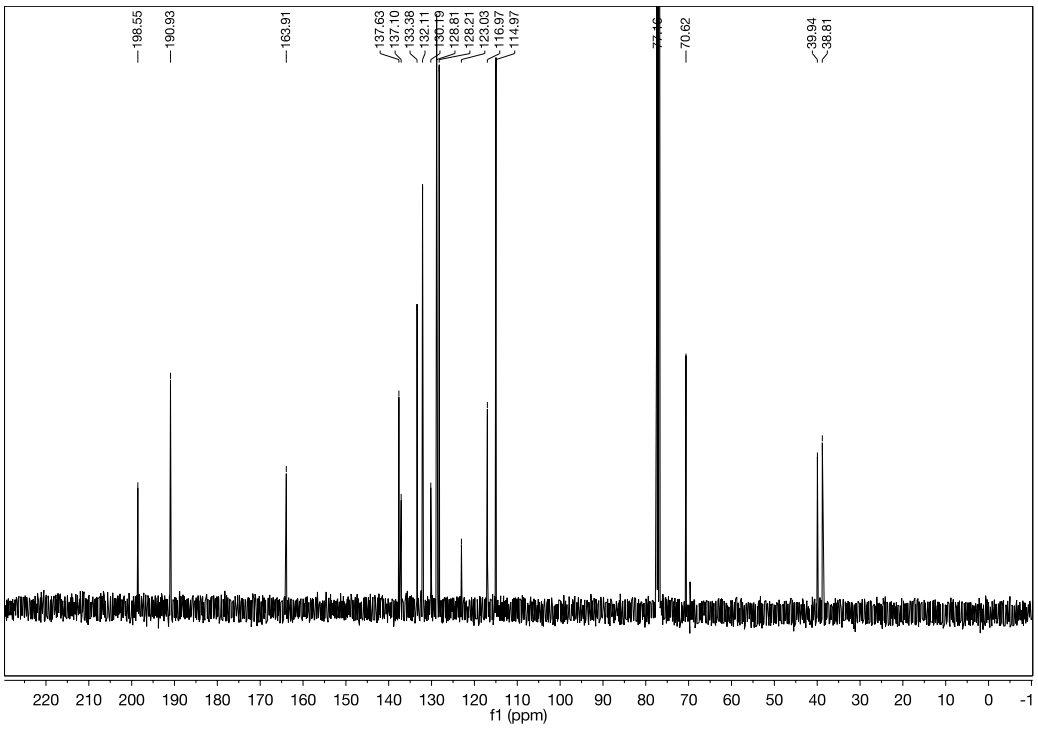
f1 (ppm)


O
H
O
O
Ph

(**3ae**)


1.00
2.04
2.17
1.06
2.21
2.13
1.05
2.03
2.07
2.08
1.06
10.5 10.0 9.5 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
f1 (ppm)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137.10
133.38
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130.19
128.81
128.21
123.03
116.97
114.97
77.16
70.62
39.94
38.81
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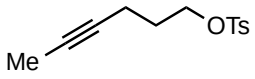
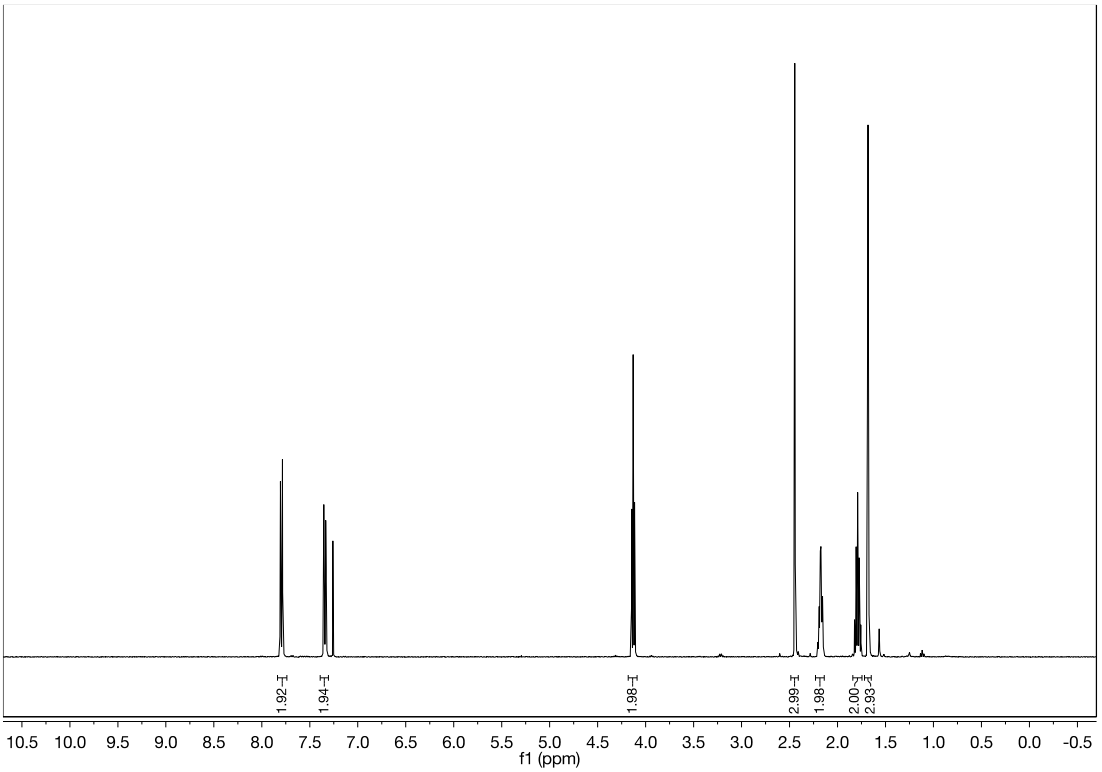
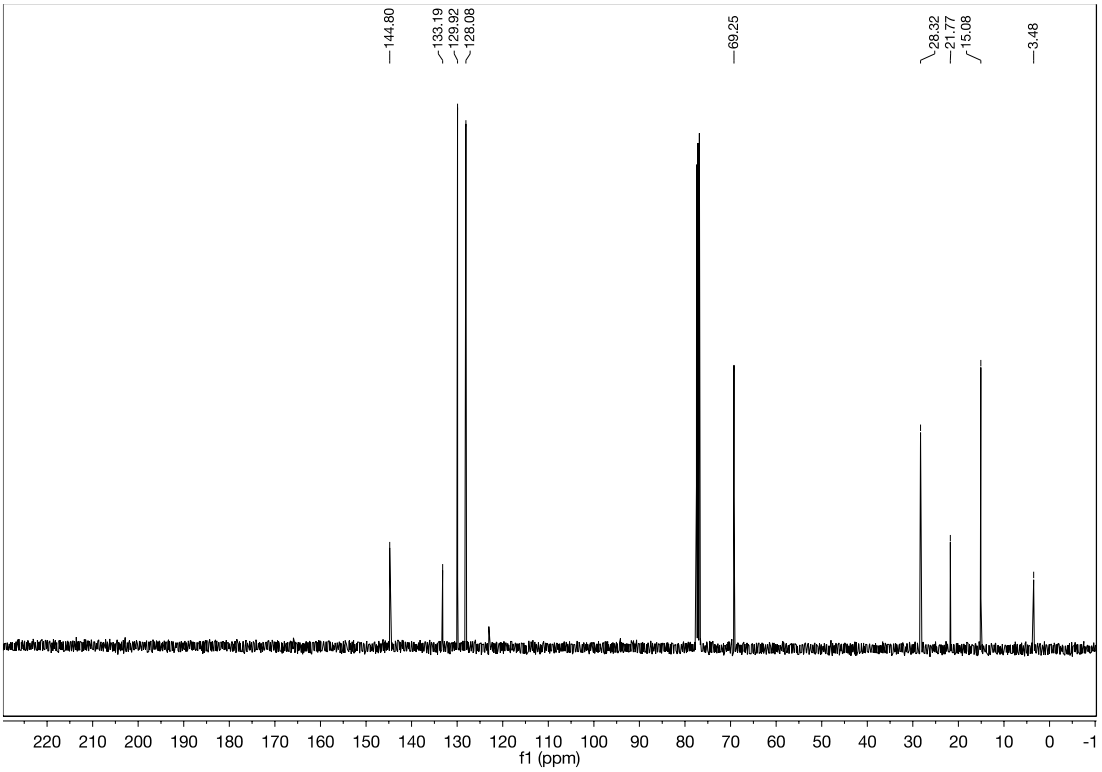
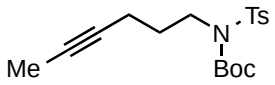
f1 (ppm)


Me
OTs

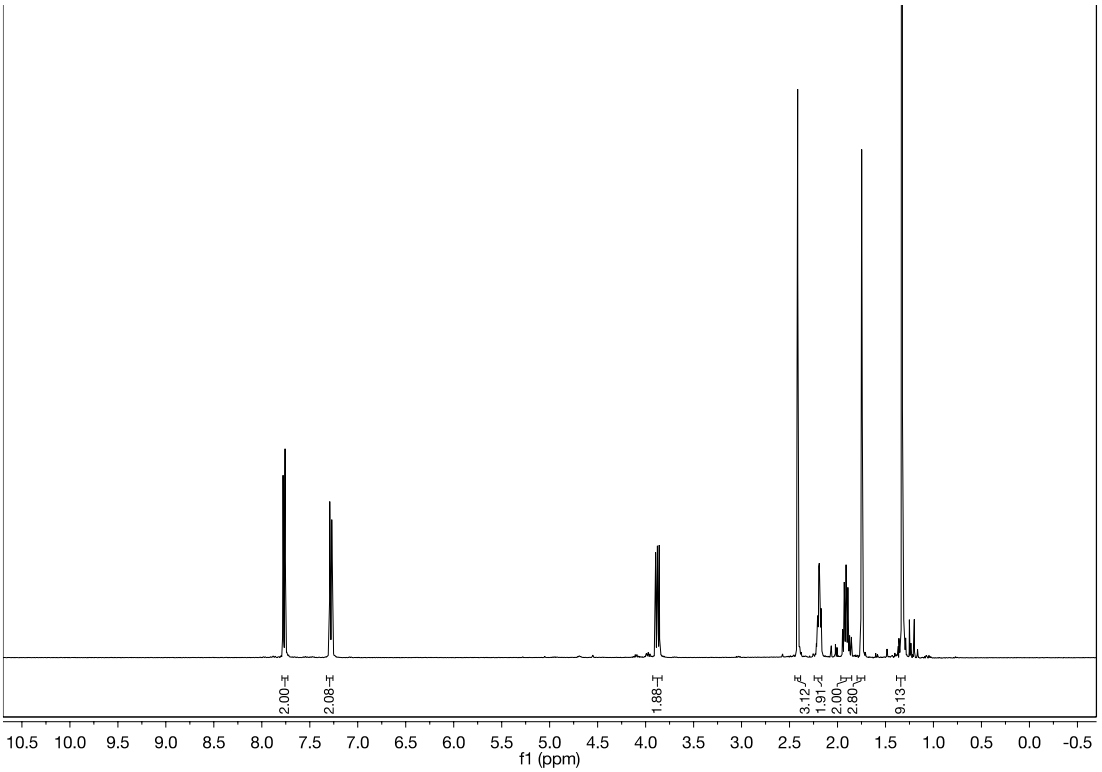
(**2t**)

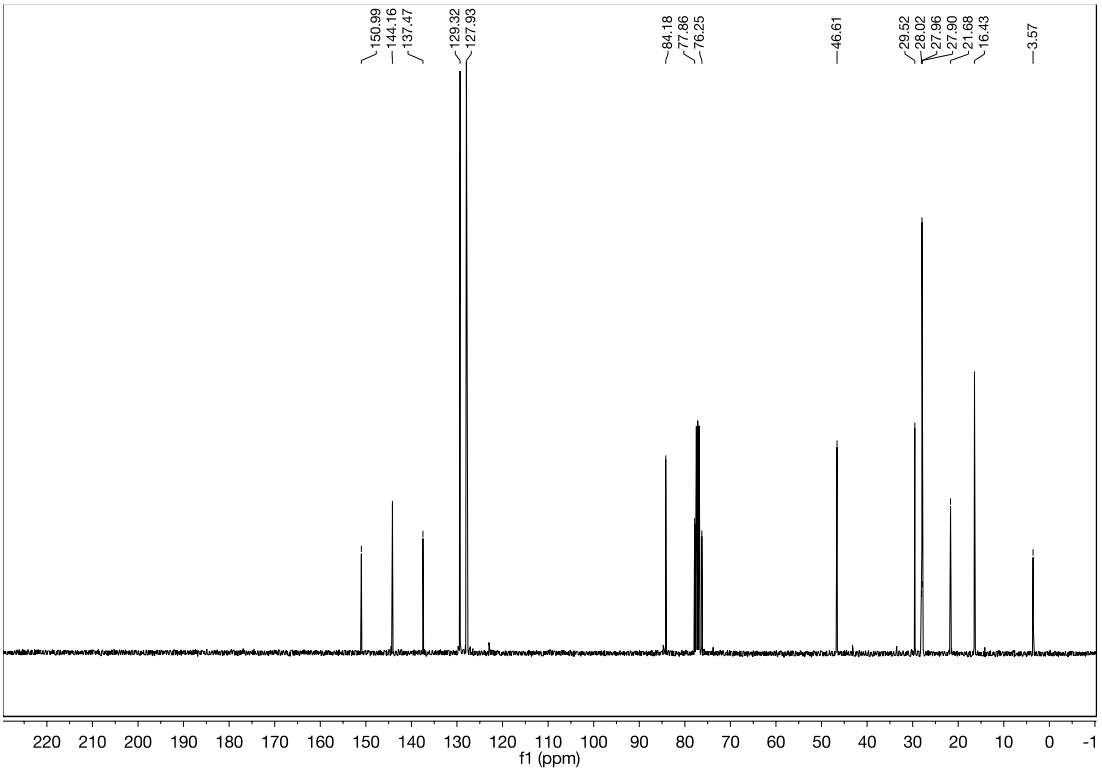

1.92
1.94
1.98
2.99
1.98
2.00
2.93
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)


144.80
133.19
129.92
128.08
69.25
28.32
21.77
15.08
3.48
220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -1
f1 (ppm)


Ts
N
Me
Boc

(**2z**)


2.00
2.08
1.88
3.12
1.91
2.00
2.80
9.13
10.5 10.0 9.5 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
f1 (ppm)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129.32
127.93
84.18
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76.25
46.61
29.52
28.02
27.96
27.90
21.68
16.43
3.57
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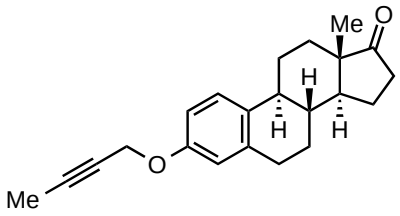
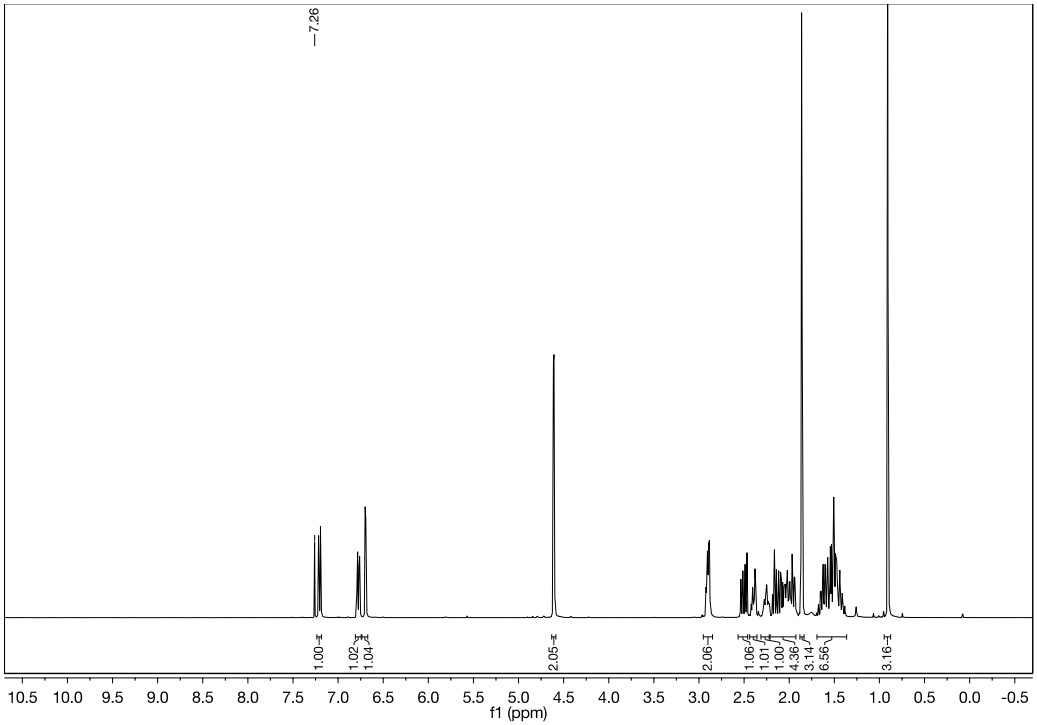
f1 (ppm)


Me
O
H
H
H
O
Me

(**2ad**)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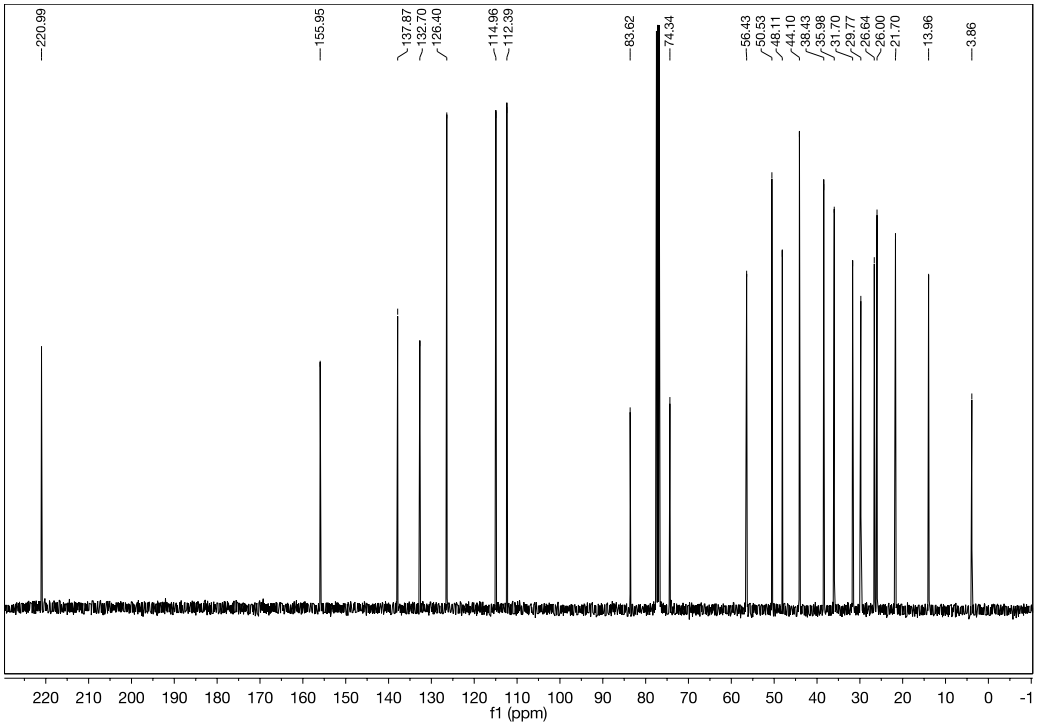
1.04
2.05
2.06
1.06
1.01
1.00
4.36
3.14
6.56
3.16
10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
f1 (ppm)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132.70
126.40
114.96
112.39
83.62
74.34
56.43
50.53
48.11
44.10
38.43
35.98
31.70
29.77
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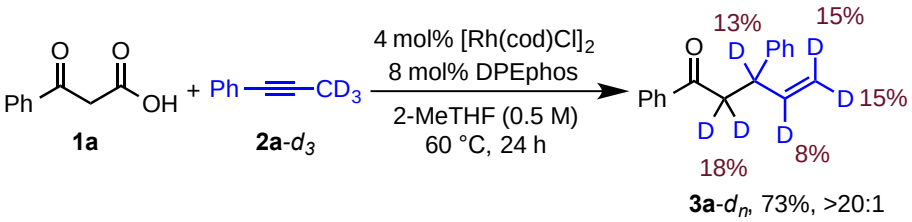
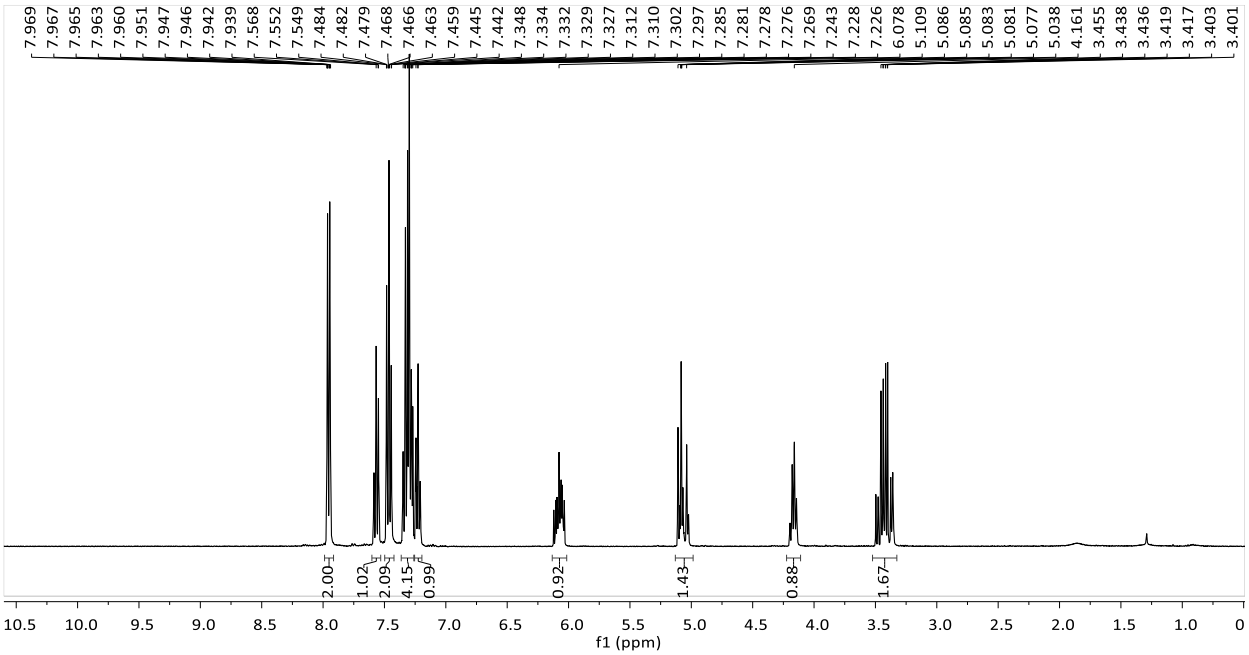
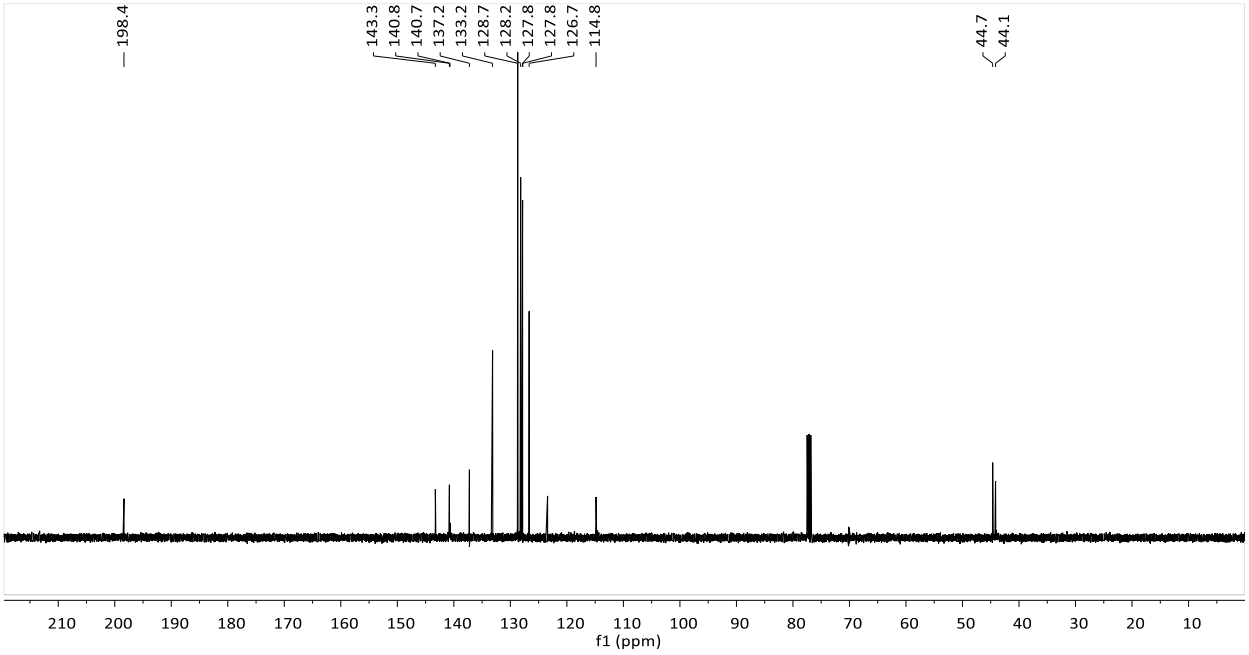
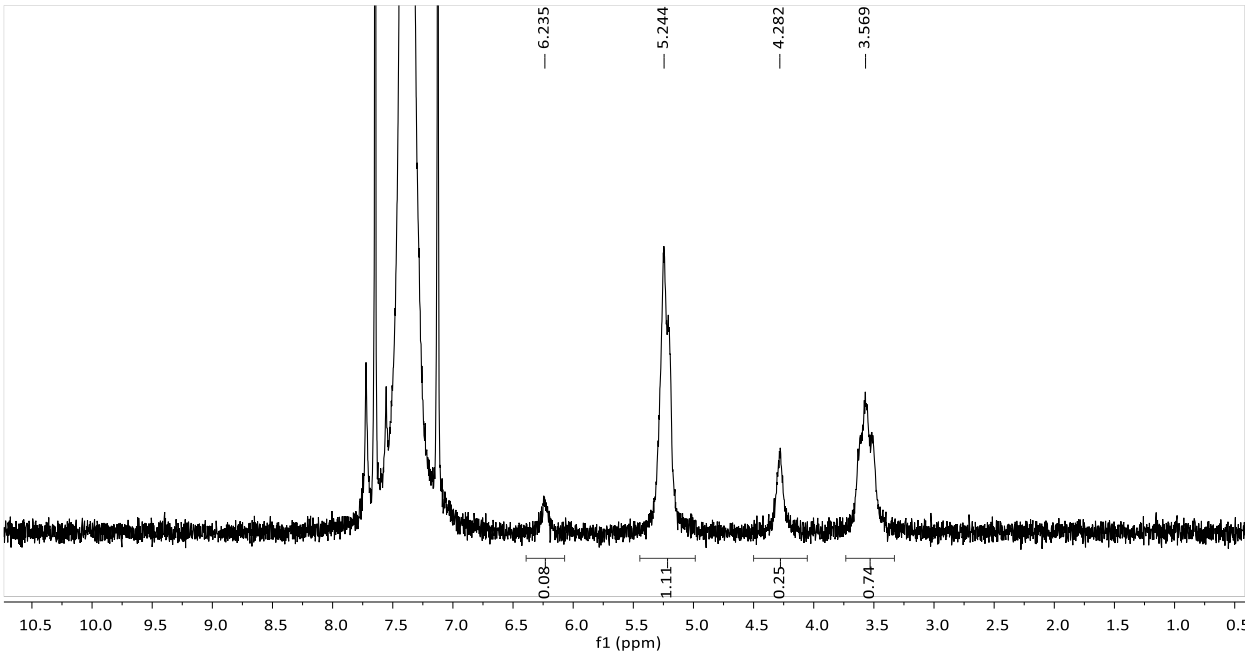
f1 (ppm)



1a **2a**-d_3 **3a**-d_n, 73%, >20:1






6.235
5.244
4.282
3.569
0.08
1.11
0.25
0.74
10.5 10.0 9.5 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
f1 (ppm)

Appendix 2.3: Supporting Information for Chapter 2.3

Stereodivergent Coupling of Aldehydes and Alkynes via Synergistic Catalysis Using Rh and Jacobsen's Amine

Table of Contents: **Page**

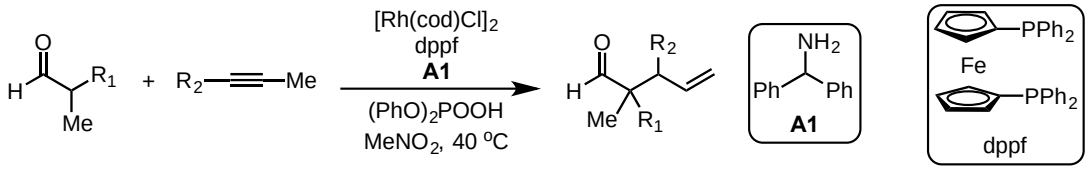
1. Materials and Methods

All reactions were run in oven-dried or flame-dried glassware under an atmosphere of N_2. Tetrahydrofuran, dichloromethane, toluene, dimethylformamide and diethyl ether were purified using an Innovative Technologies Pure Solv system, degassed by three freeze-pump-thaw cycles, and stored over 3 Å MS within an N_2 filled glove box. Dimethylsulfoxide were refluxed with CaH_2 and distilled prior to use. The molarity of organolithium reagents was determined by titration with *iso*-propanol/1,10-phenanthroline. Reactions were monitored either *via* gas chromatography using an Agilent Technologies 7890A GC system equipped with an Agilent Technologies 5975C inert XL EI/CI MSD or by analytical thin-layer chromatography on EMD Silica Gel 60 F_{254} plates. Visualization of the developed plates was performed under UV light (254 nm) or using either $KMnO_4$ or *p*-anisaldehyde stain. Column chromatography was performed with Silicycle Silia-P Flash Silica Gel using glass columns. Automated column chromatography was performed using either a Biotage SP1 or Teledyne Isco CombiFlash Rf 200 purification system. ^1H, ^{13}C, and ^{19}F NMR spectra were recorded on a Bruker DRX-400 (400 MHz ^1H, 100 MHz ^{13}C, 376.5 MHz ^{19}F, 161.9 MHz), GN-500 (500 MHz ^1H, 125.7 MHz ^{13}C), CRYO-500 (500 MHz ^1H, 125.7 MHz ^{13}C) or AVANCE-600 (600 MHz ^1H, 151 MHz ^{13}C, 565 MHz ^{19}F) spectrometer. ^1H NMR spectra were internally referenced to the residual solvent signal or TMS. ^{13}C NMR spectra were internally referenced to the residual solvent signal. Data for ^1H NMR are reported as follows: chemical shift (δ ppm), multiplicity (s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet, br = broad), coupling constant (Hz), integration. Data for ^{13}C NMR are reported in terms of chemical shift (δ, ppm). Infrared spectra were obtained on a Thermo Scientific Nicolet iS5 FT-IR spectrometer equipped with an iD5 ATR accessory. High resolution mass spectra (HRMS) was performed by the University of California, Irvine Mass Spectrometry Center. Enantiomeric excesses for stereoselective reactions were determined by chiral SFC analysis using an Agilent Technologies HPLC (1200 series) system and Aurora A5 Fusion. (*S*,*S*)- and (*R*,*R*)-**A5** were synthesized according to literature procedure.[38]

[38] Witten, M. R.; Jacobsen, E. N. *Org. Lett.* **2015,** *17*, 2772-2775.

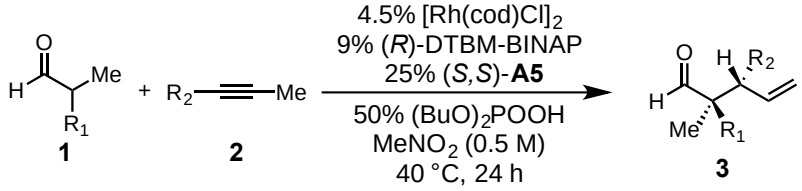
2. Aldehyde-Alkyne Coupling

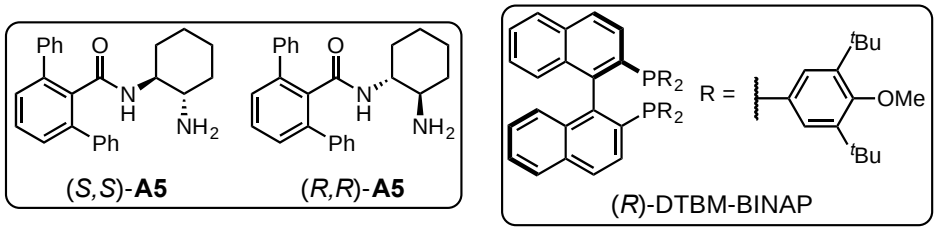
A. General Procedure for Racemic Aldehydes



To a 1 dram vial equipped with a magnetic stir bar was added $[Rh(cod)Cl]_2$ (2.0 mg, 0.004 mmol, 4 mol%), dppf (4.4 mg, 0.008 mmol, 8 mol%), diphenyl phosphate (12.5 mg, 0.05 mmol, 50 mol%), aldehyde **1** (0.1 mmol, 1 equiv.), benzhydrylamine **A1** (4.3 μL, 0.025 mmol), alkyne **2** (0.12 mmol, 1.2 equiv.) and $MeNO_2$ (200 μL, 0.5 M). The vial was then sealed with a Teflon-lined screw cap and heated to 40 °C for 24 hours. The resulting mixture was then cooled to room temperature and concentrated *in vacuo*. Diastereo- and regioselectivities were determined by ^1H NMR analysis of the crude reaction mixture. Aldehyde products **3** were isolated by flash column chromatography or preparatory TLC. SFC analysis was performed on the corresponding primary alcohol after $NaBH_4$ reduction.

B. General Procedure for Enantioenriched Aldehydes



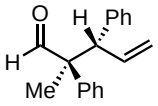


To a 1 dram vial equipped with a magnetic stir bar was added $[Rh(cod)Cl]_2$ (2.2 mg, 0.0045 mmol, 4.5 mol%), (*R*)-DTBM-BINAP (10.7 mg, 0.009 mmol, 9 mol%), dibutyl phosphate (10.5 mg, 0.05 mmol, 50 mol%), aldehyde **1** (0.1 mmol, 1 equiv.), (*S*,*S*)– or (*R*,*R*)–**A5** (9.3 mg, 0.025 mmol, 25 mol%), alkyne **2** (0.12 mmol, 1.2 equiv.) and $MeNO_2$ (200 μL, 0.5 M). The vial was then sealed with a Teflon-lined screw cap and heated to 40 °C for 24 hours. The resulting mixture was then cooled to room temperature and concentrated *in vacuo*. Diastereo- and regioselectivities were determined by ^1H NMR analysis of the crude reaction mixture. Aldehyde products **3** were isolated by flash column chromatography or preparatory TLC. SFC analysis was performed on the corresponding primary alcohol after $NaBH_4$ reduction. Immediate use of aldehydes after preparation allows for best results. Diminished *dr*'s have been observed when using older batches of aldehydes.

Safety Note:

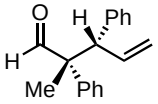
Nitromethane can undergo nitrosation with nitrous acid to generate nitroformaldehyde oxime. Upon heating in water or nitric acid decomposition occurs to form fulminic acid, which is explosive.

(2*S*,3*S*)-2-methyl-2,3-diphenylpent-4-enal (3a)



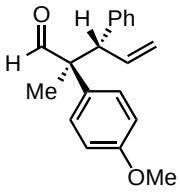
The title compound was synthesized according to the general procedure using (*R*)-DTBM-BINAP, (*S*,*S*)-**A5**, 2-phenylpropanal (**1a**) and 1-phenyl-1-propyne (**2a**). ^{1}H NMR analysis of the crude reaction mixture showed >20:1 *dr* and >20:1 branched to linear selectivity. Purification via preparatory TLC (5% ethyl acetate in hexanes) afforded the title compound as a colorless oil (19.1 mg, 76%). The ^{1}H NMR spectrum is in accordance with the literature.[39] **^{1}H NMR** (400 MHz, $CDCl_3$): δ 9.74 (s, 1H), 7.40-7.32 (m, 3H), 7.24-7.19 (m, 5H), 6.96-6.93 (m, 2H), 5.94 (ddd, *J* = 16.8, 10.4, 8.9 Hz, 1H), 5.06-5.00 (m, 2H), 4.15 (d, *J* = 9.0 Hz, 1H), 1.38 (s, 3H). **SFC** analysis (of the corresponding primary alcohol): >99% *ee*, 250 mm CHIRALCEL IB, 3% *i*PrOH, 3 mL/min, 220 nm, 44 °C, t_{R1} = 7.61 min, t_{R2} = 7.90 min, t_{R3} (minor) = 8.31 min, t_{R4} (major) = 7.70 min; **$[\alpha]^{23.2}_D$** = +41.7° (*c* = 0.545, $CHCl_3$)

(2*R*,3*S*)-2-methyl-2,3-diphenylpent-4-enal (3a)



The title compound was synthesized according to the general procedure using (*R*)-DTBM-BINAP, (*R*,*R*)-**A5**, 2-phenylpropanal (**1a**) and 1-phenyl-1-propyne (**2a**). ^{1}H NMR analysis of the crude reaction mixture showed 8:1 *dr* and >20:1 branched to linear selectivity. Purification via preparatory TLC (5% ethyl acetate in hexanes) afforded the title compound as a colorless oil (18.3 mg, 73%). The ^{1}H NMR spectrum is in accordance with the literature.[2] **^{1}H NMR** (400 MHz, $CDCl_3$): δ 9.82 (s, 1H), 7.25-7.19 (m, 3H), 7.12-7.08 (m, 5H), 6.86-6.83 (m, 2H), 6.16 (ddd, *J* = 16.9, 10.3, 8.9 Hz, 1H), 5.22-5.14 (m, 2H), 4.21-4.18 (m, 1H), 1.48-1.48 (m, 3H). **SFC** analysis (of the corresponding primary alcohol): >99% *ee*, 250 mm CHIRALCEL IB, 3% *i*PrOH, 3 mL/min, 220 nm, 44 °C, t_{R1} (major) = 7.61 min, t_{R2} (minor) = 7.90 min, t_{R3} = 8.31 min, t_{R4} = 7.70 min; **$[\alpha]^{22.4}_D$** = +17.5° (*c* = 0.395, $CHCl_3$)

(2*S*,3*S*)-2-(4-methoxyphenyl)-2-methyl-3-phenylpent-4-enal (**3b**)

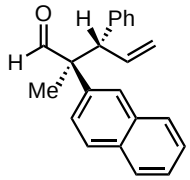


The title compound was synthesized according to the general procedure using (*R*)-DTBM-BINAP, (*S*,*S*)-**A5**, aldehyde **1b** and 1-phenyl-1-propyne (**2a**). ^{1}H NMR analysis of the crude reaction mixture showed 11:1 *dr* and >20:1 branched to linear selectivity. Purification via preparatory TLC (5% ethyl acetate in hexanes) afforded the title compound as a colorless oil (24.1 mg, 86%). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 9.68 (s, 1H), 7.22-7.19 (m, 3H), 7.13-7.11 (m, 2H), 6.96-6.93 (m, 2H), 6.92-6.90 (m, 2H), 5.93 (ddd, *J* = 16.8, 10.4, 8.8 Hz, 1H), 5.06-5.00 (m, 2H), 4.12 (d, *J* = 8.8 Hz, 1H), 3.83 (s, 3H), 1.34 (s, 3H). **^{13}C NMR** (101 MHz, $CDCl_3$): δ 202.5, 158.9, 139.9, 137.4, 130.02, 129.94, 128.1, 126.9, 117.8, 113.8, 57.1, 55.48, 55.40, 18.2. **HRMS** calculated for $C_{19}H_{20}O_2Na$ $[M+Na]^+$ 303.1361, found 303.1366. **IR** (ATR): 1721,

[39] Krautwald, S.; Sarlah, D.; Schafroth, M. A.; Carreira, E. M. *Science* **2013,** *340,* 1065.

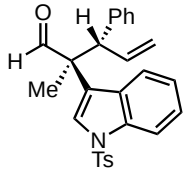
1608, 1512, 1251, 1186, 1031, 919, 828, 752, 702 cm^{-1}. **SFC** analysis (of the corresponding primary alcohol): >99% *ee*, 250 mm CHIRALCEL IB, 3% *i*PrOH, 3 mL/min, 220 nm, 44 °C, t_{R1} = 10.08 min, t_{R2} = 10.67 min, t_{R3} (major) = 11.60 min, t_{R4} (minor) = 12.32 min; $\mathbf{[\alpha]^{24.3}_D}$ = +56.3° (*c* = 0.625, $CHCl_3$)

(2*S*,3*S*)-2-methyl-2-(naphthalen-2-yl)-3-phenylpent-4-enal (3c)



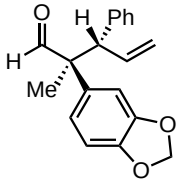
The title compound was synthesized according to the general procedure using (*R*)-DTBM-BINAP, (*S*,*S*)-**A5**, aldehyde **1c** and 1-phenyl-1-propyne (**2a**). ^{1}H NMR analysis of the crude reaction mixture showed 16:1 *dr* and >20:1 branched to linear selectivity. Purification via preparatory TLC (5% ethyl acetate in hexanes) afforded the title compound as a colorless oil (25.0 mg, 83%). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 9.81 (s, 1H), 7.87-7.81 (m, 3H), 7.66-7.65 (m, 1H), 7.53-7.49 (m, 2H), 7.39 (dd, *J* = 8.7, 2.0 Hz, 1H), 7.23-7.20 (m, 3H), 7.01-6.98 (m, 2H), 5.98 (ddd, *J* = 16.9, 10.3, 8.9 Hz, 1H), 5.08-5.02 (m, 2H), 4.29 (d, *J* = 8.8 Hz, 1H), 1.51 (s, 3H). **^{13}C NMR** (101 MHz, $CDCl_3$): δ 202.4, 139.9, 137.1, 135.7, 133.2, 132.6, 130.0, 128.29, 128.16, 128.14, 127.9, 127.6, 127.0, 126.59, 126.46, 126.36, 118.0, 57.9, 55.5, 18.1. **HRMS** calculated for $C_{22}H_{20}ONa$ $[M+Na]^+$ 323.1412, found 323.1399. **IR** (ATR): 3018, 2997, 1721, 1637, 1599, 1517, 1494, 1373, 1272, 920, 743, 703 cm^{-1}. **SFC** (of the corresponding primary alcohol): >99% *ee*, 250 mm CHIRALCEL IB, 5% *i*PrOH, 3 mL/min, 220 nm, 44 °C, t_{R1} = 12.84 min, t_{R2} = 13.62 min, t_{R3} (major) = 15.47 min, t_{R4} (minor) = 17.07 min; $\mathbf{[\alpha]^{23.8}_D}$ = +59.3° (*c* = 0.690, $CHCl_3$)

(2*S*,3*S*)-2-methyl-3-phenyl-2-(1-tosyl-1*H*-indol-3-yl)pent-4-enal (3d)



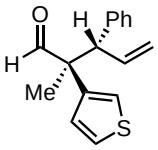
The title compound was synthesized according to the general procedure using (*R*)-DTBM-BINAP, (*S*,*S*)-**A5**, aldehyde **1d** and 1-phenyl-1-propyne (**2a**). ^{1}H NMR analysis of the crude reaction mixture showed >20:1 *dr* and >20:1 branched to linear selectivity. Purification via preparatory TLC (15% ethyl acetate in hexanes) afforded the title compound as a colorless oil (38.3 mg, 86%). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 9.70 (s, 1H), 8.01-7.99 (m, 1H), 7.75-7.72 (m, 2H), 7.60-7.57 (m, 1H), 7.35 (d, *J* = 1.9 Hz, 1H), 7.34-7.30 (m, 1H), 7.26-7.24 (m, 3H), 7.23-7.20 (m, 4H), 7.04 (dt, *J* = 5.0, 2.4 Hz, 2H), 5.99-5.90 (m, 1H), 4.97-4.89 (m, 2H), 4.35 (d, *J* = 9.3 Hz, 1H), 2.37 (s, 3H), 1.46 (s, 3H). **^{13}C NMR** (151 MHz, $CDCl_3$): δ 201.2, 145.3, 139.6, 136.8, 135.6, 135.2, 130.1, 129.8, 129.3, 128.3, 127.16, 127.02, 126.0, 124.9, 123.4, 122.3, 121.0, 117.9, 113.9, 54.8, 54.0, 21.7, 18.6. **HRMS** calculated for $C_{27}H_{25}NO_3S$ $[M+Na]^+$ 466.1453, found 466.1437. **IR** (ATR): 3143, 2975, 2860, 1722, 1599, 1453, 1267, 1171, 1132, 1095, 682 cm^{-1}. **SFC** (of the corresponding primary alcohol): >99% *ee*, 250 mm CHIRALCEL IB, 8% *i*PrOH, 4 mL/min, 220 nm, 44 °C, t_{R1} = 8.32 min, t_{R2} = 8.87 min, t_{R3} (major) = 10.42 min, t_{R4} (minor) = 10.95 min; $\mathbf{[\alpha]^{22.3}_D}$ = +12.0° (*c* = 0.510, $CHCl_3$)

(2*S*,3*S*)-2-(benzo[*d*][1,3]dioxol-5-yl)-2-methyl-3-phenylpent-4-enal (3e)



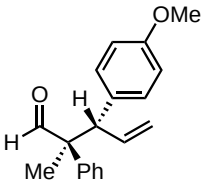
The title compound was synthesized according to the general procedure using (*R*)-DTBM-BINAP, (*S*,*S*)-**A5**, aldehyde **1e** and 1-phenyl-1-propyne (**2a**). ^{1}H NMR analysis of the crude reaction mixture showed 12:1 *dr* and >20:1 branched to linear selectivity. Purification via preparatory TLC (5% ethyl acetate in hexanes) afforded the title compound as a colorless oil (26.7 mg, 91%). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 9.64 (s, 1H), 7.23-7.20 (m, 3H), 7.00-6.97 (m, 2H), 6.81 (d, *J* = 8.1 Hz, 1H), 6.73 (d, *J* = 1.8 Hz, 1H), 6.65 (dd, *J* = 8.2, 2.0 Hz, 1H), 5.99 (q, *J* = 1.6 Hz, 2H), 5.97-5.90 (m, 1H), 5.07-5.00 (m, 2H), 4.10 (d, *J* = 8.8 Hz, 1H), 1.33 (s, 3H). **^{13}C NMR** (101 MHz, $CDCl_3$): δ 202.1, 147.9, 146.9, 139.8, 137.2, 131.9, 129.9, 128.1, 127.0, 122.4, 117.9, 109.3, 108.1, 101.3, 57.5, 55.6, 18.2. **HRMS** calculated for $C_{19}H_{18}O_3Na$ $[M+Na]^+$ 317.1154, found 317.1159. **IR** (ATR): 3082, 2921, 2798, 1719, 1620, 1498, 1474, 1264, 1152, 1113, 1054 cm^{-1}. **SFC** (of the corresponding primary alcohol): >99% *ee*, 250 mm CHIRALCEL IB, 12% *i*PrOH, 3 mL/min, 280 nm, 44 °C, t_{R1} = 3.04 min, t_{R2} = 3.13 min, t_{R3} (major) = 3.32 min, t_{R4} (minor) = 3.40 min; **$[\alpha]^{24.6}_D$** = +40.7° (*c* = 0.425, $CHCl_3$)

(2*S*,3*S*)-2-methyl-3-phenyl-2-(thiophen-3-yl)pent-4-enal (3f)



The title compound was synthesized according to the general procedure using (*R*)-DTBM-BINAP, (*S*,*S*)-**A5**, aldehyde **1f** and 1-phenyl-1-propyne (**2a**). ^{1}H NMR analysis of the crude reaction mixture showed 10:1 *dr* and >20:1 branched to linear selectivity. Purification via preparatory TLC (5% ethyl acetate in hexanes) afforded the title compound as a colorless oil (20.8 mg, 81%). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 9.72 (s, 1H), 7.36 (dd, *J* = 5.0, 3.0 Hz, 1H), 7.24-7.21 (m, 3H), 7.04-7.02 (m, 2H), 6.95-6.93 (m, 2H), 6.02 (ddd, *J* = 17.0, 10.3, 8.8 Hz, 1H), 5.11-5.02 (m, 2H), 4.03 (d, *J* = 8.8 Hz, 1H), 1.38 (s, 3H). **^{13}C NMR** (101 MHz, $CDCl_3$): δ 201.9, 139.65, 139.48, 137.0, 129.7, 128.2, 127.7, 127.1, 125.6, 123.5, 123.4, 118.1, 56.03, 56.01 18.7. **HRMS** calculated for $C_{16}H_{17}OS$ $[M+H]^+$ 257.1000, found 257.1003. **IR** (ATR): 2992, 1721, 1641, 1603, 1503, 1435, 1381, 1081, 1001, 784 cm^{-1}. **SFC** (of the corresponding primary alcohol): >99% *ee*, 250 mm CHIRALCEL IC, 3% *i*PrOH, 2.5 mL/min, 220 nm, 44 °C, t_{R1} = 11.39 min, t_{R2} = 11.88 min, t_{R3} (major) = 12.37 min, t_{R4} (minor) = 13.27 min; **$[\alpha]^{24.0}_D$** = +30.9° (*c* = 0.430, $CHCl_3$)

(2*S*,3*S*)-3-(4-methoxyphenyl)-2-methyl-2-phenylpent-4-enal (3j)



The title compound was synthesized according to the general procedure using (*R*)-DTBM-BINAP, (*S*,*S*)-**A5**, 2-phenylpropanal (**1a)** and alkyne **2j**. ^{1}H NMR analysis of the crude reaction mixture showed 17:1 *dr* and >20:1 branched to linear selectivity. Purification via preparatory TLC (5% ethyl acetate in hexanes) afforded the title compound as a colorless oil (17.9 mg, 64%). The ^{1}H NMR spectrum is in accordance with the literature.[40] **^{1}H NMR** (400 MHz, $CDCl_3$): δ 9.73 (s, 1H), 7.39-7.31 (m, 3H), 7.22-7.20 (m, 2H), 6.87-6.84 (m, 2H), 6.78-6.75 (m, 2H), 5.91 (ddd, *J* = 16.9, 10.3, 8.7 Hz, 1H), 5.04-4.97 (m, 2H), 4.10 (d, *J* = 8.7 Hz, 1H), 3.77 (s, 3H), 1.38 (s, 3H). **SFC** (of the corresponding primary alcohol): 98% *ee*,

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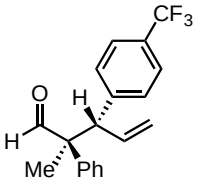
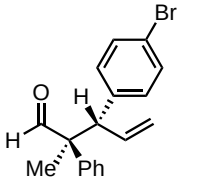
250 mm CHIRALCEL IB, 3% *i*PrOH, 3 mL/min, 220 nm, 44 °C, t_{R1} = 10.58 min, t_{R2} = 10.77 min, t_{R3} (minor) = 11.29 min, t_{R4} (major) = 11.87 min; $[\alpha]^{22.3}_{D}$ = +74.7° (*c* = 0.225, $CHCl_3$)

(2*S*,3*S*)-2-methyl-2-phenyl-3-(4-(trifluoromethyl)phenyl)pent-4-enal (3k)



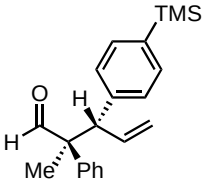
The title compound was synthesized according to the general procedure using (*R*)-DTBM-BINAP, (*S*,*S*)-**A5**, 2-phenylpropanal (**1a)** and alkyne **2k**. ^{1}H NMR analysis of the crude reaction mixture showed 15:1 *dr* and >20:1 branched to linear selectivity. Purification via preparatory TLC (2% ethyl acetate in hexanes) afforded the title compound as a colorless oil (25.7 mg, 81%). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 9.67 (s, 1H), 7.47 (dd, *J* = 8.1, 0.2 Hz, 2H), 7.41-7.34 (m, 3H), 7.18-7.16 (m, 2H), 7.05 (dd, *J* = 8.1, 2.3 Hz, 2H), 5.97-5.88 (m, 1H), 5.09-5.01 (m, 2H), 4.19 (dd, *J* = 8.8, 0.3 Hz, 1H), 1.38-1.37 (m, 3H). **^{13}C NMR** (101 MHz, $CDCl_3$): δ 201.9, 144.1, 137.5, 136.5, 130.3, 128.9, 128.6, 127.9, 125.0 (q, *J* = 3.91 Hz), 123.4, 122.9, 118.6, 57.7, 55.3, 18.3. **^{19}F NMR** (376 MHz, $CDCl_3$): δ -62.9. **HRMS** calculated for $C_{19}H_{18}F_3O$ $[M+H]^+$ 319.1310, found 319.1306. **IR** (ATR): 3021, 2999, 1724, 1332, 1272, 1142, 1092, 1045, 904, 714 cm^{-1}. **SFC** (of the corresponding primary alcohol): >99% *ee*, 250 mm CHIRALCEL IB, 3% *i*PrOH, 3 mL/min, 220 nm, 44 °C, t_{R1} = 5.94 min, t_{R2} = 6.18 min, t_{R3} (minor) = 6.61 min, t_{R4} (major) = 7.10 min; $[\alpha]^{22.7}_{D}$ = +98.7° (*c* = 0.150, $CHCl_3$)

(2*S*,3*S*)-3-(4-bromophenyl)-2-methyl-2-phenylpent-4-enal (3l)



The title compound was synthesized according to the general procedure using (*R*)-DTBM-BINAP, (*S*,*S*)-**A5**, 2-phenylpropanal (**1a)** and alkyne **2l**. ^{1}H NMR analysis of the crude reaction mixture showed 20:1 *dr* and >20:1 branched to linear selectivity. Purification via preparatory TLC (2% ethyl acetate in hexanes) afforded the title compound as a colorless oil (22.6 mg, 69%). **^{1}H NMR** (500 MHz, $CDCl_3$): δ 9.68 (s, 1H), 7.39-7.32 (m, 5H), 7.17-7.15 (m, 2H), 6.81-6.78 (m, 2H), 5.92-5.85 (m, 1H), 5.06-4.99 (m, 2H), 4.09 (d, *J* = 8.7 Hz, 1H), 1.36 (s, 3H). **^{13}C NMR** (151 MHz, $CDCl_3$): δ 202.2, 138.9, 136.8, 131.7, 131.2, 128.9, 128.5, 127.7, 120.9, 118.2, 57.7, 55.0, 18.2. **HRMS** calculated for $C_{18}H_{17}BrONa$ $[M+Na]^+$ 351.0360, found 351.0364. **IR** (ATR): 3011, 2991, 1722, 1601, 1499, 1204, 1125, 991, 745, 686 cm^{-1}. **SFC** (of the corresponding primary alcohol): >99% *ee*, 250 mm CHIRALCEL IB, 3% *i*PrOH, 3 mL/min, 220 nm, 44 °C, t_{R1} = 13.07 min, t_{R2} = 13.49 min, t_{R3} (minor) = 13.90 min, t_{R4} (major) = 14.95 min; $[\alpha]^{22.3}_{D}$ = +21.7° (*c* = 0.180, $CHCl_3$)

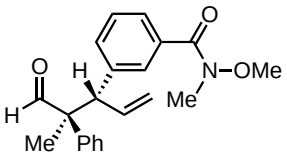
(2*S*,3*S*)-2-methyl-2-phenyl-3-(4-(trimethylsilyl)phenyl)pent-4-enal (3m)



The title compound was synthesized according to the general procedure using (*R*)-DTBM-BINAP, (*S*,*S*)-**A5**, 2-phenylpropanal (**1a)** and alkyne **2m**. ^{1}H NMR analysis of the crude reaction mixture showed 20:1 *dr* and >20:1 branched to linear selectivity. Purification via preparatory TLC (10% ethyl acetate in hexanes) afforded the title compound as a colorless oil (26.7 mg, 83%). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 9.72 (s, 1H), 7.40-7.34 (m, 5H), 7.25-7.23 (m, 2H), 6.95 (d, *J* = 7.9 Hz, 2H), 5.91 (ddd, *J* = 16.4, 10.8, 9.0 Hz, 1H), 5.04-4.99 (m, 2H), 4.16 (d, *J* = 9.0 Hz, 1H), 1.39 (s, 3H), 0.24 (s, 9H). **^{13}C NMR** (126 MHz, $CDCl_3$): δ 202.5, 140.3, 138.9, 138.2, 137.0, 133.2, 129.2, 128.9, 128.4, 127.5, 117.9, 57.8, 55.5, 17.8, -0.9. **HRMS** calculated for $C_{21}H_{26}OSi$ $[M]^+$ 322.1753, found 322.1748. **IR** (ATR): 3011, 2997, 1721, 1644,

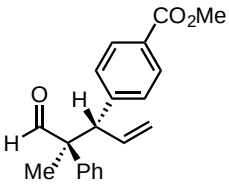
1250, 1002, 984, 766, 695 cm^{-1}. **SFC** (of the corresponding primary alcohol): >99% *ee*, 250 mm CHIRALCEL IB, 3% *i*PrOH, 2 mL/min, 220 nm, 44 °C, t_{R1} = 10.03 min, t_{R2} = 10.49 min, t_{R3} (minor) = 10.91 min, t_{R4} (major) = 12.26 min; $[\alpha]^{23.0}_{D}$ = +88.9° (*c* = 0.360, $CHCl_3$)

_N_-methoxy-_N_-methyl-3-((3*S*,4*S*)-4-methyl-5-oxo-4-phenylpent-1-en-3-yl)benzamide (3i)



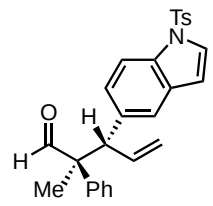
The title compound was synthesized according to the general procedure using (*R*)-DTBM-BINAP, (*S*,*S*)-**A5**, 2-phenylpropanal (**1a)** and alkyne **2i**. ^{1}H NMR analysis of the crude reaction mixture showed 17:1 *dr* and >20:1 branched to linear selectivity. Purification via preparatory TLC (30% ethyl acetate in hexanes) afforded the title compound as a colorless oil (26.1 mg, 77%). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 9.70 (s, 1H), 7.53-7.50 (m, 1H), 7.40-7.32 (m, 5H), 7.24-7.20 (m, 2H), 7.05-7.02 (m, 1H), 5.98-5.89 (m, 1H), 5.06-4.98 (m, 2H), 4.20 (d, *J* = 8.7 Hz, 1H), 3.51 (s, 3H), 3.32 (s, 3H), 1.40 (s, 3H). **^{13}C NMR** (101 MHz, $CDCl_3$): δ 202.1, 169.9, 139.7, 137.9, 136.7, 133.9, 132.2, 129.8, 128.72, 128.57, 127.86, 127.67, 126.9, 118.3, 61.2, 57.8, 55.4, 17.8. **HRMS** calculated for $C_{21}H_{23}NO_3Na$ $[M+Na]^+$ 360.1576, found 360.1582. **IR** (ATR): 3022, 2995, 1726, 1633, 1382, 1222, 980, 777, 555, 438 cm^{-1}. **SFC** (of the corresponding primary alcohol): 4% *ee*, 150 mm CHIRALCEL ODH, 7% *i*PrOH, 2 mL/min, 220 nm, 44 °C, t_{R1} (minor) = 13.15 min, t_{R2} = 14.43 min, t_{R3} = 16.55 min, t_{R4} (major) = 17.42 min; $[\alpha]^{23.2}_{D}$ = +53.8° (*c* = 0.145, $CHCl_3$)

Methyl 4-((3*S*,4*S*)-4-methyl-5-oxo-4-phenylpent-1-en-3-yl)benzoate (3n)



The title compound was synthesized according to the general procedure using (*R*)-DTBM-BINAP, (*S*,*S*)-**A5**, 2-phenylpropanal (**1a)** and alkyne **2n**. ^{1}H NMR analysis of the crude reaction mixture showed >20:1 *dr* and >20:1 branched to linear selectivity. Purification via preparatory TLC (10% ethyl acetate in hexanes) afforded the title compound as a colorless oil (24.5 mg, 80%). The ^{1}H NMR spectrum is in accordance with the literature.[41] **^{1}H NMR** (400 MHz, $CDCl_3$): δ 9.69 (s, 1H), 7.89-7.87 (m, 2H), 7.38-7.33 (m, 3H), 7.17-7.15 (m, 2H), 7.01-6.99 (m, 2H), 5.93 (ddd, *J* = 16.9, 10.3, 8.9 Hz, 1H), 5.09-5.01 (m, 2H), 4.18 (d, *J* = 8.9 Hz, 1H), 3.89 (s, 3H), 1.37 (d, *J* = 2.7 Hz, 3H). **SFC** (of the corresponding primary alcohol): >99% *ee*, 150 mm CHIRALCEL ADH, 5% *i*PrOH, 3 mL/min, 220 nm, 44 °C, t_{R1} (major) = 6.40 min, t_{R2} (minor) = 7.15 min, t_{R3} = 8.33 min, t_{R4} = 9.35 min; $[\alpha]^{23.4}_{D}$ = +83.0° (*c* = 0.230, $CHCl_3$)

(2*S*,3*S*)-2-methyl-2-phenyl-3-(1-tosyl-1*H*-indol-5-yl)pent-4-enal (3g)

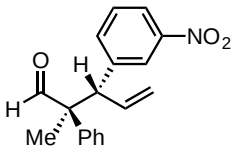


The title compound was synthesized according to the general procedure using (*R*)-DTBM-BINAP, (*S*,*S*)-**A5**, 2-phenylpropanal (**1a**) and alkyne **2g**. ^{1}H NMR analysis of the crude reaction mixture showed 20:1 *dr* and >20:1 branched to linear selectivity. Purification via preparatory TLC (10% ethyl acetate in hexanes) afforded the title compound as a colorless oil (31.4 mg, 71%). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 9.71 (s, 1H), 7.81-7.78 (m, 1H), 7.76-7.73 (m, 2H), 7.51 (d, *J* = 3.6 Hz, 1H), 7.38-7.32 (m, 3H), 7.23-7.21 (m, 2H), 7.18-7.16 (m, 2H), 7.12 (d, *J* = 1.7 Hz, 1H), 6.86 (dd, *J* =

[41] Krautwald, S.; Sarlah, D.; Schafroth, M. A.; Carreira, E. M. *Science* **2013,** *340,* 1065.

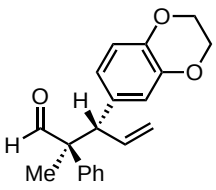
8.7, 1.7 Hz, 1H), 6.54 (dd, *J* = 3.7, 0.8 Hz, 1H), 5.94 (ddd, *J* = 16.8, 10.4, 8.9 Hz, 1H), 5.03-4.97 (m, 2H), 4.21-4.19 (m, 1H), 2.34 (s, 3H), 1.36 (s, 3H). **^{13}C NMR** (101 MHz, $CDCl_3$): δ 202.6, 145.1, 138.1, 137.4, 135.5, 134.9, 133.9, 130.7, 130.0, 128.9, 128.4, 127.6, 127.0, 126.60, 126.54, 122.5, 117.8, 113.0, 109.0, 57.9, 55.4, 21.7, 18.1. **HRMS** calculated for $C_{27}H_{26}NO_3S$ $[M+H]^+$ 444.1633, found 444.1639. **IR** (ATR): 3142, 2981, 2871, 1724, 1610, 1448, 1278, 1199, 1152, 1078, 691 cm^{-1}. **SFC** (of the corresponding primary alcohol): 93% *ee*, 150 mm CHIRALCEL ASH, 7% *i*PrOH, 1.5 mL/min, 220 nm, 44 °C, t_{R1} = 17.04 min, t_{R2} = 18.42 min, t_{R3} (minor) = 20.38 min, t_{R4} (major) = 23.40 min; **$[\alpha]^{25.1}_D$** = +42.3° (*c* = 0.350, $CHCl_3$)

(2*S*,3*S*)-2-methyl-3-(3-nitrophenyl)-2-phenylpent-4-enal (3o)



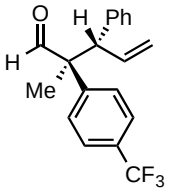
The title compound was synthesized according to the general procedure using (*R*)-DTBM-BINAP, (*S*,*S*)-**A5**, 2-phenylpropanal (**1a**) and alkyne **2o**. ^{1}H NMR analysis of the crude reaction mixture showed >20:1 *dr* and >20:1 branched to linear selectivity. Purification via preparatory TLC (10% ethyl acetate in hexanes) afforded the title compound as a colorless oil (22.0 mg, 75%). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 9.65 (s, 1H), 8.06 (ddd, *J* = 8.1, 2.3, 1.1 Hz, 1H), 7.79-7.78 (m, 1H), 7.42-7.35 (m, 5H), 7.16-7.13 (m, 2H), 5.96 (ddd, *J* = 16.9, 10.3, 8.8 Hz, 1H), 5.12-5.01 (m, 2H), 4.22 (d, *J* = 8.9 Hz, 1H), 1.41 (s, 3H). **^{13}C NMR** (126 MHz, $CDCl_3$): δ 201.6, 147.9, 142.2, 137.1, 136.30, 136.11, 128.88, 128.77, 128.68, 128.1, 124.9, 122.0, 119.1, 57.8, 55.3, 18.3. **HRMS** calculated for $C_{18}H_{17}NO_3Na$ $[M+Na]^+$ 318.1106, found 318.1110. **IR** (ATR): 3011, 2999, 1719, 1601, 1522, 1499, 1352, 1111, 933, 877, 692 cm^{-1}. **SFC** (of the corresponding primary alcohol): 72% *ee*, 250 mm CHIRALCEL IB, 3% *i*PrOH, 3 mL/min, 220 nm, 44 °C, t_{R1} = 15.16 min, t_{R2} = 15.78 min, t_{R3} (minor) = 16.63 min, t_{R4} (major) = 18.52 min; **$[\alpha]^{25.3}_D$** = +47.2° (*c* = 0.125, $CHCl_3$)

(2*S*,3*S*)-3-(2,3-dihydrobenzo[*b*][1,4]dioxin-6-yl)-2-methyl-2-phenylpent-4-enal (3h)



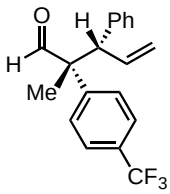
The title compound was synthesized according to the general procedure using (*R*)-DTBM-BINAP, (*S*,*S*)-**A5**, 2-phenylpropanal (**1a**) and alkyne **2h**. ^{1}H NMR analysis of the crude reaction mixture showed 16:1 *dr* and >20:1 branched to linear selectivity. Purification via preparatory TLC (10% ethyl acetate in hexanes) afforded the title compound as a colorless oil (29.6 mg, 96%). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 9.72 (s, 1H), 7.40-7.35 (m, 2H), 7.33-7.30 (m, 1H), 7.24-7.22 (m, 2H), 6.71 (d, *J* = 8.3 Hz, 1H), 6.50 (d, *J* = 2.2 Hz, 1H), 6.42 (ddd, *J* = 8.3, 2.2, 0.4 Hz, 1H), 5.85 (ddd, *J* = 16.8, 10.4, 8.8 Hz, 1H), 5.02-4.97 (m, 2H), 4.22 (s, 4H), 4.06 (d, *J* = 8.8 Hz, 1H), 1.39 (s, 3H). **^{13}C NMR** (126 MHz, $CDCl_3$): δ 202.5, 143.1, 142.5, 138.3, 137.1, 133.0, 128.8, 128.4, 127.5, 122.8, 118.6, 117.7, 116.8, 64.5, 57.8, 54.8, 17.7. **HRMS** calculated for $C_{20}H_{21}O_3$ $[M+H]^+$ 309.1491, found 309.1495. **IR** (ATR): 3042, 2991, 2988, 1722, 1620, 1498, 1474, 1264, 1174, 1154, 1123, 1042 788, 693, cm^{-1}. **SFC** (of the corresponding primary alcohol): >99% *ee*, 250 mm CHIRALCEL IB, 7% *i*PrOH, 2 mL/min, 220 nm, 44 °C, t_{R1} = 15.60 min, t_{R2} = 16.03 min, t_{R3} (minor) = 17.29 min, t_{R4} (major) = 18.67 min; **$[\alpha]^{25.2}_D$** = +47.3° (*c* = 0.440, $CHCl_3$)

(2*S*,3*S*)-2-methyl-3-phenyl-2-(4-(trifluoromethyl)phenyl)pent-4-enal (3p)



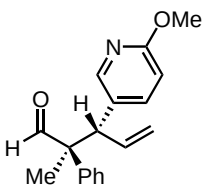
The title compound was synthesized according to the general procedure using (*R*)-DTBM-BINAP, (*S*,*S*)-**A5**, aldehyde **1p** and 1-phenyl-1-propyne (**2a**). ^{1}H NMR analysis of the crude reaction mixture showed 10:1 *dr* and >20:1 branched to linear selectivity. Purification via preparatory TLC (5% ethyl acetate in hexanes) afforded the title compound as a colorless oil (27.0 mg, 85%). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 9.73 (s, 1H), 7.64-7.61 (m, 2H), 7.33-7.31 (m, 2H), 7.24-7.21 (m, 3H), 6.92-6.90 (m, 2H), 5.92 (ddd, *J* = 16.9, 10.3, 9.0 Hz, 1H), 5.10-5.03 (m, 2H), 4.12 (d, *J* = 9.0 Hz, 1H), 1.42 (s, 3H). **^{13}C NMR** (101 MHz, $CDCl_3$): δ 201.7, 142.4, 139.1, 136.5, 129.8, 129.3, 128.3, 127.3, 125.2 (q, *J* = 3.67 Hz), 118.5, 57.9, 55.9, 18.3. **^{19}F NMR** (565 MHz; CDCl3): δ -62.5. **HRMS** calculated for $C_{19}H_{18}F_3O$ $[M+H]^+$ 319.1310, found 319.1313. **IR** (ATR): 3011, 2988, 1725, 1325, 1166, 1121, 1077, 1015, 702 cm^{-1}. **SFC** (of the corresponding primary alcohol): >99% *ee*, 250 mm CHIRALCEL IB, 3% *i*PrOH, 3 mL/min, 220 nm, 44 °C, t_{R1} = 4.59 min, t_{R2} = 4.99 min, t_{R3} (major) = 5.94 min, t_{R4} (minor) = 6.85 min; **$[\alpha]^{23.4}_D$** = +28.7° (*c* = 0.565, $CHCl_3$)

(2*R*,3*S*)-2-methyl-3-phenyl-2-(4-(trifluoromethyl)phenyl)pent-4-enal (3p)



The title compound was synthesized according to the general procedure using (*R*)-DTBM-BINAP, (*R*,*R*)-**A5**, aldehyde **1p** and 1-phenyl-1-propyne (**2a**). ^{1}H NMR analysis of the crude reaction mixture showed 12:1 *dr* and >20:1 branched to linear selectivity. Purification via preparatory TLC (5% ethyl acetate in hexanes) afforded the title compound as a colorless oil (29.6 mg, 93%). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 9.83 (s, 1H), 7.54-7.52 (m, 2H), 7.21-7.19 (m, 2H), 7.15-7.11 (m, 3H), 6.84-6.81 (m, 2H), 6.11 (ddd, *J* = 16.9, 10.3, 8.9 Hz, 1H), 5.25-5.17 (m, 2H), 4.18 (d, *J* = 9.0 Hz, 1H), 1.55 (s, 3H). **^{13}C NMR** (101 MHz, $CDCl_3$): δ 201.9, 143.0, 139.0, 136.0, 129.5, 128.5, 128.1, 127.0, 125.3 (q, *J* = 3.72 Hz), 119.1, 57.7, 55.9, 17.3. **^{19}F NMR** (565 MHz, $CDCl_3$): δ -62.6. **HRMS** calculated for $C_{19}H_{18}F_3O$ $[M+H]^+$ 319.1310, found 319.1314. **IR** (ATR): 3012, 2995, 1723, 1344, 1171, 1118, 1081, 1021, 711 cm^{-1}. **SFC** (of the corresponding primary alcohol): >99% *ee*, 250 mm CHIRALCEL IB, 3% *i*PrOH, 3 mL/min, 220 nm, 44 °C, t_{R1} = 4.59 min, t_{R2} = 4.99 min, t_{R3} (major) = 5.94 min, t_{R4} (minor) = 6.85 min; **$[\alpha]^{24.5}_D$** = +20.6° (*c* = 0.720, $CHCl_3$)

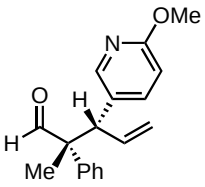
(2*S*,3*S*)-3-(6-methoxypyridin-3-yl)-2-methyl-2-phenylpent-4-enal (3q)



The title compound was synthesized according to the general procedure using (*R*)-DTBM-BINAP, (*S*,*S*)-**A5**, 2-phenylpropanal (**1a**) and alkyne **2q**. ^{1}H NMR analysis of the crude reaction mixture showed >20:1 *dr* and >20:1 branched to linear selectivity. Purification via preparatory TLC (10% ethyl acetate in hexanes) afforded the title compound as a colorless oil (20.5 mg, 73%). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 9.67 (s, 1H), 7.85 (d, *J* = 2.4 Hz, 1H), 7.40-7.33 (m, 3H), 7.18-7.16 (m, 2H), 7.05 (dd, *J* = 8.5, 2.5 Hz, 1H), 6.60 (d, *J* = 8.7 Hz, 1H), 5.90 (ddd, *J* = 17.0, 10.3, 8.5 Hz, 1H), 5.08-4.97 (m, 2H), 4.07 (d, *J* = 8.4 Hz, 1H), 3.92 (s, 3H), 1.40 (s, 3H). **^{13}C NMR** (151 MHz, $CDCl_3$): δ 202.1, 163.1, 147.6, 140.3, 137.6, 136.6, 128.73, 128.62, 127.8, 118.3, 110.2, 57.7, 53.7, 52.2, 18.2. **HRMS** calculated for $C_{18}H_{19}NO_2Na$ $[M+Na]^+$ 304.1313, found 304.1308. **IR** (ATR): 2993, 2952, 2837, 1720, 1611, 1570, 1492, 1370, 1291, 870 cm^{-1}. **SFC** (of the corresponding primary alcohol): >99% *ee*, 150 mm CHIRALCEL OJH, 1% *i*PrOH, 1 mL/min,

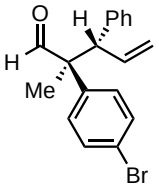
220 nm, 44 °C, t_{R1} = 15.54 min, t_{R2} (minor) = 18.67 min, t_{R3} = 19.59 min, t_{R4} (major) = 20.33 min; $[\alpha]^{24.7}_{D}$ = +101.5° (*c* = 0.135, $CHCl_3$)

(2*R*,3*S*)-3-(6-methoxypyridin-3-yl)-2-methyl-2-phenylpent-4-enal (3q)



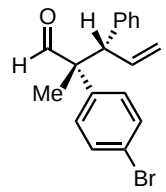
The title compound was synthesized according to the general procedure using (*R*)-DTBM-BINAP, (*R*,*R*)-**A5**, 2-phenylpropanal (**1a**) and alkyne **2q**. ^{1}H NMR analysis of the crude reaction mixture showed 4:1 *dr* and >20:1 branched to linear selectivity. Purification via preparatory TLC (10% ethyl acetate in hexanes) afforded the title compound as a colorless oil (23.7 mg, 84%). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 9.73 (s, 1H), 7.67 (d, *J* = 2.5 Hz, 1H), 7.33-7.27 (m, 3H), 7.09-7.06 (m, 2H), 6.99 (dd, *J* = 8.6, 2.5 Hz, 1H), 6.49 (dd, *J* = 8.6, 0.4 Hz, 1H), 6.07 (ddd, *J* = 17.0, 10.3, 8.6 Hz, 1H), 5.23-5.12 (m, 2H), 4.16 (d, *J* = 8.6 Hz, 1H), 3.85 (s, 3H), 1.51 (s, 3H). **^{13}C NMR** (151 MHz, $CDCl_3$): δ 202.0, 162.7, 147.2, 140.1, 138.0, 136.2, 128.7, 128.1, 127.8, 118.9, 109.9, 57.6, 52.1, 16.8. **HRMS** calculated for $C_{18}H_{19}NO_2Na$ $[M+Na]^+$ 304.1313, found 304.1316. **IR** (ATR): 2999, 2955, 2841, 1721, 1617, 1566, 1499, 1377, 870 cm^{-1}. **SFC** (of the corresponding primary alcohol): >99% *ee*, 150 mm CHIRALCEL OJH, 1% *i*PrOH, 1 mL/min, 220 nm, 44 °C, t_{R1} (major) = 15.54 min, t_{R2} = 18.67 min, t_{R3} (minor) = 19.59 min, t_{R4} = 20.33 min; $[\alpha]^{25.1}_{D}$ = +15.6° (*c* = 0.090, $CHCl_3$)

(2*S*,3*S*)-2-(4-bromophenyl)-2-methyl-3-phenylpent-4-enal (3r)



The title compound was synthesized according to the general procedure using (*R*)-DTBM-BINAP, (*S*,*S*)-**A5**, aldehyde **1r** and 1-phenyl-1-propyne (**2a**). ^{1}H NMR analysis of the crude reaction mixture showed 13:1 *dr* and >20:1 branched to linear selectivity. Purification via preparatory TLC (2% ethyl acetate in hexanes) afforded the title compound as a colorless oil (27.4 mg, 83%). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 9.69 (s, 1H), 7.50-7.48 (m, 2H), 7.24-7.21 (m, 3H), 7.08-7.05 (m, 2H), 6.94-6.91 (m, 2H), 5.91 (ddd, *J* = 16.9, 10.3, 9.0 Hz, 1H), 5.08-5.01 (m, 2H), 4.08 (d, *J* = 9.0 Hz, 1H), 1.35 (s, 3H). **^{13}C NMR** (101 MHz, $CDCl_3$): δ 201.9, 139.3, 137.2, 136.8, 131.5, 130.7, 129.8, 128.2, 127.2, 123.4, 121.9, 118.3, 57.5, 55.7, 18.2. **HRMS** calculated for $C_{18}H_{18}BrO$ $[M+H]^+$ 329.0541, found 329.0539. **IR** (ATR): 3001, 1727, 1659, 1222, 1140, 744, 645 cm^{-1}. **SFC** (of the corresponding primary alcohol): >99% *ee*, 250 mm CHIRALCEL IB, 3% *i*PrOH, 3 mL/min, 220 nm, 44 °C, t_{R1} = 11.32 min, t_{R2} = 12.76 min, t_{R3} (major) = 13.48 min, t_{R4} (minor) = 14.76 min; $[\alpha]^{22.9}_{D}$ = +25.1° (*c* = 0.490, $CHCl_3$)

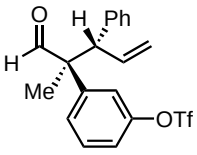
(2*R*,3*S*)-2-(4-bromophenyl)-2-methyl-3-phenylpent-4-enal (3r)



The title compound was synthesized according to the general procedure using (*R*)-DTBM-BINAP, (*R*,*R*)-**A5**, aldehyde **1r** and 1-phenyl-1-propyne (**2a**). ^{1}H NMR analysis of the crude reaction mixture showed 10:1 *dr* and >20:1 branched to linear selectivity. Purification via preparatory TLC (2% ethyl acetate in hexanes) afforded the title compound as a colorless oil (28.0 mg, 85%). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 9.77 (s, 1H), 7.42-7.39 (m, 2H), 7.15-7.11 (m, 3H), 6.97-6.94 (m, 2H), 6.86-6.83 (m, 2H), 6.11 (ddd, *J* = 16.9, 10.2, 9.0 Hz, 1H), 5.23-5.15 (m, 2H), 4.14 (d, *J* = 8.9 Hz, 1H), 1.48 (s, 3H). **^{13}C NMR** (151 MHz, $CDCl_3$): δ 201.9, 139.2, 136.3, 131.51, 131.46, 129.8, 129.5, 128.0, 126.9, 121.6, 118.9, 57.3, 55.7, 17.1.

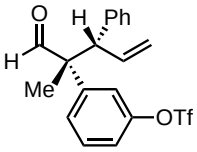
HRMS calculated for $C_{18}H_{18}BrO$ $[M+H]^+$ 329.0541, found 329.0544. **IR** (ATR): 2998, 1725, 1666, 1300, 1254, 1189, 654 cm^{-1}. **SFC** (of the corresponding primary alcohol): >99% *ee*, 250 mm CHIRALCEL IB, 3% *i*PrOH, 3 mL/min, 220 nm, 44 °C, t_{R1} (minor) = 11.32 min, t_{R2} (major) = 12.76 min, t_{R3} = 13.48 min, t_{R4} = 14.76 min; $[\alpha]^{22.6}_{D}$ = +13.3° (*c* = 1.40, $CHCl_3$)

3-((2*S*,3*S*)-2-methyl-1-oxo-3-phenylpent-4-en-2-yl)phenyl trifluoromethanesulfonate (3s)



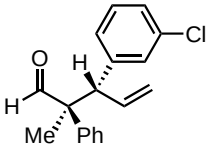
The title compound was synthesized according to the general procedure using (*R*)-DTBM-BINAP, (*S*,*S*)-**A5**, aldehyde **1s** and 1-phenyl-1-propyne (**2a**). ^{1}H NMR analysis of the crude reaction mixture showed >20:1 *dr* and >20:1 branched to linear selectivity. Purification via preparatory TLC (15% ethyl acetate in hexanes) afforded the title compound as a colorless oil (37.9 mg, 95%). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 9.71 (s, 1H), 7.45 (t, *J* = 8.1 Hz, 1H), 7.25-7.21 (m, 5H), 7.11 (t, *J* = 2.1 Hz, 1H), 6.90-6.88 (m, 2H), 5.97-5.88 (m, 1H), 5.07 (t, *J* = 13.1 Hz, 2H), 4.07 (d, *J* = 9.1 Hz, 1H), 1.40 (s, 3H). **^{13}C NMR** (151 MHz, $CDCl_3$): δ 201.4, 149.7, 141.5, 138.7, 136.3, 129.88, 129.68, 129.0, 128.4, 127.4, 122.1, 120.4, 118.7, 57.8, 56.1, 18.3. **^{19}F NMR** (565 MHz, $CDCl_3$): δ -72.8. **HRMS** calculated for $C_{19}H_{17}F_3O_4S$ $[M+Na]^+$ 421.0697, found 421.0693. **IR** (ATR): 3000, 2790, 2733, 1724, 1590, 1499, 1444, 1220, 1133, 774 cm^{-1}. **SFC** (of the corresponding primary alcohol): >99% *ee*, 250 mm CHIRALCEL IB, 2% *i*PrOH, 2 mL/min, 220 nm, 44 °C, t_{R1} = 11.60 min, t_{R2} = 12.30 min, t_{R3} (major) = 13.22 min, t_{R4} (minor) = 14.58 min; $[\alpha]^{22.5}_{D}$ = +16.9° (*c* = 0.835, $CHCl_3$)

3-((2*R*,3*S*)-2-methyl-1-oxo-3-phenylpent-4-en-2-yl)phenyl trifluoromethanesulfonate (3s)



The title compound was synthesized according to the general procedure using (*R*)-DTBM-BINAP, (*R*,*R*)-**A5**, aldehyde **1s** and 1-phenyl-1-propyne (**2a**). ^{1}H NMR analysis of the crude reaction mixture showed 3:1 *dr* and >20:1 branched to linear selectivity. Purification via preparatory TLC (15% ethyl acetate in hexanes) afforded the title compound as a colorless oil (33.2 mg, 83%). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 9.79 (s, 1H), 7.34 (t, *J* = 8.1 Hz, 1H), 7.24-7.21 (m, 2H), 7.13-7.11 (m, 3H), 7.01 (t, *J* = 2.1 Hz, 1H), 6.83-6.81 (m, 2H), 6.15-6.06 (m, 1H), 5.26-5.18 (m, 2H), 4.13 (d, *J* = 9.1 Hz, 1H), 1.55 (s, 3H). **^{13}C NMR** (151 MHz, $CDCl_3$): δ 201.5, 149.7, 142.1, 138.8, 135.8, 130.0, 129.7, 129.4, 128.2, 127.1, 121.2, 120.2, 119.3, 57.6, 56.1, 17.0. **^{19}F NMR** (565 MHz, $CDCl_3$): δ -72.8. **HRMS** calculated for $C_{19}H_{17}F_3O_4S$ $[M+Na]^+$ 421.0697, found 421.0691. **IR** (ATR): 2995, 2792, 2732, 1720, 1590, 1503, 1449, 1136, 778 cm^{-1}. **SFC** (of the corresponding primary alcohol): >99% *ee*, 250 mm CHIRALCEL IB, 2% *i*PrOH, 2 mL/min, 220 nm, 44 °C, t_{R1} (minor) = 11.60 min, t_{R2} (major) = 12.30 min, t_{R3} = 13.22 min, t_{R4} = 14.58 min; $[\alpha]^{22.7}_{D}$ = +4.0° (*c* = 0.470, $CHCl_3$)

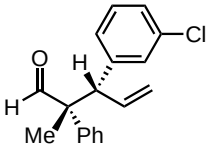
(2*S*,3*S*)-3-(3-chlorophenyl)-2-methyl-2-phenylpent-4-enal (3t)



The title compound was synthesized according to the general procedure using (*R*)-DTBM-BINAP, (*S*,*S*)-**A5**, 2-phenylpropanal (**1a)** and alkyne **2t**. ^{1}H NMR analysis of the crude reaction mixture showed 16:1 *dr* and >20:1 branched to linear selectivity. Purification via preparatory TLC (2% ethyl acetate in hexanes) afforded the title compound as a colorless oil (21.2 mg, 75%). **^{1}H NMR** (500 MHz, $CDCl_3$): δ 9.69 (s, 1H), 7.40-7.37 (m, 2H), 7.35-7.32 (m, 1H), 7.19-7.17 (m, 3H), 7.15 (m, 1H),

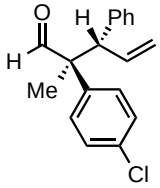
6.90 (m, 1H), 6.82 (d, *J* = 7.5 Hz, 1H), 5.88 (ddd, *J* = 16.9, 10.1, 9.0 Hz, 1H), 5.07-5.01 (m, 2H), 4.10 (d, *J* = 8.9 Hz, 1H), 1.38 (s, 3H). **^{13}C NMR** (151 MHz, $CDCl_3$): δ 202.1, 142.0, 137.6, 136.6, 133.9, 130.0, 129.3, 128.8, 128.5, 128.2, 127.8, 127.1, 118.4, 57.7, 55.2, 18.2. **HRMS** calculated for $C_{18}H_{17}ClONa$ $[M+Na]^+$ 307.0866, found 307.0861. **IR** (ATR): 3028, 2997, 1721, 1631, 1555, 1122, 713, 640 cm^{-1}. **SFC** (of the corresponding primary alcohol): 99% *ee*, 250 mm CHIRALCEL IB, 8% *i*PrOH, 2 mL/min, 220 nm, 44 °C, t_{R1} = 6.72 min, t_{R2} = 7.05 min, t_{R3} (minor) = 7.30 min, t_{R4} (major) = 7.87 min; **$[\alpha]^{19.4}_D$** = +29.5° (*c* = 0.505, $CHCl_3$)

(2*R*,3*S*)-3-(3-chlorophenyl)-2-methyl-2-phenylpent-4-enal (3t)



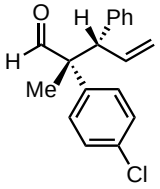
The title compound was synthesized according to the general procedure using (*R*)-DTBM-BINAP, (*R*,*R*)-**A5**, 2-phenylpropanal (**1a)** and alkyne **2t**. ^{1}H NMR analysis of the crude reaction mixture showed 5:1 *dr* and >20:1 branched to linear selectivity. Purification via preparatory TLC (2% ethyl acetate in hexanes) afforded the title compound as a colorless oil (24.2 mg, 85%). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 9.75 (s, 1H), 7.29 (dq, *J* = 6.9, 1.1 Hz, 2H), 7.19-7.16 (m, 1H), 7.09-7.05 (m, 3H), 7.03-6.99 (m, 1H), 6.79 (td, *J* = 1.7, 0.4 Hz, 1H), 6.69 (dddd, *J* = 7.6, 1.7, 1.2, 0.5 Hz, 1H), 6.09 (ddd, *J* = 16.9, 10.3, 8.9 Hz, 1H), 5.24-5.15 (m, 2H), 4.17 (d, *J* = 8.8 Hz, 1H), 1.51 (s, 3H). **^{13}C NMR** (101 MHz, $CDCl_3$): δ 202.0, 141.8, 138.2, 136.1, 133.6, 129.8, 129.0, 128.6, 128.07, 127.89, 127.6, 126.8, 119.1, 57.6, 55.2, 16.9. **HRMS** calculated for $C_{18}H_{18}ClO$ 285.1046, found 285.1050. **IR** (ATR): 3014, 3000, 1724, 1644, 1156, 722, 633, 554 cm^{-1}. **SFC** (of the corresponding primary alcohol): >99% *ee*, 250 mm CHIRALCEL IB, 8% *i*PrOH, 2 mL/min, 220 nm, 44 °C, t_{R1} (major) = 6.72 min, t_{R2} (minor) = 7.05 min, t_{R3} = 7.30 min, t_{R4} = 7.87 min; **$[\alpha]^{24.9}_D$** = +31.2° (*c* = 0.250, $CHCl_3$)

(2*S*,3*S*)-2-(4-chlorophenyl)-2-methyl-3-phenylpent-4-enal (3u)



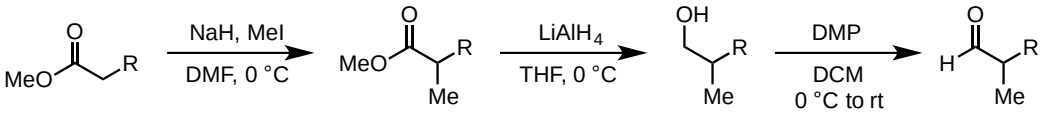
The title compound was synthesized according to the general procedure using (*R*)-DTBM-BINAP, (*S*,*S*)-**A5**, aldehyde **1u** and 1-phenyl-1-propyne (**2a**). ^{1}H NMR analysis of the crude reaction mixture showed 15:1 *dr* and >20:1 branched to linear selectivity. Purification via preparatory TLC (2% ethyl acetate in hexanes) afforded the title compound as a colorless oil (19.4 mg, 68%). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 9.69 (s, 1H), 7.36-7.32 (m, 2H), 7.23-7.21 (m, 3H), 7.14-7.11 (m, 2H), 6.94-6.91 (m, 2H), 5.92 (ddd, *J* = 16.9, 10.3, 9.0 Hz, 1H), 5.08-5.01 (m, 2H), 4.09 (d, *J* = 9.0 Hz, 1H), 1.36 (s, 3H). **^{13}C NMR** (151 MHz, $CDCl_3$): δ 202.0, 139.3, 136.79, 136.69, 133.6, 130.3, 129.8, 128.5, 128.2, 127.2, 118.3, 57.5, 55.7, 18.2. **HRMS** calculated for $C_{18}H_{17}ClO$ $[M]^+$ 284.0968, found 284.0971. **IR** (ATR): 3030, 2989, 1721, 1622, 1510, 1210, 1101, 701, 692 cm^{-1}. **SFC** (of the corresponding primary alcohol): >99% *ee*, 250 mm CHIRALCEL IB, 3% *i*PrOH, 3 mL/min, 220 nm, 44 °C, t_{R1} = 9.07 min, t_{R2} = 10.08 min, t_{R3} (major) = 10.75 min, t_{R4} (minor) = 11.67 min;
$[\alpha]^{23.5}_D$ = +38.9° (*c* = 0.63, $CHCl_3$)

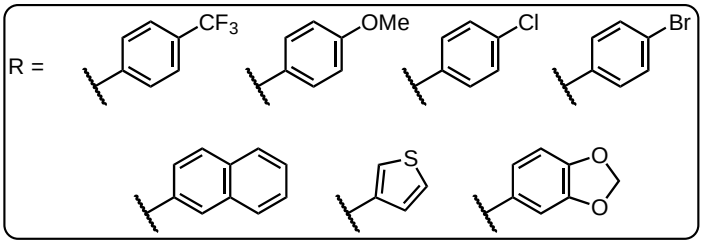
(2*R*,3*S*)-2-(4-chlorophenyl)-2-methyl-3-phenylpent-4-enal (3u)



The title compound was synthesized according to the general procedure using (*R*)-DTBM-BINAP, (*R*,*R*)-**A5**, aldehyde **1u** and 1-phenyl-1-propyne (**2a**). ^{1}H NMR analysis of the crude reaction mixture showed 8:1 *dr* and >20:1 branched to linear selectivity. Purification via preparatory TLC (2% ethyl acetate in hexanes) afforded the title compound as a colorless oil (24.1 mg, 85%). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 9.77 (s, 1H), 7.27-7.22 (m, 2H), 7.15-7.11 (m, 3H), 7.02-6.99 (m, 2H), 6.85-6.83 (m, 2H), 6.11 (ddd, *J* = 16.9, 10.3, 8.9 Hz, 1H), 5.23-5.15 (m, 2H), 4.14 (d, *J* = 8.9 Hz, 1H), 1.50 (s, 3H). **^{13}C NMR** (151 MHz, $CDCl_3$): δ 202.0, 139.3, 137.3, 136.3, 133.4, 129.55, 129.48, 128.6, 128.0, 126.9, 118.9, 57.3, 55.8, 17.1. **HRMS** calculated for $C_{18}H_{17}ClO$ $[M]^+$ 284.0968, found 284.0966. **IR** (ATR): 3030, 2989, 1723, 1619, 1521, 1310, 1132, 722, 622, 533 cm^{-1}. **SFC** (of the corresponding primary alcohol): >99% *ee*, 250 mm CHIRALCEL IB, 3% *i*PrOH, 3 mL/min, 220 nm, 44 °C, t_{R1} (minor) = 9.07 min, t_{R2} (major) = 10.08 min, t_{R3} = 10.75 min, t_{R4} = 11.67 min; **$[\alpha]^{22.0}_D$** = +5.9° (*c* = 0.43, $CHCl_3$)

3. Preparation of Aldehyde and Alkyne Substrates





General Procedure for Ester α-Methylation

To a flame-dried round bottom was added NaH as a 60% dispersion in mineral oil. After addition of DMF (0.3 M), the resulting slurry was cooled to 0 °C. After dropwise addition of the appropriate ester (1 equiv.), at 0 °C, the reaction mixture was stirred for 5 minutes 0 °C. Hydrogen gas evolution was observed. After slow addition of methyl iodide 0 °C, the reaction mixture was allowed to warm to room temperature. After reaction completion, the reaction mixture was quenched with an aqueous saturated NH_4Cl solution and extracted with Et_2O. The combined organic layers were washed with H_2O and brine, dried with anhydrous $MgSO_4$, filtered and concentrated *in vacuo*. The crude methylated ester was used without further purification.

General Procedure for Ester Reduction

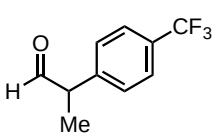
To a flame-dried round bottom was added $LiAlH_4$ (2 equiv.). After addition of THF (0.4 M), the resulting slurry was cooled to 0 °C. A THF solution of the crude methylated ester (1 equiv.) was slowly added to the $LiAlH_4$ slurry at 0 °C. After ester addition, the reaction mixture was allowed to warm to room temperature. Upon complete reduction,

the reaction mixture was quenched using the Fieser work up. The obtained crude alcohol was used without further purification.

General Procedure for Alcohol Oxidation

Crude alcohol (1 equiv.) was added to a flame-dried round bottom and dissolved in DCM (0.4 M). The resulting solution was cooled to 0 °C. Dess-Martin periodinane (1.1 equiv.) was added in one portion at 0 °C. After the addition of DMP, the reaction mixture was allowed to warm to room temperature. Upon complete oxidation, the reaction mixture was quenched was saturated aqueous $Na_2S_2O_3$ and saturated aqueous $NaHCO_3$ solutions. After extraction with DCM, the combined organic layers were washed with H_2O and brine, dried with anhydrous $MgSO_4$, filtered, and concentrated *in vacuo*. Flash column chromatography with a mixture of EtOAc in hexanes afforded the desired α-substituted aldehyde.

2-(4-(trifluoromethyl)phenyl)propanal (1p)

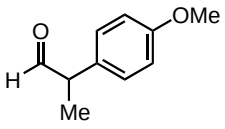


Prepared according to the general procedures for ester α-methylation, ester reduction, and alcohol oxidation using methyl 2-(4-(trifluoromethyl)phenyl)acetate (1.93 g, 8.8 mmol, 1 equiv.), NaH (336 mg, 8.4 mmol, 0.95 equiv.), MeI (1.25 g, 8.8 mmol, 1 equiv.), and DMF (30 mL, 0.3 M). The reaction was found to be complete after 30 minutes at room temperature.

Crude methyl 2-(4-(trifluoromethyl)phenyl)propanoate (1 equiv.) was reduced to the corresponding alcohol using $LiAlH_4$ (668 mg, 17.6 mmol, 2 equiv.) and THF (30 mL, 0.3 M). The reaction was found to be complete after 20 minutes at room temperature and yielded the desired alcohol as a colorless oil (1.02 g, 5.0 mmol, 57% over 2 steps) which was used without further purification.

Crude 2-(4-(trifluoromethyl)phenyl)propan-1-ol (823 mg, 4.0 mmol, 1 equiv.) was oxidized to the corresponding alcohol using DMP (1.87 g, 4.4 mmol, 1.1 equiv.) and DCM (10 mL, 0.4 M). The oxidation was found to be complete after 1 hour at room temperature. The crude material was purified by column chromatography using 5% EtOAc in hexanes to afford the desired aldehyde as a colorless oil (261 mg, 1.28 mmol, 32%). The ^{1}H NMR spectrum is in accordance with the literature.[42] **^{1}HNMR** (400 MHz, $CDCl_3$): δ 9.70 (s, 1H), 7.64 (d, *J* = 8.0 Hz, 2H), 7.34 (d, *J* = 8.1 Hz, 2H), 3.72 (q, *J* = 7.2 Hz, 1H), 1.49 (d, *J* = 7.2 Hz, 3H).

2-(4-methoxyphenyl)propanal (1b)



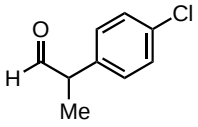
Prepared according to the general procedures for ester α-methylation, ester reduction, and alcohol oxidation using methyl 2-(4-methoxyphenyl)acetate (1.08 g, 6.0 mmol, 1 equiv.), NaH (264 mg, 6.6 mmol, 1.1 equiv.), MeI (937 mg, 6.6 mmol, 1.1 equiv.), and DMF (20 mL, 0.3 M). The reaction was found to be complete after 2 hours at room temperature.

[42] J. A. Friest, Y. Maezato, S. Broussy, P. Blum, D. B. Berkowitz, *J. Am. Chem. Soc.*, **2010,** *132*, 5930.

Crude methyl 2-(4-methoxyphenyl)propanoate (1 equiv.) was reduced to the corresponding alcohol using $LiAlH_4$ (455 mg, 12 mmol, 2 equiv.) and THF (20 mL, 0.3 M). The reaction was found to be complete after 25 minutes at room temperature and yielded the desired alcohol as a yellow oil (863 mg, 5.2 mmol, 87% over 2 steps) which was used without further purification.

Crude 2-(4-methoxyphenyl)propan-1-ol (641 mg, 3.9 mmol, 1 equiv.) was oxidized to the corresponding alcohol using DMP (1.8 g, 4.2 mmol, 1.1 equiv.) and DCM (10 mL, 0.4 M). The oxidation was found to be complete after 1 hour at room temperature. The crude material was purified by column chromatography using 5% EtOAc in hexanes to afford the desired aldehyde as a colorless oil (359 mg, 2.1 mmol, 55%). The ^{1}H NMR spectrum is in accordance with the literature.[43] **^{1}HNMR** (400 MHz, $CDCl_3$): δ 9.65 (s, 1H), 7.14-7.11 (m, 2H), 6.93-6.90 (m, 2H), 3.81 (s, 3H), 3.58 (q, *J* = 7.1 Hz, 1H), 1.42 (d, *J* = 7.1 Hz, 3H).

2-(4-chlorophenyl)propanal (1u)

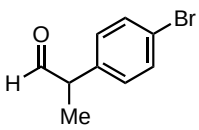


Prepared according to the general procedures for ester α-methylation, ester reduction, and alcohol oxidation using methyl 2-(4-chlorophenyl)acetate (1.85 g, 10 mmol, 1 equiv.), NaH (400 mg, 10 mmol, 1 equiv.), MeI (1.42 g, 10 mmol, 1 equiv.), and DMF (30 mL, 0.33 M). The reaction was found to be complete after 2 hours at room temperature.

Crude methyl 2-(4-chlorophenyl)propanoate (1 equiv.) was reduced to the corresponding alcohol using $LiAlH_4$ (760 mg, 20 mmol, 2 equiv.) and THF (30 mL, 0.33 M). The reaction was found to be complete after 5 minutes at room temperature and yielded the desired alcohol as a colorless oil (1.46 g, 8.6 mmol, 86% over 2 steps) which was used without further purification.

Crude 2-(4-chlorophenyl)propan-1-ol (683 mg, 4 mmol, 1 equiv.) was oxidized to the corresponding alcohol using DMP (1.87 g, 4.4 mmol, 1.1 equiv.) and DCM (10 mL, 0.4 M). The oxidation was found to be complete after 1 hour at room temperature. The crude material was purified by column chromatography using 2% EtOAc in hexanes to afford the desired aldehyde as a colorless oil (205 mg, 1.2 mmol, 30%). The ^{1}H NMR spectrum is in accordance with the literature.[44] **^{1}HNMR** (400 MHz, $CDCl_3$): δ 9.66 (d, *J* = 1.4 Hz, 1H), 7.37-7.33 (m, 2H), 7.16-7.13 (m, 2H), 3.62 (q, *J* = 7.1 Hz, 1H), 1.44 (d, *J* = 7.1 Hz, 3H).

2-(4-bromophenyl)propanal (1r)



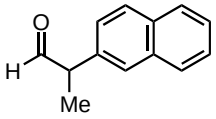
Prepared according to the general procedures for ester α-methylation, ester reduction, and alcohol oxidation using methyl 2-(4-bromophenyl)acetate (2.29 g, 10 mmol, 1 equiv.), NaH (400 mg, 10 mmol, 1 equiv.), MeI (1.42 g, 10 mmol, 1 equiv.), and DMF (30 mL, 0.33 M). The reaction was found to be complete after 1.5 hours at room temperature.

[43] S. Hoffmann, M. Nicoletti, B. List, *J. Am. Chem. Soc.*, **2006,** *128*, 13074.
[44] M. R. Witten, E. N. Jacobsen, *Org. Lett.*, **2015,** *17*, 2772.

Crude methyl 2-(4-bromophenyl)propanoate (1 equiv.) was reduced to the corresponding alcohol using $LiAlH_4$ (760 mg, 20 mmol, 2 equiv.) and THF (30 mL, 0.33 M). The reaction was found to be complete after 5 minutes at room temperature and yielded the desired alcohol as a colorless oil (1.90 g, 8.8 mmol, 88% over 2 steps) which was used without further purification.

Crude 2-(4-bromophenyl)propan-1-ol (860 mg, 4 mmol, 1 equiv.) was oxidized to the corresponding alcohol using DMP (1.87 g, 4.4 mmol, 1.1 equiv.) and DCM (10 mL, 0.4 M). The oxidation was found to be complete after 1 hour at room temperature. The crude material was purified by column chromatography using 2% EtOAc in hexanes to afford the desired aldehyde as a colorless oil (275 mg, 1.3 mmol, 32%). The ^{1}H NMR spectrum is in accordance with the literature.[3] **^{1}HNMR** (400 MHz, $CDCl_3$): δ 9.66 (d, *J* = 1.2 Hz, 1H), 7.52-7.49 (m, 2H), 7.10-7.07 (m, 2H), 3.60 (q, *J* = 7.1 Hz, 1H), 1.44 (d, *J* = 7.1 Hz, 3H).

2-(naphthalen-2-yl)propanal (1c)

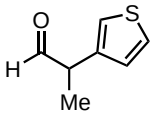


Prepared according to the general procedures for ester α-methylation, ester reduction, and alcohol oxidation using methyl 2-(naphthalen-2-yl)acetate (1.6 g, 8 mmol, 1 equiv.), NaH (352 mg, 8.8 mmol, 1.1 equiv.), MeI (1.25 g, 8.8 mmol, 1 equiv.), and DMF (20 mL, 0.4 M). The reaction was found to be complete after 1 hour at room temperature.

Crude methyl 2-(naphthalen-2-yl)propanoate (1 equiv.) was reduced to the corresponding alcohol using $LiAlH_4$ (607 mg, 16 mmol, 2 equiv.) and THF (20 mL, 0.4 M). The reaction was found to be complete after 5 minutes at room temperature and yielded the desired alcohol as a white solid (1.49 g, 8 mmol, quantitative over 2 steps) which was used without further purification.

Crude 2-(naphthalen-2-yl)propan-1-ol (559 mg, 3 mmol, 1 equiv.) was oxidized to the corresponding alcohol using DMP (1.4 g, 3.3 mmol, 1.1 equiv.) and DCM (8 mL, 0.4 M). The oxidation was found to be complete after 1 hour at room temperature. The crude material was purified by column chromatography using 2% EtOAc in hexanes to afford the desired aldehyde as a white solid (235 mg, 1.3 mmol, 42%). The ^{1}H NMR spectrum is in accordance with the literature.[3] **^{1}HNMR** (400 MHz, $CDCl_3$): δ 9.77 (d, *J* = 1.4 Hz, 1H), 7.88-7.81 (m, 3H), 7.68 (d, *J* = 1.2 Hz, 1H), 7.53-7.47 (m, 2H), 7.33 (dd, *J* = 8.4, 1.8 Hz, 1H), 3.81 (q, *J* = 7.0 Hz, 1H), 1.55 (d, *J* = 7.1 Hz, 3H).

2-(thiophen-3-yl)propanal (1f)

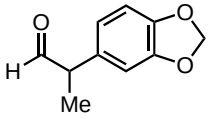


Prepared according to the general procedures for ester α-methylation, ester reduction, and alcohol oxidation using methyl 2-(thiophen-3-yl)acetate (1.2 g, 7.7 mmol, 1 equiv.), NaH (323 mg, 8.1 mmol, 1.05 equiv.), MeI (1.15 g, 8.1 mmol, 1.05 equiv.), and DMF (25 mL, 0.3 M). The reaction was found to be complete after 1 hour at room temperature.

Crude methyl 2-(thiophen-3-yl)propanoate (1 equiv.) was reduced to the corresponding alcohol using $LiAlH_4$ (583 mg, 15.4 mmol, 2 equiv.) and THF (20 mL, 0.4 M). The reaction was found to be complete after 5 minutes at room temperature and yielded the desired alcohol as a yellow oil (1.02 g, 7.2 mmol, 94% over 2 steps) which was used without further purification.

Crude 2-(thiophen-3-yl)propan-1-ol (427 mg, 3 mmol, 1 equiv.) was oxidized to the corresponding alcohol using DMP (1.4 g, 3.3 mmol, 1.1 equiv.) and DCM (8 mL, 0.4 M). The oxidation was found to be complete after 1 hour at room temperature. The crude material was purified by column chromatography using 5% Et_2O in pentanes to afford the desired aldehyde as a yellow oil (203 mg, 1.45 mmol, 48%). The ^{1}H NMR spectrum is in accordance with the literature.[45] **^{1}HNMR** (400 MHz, $CDCl_3$): δ 9.65 (d, *J* = 1.8 Hz, 1H), 7.36 (ddd, *J* = 5.0, 2.9, 0.3 Hz, 1H), 7.12 (ddd, *J* = 2.9, 1.3, 0.8 Hz, 1H), 6.99 (ddd, *J* = 5.0, 1.4, 0.4 Hz, 1H), 3.75 (qd, *J* = 7.1, 1.8 Hz, 1H), 1.46 (d, *J* = 7.1 Hz, 3H).

2-(benzo[*d*][1,3]dioxol-5-yl)propanal (1e)

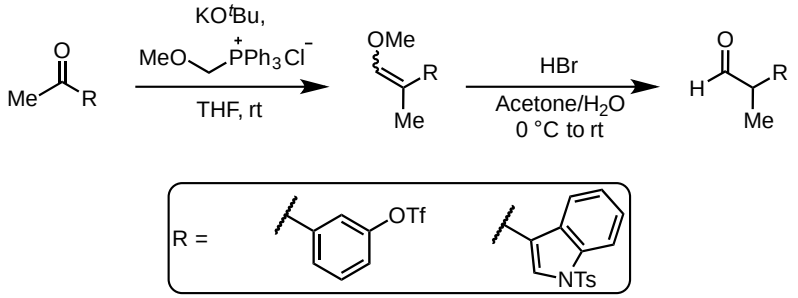


Prepared according to the general procedures for ester α-methylation, ester reduction, and alcohol oxidation using methyl 2-(benzo[*d*][1,3]dioxol-5-yl)acetate (2.0 g, 10.3 mmol, 1 equiv.), NaH (452 mg, 11.3 mmol, 1.1 equiv.), MeI (1.60 g, 11.3 mmol, 1.1 equiv.), and DMF (35 mL, 0.3 M). The reaction was found to be complete after 2 hours at room temperature.

Crude methyl 2-(benzo[*d*][1,3]dioxol-5-yl)propanoate (1 equiv.) was reduced to the corresponding alcohol using $LiAlH_4$ (1.17 g, 30.9 mmol, 3 equiv.) and THF (30 mL, 0.33 M). The reaction was found to be complete after 5 minutes at room temperature and yielded the desired alcohol as a colorless oil (1.83 g, 10.2 mmol, 99% over 2 steps) which was used without further purification.

Crude 2-(benzo[*d*][1,3]dioxol-5-yl)propan-1-ol (1.26 g, 7 mmol, 1 equiv.) was oxidized to the corresponding alcohol using DMP (3.27 g, 7.7 mmol, 1.1 equiv.) and DCM (18 mL, 0.4 M). The oxidation was found to be complete after 1 hour at room temperature. The crude material was purified by column chromatography using 5% EtOAc in hexanes to afford the desired aldehyde as a colorless oil (752 mg, 4.2 mmol, 61%). The ^{1}H NMR spectrum is in accordance with the literature.[46] **^{1}HNMR** (400 MHz, $CDCl_3$): δ 9.63 (d, *J* = 1.5 Hz, 1H), 6.81 (dd, *J* = 7.8, 0.4 Hz, 1H), 6.68-6.65 (m, 2H), 5.96 (d, *J* = 1.5 Hz, 2H), 3.55 (qd, *J* = 7.1, 1.4 Hz, 1H), 1.40 (d, *J* = 7.1 Hz, 3H).

[45] R. Tanaka, K. Nakano, K. Nozaki, *J. Org. Chem.*, **2007,** *72*, 8671.
[46] Z.-Q. Rong, Y. Zhang, R. H. B. Chua, H.-J. Pan, Y. Zhao, *J. Am. Chem. Soc.*, **2015,** *137*, 4944.



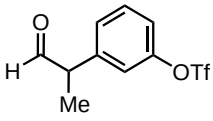
General Procedure for Ketone Olefination

(Methoxymethyl)triphenylphosphnium chloride (1.65 equiv.) was added to a flame-dried round bottom and dissolved in THF (0.5 M). To the resulting slurry was added KO^{t}Bu (1.55 equiv.) at room temperature. After stirring for 30 minutes at room temperature, ketone (1 equiv.) wasa added. The reaction mixture was allowed to stir at room temperature. Upon completion, the reaction mixture was concentrated *in vacuo*, then dissolved in hexanes and allowed to stir for 30 minutes. The reaction mixture was then filtered and concentrated *in vacuo*. The obtained crude enol ether was used without further purification.

General Procedure for Enol Ether Hydrolysis

A 4:1 acetone/H_2O solution (0.5 M) of enol ether (1 equiv.) was cooled to 0 °C. To this solution was added 48% aqueous HBr (10 equiv.). After HBr addition, the reaction mixture was warmed to room temperature. Upon completion, the reaction mixture was quenched with saturated aqueous $NaHCO_3$ and extracted with Et_2O. The combined organic layers were concentrated *in vacuo*. The obtained crude residue was purified by column chromatography to afford the desired aldehyde.

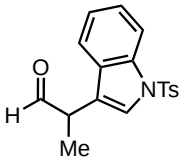
3-(1-oxopropan-2-yl)phenyl trifluoromethanesulfonate (1s)



Prepared according to the general procedures for ketone olefination and enol ether hydrolysis using 3-acetylphenyl trifluoromethanesulfonate (2.68 g, 10 mmol, 1 equiv.), (methoxymethyl)triphenylphosphnium chloride (5.65 g, 16.5 mmol, 1.65 equiv.), KO^{t}Bu (1.74 g, 15.5 mmol, 1.55 equiv.), and THF (30 mL, 0.33 M). The reaction was found to be complete after 24 hours at room temperature and afforded the desired enol ether (2.01 g, 6.8 mmol, 68%) which was used crude without further purification.

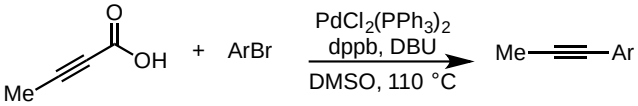
Crude 3-(1-methoxyprop-1-en-2-yl)phenyl trifluoromethanesulfonate (889 mg, 3 mmol, 1 equiv.) was hydrolyzed using 48% aqueous HBr (3.5 mL, 30 mmol, 10 equiv.) and a 4:1 mixture of acetone/H_2O (6 mL, 0.5 M). Hydrolysis was complete after 18 hours at room temperature. The crude material was purified by column chromatography using 10% EtOAc in hexanes to afford the desired aldehyde as a colorless oil (512 mg, 1.81 mmol, 60%). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 9.70 (d, *J* = 1.3 Hz, 1H), 7.48 (t, *J* = 8.0 Hz, 1H), 7.27-7.22 (m, 3H), 7.15-7.13 (m, 1H), 3.70 (q, *J* = 7.1 Hz, 1H), 1.49 (d, *J* = 7.1 Hz, 3H). **^{13}C NMR** (126 MHz, $CDCl_3$): δ 199.9, 150.1, 140.9, 130.9, 128.4, 121.4, 120.6, 118.8 (q, J = 320.5 Hz), 52.5, 14.7. **^{19}F NMR** (376 MHz, $CDCl_3$): δ -73.3. **HRMS** calculated for $C_{10}H_9F_3O_4SNa$ $[M+Na]^+$ 305.0071, found 305.0068. **IR** (ATR): 2911, 1721, 1580, 1499, 1199, 774 cm^{-1}.

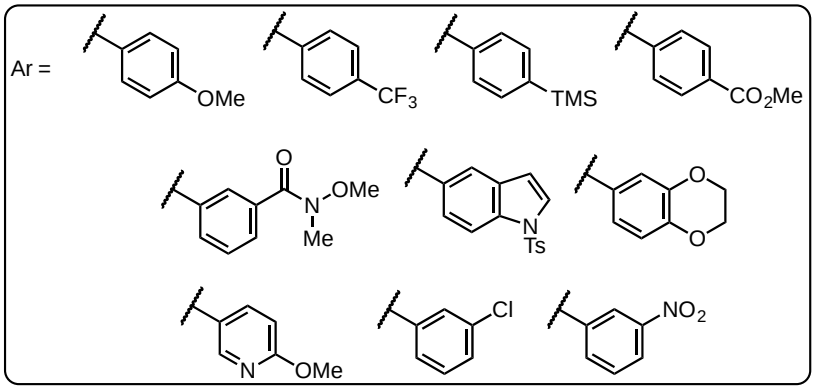
2-(1-tosyl-1*H*-indol-3-yl)propanal (1d)



Prepared according to the general procedures for ketone olefination and enol ether hydrolysis using 1-(1-tosyl-1*H*-indol-3-yl)ethan-1-one (2.19 g, 7 mmol, 1 equiv.), (methoxymethyl)triphenylphosphnium chloride (1.12 g, 11.55 mmol, 1.65 equiv.), KO^{t}Bu (1.22 g, 10.85 mmol, 1.55 equiv.), and THF (30 mL, 0.25 M). The reaction was found to be complete after 24 hours at room temperature and afforded the desired enol ether (565 mg, 1.7 mmol, 24%) which was used crude without further purification.

Crude 3-(1-methoxyprop-1-en-2-yl)-1-tosyl-1*H*-indole (565 mg, 1.7 mmol, 1 equiv.) was hydrolyzed using 48% aqueous HBr (2 mL, 17 mmol, 10 equiv.) and a 4:1 mixture of acetone/H_2O (25 mL, 0.05 M). Hydrolysis was complete after 18 hours at room temperature. The crude material was purified by column chromatography using 15% EtOAc in hexanes to afford the desired aldehyde as a colorless oil (226 mg, 0.69 mmol, 41%). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 9.61 (d, *J* = 2.0 Hz, 1H), 7.99 (d, *J* = 8.3 Hz, 1H), 7.79-7.76 (m, 2H), 7.47 (d, *J* = 7.8 Hz, 2H), 7.34 (ddd, *J* = 8.3, 7.3, 1.1 Hz, 1H), 7.27-7.23 (m, 3H), 3.81 (ddd, *J* = 7.1, 1.9, 0.8 Hz, 1H), 2.35 (s, 3H), 1.52 (d, *J* = 7.1 Hz, 3H). **^{13}C NMR** (151 MHz, $CDCl_3$): δ 200.0, 145.3, 135.44, 135.24, 130.1, 129.9, 127.0, 125.3, 123.9, 123.5, 119.7, 119.2, 114.0, 44.2, 21.7, 13.6. **HRMS** calculated for $C_{18}H_{18}NO_3S$ $[M+H]^+$ 328.1007, found 328.1012. **IR** (ATR): 2995, 1719, 1610, 1553, 1282, 1154, 1002, 552 cm^{-1}.

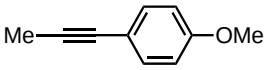




General Procedure for Decarboxylative Cross-Coupling

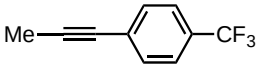
To a flame dried Schlenk tube was added $PdCl_2(PPh_3)_2$ (5 mol%), 1,4-bis(diphenylphosphino)butane (10 mol%), and DMSO (0.5 M). To the resulting solution was added aryl halide (1 equiv.), 2-butynoic acid (1.2 equiv.), and DBU (3 equiv.). The reaction mixture was then heated to 110 °C. Upon reaction completion, the reaction mixture was cooled to room temperature, quenched with H_2O, and extracted with DCM. The combined organic layers were washed with H_2O and brine, dried with anhydrous $MgSO_4$, filter, and concentrated *in vacuo*. The crude residue was purified by column chromatography to afford the desired alkyne.

1-methoxy-4-(prop-1-yn-1-yl)benzene (2j)



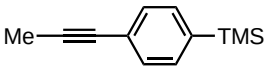
Prepared according to the general procedure for decarboxylative cross-coupling using $PdCl_2(PPh_3)_2$ (176 mg, 0.25 mmol, 5 mol%), 1,4-bis(diphenylphosphino)butane (213 mg, 0.50 mmol, 10 mol%), and DMSO (10 mL, 0.5 M). To the resulting solution was added 1-bromo-4-methoxybenzene (935 mg, 5 mmol, 1 equiv.), 2-butynoic acid (505 mg, 6 mmol, 1.2 equiv.), and DBU (2.2 mL, 15 mmol, 3 equiv.). The reaction was complete after 1 hour at 110 °C. Purification by column chromatography using 2% EtOAc in hexanes afforded the desired alkyne as a colorless oil (565 mg, 3.86 mmol, 77%). The ^{1}H NMR was in accordance with the literature.[47] **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.33-7.30 (m, 2H), 6.82-6.80 (m, 2H), 3.80 (s, 3H), 2.03 (s, 3H).

1-(prop-1-yn-1-yl)-4-(trifluoromethyl)benzene (2k)



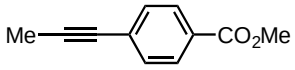
Prepared according to the general procedure for decarboxylative cross-coupling using $PdCl_2(PPh_3)_2$ (176 mg, 0.25 mmol, 5 mol%), 1,4-bis(diphenylphosphino)butane (213 mg, 0.50 mmol, 10 mol%), and DMSO (10 mL, 0.5 M). To the resulting solution was added 1-bromo-4-(trifluoromethyl)benzene (1.13 g, 5 mmol, 1 equiv.), 2-butynoic acid (505 mg, 6 mmol, 1.2 equiv.), and DBU (2.2 mL, 15 mmol, 3 equiv.). The reaction was complete after 1 hour at 110 °C. Purification by column chromatography using 2% EtOAc in hexanes afforded the desired alkyne as a colorless oil (643 mg, 3.49 mmol, 70%). The ^{1}H NMR was in accordance with the literature.[6] **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.54-7.52 (m, 2H), 7.48 (d, J = 8.3 Hz, 2H), 2.08-2.06 (m, 3H).

Trimethyl(4-(prop-1-yn-1-yl)phenyl)silane (2m)



Prepared according to the general procedure for decarboxylative cross-coupling using $PdCl_2(PPh_3)_2$ (176 mg, 0.25 mmol, 5 mol%), 1,4-bis(diphenylphosphino)butane (213 mg, 0.50 mmol, 10 mol%), and DMSO (10 mL, 0.5 M). To the resulting solution was added (4-bromophenyl)trimethylsilane (1.15 g, 5 mmol, 1 equiv.), 2-butynoic acid (505 mg, 6 mmol, 1.2 equiv.), and DBU (2.2 mL, 15 mmol, 3 equiv.). The reaction was complete after 1 hour at 110 °C. Purification by column chromatography using 2% EtOAc in hexanes afforded the desired alkyne as a colorless oil (679 mg, 3.6 mmol, 72%). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.44-7.42 (m, 2H), 7.37-7.35 (m, 2H), 2.05 (s, 3H), 0.25 (s, J = 6.6 Hz, 9H). **^{13}C NMR** (101 MHz, $CDCl_3$): δ 140.1, 133.3, 130.7, 124.5, 86.3, 80.0, 4.6, -1.1. **HRMS** calculated for $C_{12}H_{20}NSi$ $[M+NH_4]^+$ 206.1365, found 206.1371. **IR** (ATR): 3001, 2100, 1251 cm^{-1}.

Methyl 4-(prop-1-yn-1-yl)benzoate (2n)

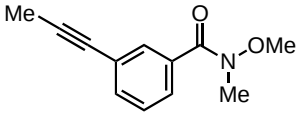


Prepared according to the general procedure for decarboxylative cross-coupling using $PdCl_2(PPh_3)_2$ (176 mg, 0.25 mmol, 5 mol%), 1,4-bis(diphenylphosphino)butane (213 mg, 0.50 mmol, 10 mol%), and DMSO (10 mL, 0.5 M). To the resulting solution was added methyl 4-bromobenzoate (1.08 g, 5 mmol, 1 equiv.), 2-butynoic acid (505 mg, 6 mmol, 1.2 equiv.), and DBU (2.2 mL, 15 mmol, 3 equiv.). The

[47] S. Liu, J. Sawicki, T. G. Driver, *Org. Lett.*, **2012,** *14,* 3744.

reaction was complete after 1 hour at 110 °C. Purification by column chromatography using 5% EtOAc in hexanes afforded the desired alkyne as a white solid (755 mg, 4.4 mmol, 87%). The ^{1}H NMR was in accordance with the literature.[48] **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.96-7.94 (m, 2H), 7.43 (d, *J* = 8.4 Hz, 2H), 3.90 (d, *J* = 4.0 Hz, 3H), 2.07-2.06 (m, 3H).

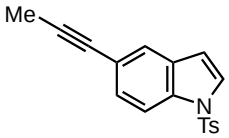
_N_-methoxy-_N_-methyl-3-(prop-1-yn-1-yl)benzamide (2i)



Prepared according to the general procedure for decarboxylative cross-coupling using $PdCl_2(PPh_3)_2$ (176 mg, 0.25 mmol, 5 mol%), 1,4-bis(diphenylphosphino)butane (213 mg, 0.50 mmol, 10 mol%), and DMSO (10 mL, 0.5 M). To the resulting solution was added 3-bromo-*N*-methoxy-*N*-methylbenzamide (1.22 g, 5 mmol, 1 equiv.), 2-butynoic acid (505 mg, 6 mmol, 1.2 equiv.), and DBU (2.2 mL, 15 mmol, 3 equiv.). The reaction was complete after 1 hour at 110 °C. Purification by column chromatography using 20% EtOAc in hexanes afforded the desired alkyne as a colorless oil (321 mg, 1.6 mmol, 32%).

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.68-7.68 (m, 1H), 7.55 (dt, *J* = 7.8, 1.4 Hz, 1H), 7.46 (dt, *J* = 7.7, 1.4 Hz, 1H), 7.31 (t, *J* = 7.8 Hz, 1H), 3.54 (s, 3H), 2.05 (s, 3H). **^{13}C NMR** (101 MHz, $CDCl_3$): δ 169.3, 134.3, 133.6, 131.3, 128.1, 127.3, 124.1, 86.8, 79.2, 61.2, 33.9, 4.4. **HRMS** calculated for $C_{12}H_{13}NO_2Na$ $[M+Na]^+$ 226.0844, found 226.0841. **IR** (ATR): 2990, 2211, 1640, 1383, 1241, 900, 748 cm^{-1}.

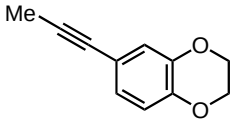
5-(prop-1-yn-1-yl)-1-tosyl-1*H*-indole (2g)



Prepared according to the general procedure for decarboxylative cross-coupling using $PdCl_2(PPh_3)_2$ (176 mg, 0.25 mmol, 5 mol%), 1,4-bis(diphenylphosphino)butane (213 mg, 0.50 mmol, 10 mol%), and DMSO (10 mL, 0.5 M). To the resulting solution was added 5-bromo-1-tosyl-1*H*-indole (1.75 g, 5 mmol, 1 equiv.), 2-butynoic acid (505 mg, 6 mmol, 1.2 equiv.), and DBU (2.2 mL, 15 mmol, 3 equiv.). The reaction was complete after 1 hour at 110 °C. Purification by column chromatography using 8% EtOAc in hexanes afforded the desired alkyne as a colorless oil (1.06 g, 3.5 mmol, 69%).

^{1}H NMR (400 MHz, $CDCl_3$): δ 7.89 (d, *J* = 8.6 Hz, 1H), 7.75-7.72 (m, 2H), 7.55 (t, *J* = 3.0 Hz, 2H), 7.33 (dd, *J* = 8.6, 1.5 Hz, 1H), 7.21 (d, *J* = 8.3 Hz, 2H), 6.59 (d, *J* = 3.6 Hz, 1H), 2.33 (s, 3H), 2.04 (d, *J* = 5.5 Hz, 3H). **^{13}C NMR** (101 MHz, $CDCl_3$): δ 145.2, 135.2, 134.0, 130.8, 130.0, 128.1, 127.2, 126.9, 124.6, 119.2, 113.5, 109.0, 85.0, 79.8, 21.7, 4.4. **HRMS** calculated for $C_{18}H_{15}NO_2SNa$ $[M+Na]^+$ 332.0721, found 332.0721. **IR** (ATR): 2995, 2198, 1631, 1544, 1145, 1077, 654 cm^{-1}.

6-(prop-1-yn-1-yl)-2,3-dihydrobenzo[*b*][1,4]dioxine (2h)

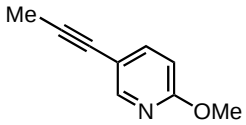


Prepared according to the general procedure for decarboxylative cross-coupling using $PdCl_2(PPh_3)_2$ (176 mg, 0.25 mmol, 5 mol%), 1,4-bis(diphenylphosphino)butane (213 mg, 0.50 mmol, 10 mol%), and DMSO (10 mL, 0.5 M). To the resulting solution was added 6-bromo-2,3-dihydrobenzo[*b*][1,4]dioxine (1.08 g, 5 mmol, 1 equiv.), 2-butynoic acid (505 mg, 6 mmol, 1.2 equiv.),

[48] R. Tomita, T. Koike, M. Akita, *Angew. Chem. Int. Ed.*, **2015,** *127,* 13115.

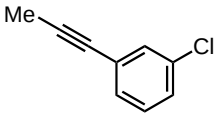
and DBU (2.2 mL, 15 mmol, 3 equiv.). The reaction was complete after 1 hour at 110 °C. Purification by column chromatography using 5% EtOAc in hexanes afforded the desired alkyne as a colorless oil (660 mg, 3.8 mmol, 76%). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 6.90 (d, *J* = 1.9 Hz, 1H), 6.87 (dd, *J* = 8.3, 2.0 Hz, 1H), 6.76 (d, *J* = 8.3 Hz, 1H), 4.24-4.23 (m, 4H). **^{13}C NMR** (101 MHz, $CDCl_3$): δ 143.6, 143.3, 125.1, 120.4, 117.3, 117.1, 84.2, 79.4, 64.55, 64.40, 4.4. **HRMS** calculated for $C_{11}H_{11}O_2$ $[M+H]^+$ 175.0759, found 175.0684. **IR** (ATR): 3042, 2991, 2133, 1620, 1555, 1174, 1123, 1112, 888, 642 cm^{-1}.

2-methoxy-5-(prop-1-yn-1-yl)pyridine (2q)



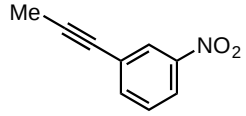
Prepared according to the general procedure for decarboxylative cross-coupling using $PdCl_2(PPh_3)_2$ (176 mg, 0.25 mmol, 5 mol%), 1,4-bis(diphenylphosphino)butane (213 mg, 0.50 mmol, 10 mol%), and DMSO (10 mL, 0.5 M). To the resulting solution was added 5-bromo-2-methoxypyridine (940 mg, 5 mmol, 1 equiv.), 2-butynoic acid (505 mg, 6 mmol, 1.2 equiv.), and DBU (2.2 mL, 15 mmol, 3 equiv.). The reaction was complete after 2 hours at 110 °C. Purification by column chromatography using 3% EtOAc in hexanes afforded the desired alkyne as a yellow oil (410 mg, 2.8 mmol, 56%). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 8.20 (d, *J* = 2.2 Hz, 1H), 7.55 (dd, *J* = 8.6, 2.3 Hz, 1H), 6.66 (d, *J* = 8.6 Hz, 1H), 3.93 (s, 3H), 2.04 (s, 3H). **^{13}C NMR** (101 MHz, $CDCl_3$): δ 163.0, 149.7, 141.4, 114.0, 110.6, 87.3, 76.5, 53.8, 4.5. **HRMS** calculated for C_9H_9NONa $[M+Na]^+$ 170.0582, found 170.0579. **IR** (ATR): 2993, 2952, 2837, 1622, 1574, 1497, 1373, 1299, 865 cm^{-1}.

1-chloro-3-(prop-1-yn-1-yl)benzene (2t)



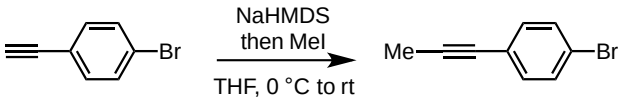
Prepared according to the general procedure for decarboxylative cross-coupling using $PdCl_2(PPh_3)_2$ (176 mg, 0.25 mmol, 5 mol%), 1,4-bis(diphenylphosphino)butane (213 mg, 0.50 mmol, 10 mol%), and DMSO (10 mL, 0.5 M). To the resulting solution was added 1-chloro-3-iodobenzene (1.19 g, 5 mmol, 1 equiv.), 2-butynoic acid (505 mg, 6 mmol, 1.2 equiv.), and DBU (2.2 mL, 15 mmol, 3 equiv.). The reaction was complete after 1 hours at 110 °C. Purification by column chromatography using pentanes afforded the desired alkyne as a yellow oil (508 mg, 3.37 mmol, 67%). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.37 (t, *J* = 1.6 Hz, 1H), 7.27-7.18 (m, 3H), 2.05 (s, 3H). **^{13}C NMR** (101 MHz, $CDCl_3$): δ 134.1, 131.6, 129.8, 129.5, 128.0, 125.9, 87.4, 78.6, 4.5. **HRMS** calculated for C_9H_7Cl $[M]^+$ 150.0236, found 150.0231. **IR** (ATR): 3033, 2989, 1655, 1248, 1170, 865, 699 cm^{-1}.

1-nitro-3-(prop-1-yn-1-yl)benzene (2o)



Prepared according to the general procedure for decarboxylative cross-coupling using $PdCl_2(PPh_3)_2$ (176 mg, 0.25 mmol, 5 mol%), 1,4-bis(diphenylphosphino)butane (213 mg, 0.50 mmol, 10 mol%), and DMSO (10 mL, 0.5 M). To the resulting solution was added 1-iodo-3-nitrobenzene (1.25 g, 5 mmol, 1 equiv.), 2-butynoic acid (505 mg, 6 mmol, 1.2 equiv.), and DBU (2.2 mL, 15 mmol, 3 equiv.). The reaction was complete after 1 hours at 110 °C. Purification by column chromatography using 5% EtOAc in hexanes afforded the desired alkyne as a yellow oil (187 mg, 1.2 mmol, 23%). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 8.22 (t, *J* = 1.9 Hz, 1H), 8.12-8.10 (m, 1H), 7.67 (d, *J* = 7.7 Hz, 1H), 7.45 (t, *J* = 8.0 Hz, 1H), 2.07-2.06 (m,

3H). **^{13}C NMR** (101 MHz, $CDCl_3$): δ 148.2, 137.4, 129.3, 126.5, 126.0, 122.4, 89.2, 77.8, 4.5. **HRMS** calculated for $C_9H_7NO_2Na$ $[M+Na]^+$ 184.0374, found 184.0382. **IR** (ATR): 3011, 2999, 1621, 1522, 1352, 1114, 881, 696 cm^{-1}.



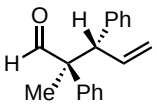
1-bromo-4-(prop-1-yn-1-yl)benzene (2l)

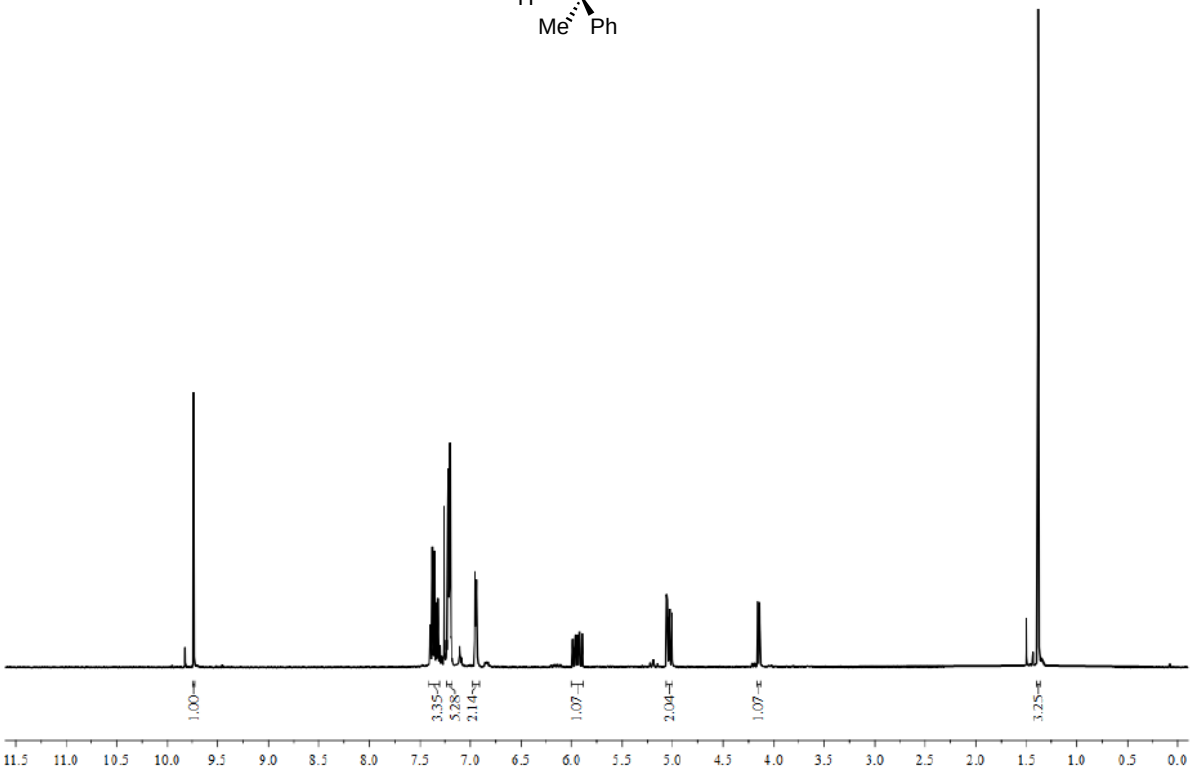
To a flame-dried round bottom was added 1-bromo-4-ethynylbenzene (905 mg, 5 mmol, 1 equiv.) and THF (20 mL, 0.25 M). The resulting solution was cooled to 0 °C. A 1.0 M THF solution of NaHMDS (7.5 mL, 7.5 mmol, 1.5 equiv.) was slowly added. The reaction mixture was then allowed to stir for 5 minutes at 0 °C. After the addition of MeI (2.13 g, 15 mmol, 3 equiv.), the reaction mixture was warmed to room temperature and stirred for 24 hours. The reaction mixture was quenched with H_2O and extracted with Et_2O. The combined organic layers were washed with H_2O and brine, dried with anhydrous $MgSO_4$, filtered, and concentrated *in vacuo*. The resulting crude residue was purified by column chromatography using pentanes to afford the desired alkyne as a colorless oil (714 mg, 3.66 mmol, 73%). The ^{1}H NMR is in accordance with the literature.[49] **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.42-7.39 (m, 2H), 7.25-7.23 (m, 2H), 2.03 (s, 3H).

[49] T. Fujihara, Y. Tani, K. Semba, J. Terao, Y. Tsuji, *Angew. Chem. Int. Ed.*, **2012**, *51*, 11487

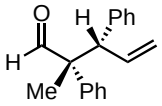
4. NMR Spectra

(*S*,*S*)-**3a**





(*R*,*S*)-**3a**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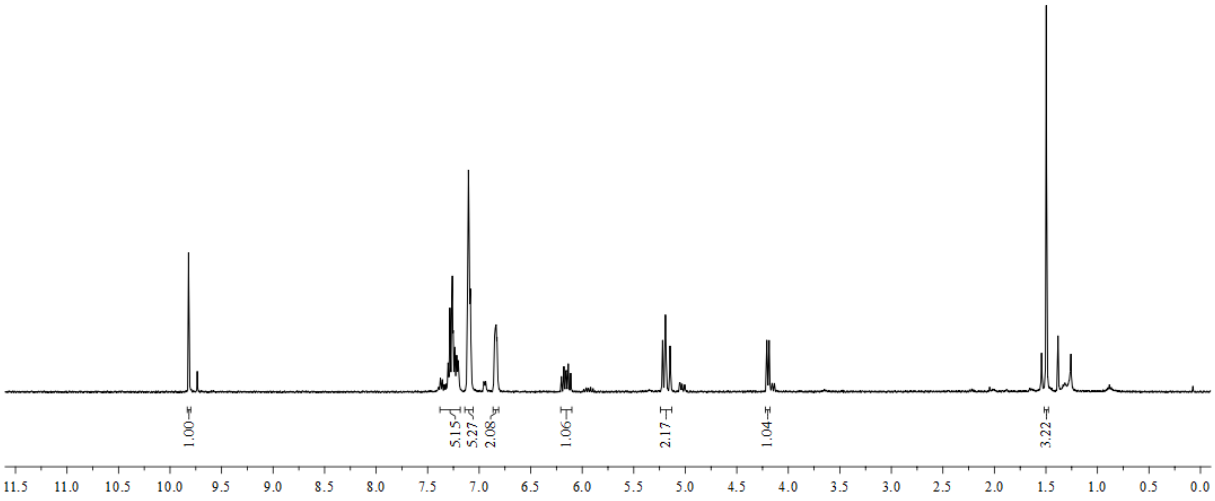
H
Ph
H
Me
Ph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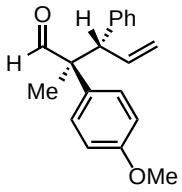
1.06
2.17
1.04
3.22
11.5
11.0
10.5
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0

(*S*,*S*)-**3b**


O
H
Ph
H
Me
OMe

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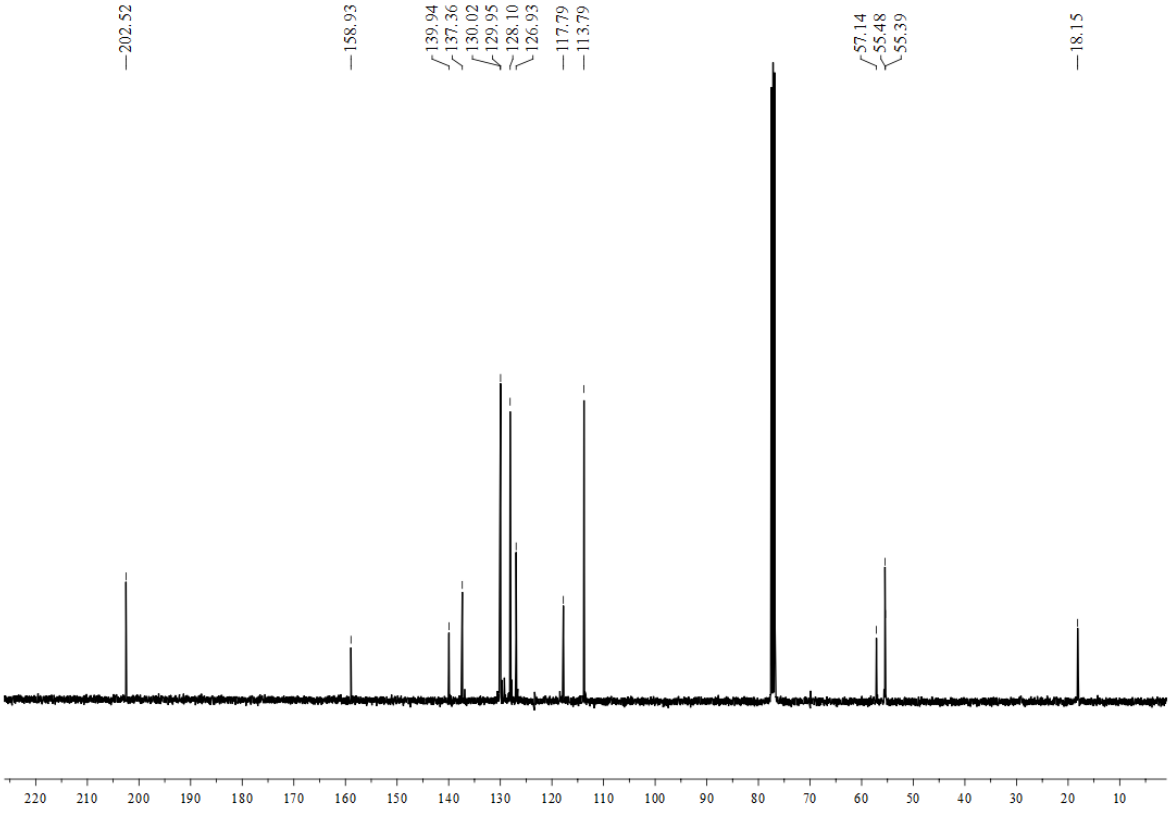
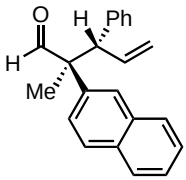
2.92
2.62
2.00
2.35
1.09
2.21
1.02
3.32
3.34
11.5 11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0


202.52
158.93
139.94
137.36
130.02
129.95
128.10
126.93
117.79
113.79
57.14
55.48
55.39
18.15
220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10

(*S*,*S*)-**3c**


O
H
Ph
H
Me

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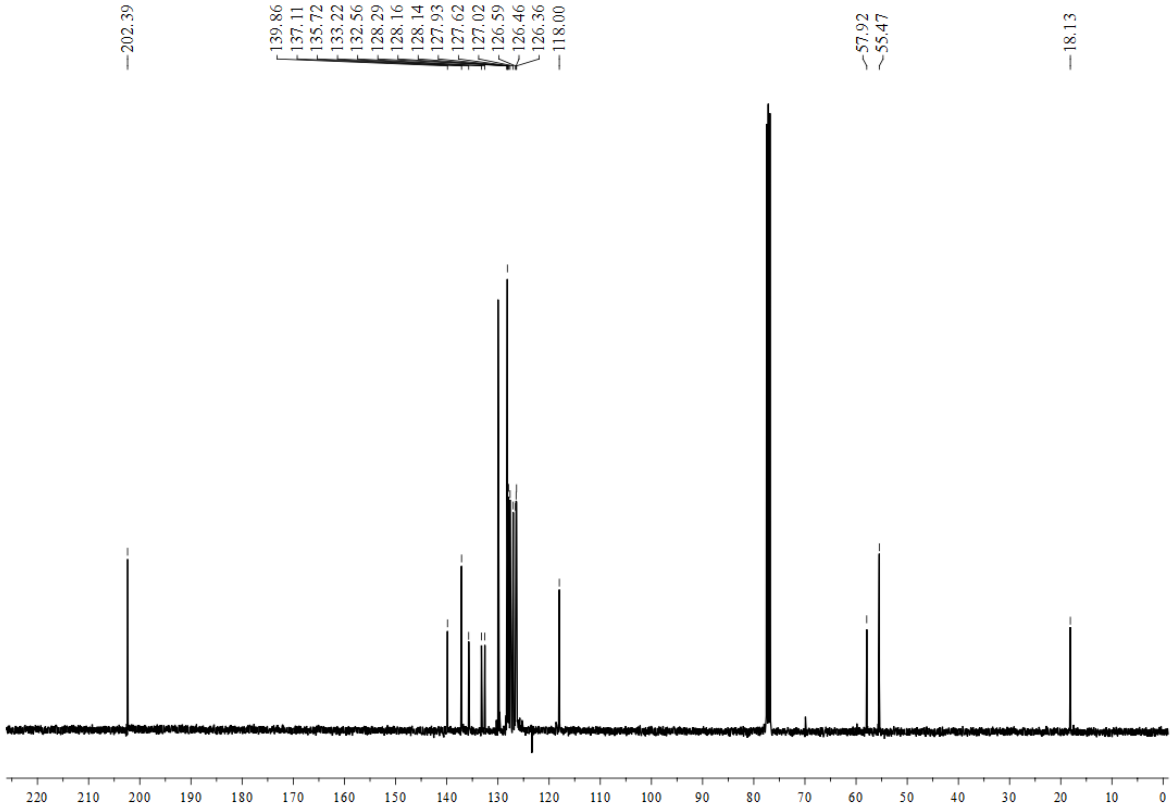
1.24
3.17
2.18
1.06
2.16
1.04
3.20
11.5 11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0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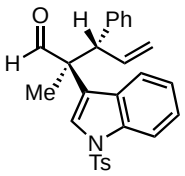
135.72
133.22
132.56
128.29
128.16
128.14
127.93
127.62
127.02
126.59
126.46
126.36
118.00
57.92
55.47
18.13
220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0

(*S*,*S*)-**3d**


O
H
Ph
H
Me
N
Ts

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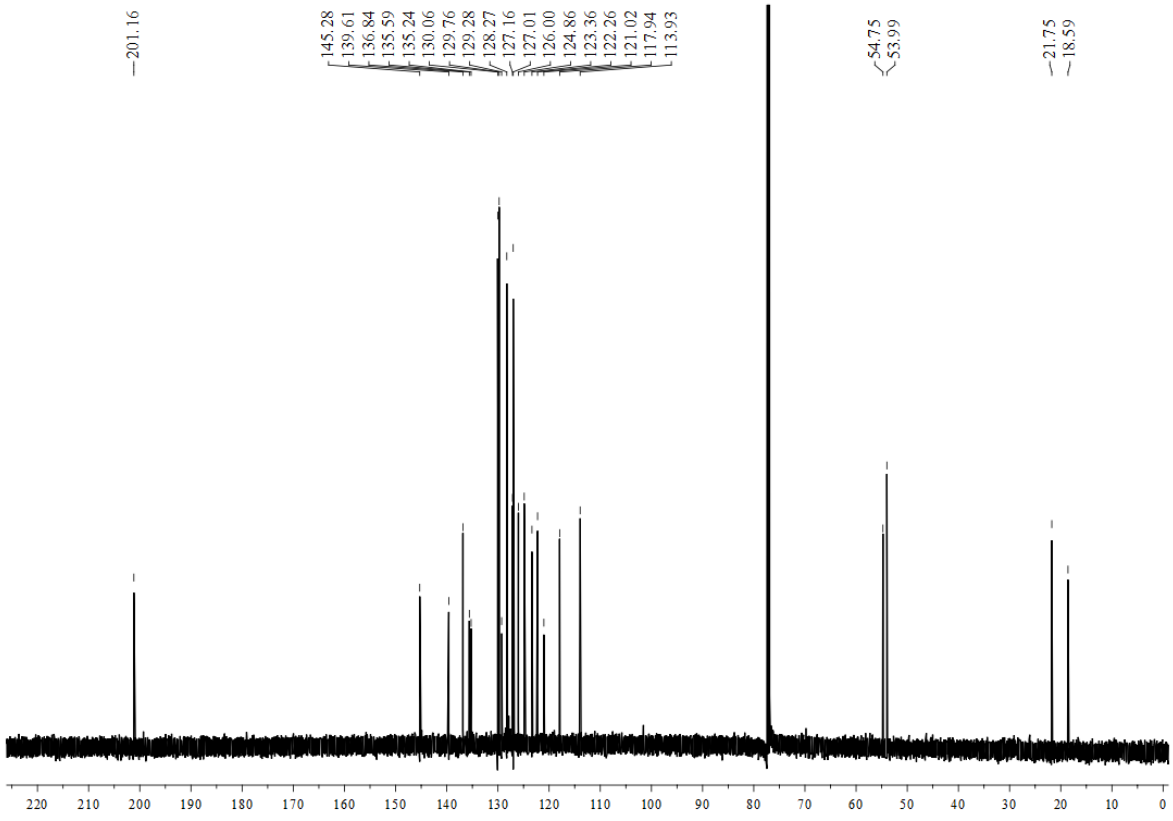
1.12
1.10
1.16
3.58
4.14
2.27
1.06
2.11
1.06
3.32
3.06
11.5 11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0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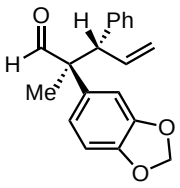
127.16
127.01
126.00
124.86
123.36
122.26
121.02
117.94
113.93
54.75
53.99
21.75
18.59
220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0

(*S*,*S*)-**3e**


O
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Ph
H
Me
O
O

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1.26
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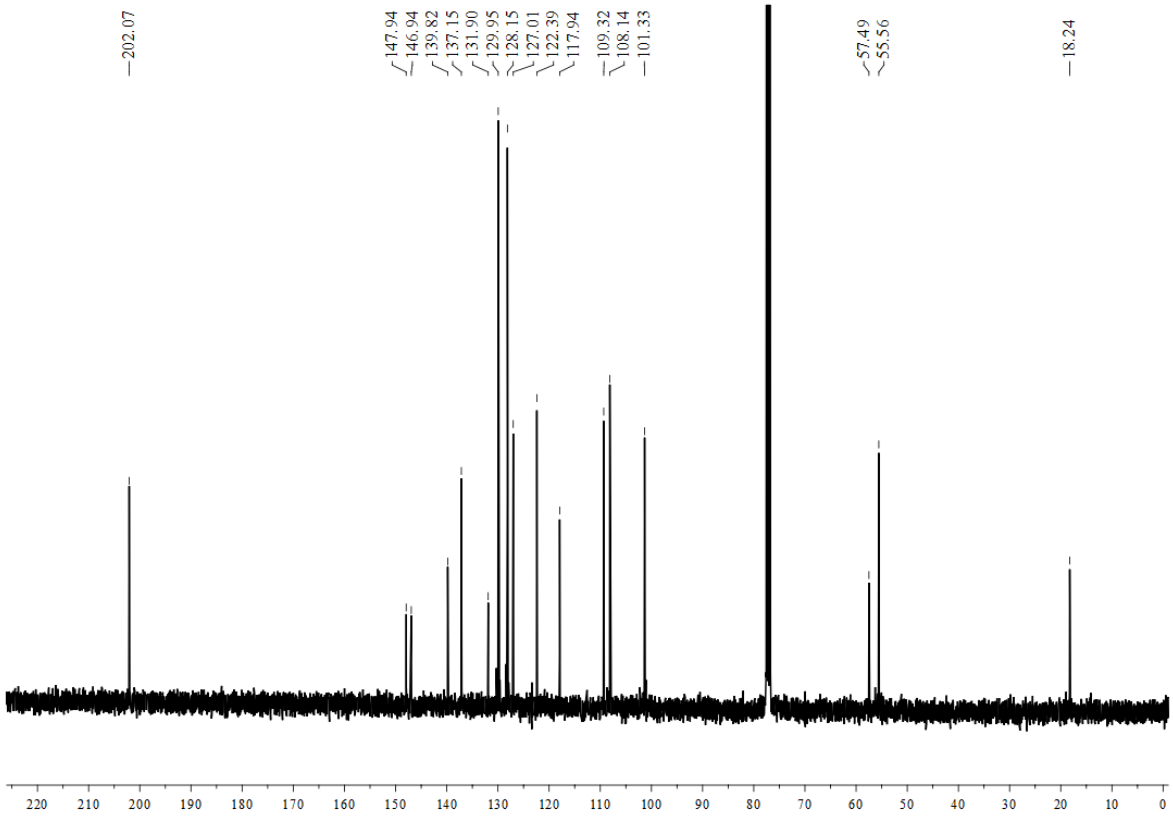
2.22
1.08
3.56
11.5 11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0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137.15
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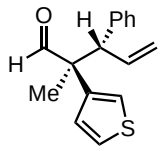
129.95
128.15
127.01
122.39
117.94
109.32
108.14
101.33
57.49
55.56
18.24
220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0

(*S*,*S*)-**3f**


O
H
Ph
H
Me
S

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2.16
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1.11
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1.10
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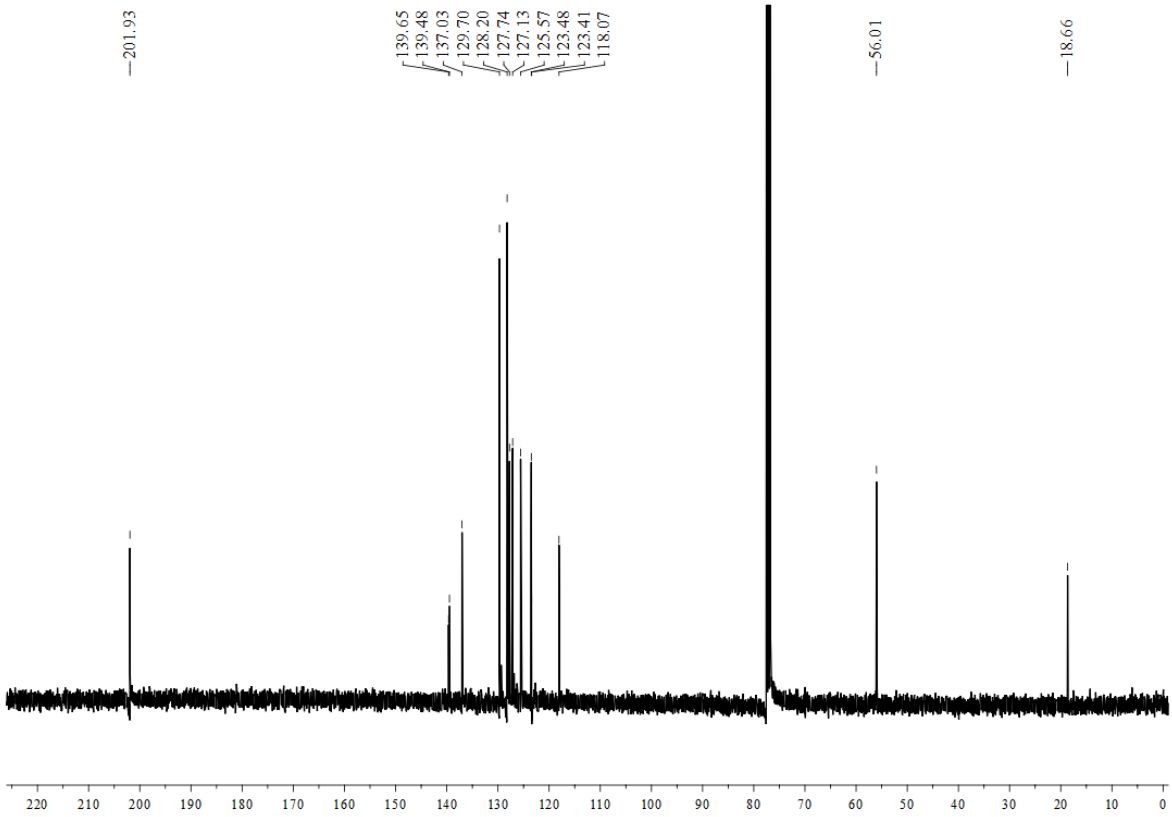
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123.41
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56.01
18.66
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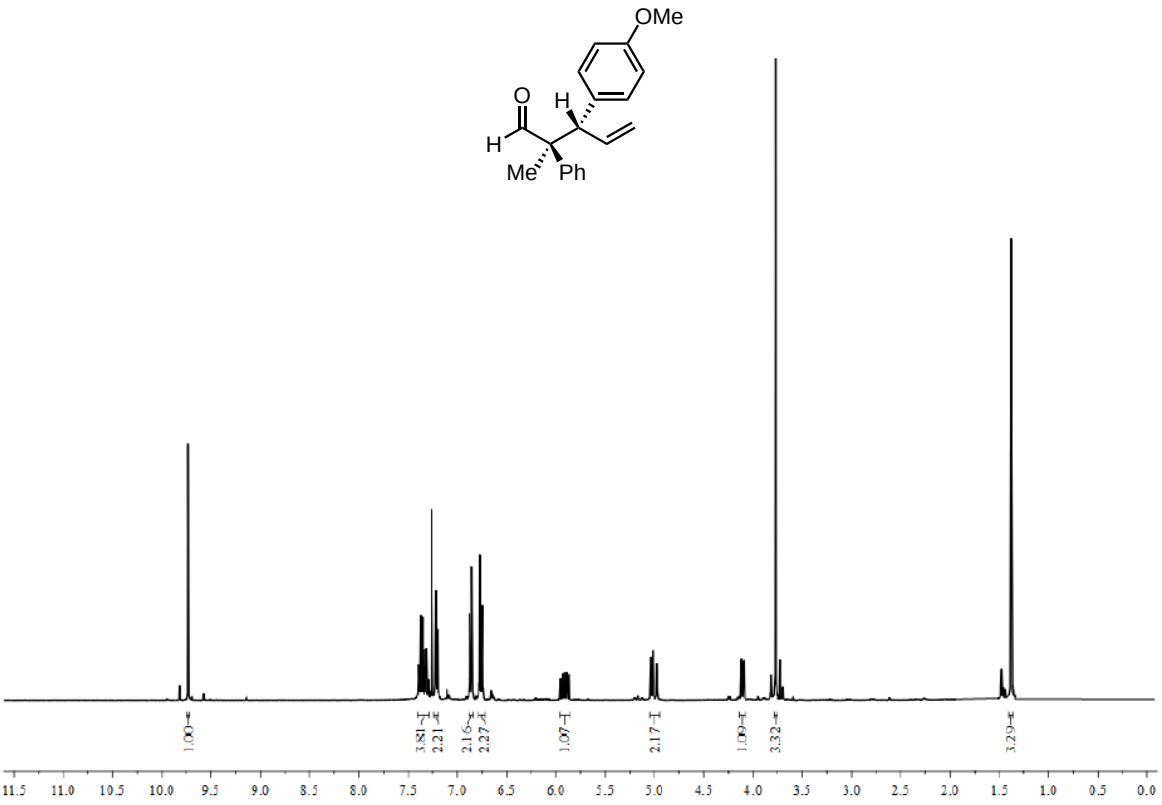
(*S*,*S*)-**3j**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6.0
5.5
5.0
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2.0
1.5
1.0
0.5
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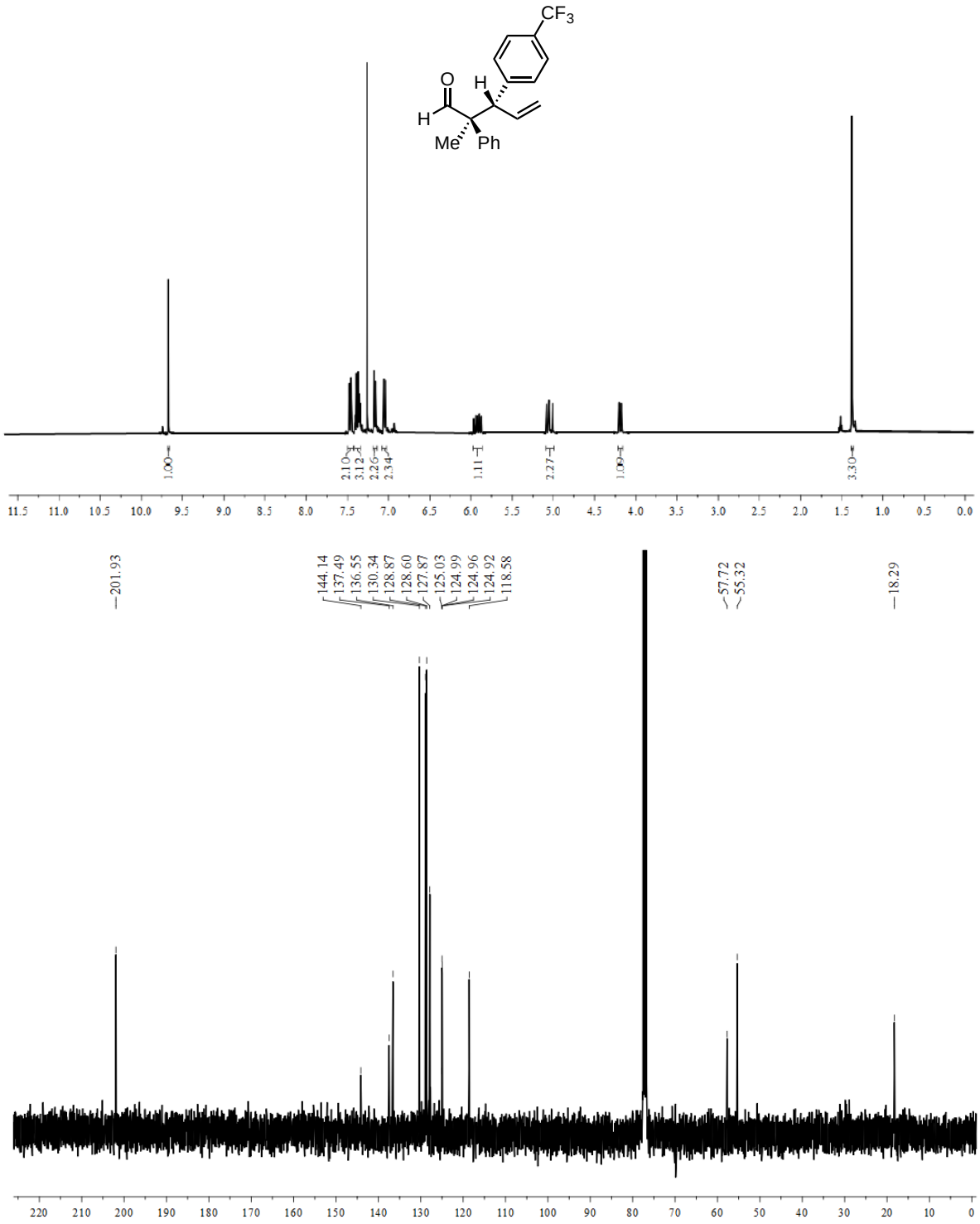
(*S*,*S*)-**3k**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H
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3.30
201.93
144.14
137.49
136.55
130.34
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127.87
125.03
124.99
124.96
124.92
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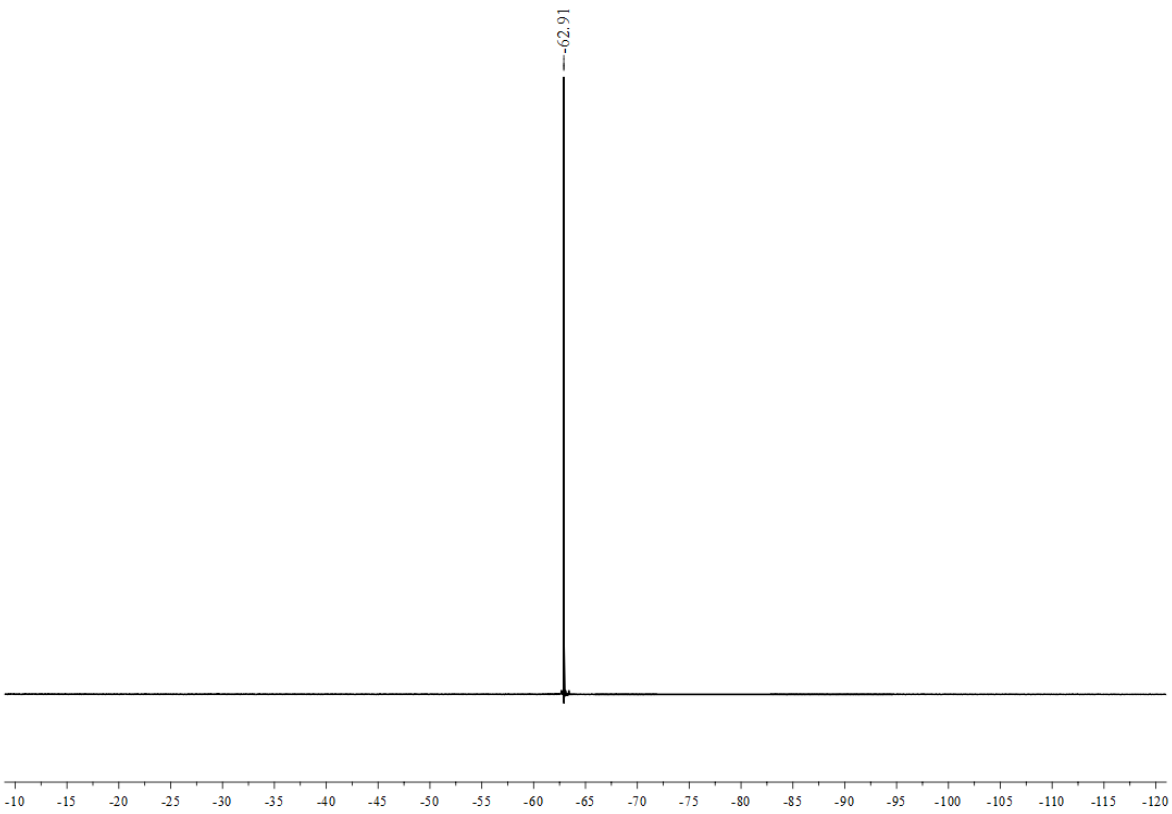
57.72
55.32
18.29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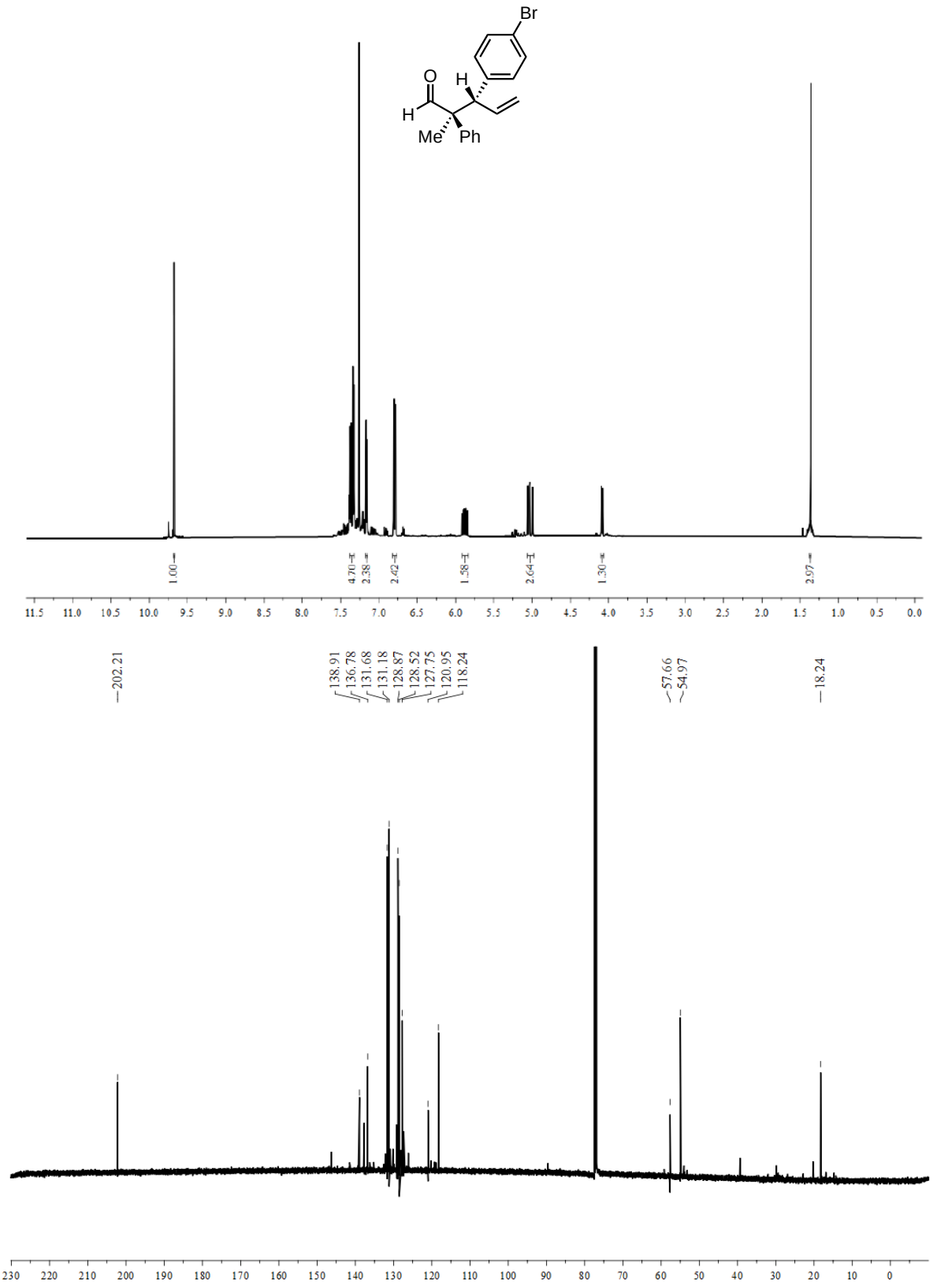
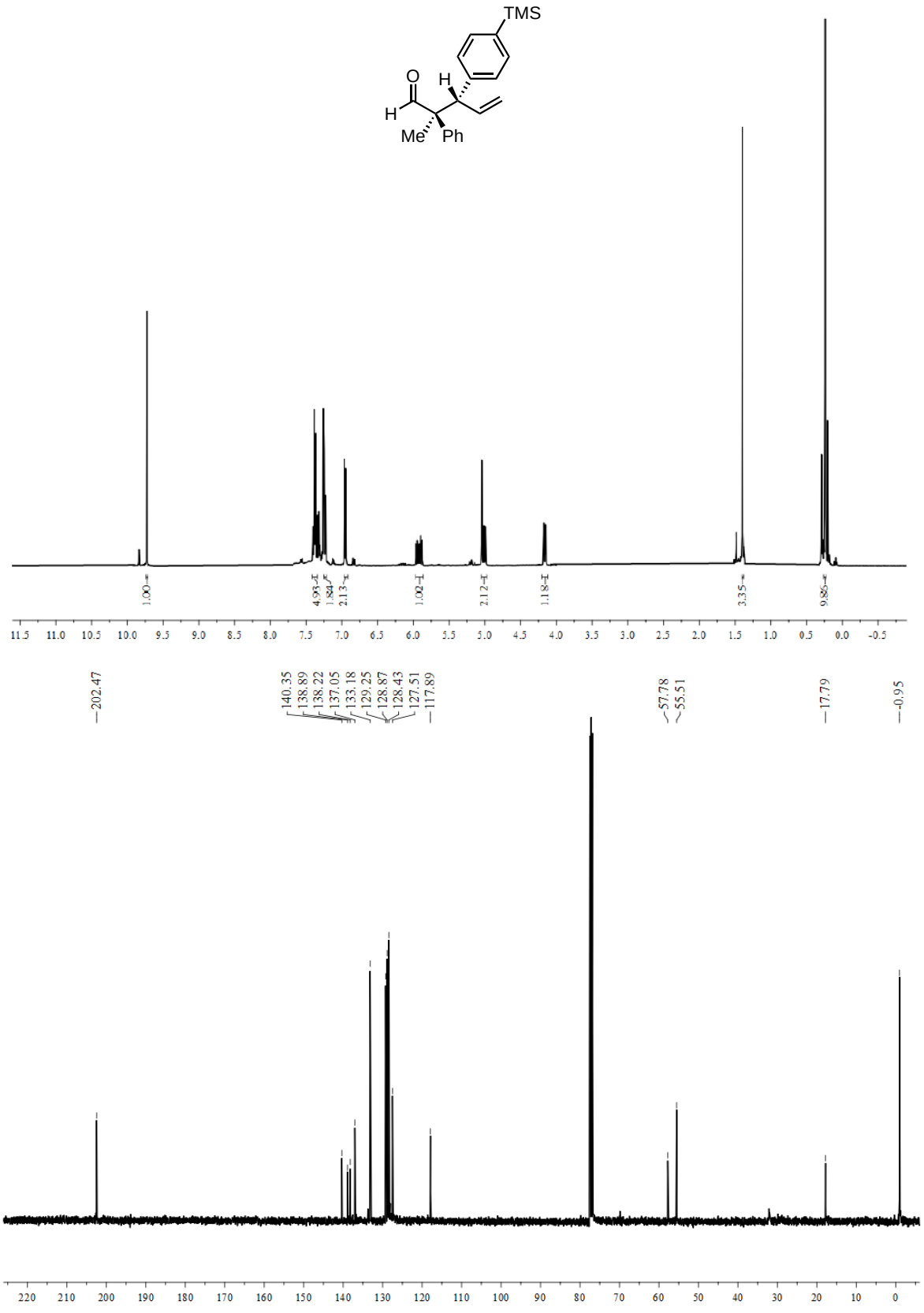
-10
-15
-20
-25
-30
-35
-40
-45
-50
-55
-60
-65
-70
-75
-80
-85
-90
-95
-100
-105
-110
-115
-120

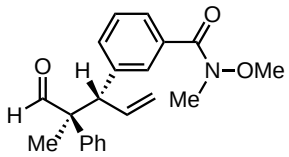
(*S*,*S*)-**3l**


Br
O
H
H
Me
Ph
1.00
4.70
2.38
2.42
1.58
2.64
1.30
2.97
202.21
138.91
136.78
131.68
131.18
128.87
128.52
127.75
120.95
118.24
57.66
54.97
18.24

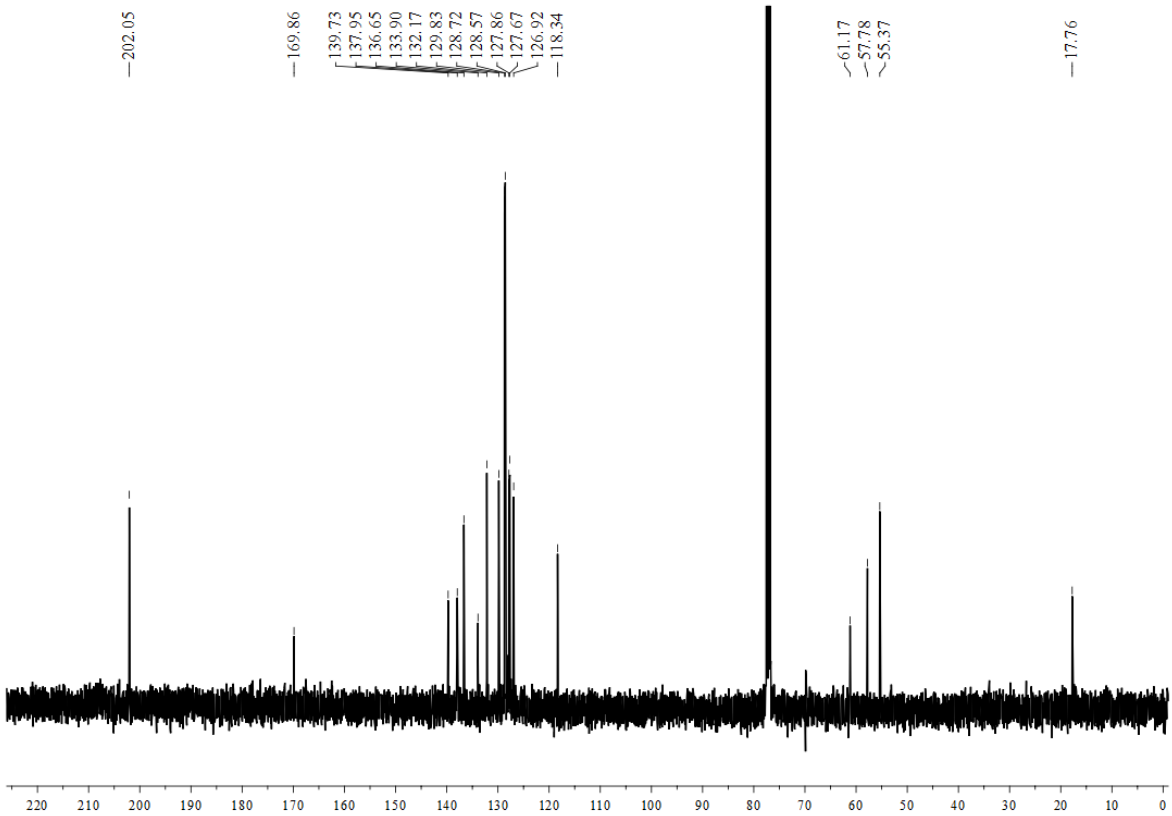
(*S*,*S*)-**3m**


TMS
O
H
H
Me
Ph
1.00
4.93
1.84
2.13
1.02
2.12
1.18
3.35
9.85
11.5 11.0 10.5 10.0 9.5 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
202.47
140.35
138.89
138.22
137.05
133.18
129.25
128.87
128.43
127.51
117.89
57.78
55.51
17.79
0.95
220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0

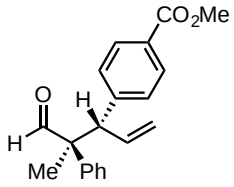
(*S*,*S*)-**3i**

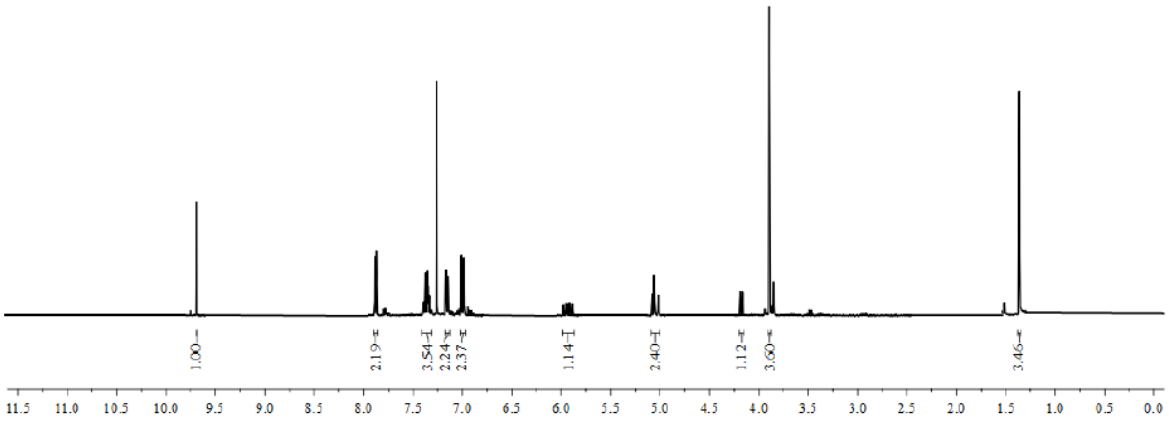

O
H
N–OMe
Me
O
H
Me
Ph

1.00
1.13
4.66
2.38
1.11
1.10
2.27
1.06
3.27
3.42
3.37
11.5 11.0 10.5 10.0 9.5 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


202.05
169.86
139.73
137.95
136.65
133.90
132.17
129.83
128.72
128.57
127.86
127.67
126.92
118.34
61.17
57.78
55.37
17.76
220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0

(*S*,*S*)-**3n**


CO2Me
O
H
H
Me
Ph


1.00
2.19
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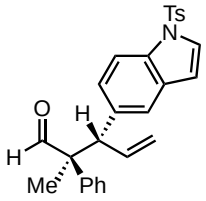
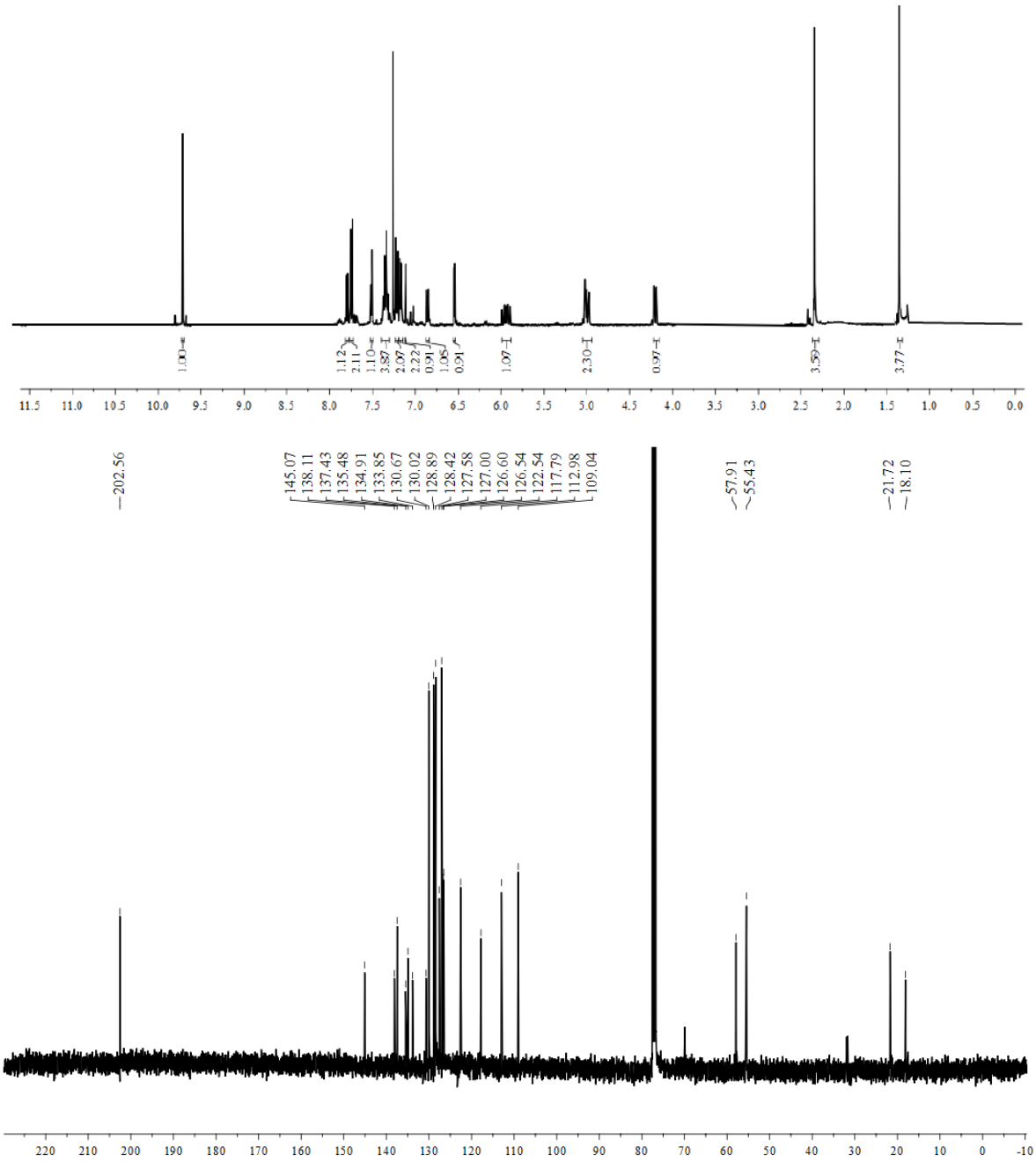
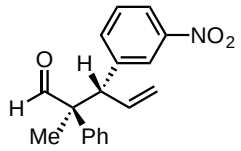
2.24
2.37
1.14
2.40
1.12
3.60
3.46
11.5 11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0

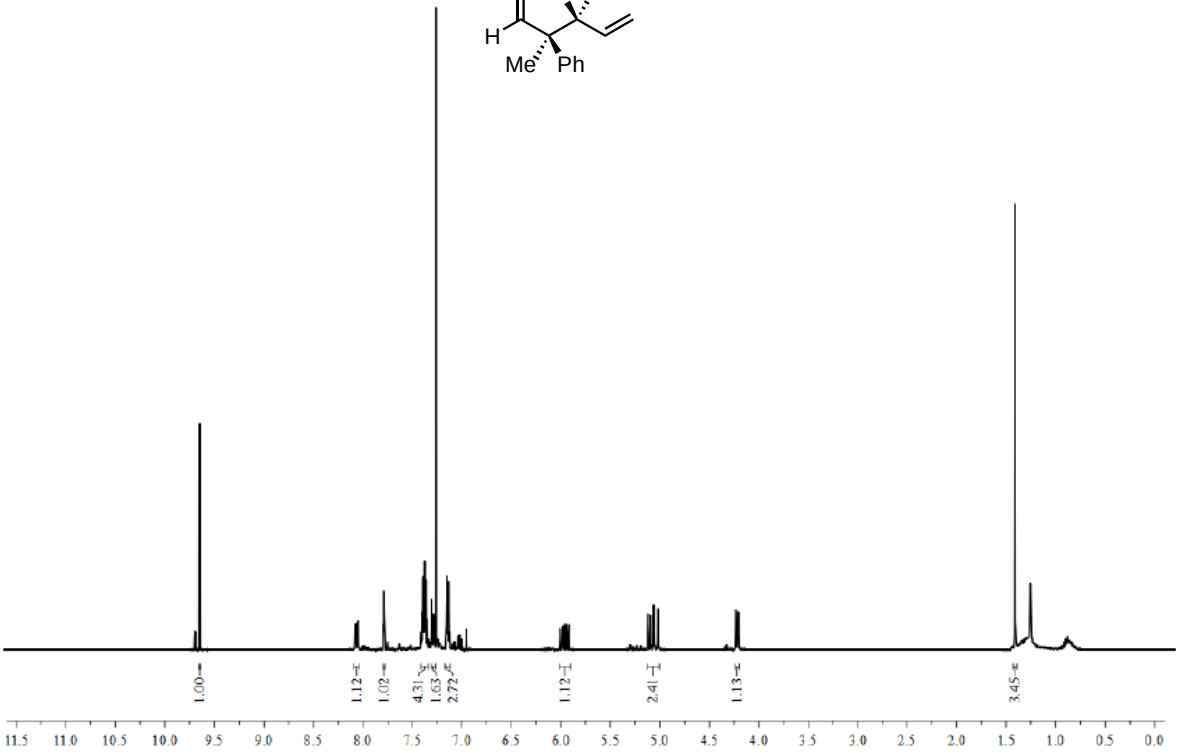
(*S*,*S*)-**3g**

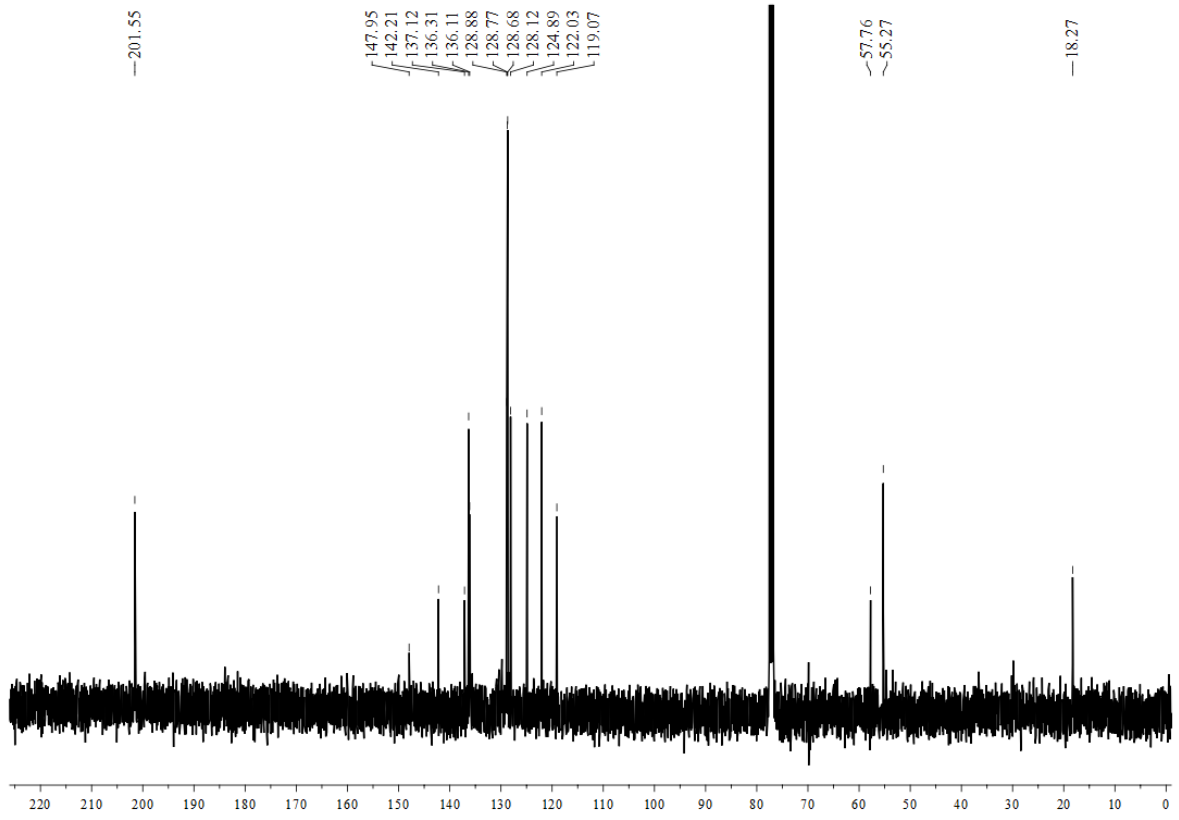

Ts
N
O
H
H
Me
Ph


1.00
1.12
2.11
1.10
3.87
2.07
2.22
0.91
1.05
0.91
1.07
2.30
0.97
3.59
3.77
202.56
145.07
138.11
137.43
135.48
134.91
133.85
130.67
130.02
128.89
128.42
127.58
127.00
126.60
126.54
122.54
117.79
112.98
109.04
57.91
55.43
21.72
18.10

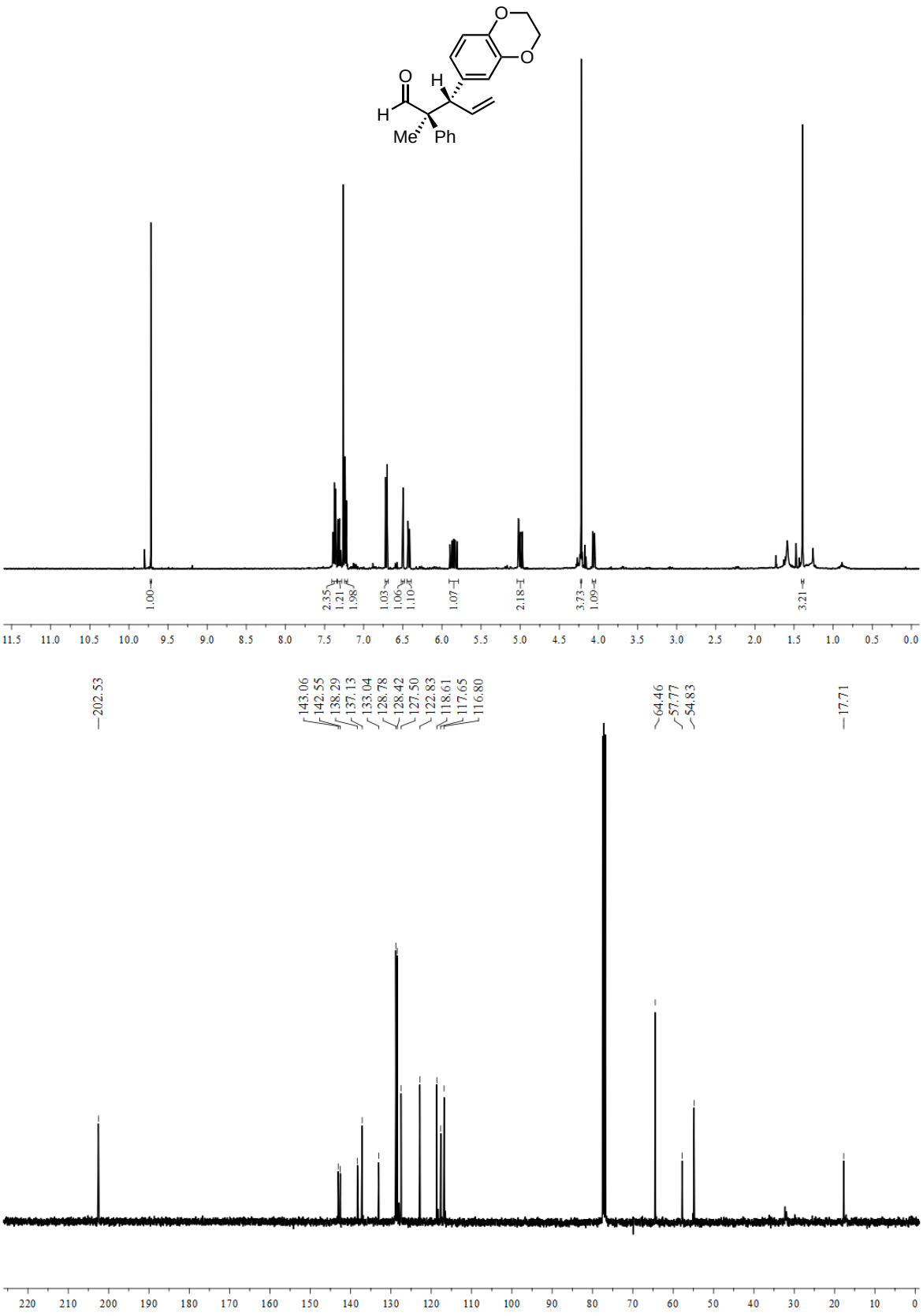
(*S*,*S*)-**3o**


NO2
O
H
H
Me
Ph

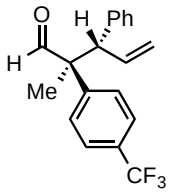

1.00
1.12
1.02
4.31
1.63
2.72
1.12
2.41
1.13
3.45
11.5 11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0


201.55
147.95
142.21
137.12
136.31
136.11
128.88
128.77
128.68
128.12
124.89
122.03
119.07
57.76
55.27
18.27
220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0

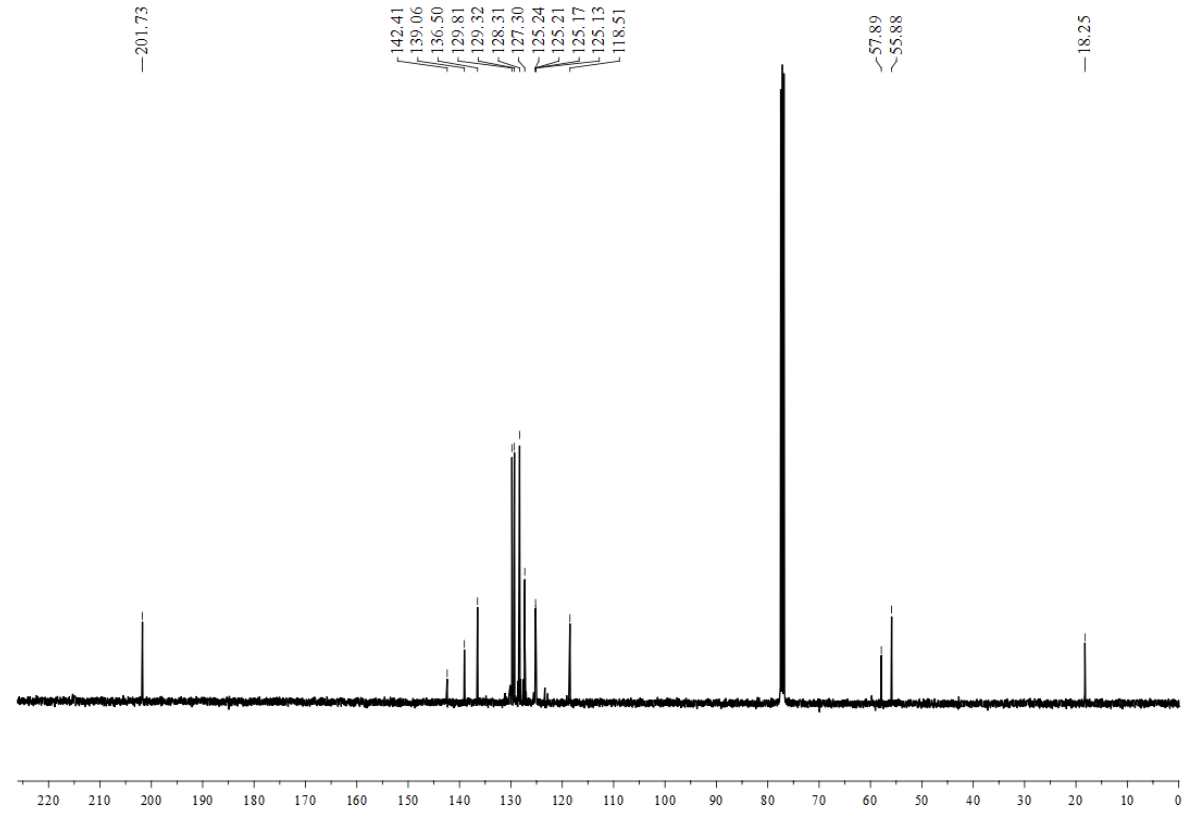
(*S*,*S*)-**3h**

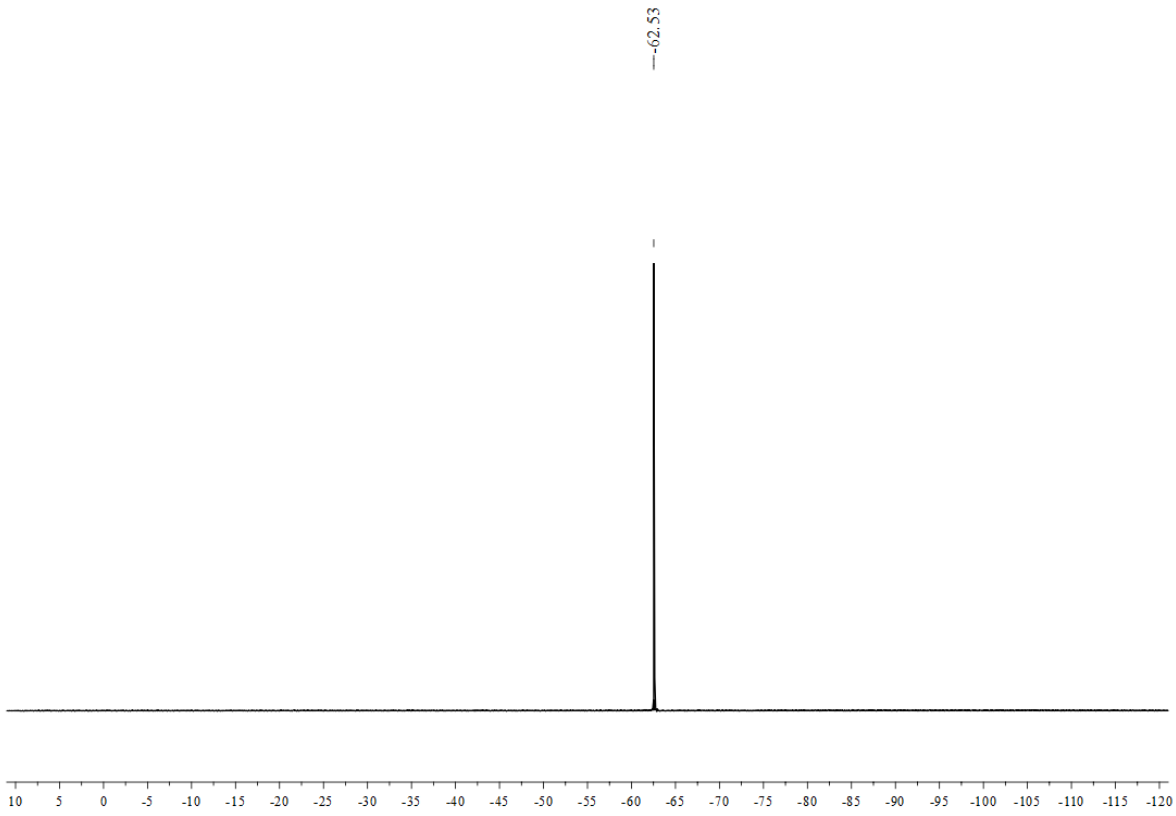

O
O
H
O
H
Me
Ph
1.00
2.35
1.21
1.98
1.03
1.06
1.10
1.07
2.18
3.73
1.09
3.21
11.5 11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
202.53
143.06
142.55
138.29
137.13
133.04
128.78
128.42
127.50
122.83
118.61
117.65
116.80
64.46
57.77
54.83
17.71
220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0

(*S*,*S*)-**3p**

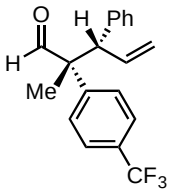

O
H
Ph
H
Me
CF3

1.00
2.13
2.17
3.00
2.20
1.06
2.24
1.07
3.17
11.5 11.0 10.5 10.0 9.5 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

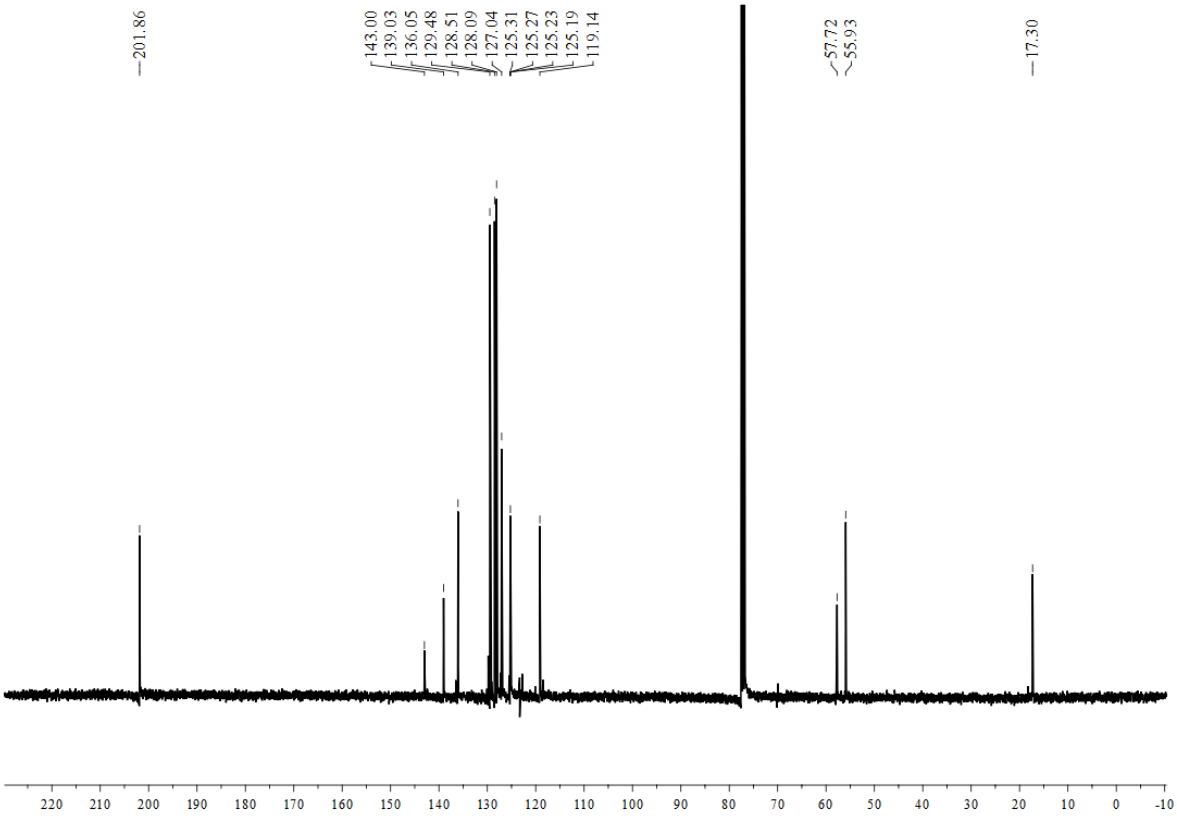

201.73
142.41
139.06
136.50
129.81
129.32
128.31
127.30
125.24
125.21
125.17
125.13
118.51
57.89
55.88
18.25
220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0

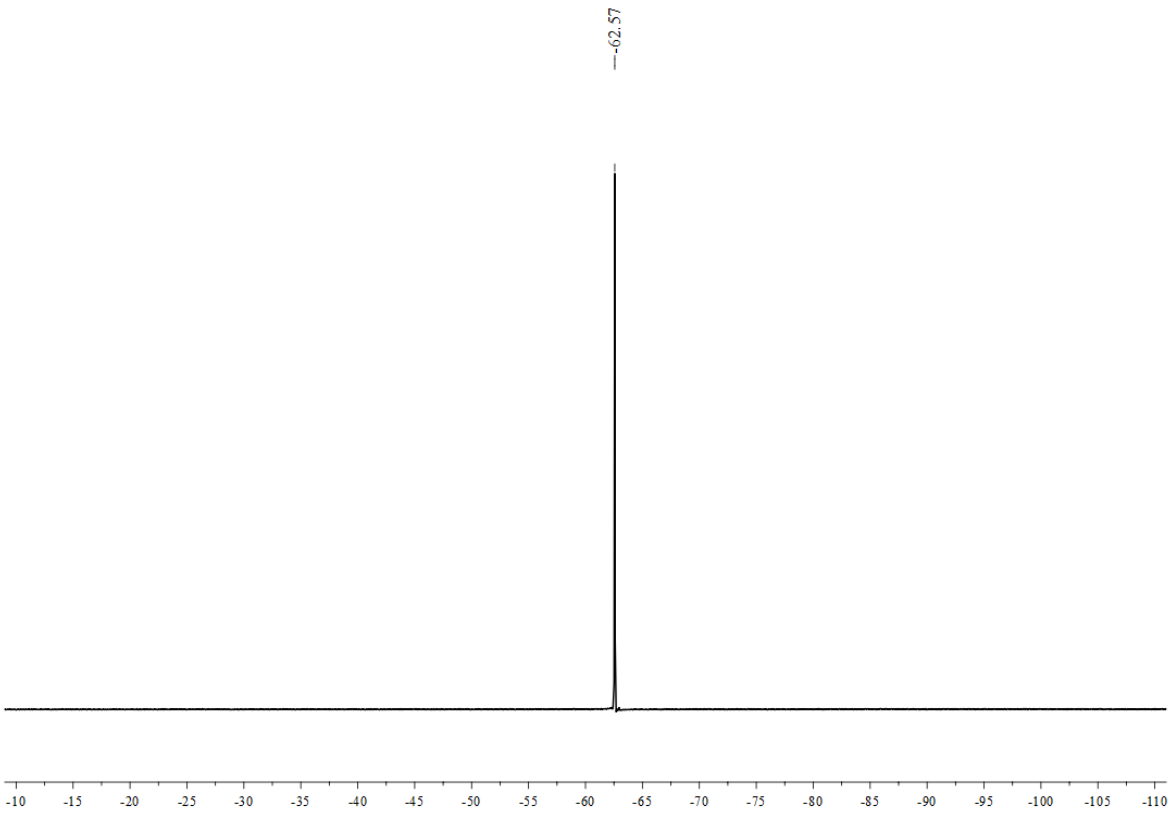

-62.53
10 5 0 -5 -10 -15 -20 -25 -30 -35 -40 -45 -50 -55 -60 -65 -70 -75 -80 -85 -90 -95 -100 -105 -110 -115 -120

(*R*,*S*)-**3p**

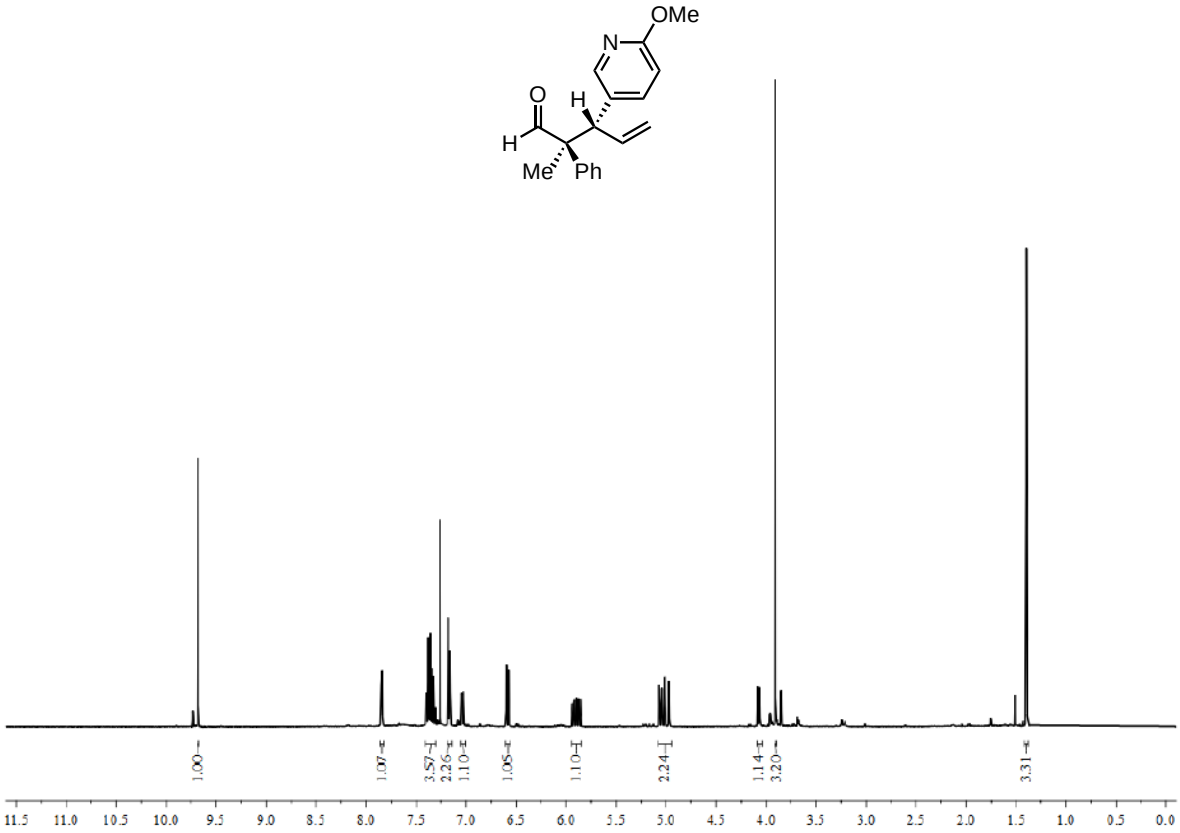

O
H
Ph
H
Me
CF3

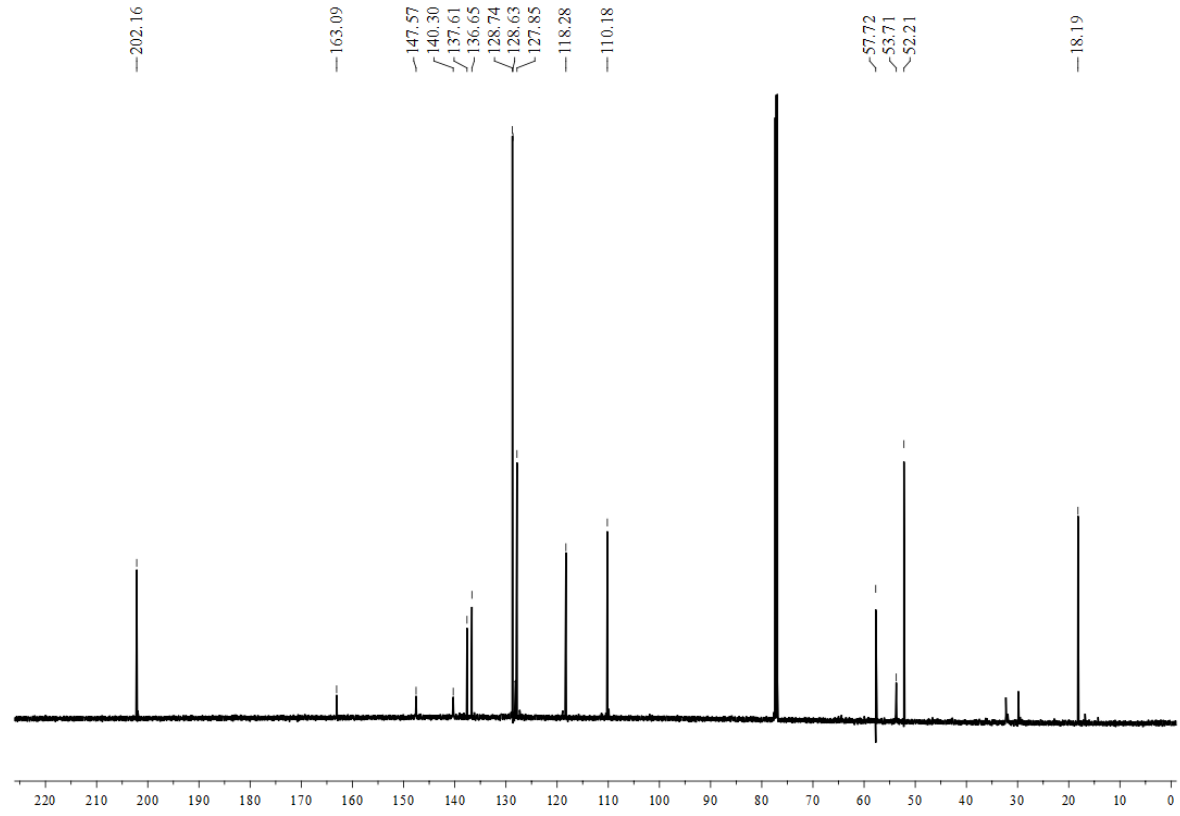
1.00
2.12
2.03
3.06
2.01
1.03
2.09
1.04
3.12
11.5 11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0


201.86
143.00
139.03
136.05
129.48
128.51
128.09
127.04
125.31
125.27
125.23
125.19
119.14
57.72
55.93
17.30
220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10


-62.57
-10
-15
-20
-25
-30
-35
-40
-45
-50
-55
-60
-65
-70
-75
-80
-85
-90
-95
-100
-105
-110

(*S*,*S*)-**3q**


OMe
N
O
H
H
Me
Ph
1.00
1.07
3.57
2.26
1.10
1.05
1.10
2.24
1.14
3.20
3.31
11.5 11.0 10.5 10.0 9.5 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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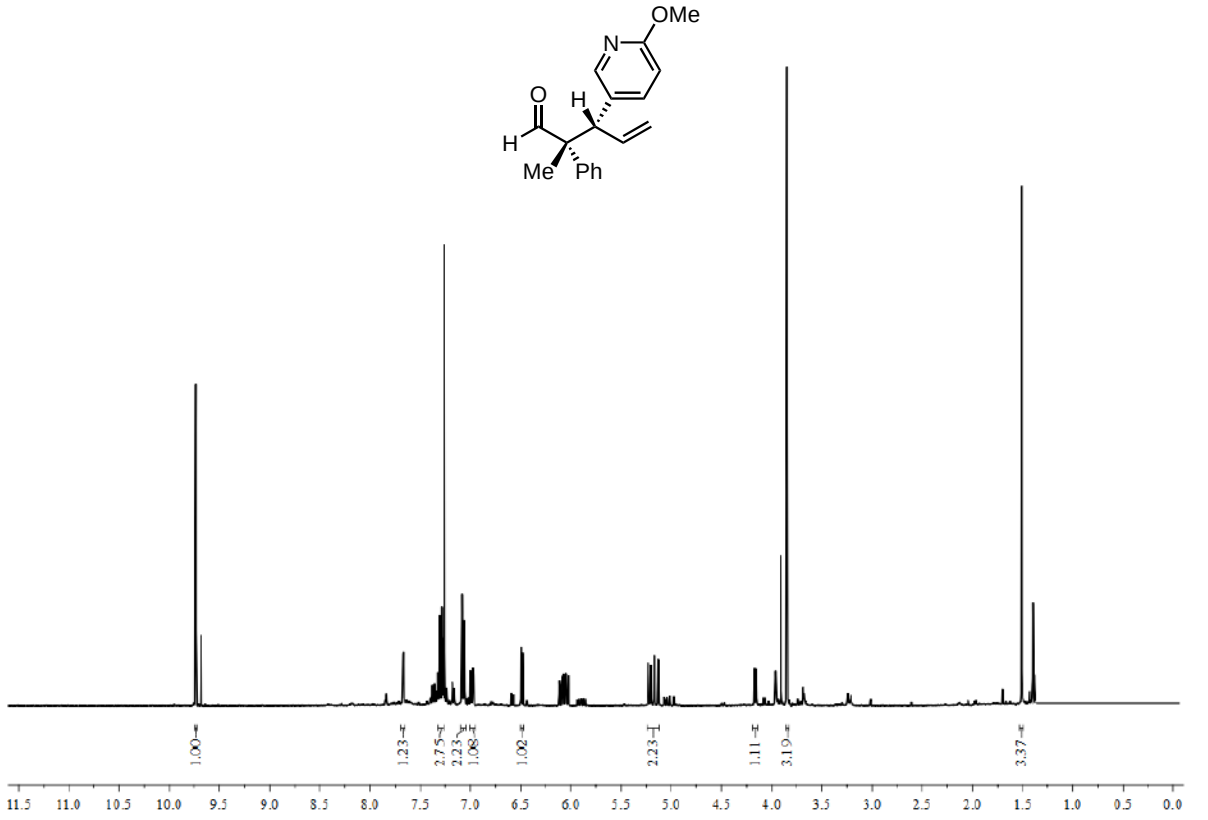
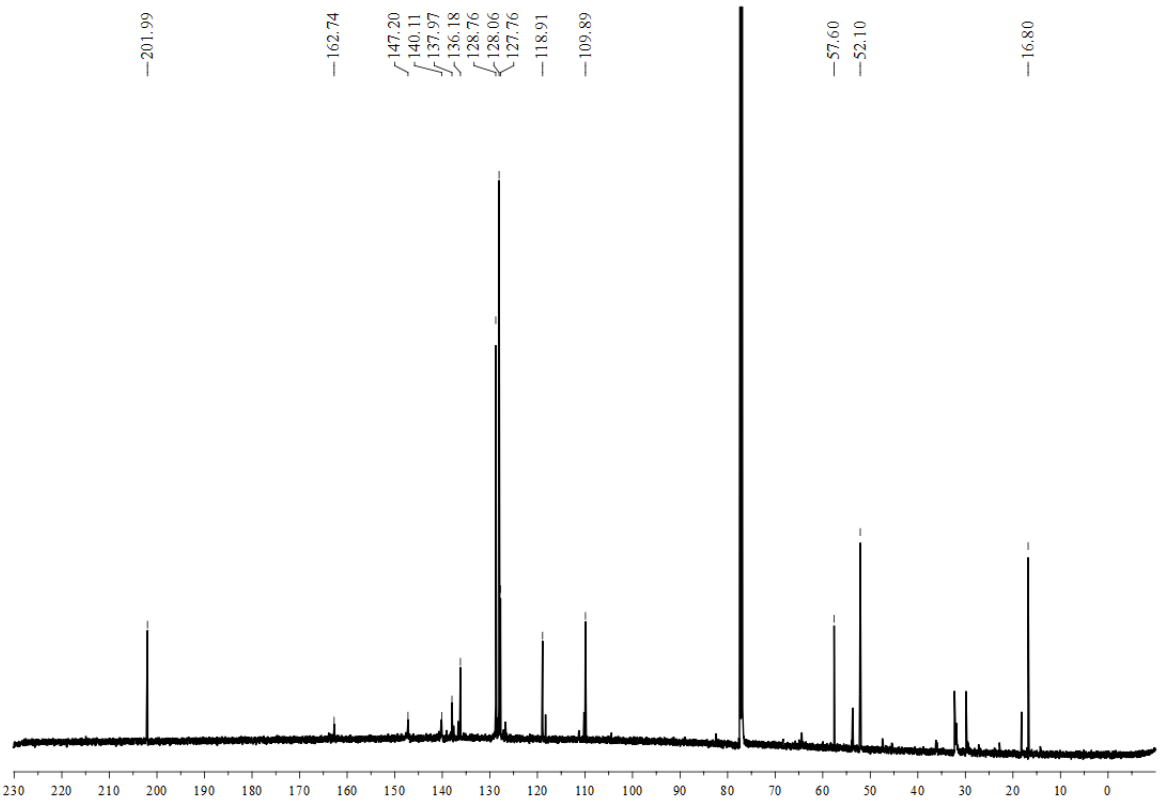
163.09
147.57
140.30
137.61
136.65
128.74
128.63
127.85
118.28
110.18
57.72
53.71
52.21
18.19
220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0

(*R*,*S*)-**3q**


OMe
N
O
H
H
Me
Ph
1.00
1.23
2.75
2.23
1.08
1.02
2.23
1.11
3.19
3.37
11.5 11.0 10.5 10.0 9.5 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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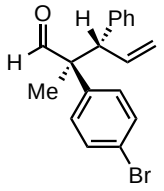
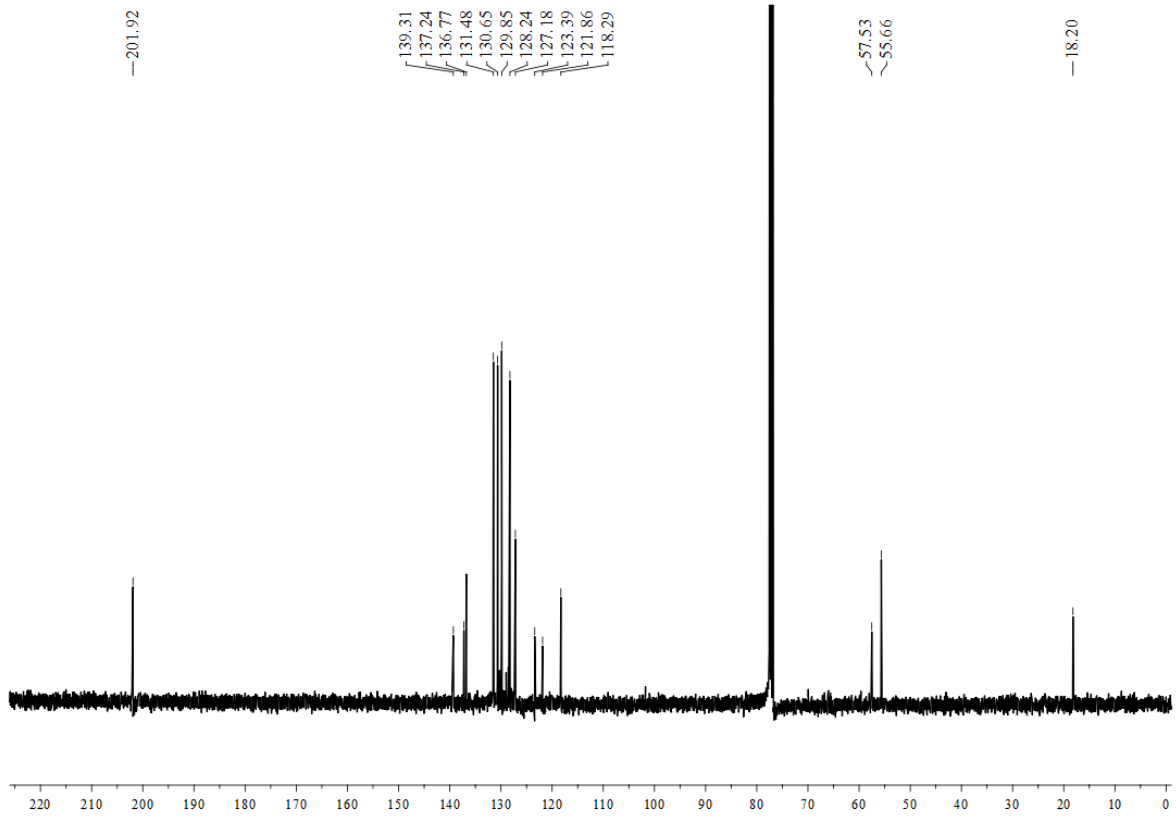
147.20
140.11
137.97
136.18
128.76
128.06
127.76
118.91
109.89
57.60
52.10
16.80
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0

(*S*,*S*)-**3r**


O
H
H
Ph
Me
Br

1.00
2.08
2.96
2.00
2.20
1.06
2.11
1.07
3.30
11.5 11.0 10.5 10.0 9.5 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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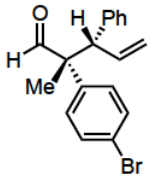
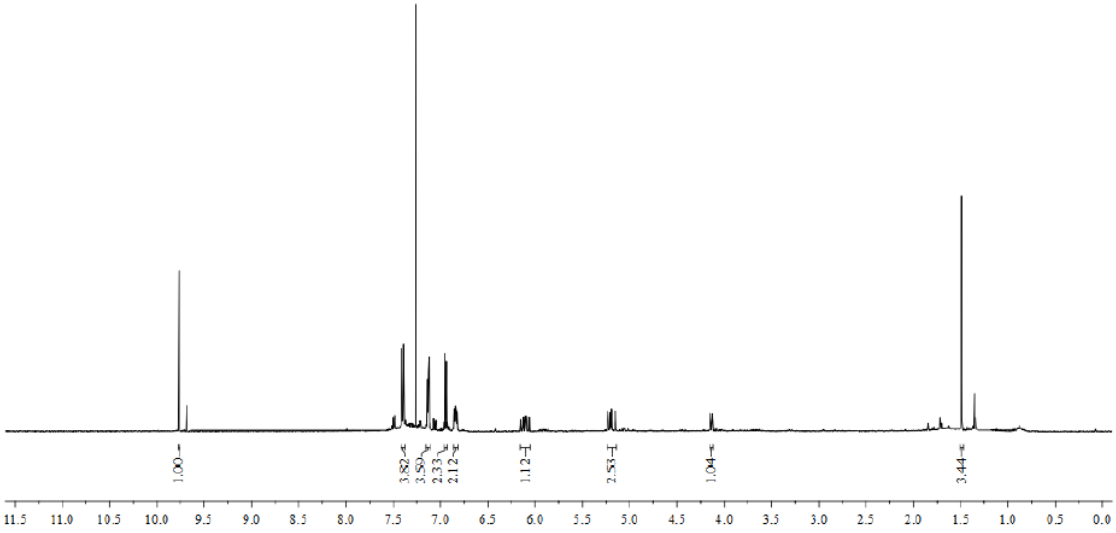
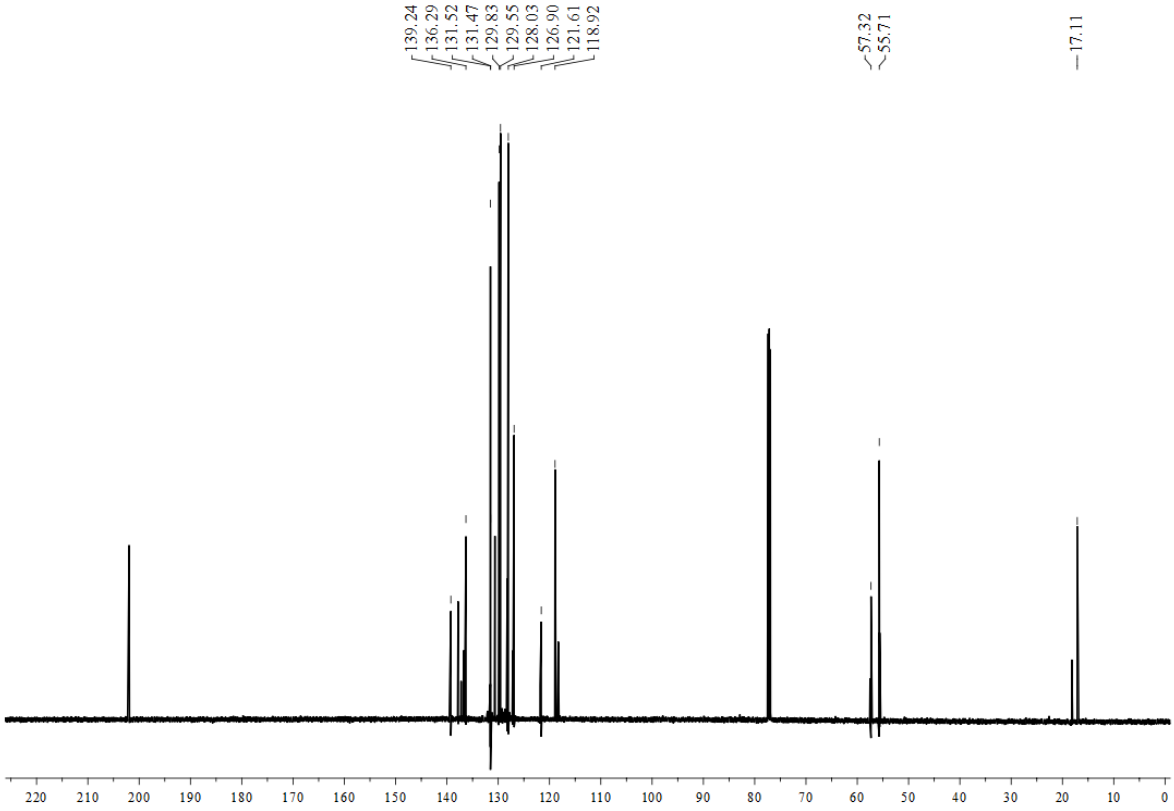
137.24
136.77
131.48
130.65
129.85
128.24
127.18
123.39
121.86
118.29
57.53
55.66
18.20
220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0

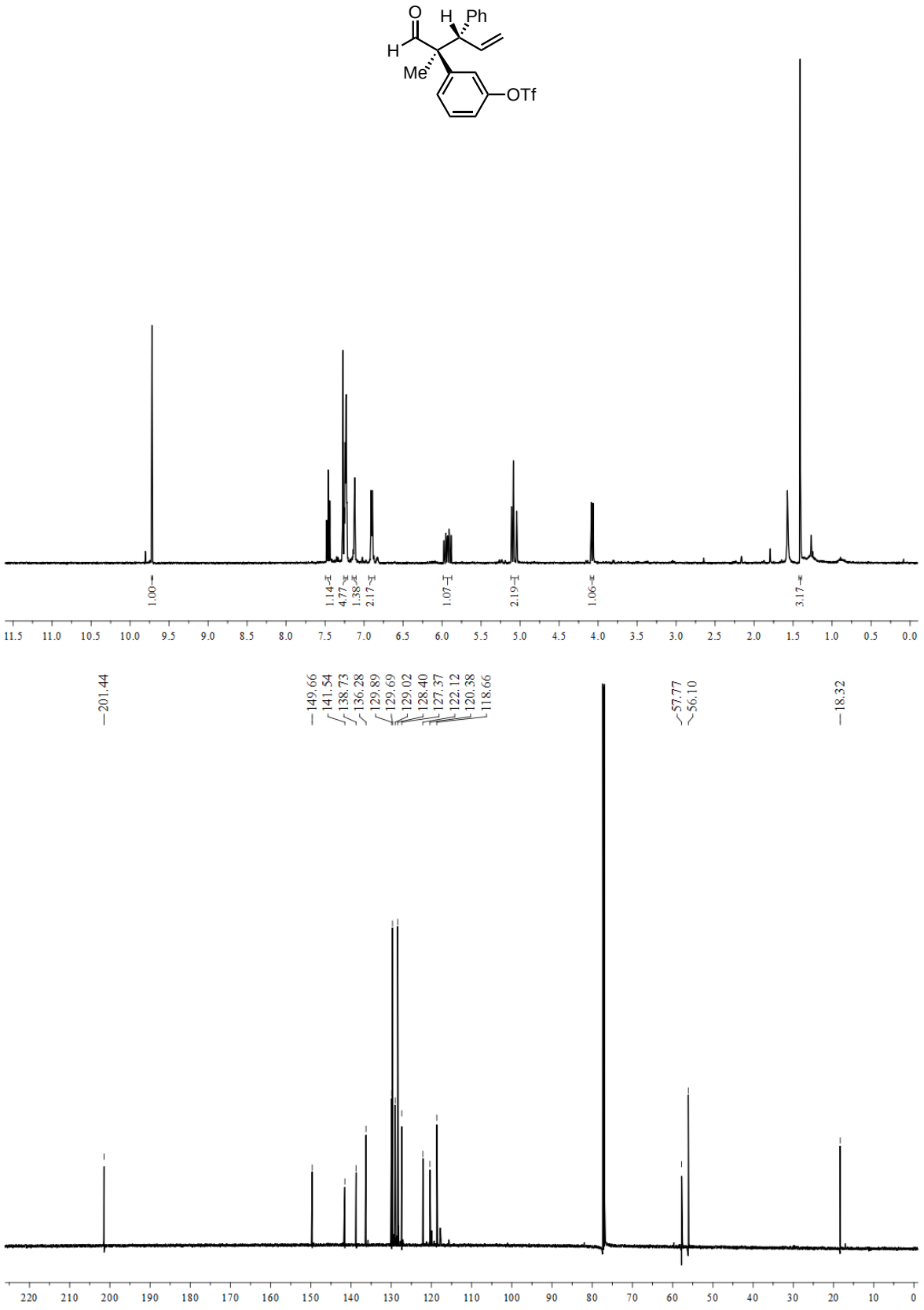
(*R*,*S*)-**3r**

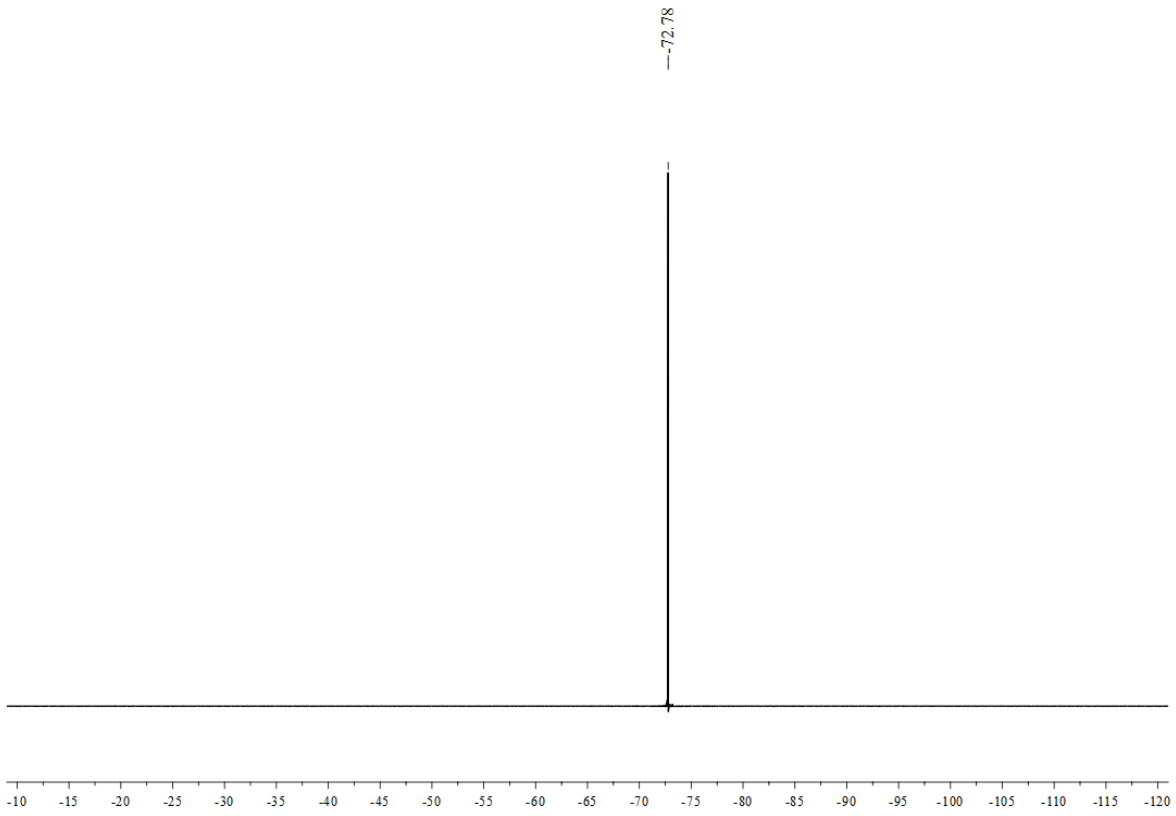

O
H
Ph
H
Me
Br


1.00
3.82
3.59
2.33
2.12
1.12
2.53
1.04
3.44
11.5 11.0 10.5 10.0 9.5 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

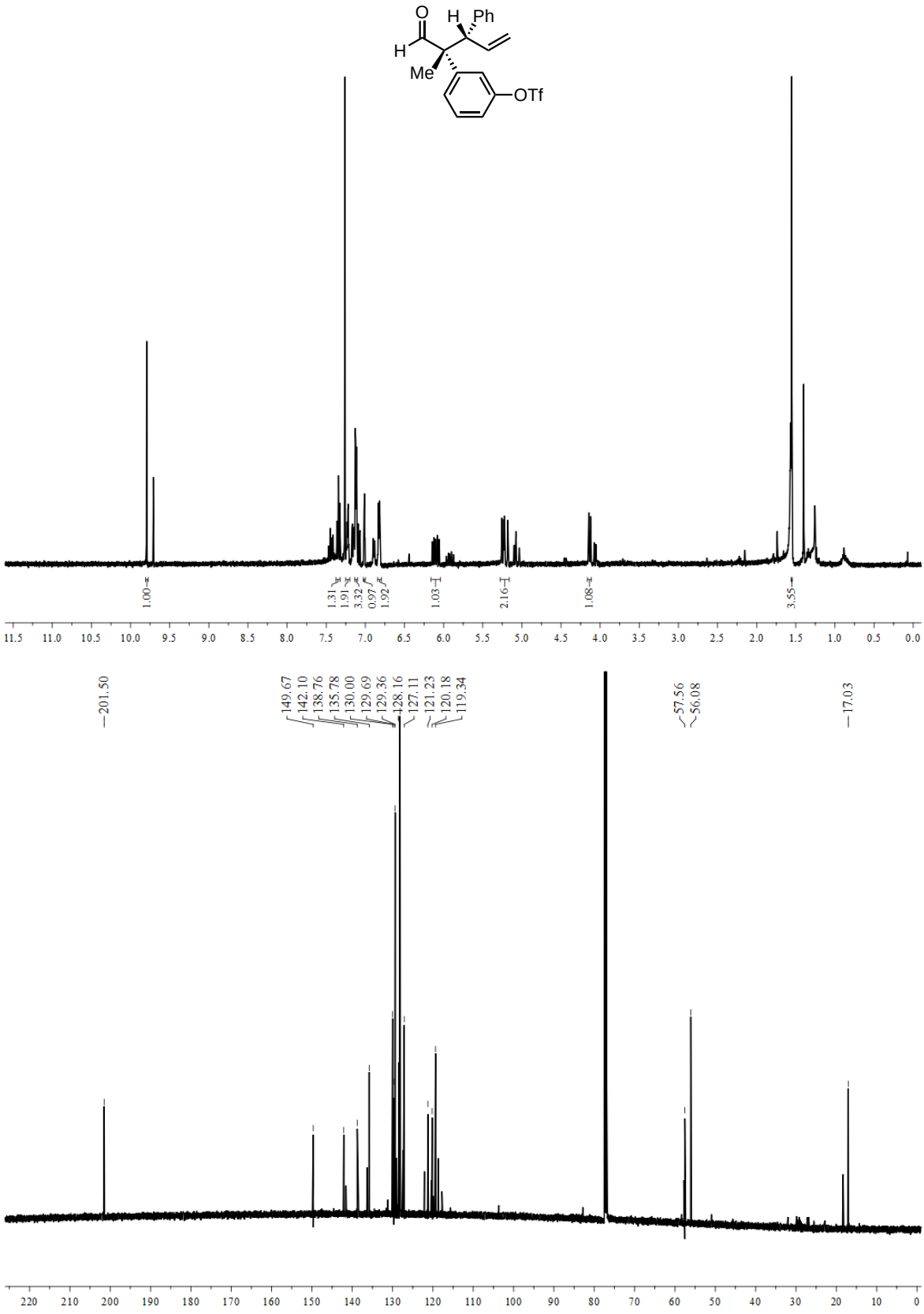

139.24
136.29
131.52
131.47
129.83
129.55
128.03
126.90
121.61
118.92
57.32
55.71
17.11
220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0

(*S*,*S*)-**3s**


1.00
1.14
4.77
1.38
2.17
1.07
2.19
1.06
3.17
201.44
149.66
141.54
138.73
136.28
129.89
129.69
129.02
128.40
127.37
122.12
120.38
118.66
57.77
56.10
18.32


-72.78
-10
-15
-20
-25
-30
-35
-40
-45
-50
-55
-60
-65
-70
-75
-80
-85
-90
-95
-100
-105
-110
-115
-120

(*R*,*S*)-**3s**


O
H
Ph
H
Me
OTf
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1.91
3.32
0.97
1.92
1.03
2.16
1.08
3.55
201.50
149.67
142.10
138.76
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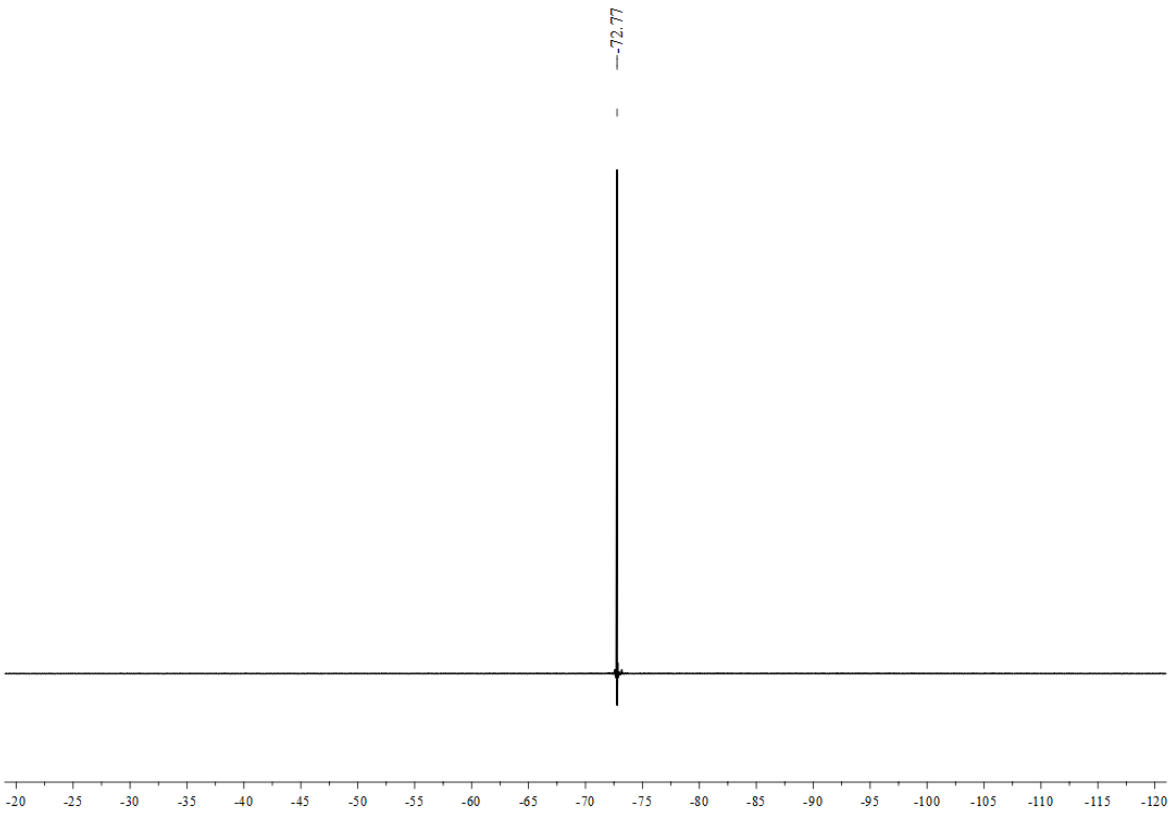
129.69
129.36
128.16
127.11
121.23
120.18
119.34
57.56
56.08
17.03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-85
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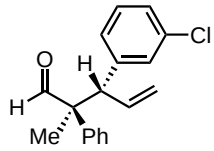
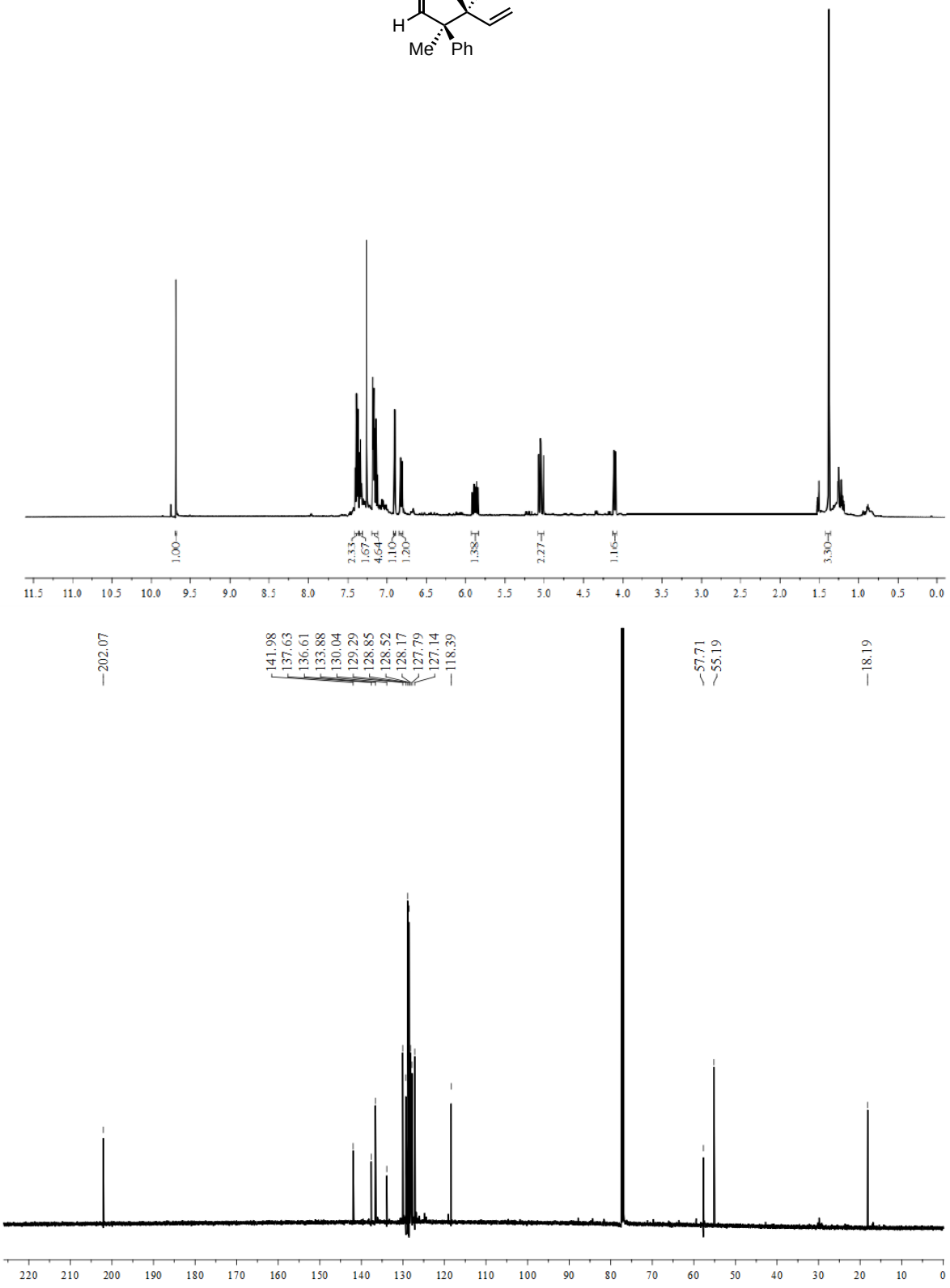
-95
-100
-105
-110
-115
-120

(*S*,*S*)-**3t**


Cl
O
H
H
Me
Ph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2.27
1.16
3.30
202.07
141.98
137.63
136.61
133.88
130.04
129.29
128.85
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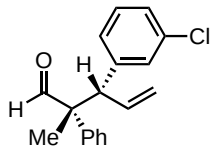
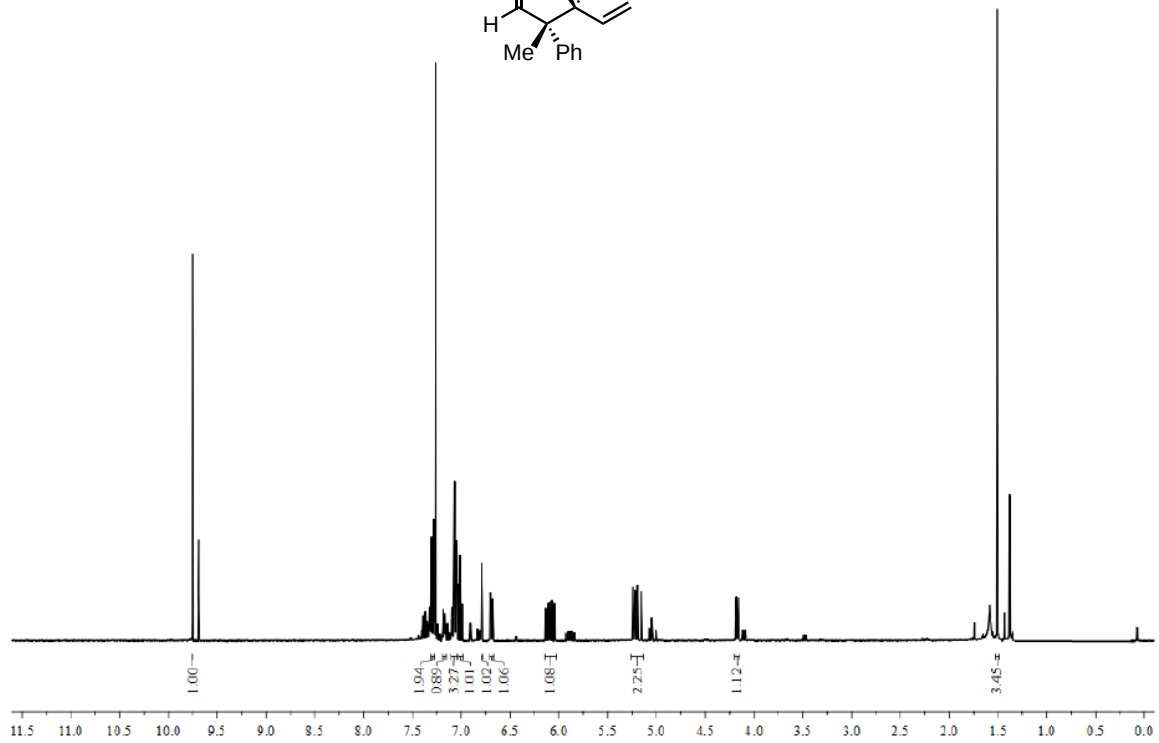
128.17
127.79
127.14
118.39
57.71
55.19
18.19

(*R*,*S*)-**3t**


Cl
O
H
H
Me
Ph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1.94
0.89
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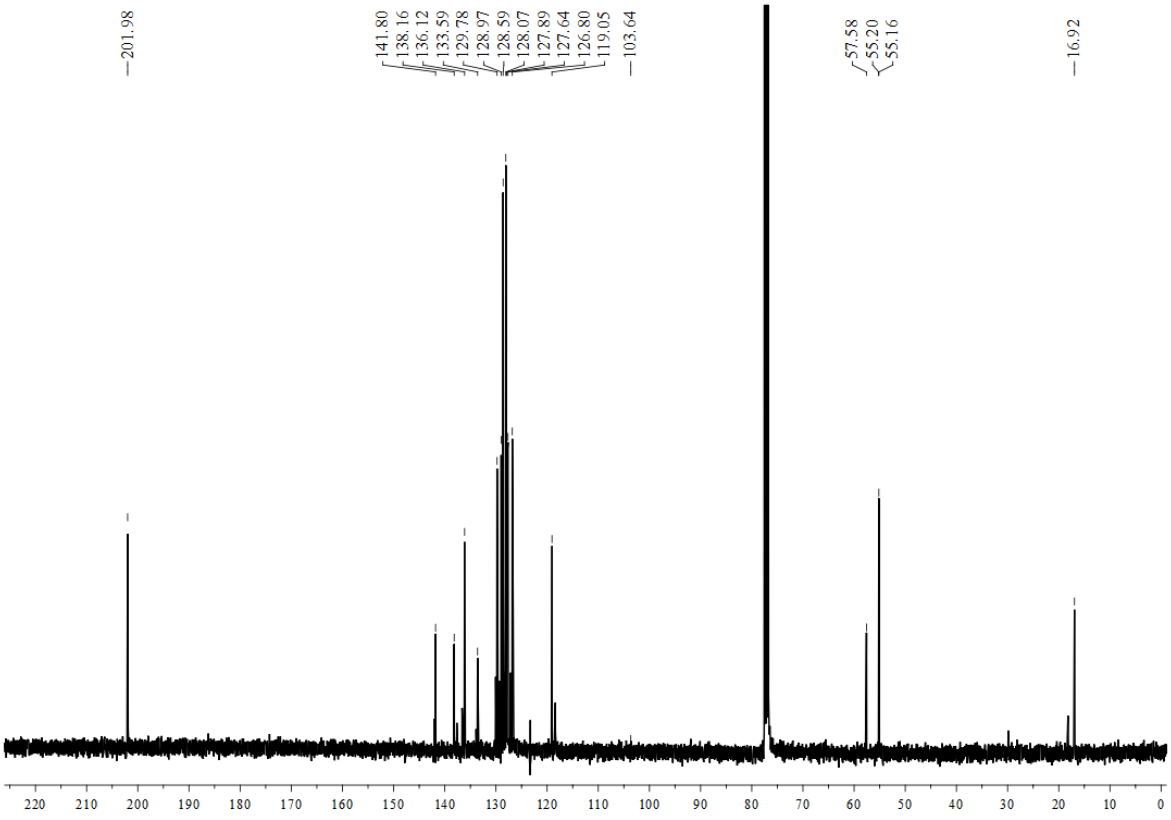
1.02
1.06
1.08
2.25
1.12
3.45
11.5 11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0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128.59
128.07
127.89
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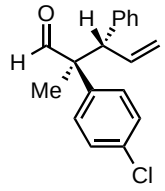
126.80
119.05
103.64
57.58
55.20
55.16
16.92
220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0

(*S*,*S*)-**3u**


O
H
Ph
H
Me
Cl

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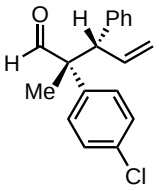
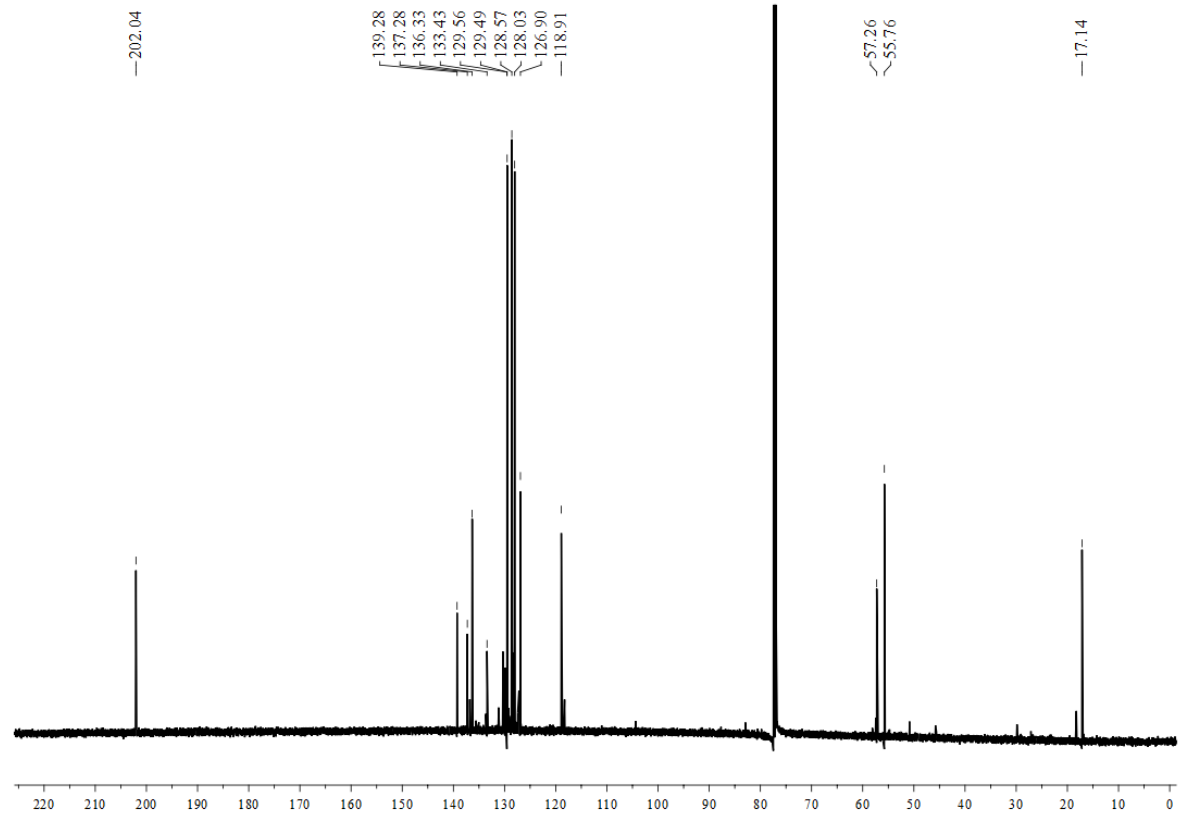
1.08
2.23
1.07
3.37
11.5 11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
201.91
139.24
136.69
136.60
133.55
130.20
129.75
128.43
128.14
127.07
118.17
57.35
55.61
18.14
230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10

(*R*,*S*)-**3u**


O
H
H
Ph
Me
Cl

1.00
3.52
3.58
2.17
2.08
1.09
2.30
1.08
3.23
11.0 10.5 10.0 9.5 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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139.28
137.28
136.33
133.43
129.56
129.49
128.57
128.03
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118.91
57.26
55.76
17.14
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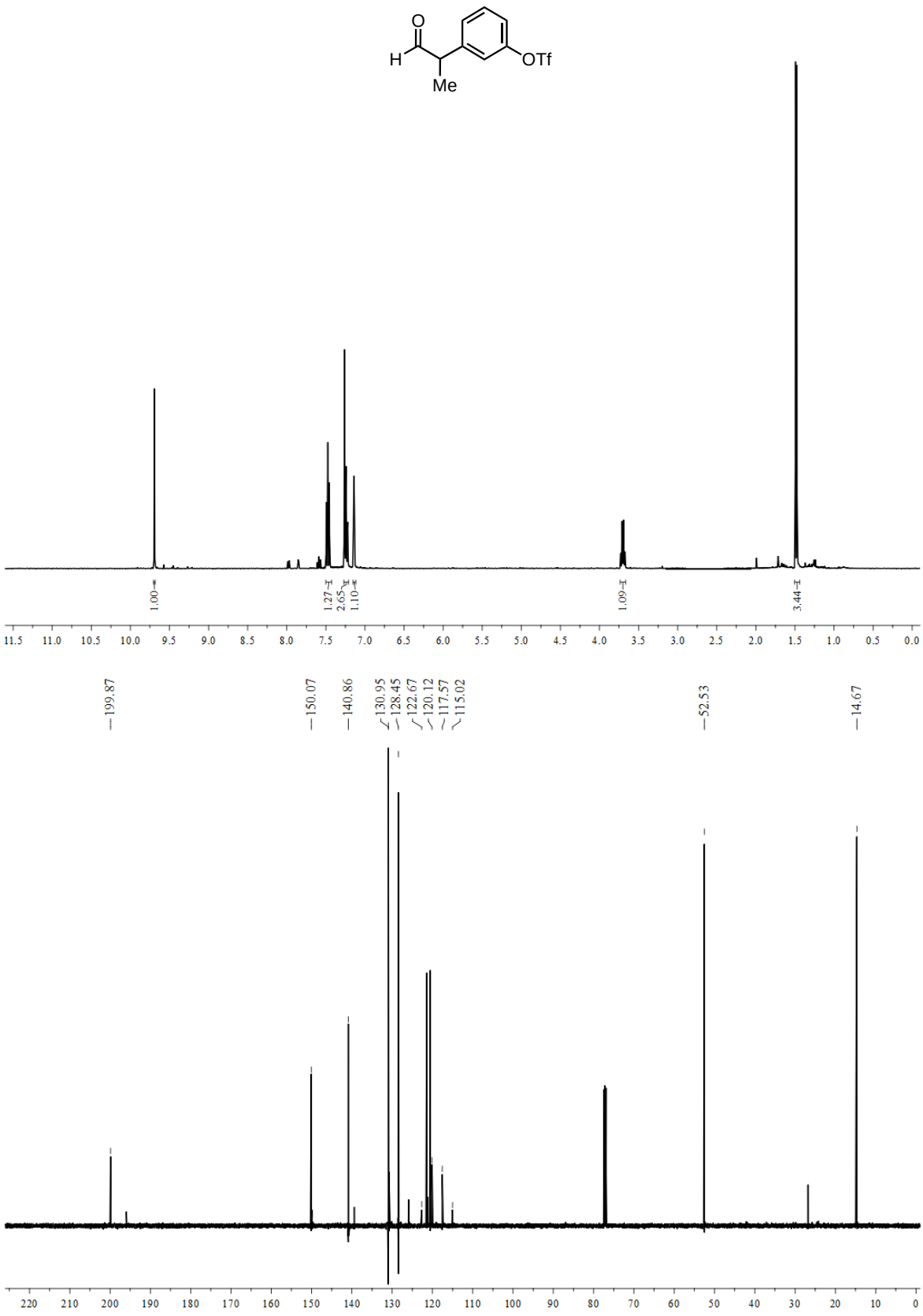
1s


O
H
OTf
Me
1.00
1.27
2.65
1.10
1.09
3.44
199.87
150.07
140.86
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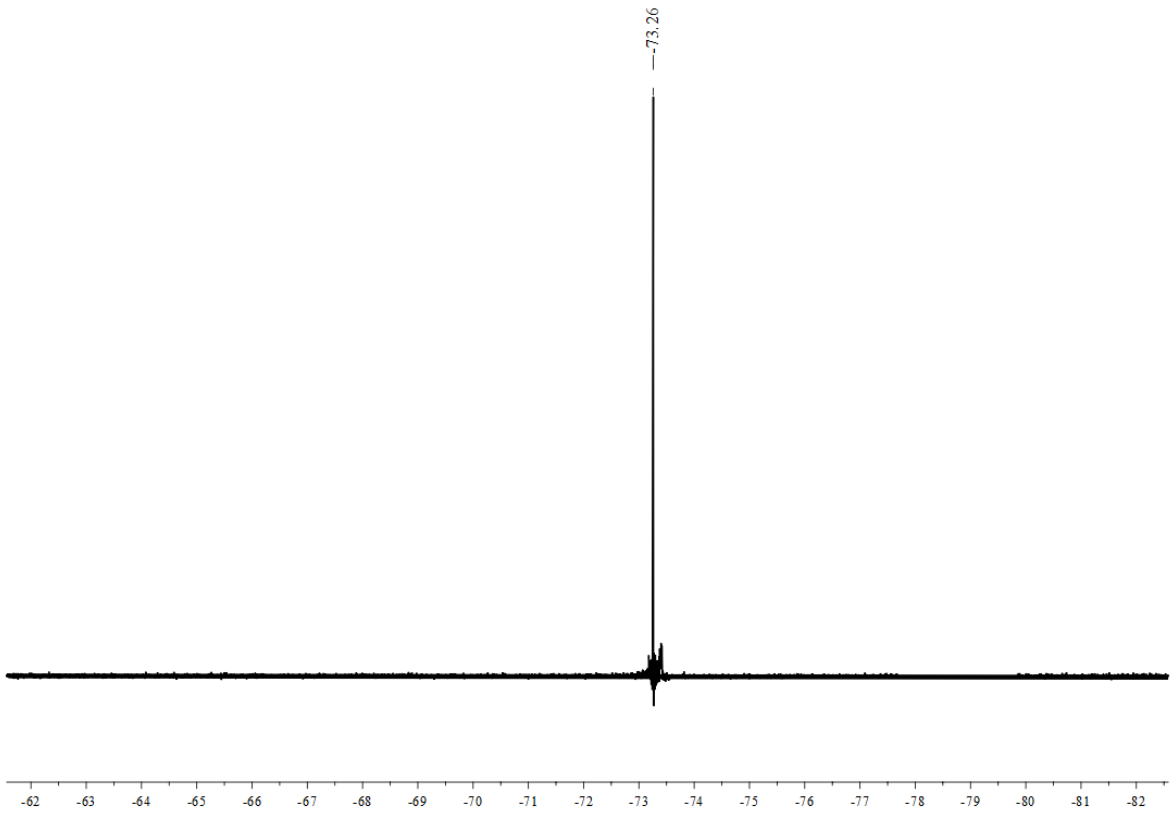
128.45
122.67
120.12
117.57
115.02
52.53
14.67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-62
-63
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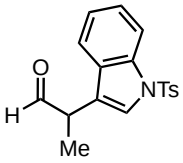
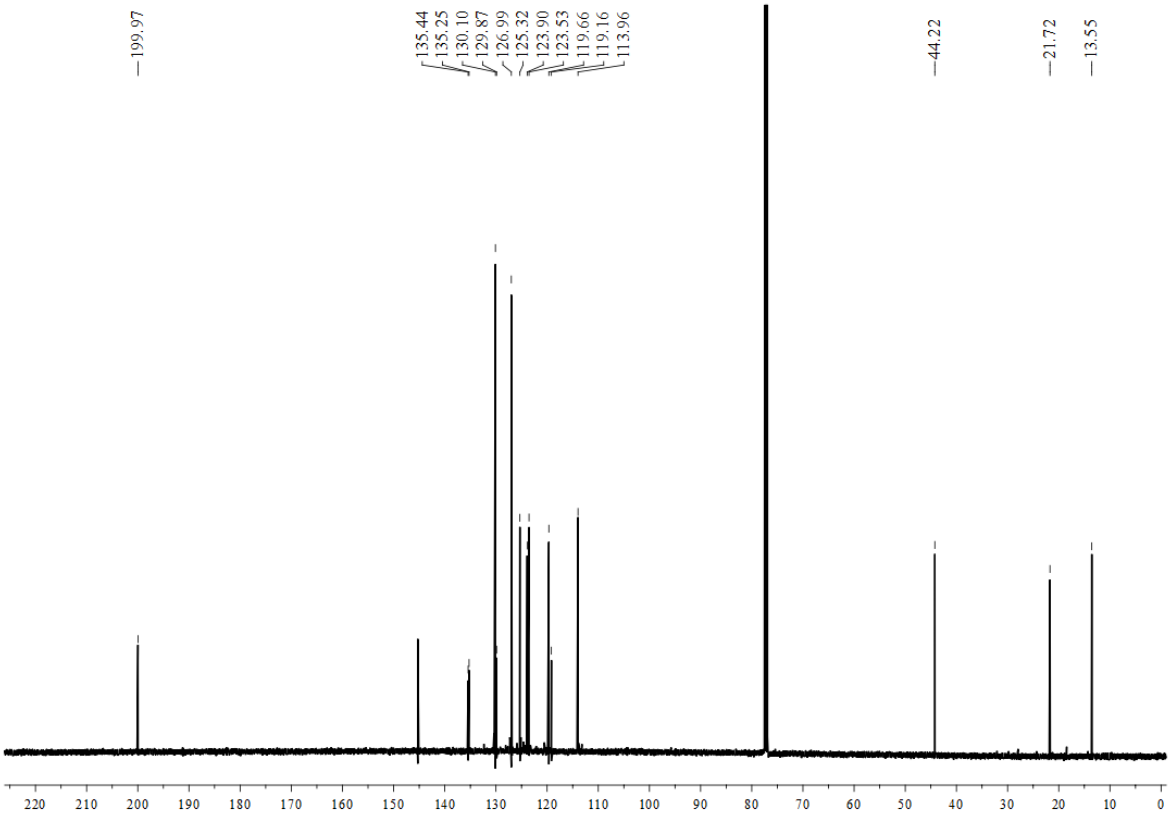
-81
-82

1d


O
H
NTs
Me

1.00
1.29
2.66
2.24
1.59
4.76
1.09
3.88
3.19
11.5 11.0 10.5 10.0 9.5 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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130.10
129.87
126.99
125.32
123.90
123.53
119.66
119.16
113.96
44.22
21.72
13.55
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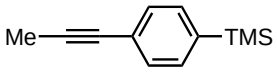
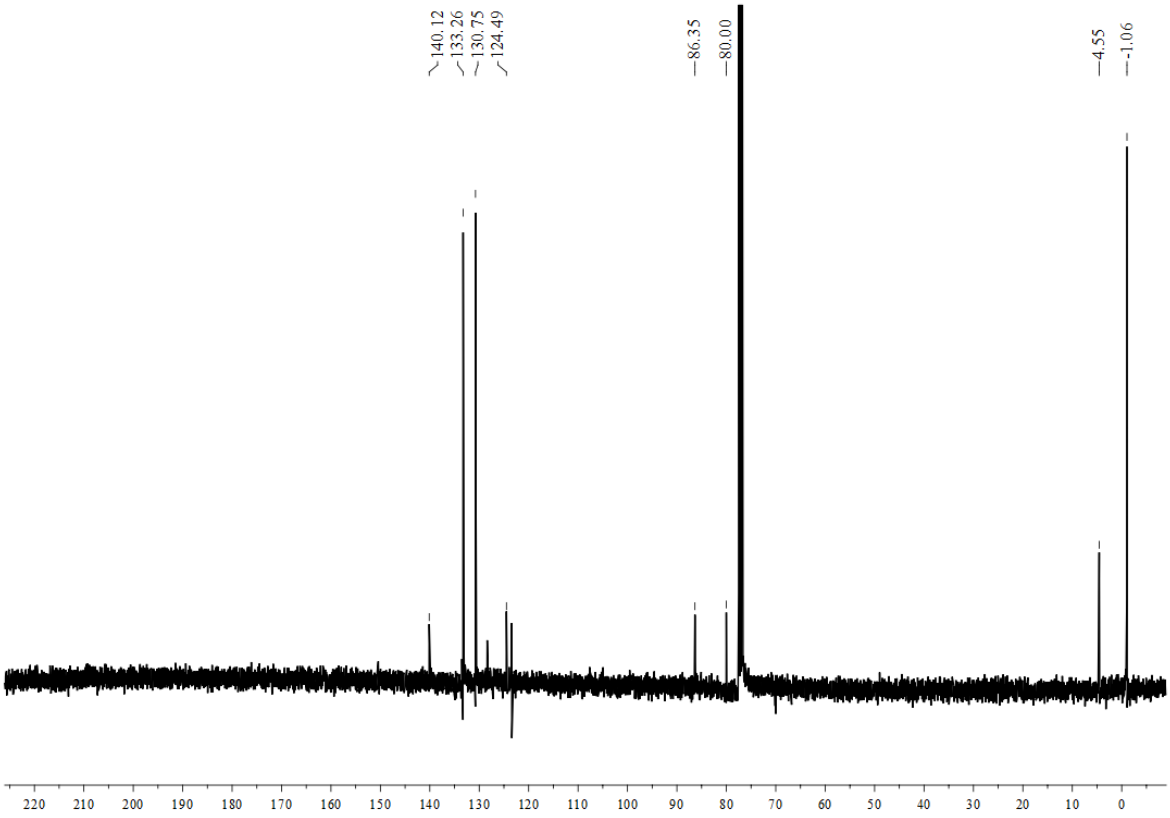
2j


Me
TMS

2.00
1.90
2.89
8.62
10.0 9.5 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


140.12
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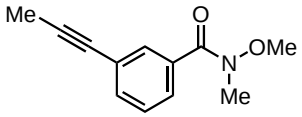
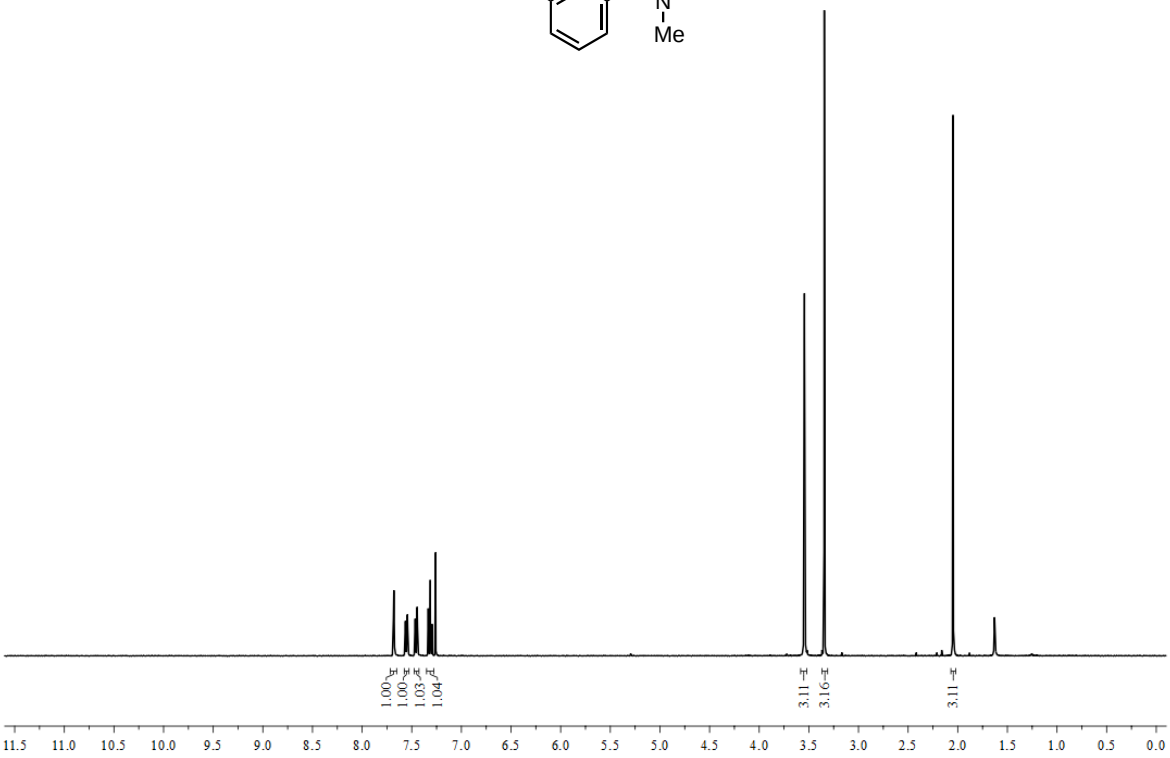
130.75
124.49
86.35
80.00
4.55
-1.06
220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0

2k


Me
O
N
OMe
Me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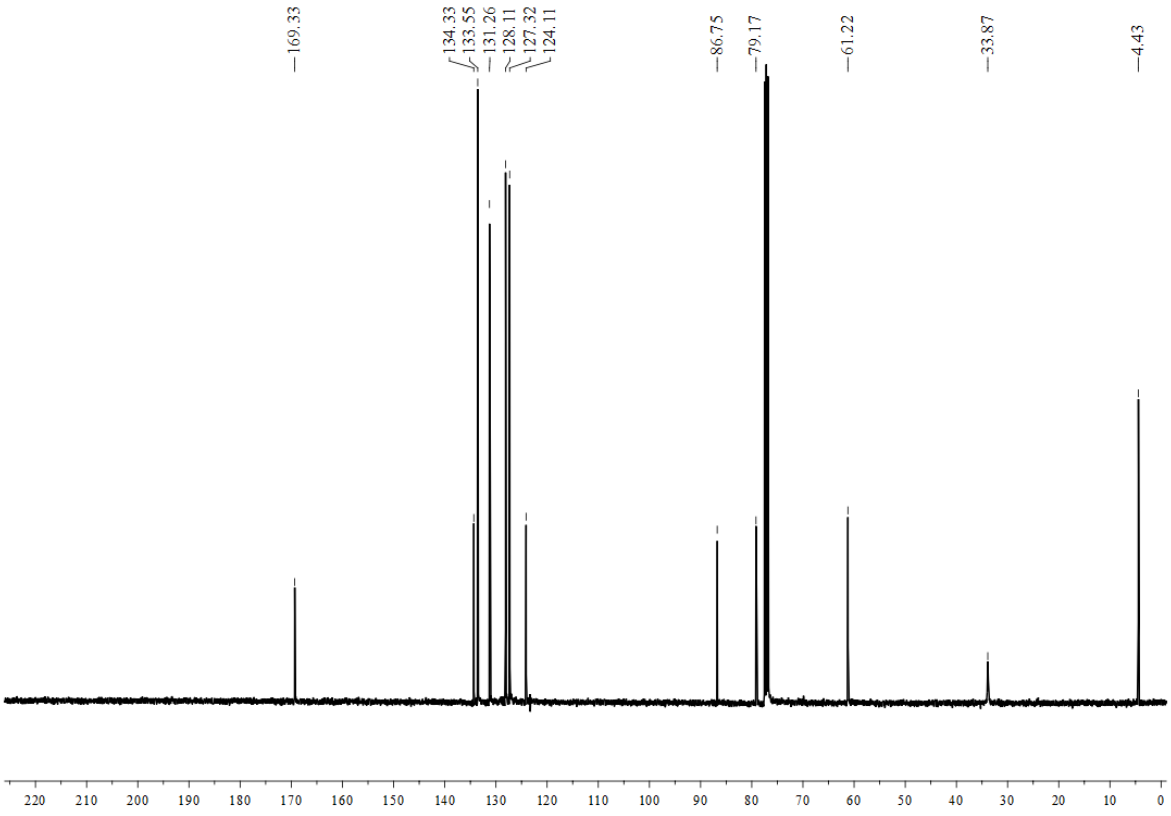
1.00
1.03
1.04
3.11
3.16
3.11
11.5 11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0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127.32
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86.75
79.17
61.22
33.87
4.43
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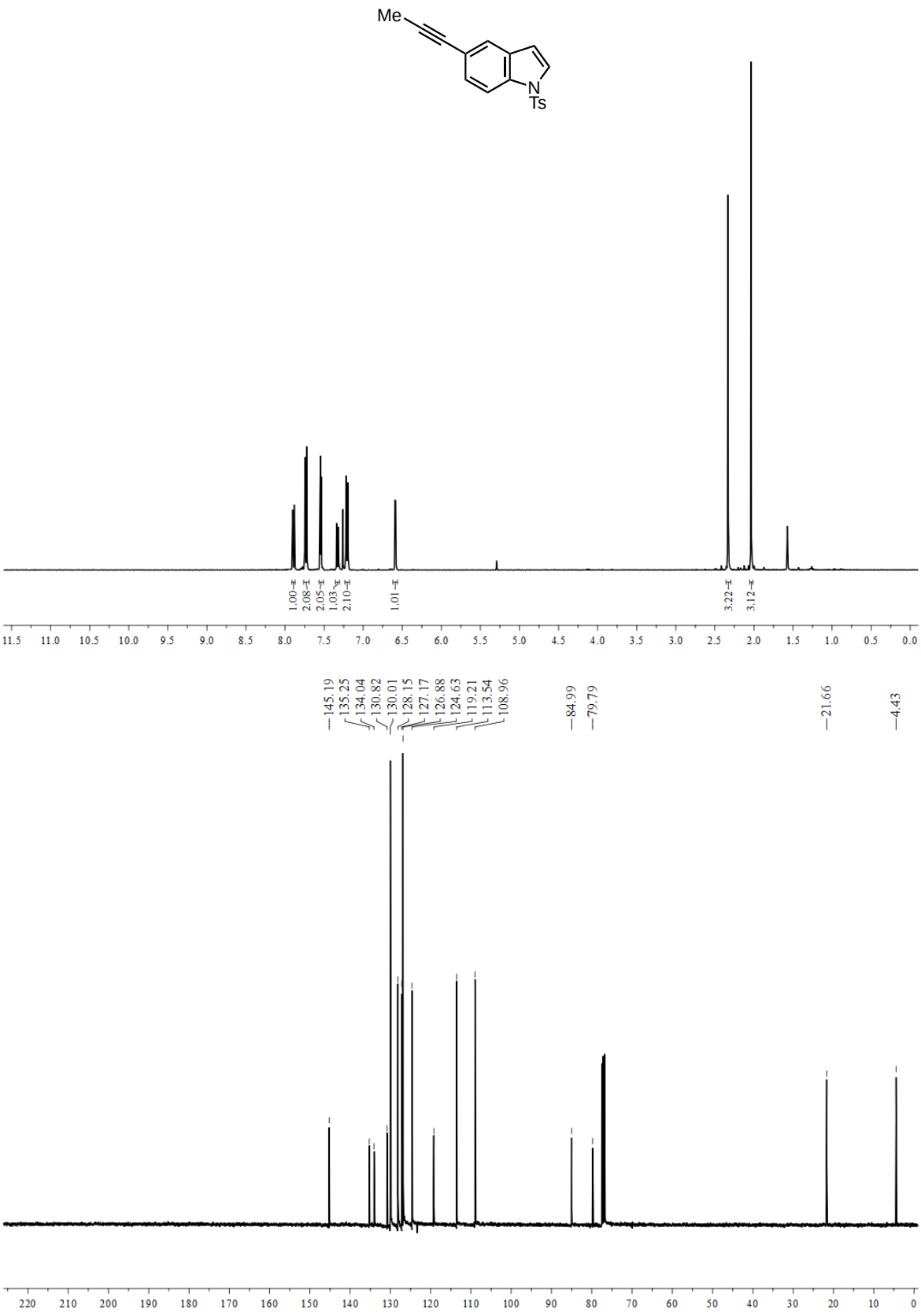
2m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N
Ts
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2.05
1.03
2.10
1.01
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3.12
145.19
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134.04
130.82
130.01
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126.88
124.63
119.21
113.54
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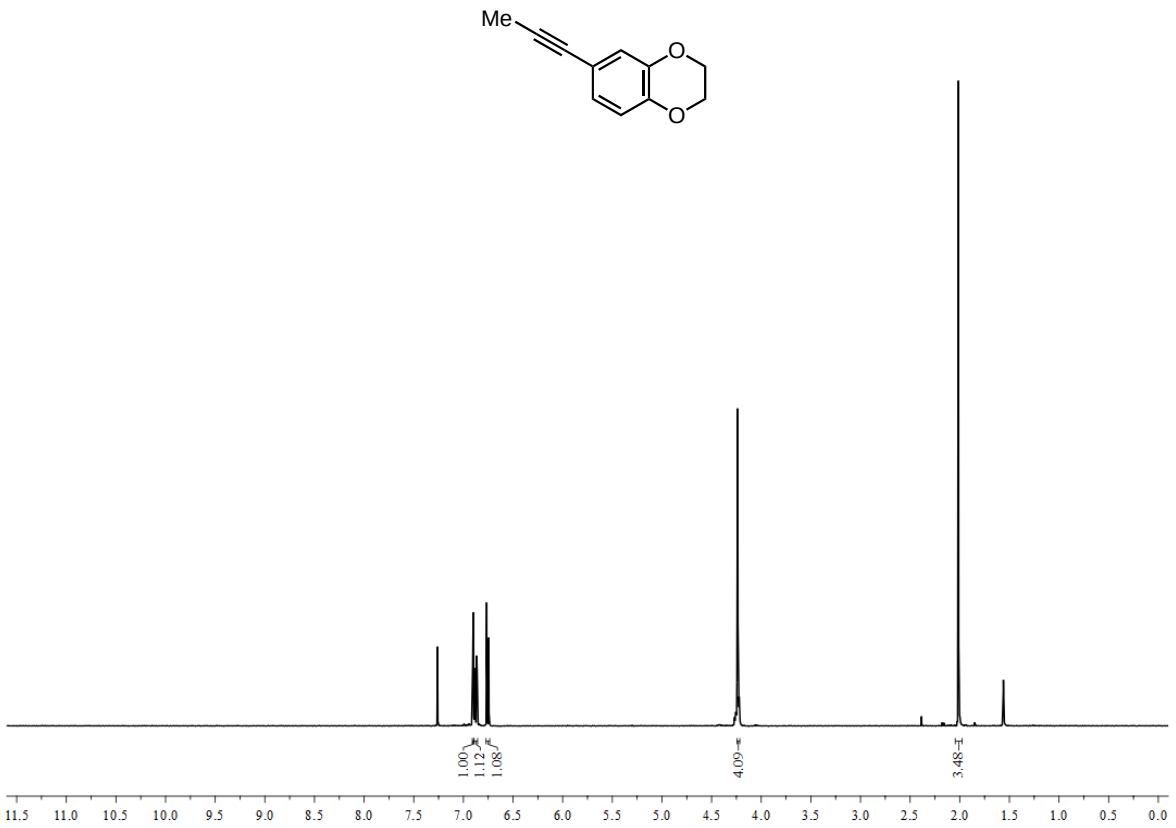
84.99
79.79
21.66
4.43

2o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O
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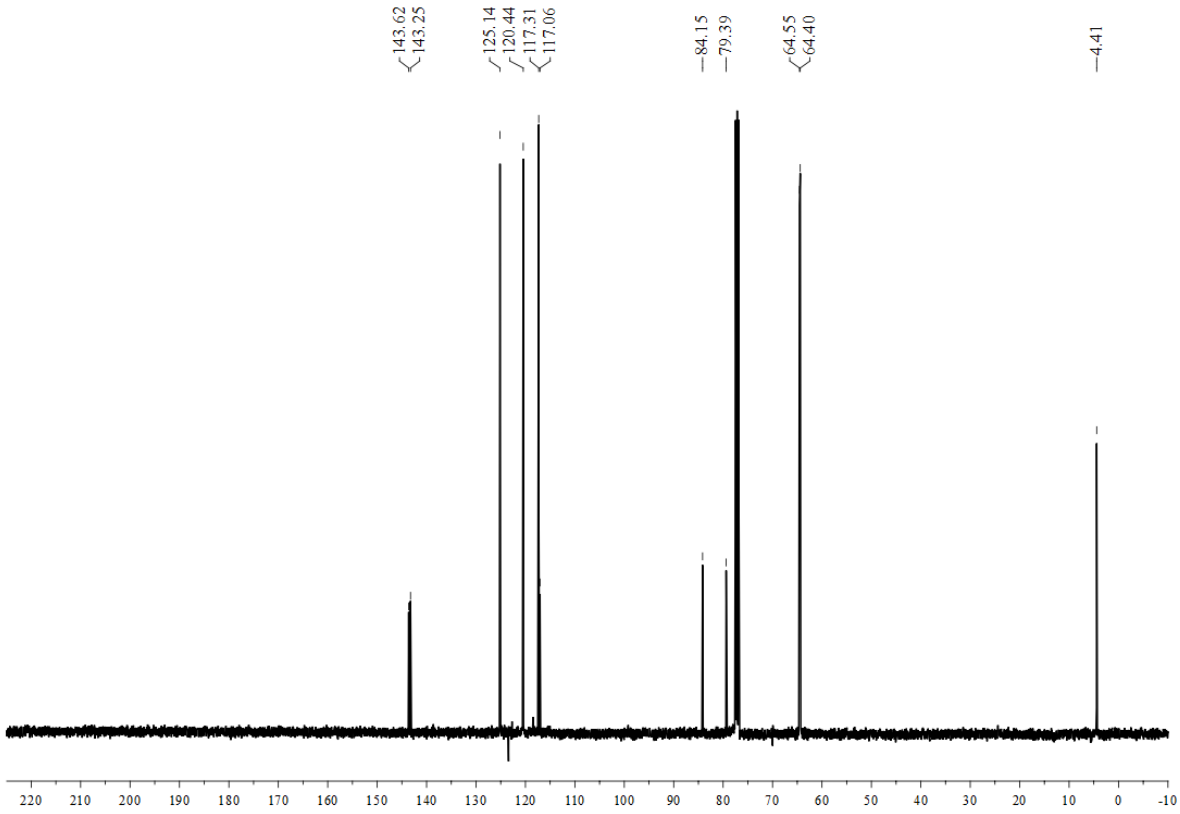
1.08
4.09
3.48
11.5 11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0


143.62
143.25
125.14
120.44
117.31
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84.15
79.39
64.55
64.40
4.41
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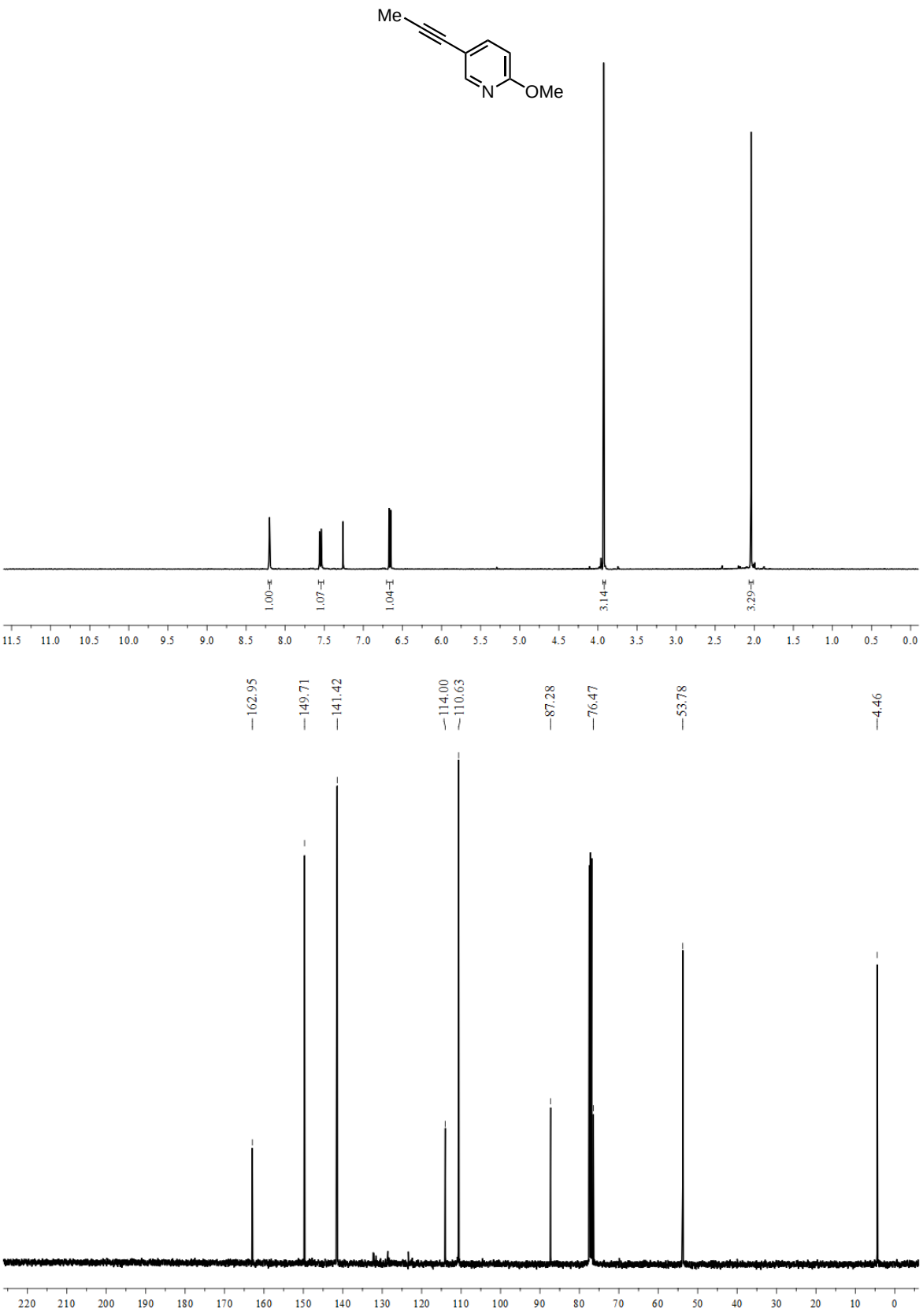
2q


Me
N
OMe
1.00
1.07
1.04
3.14
3.29
11.5 11.0 10.5 10.0 9.5 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
162.95
149.71
141.42
114.00
110.63
87.28
76.47
53.78
4.46
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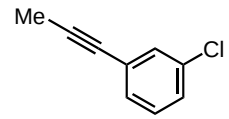
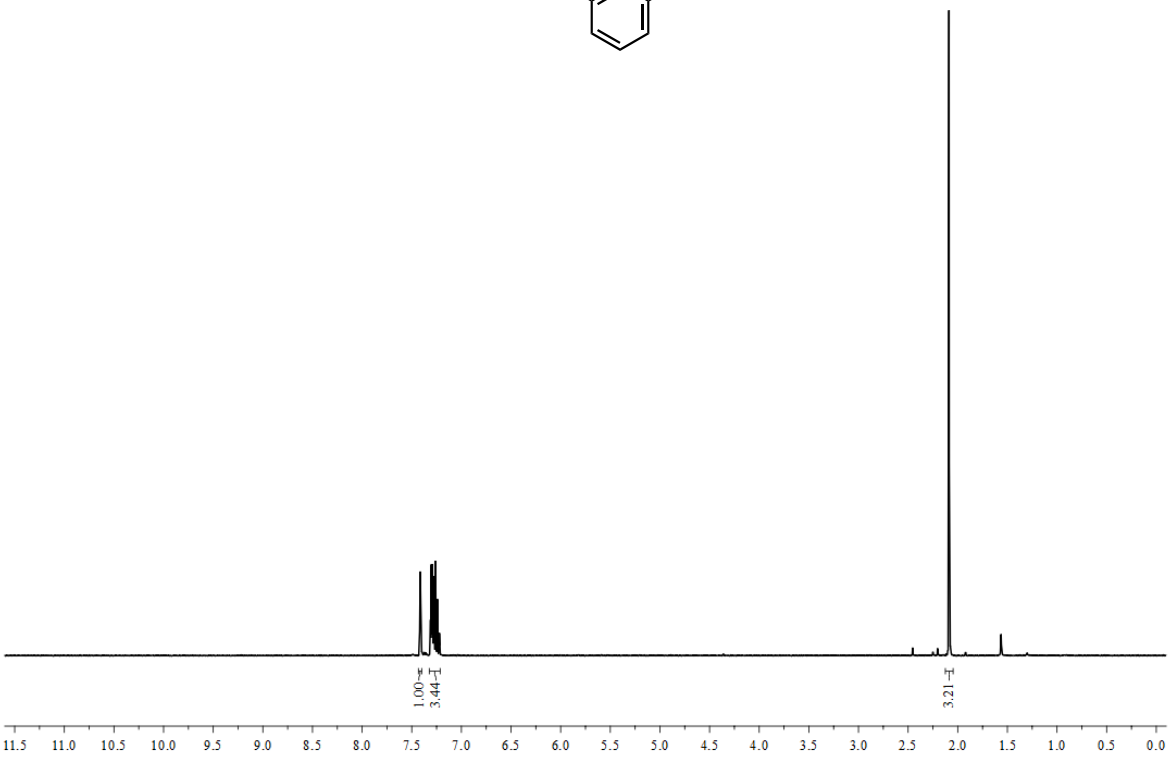
2t


Me
Cl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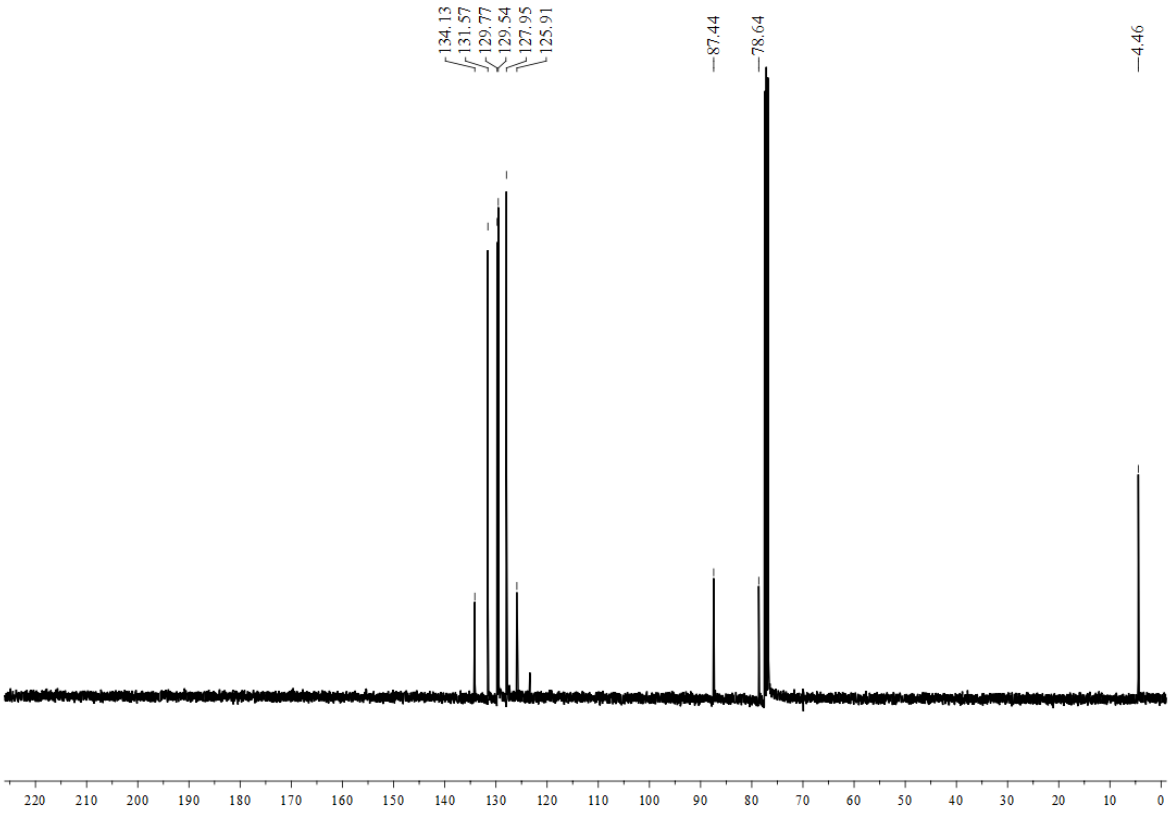
3.44
3.21
11.5 11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0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131.57
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129.54
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78.64
4.46
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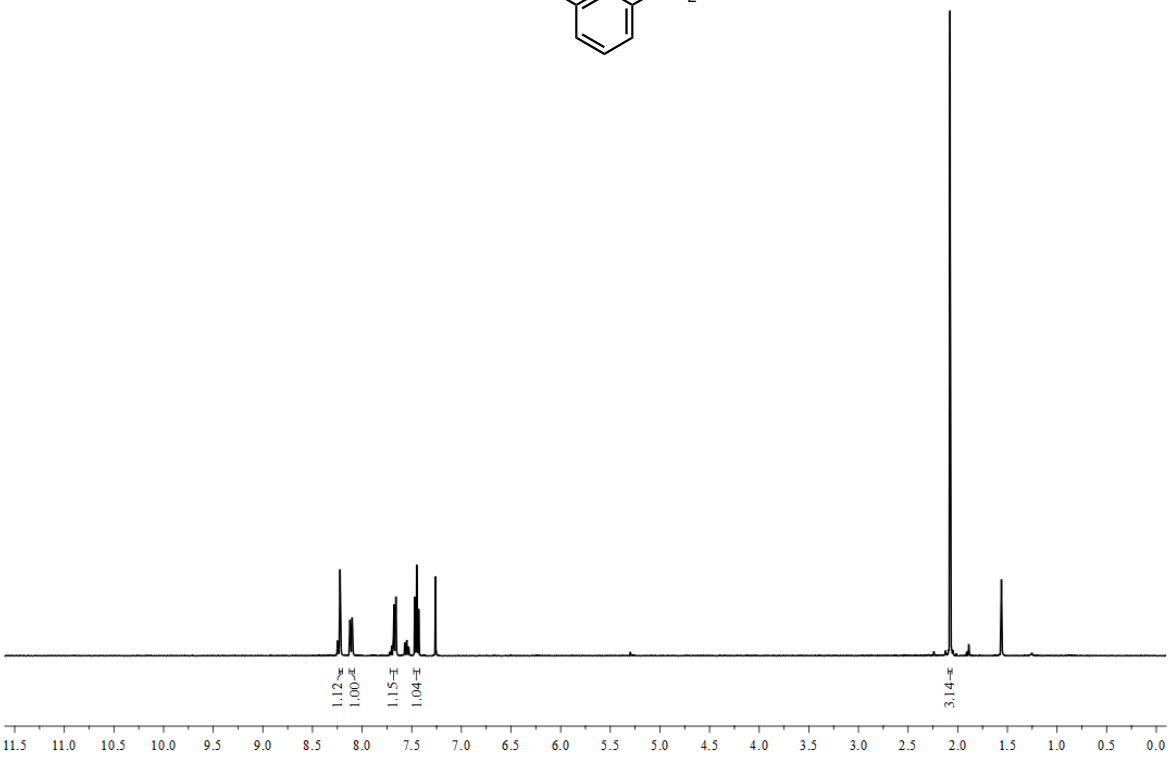
2n


Me
NO2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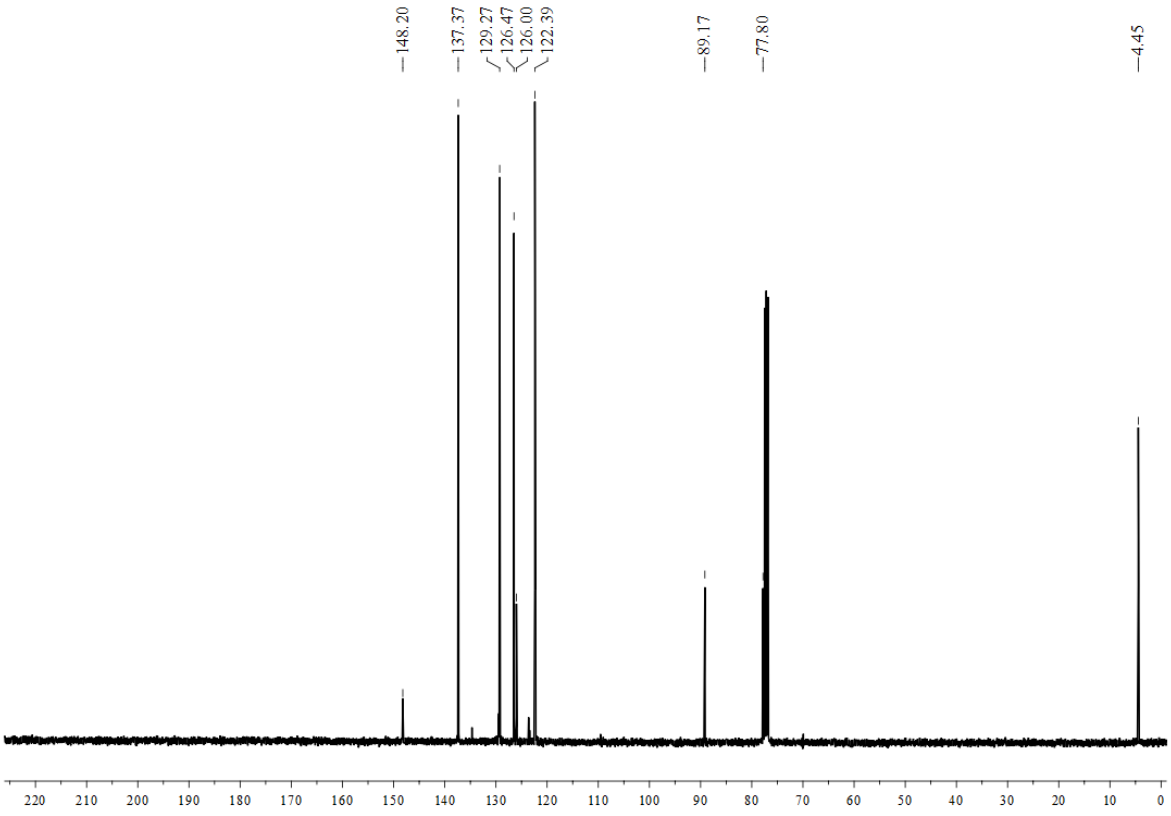
1.00
1.15
1.04
3.14
11.5 11.0 10.5 10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0


148.20
137.37
129.27
126.47
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77.80
4.45
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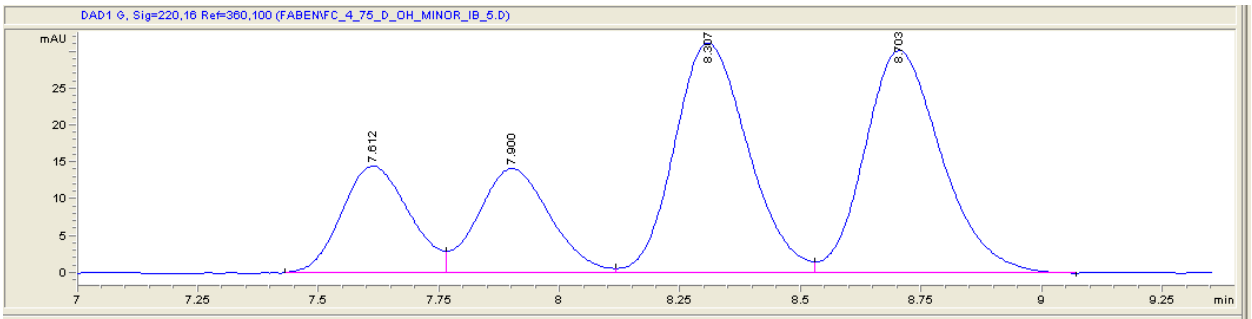
5. SFC Traces

Racemic



File Information	
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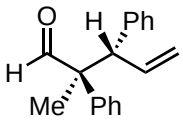
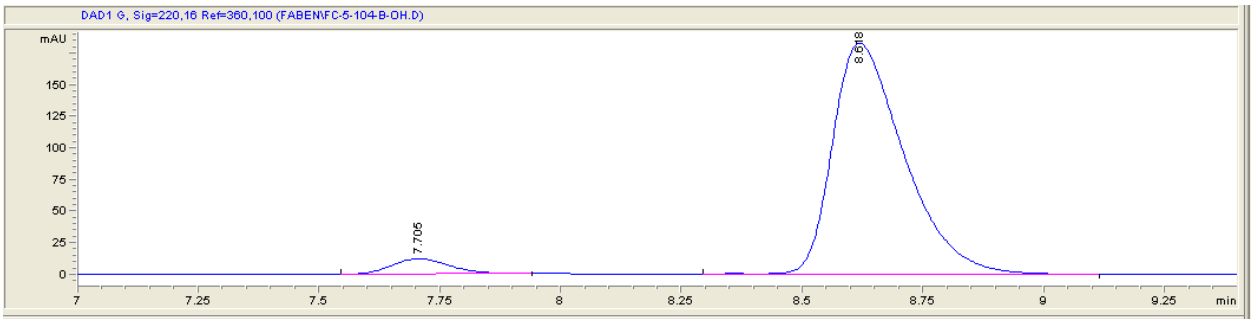
File Path	C:\CHEM32\1\DATA\FABEN\
Date	08-Sep-15, 19:45:33
Sample	FC_4_75_D_OH_MINOR_IB_5

#	Time	Area	Height	Width	Area%	Symmetry
1	7.612	141.9	14.5	0.1492	14.856	0.838
2	7.9	147.7	14.1	0.1618	15.457	0.843
3	8.307	330.6	31.2	0.1646	34.607	0.808
4	8.703	335.1	30.2	0.1724	35.081	0.77



(*S*,*S*)-**3a**

Enantiomerically Pure



File Information	
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File Path	C:\CHEM32\1\DATA\FABEN\

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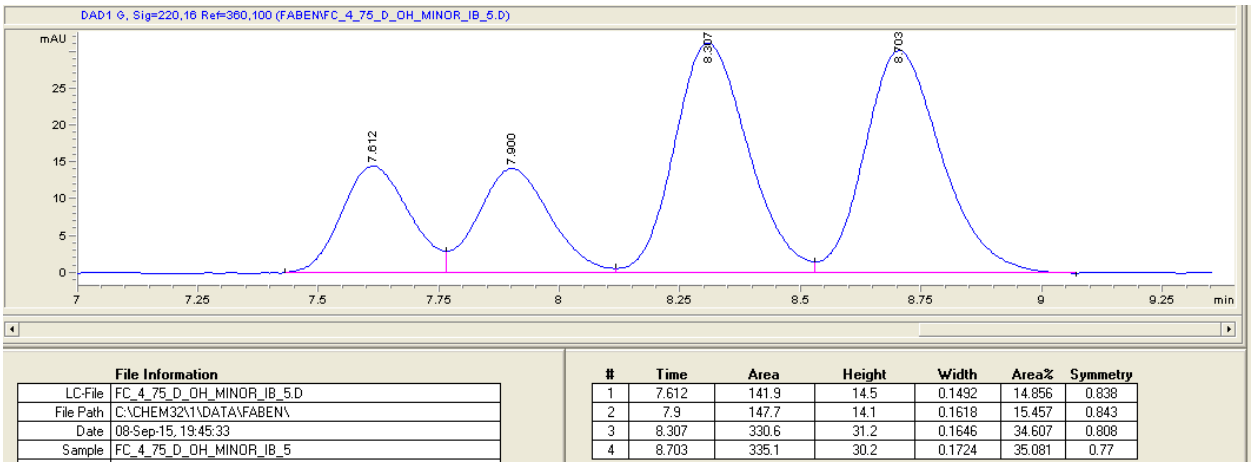
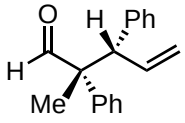
2	8.618	1889.4	183	0.1585	94.595	0.575

Racemic



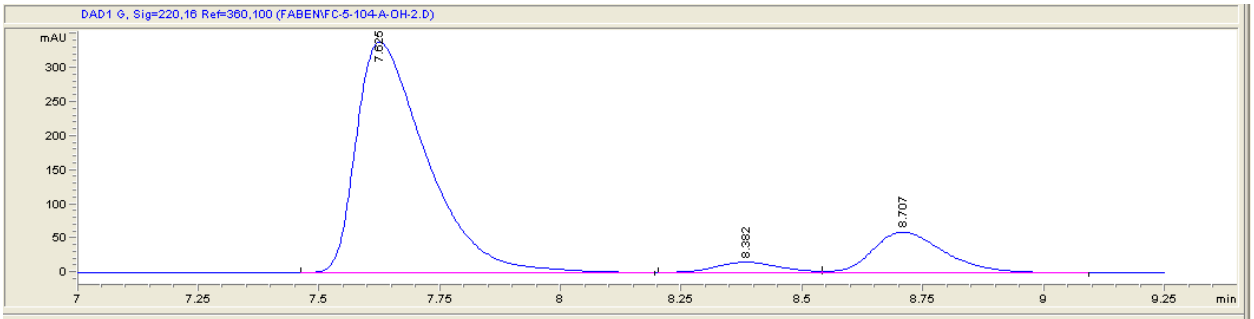
File Information	
LC-File	FC_4_75_D_OH_MINOR_IB_5.D
File Path	C:\CHEM32\1\DATA\FABEN\
Date	08-Sep-15, 19:45:33
Sample	FC_4_75_D_OH_MINOR_IB_5

#	Time	Area	Height	Width	Area%	Symmetry
1	7.612	141.9	14.5	0.1492	14.856	0.838
2	7.9	147.7	14.1	0.1618	15.457	0.843
3	8.307	330.6	31.2	0.1646	34.607	0.808
4	8.703	335.1	30.2	0.1724	35.081	0.77



(*R*,*S*)-**3a**

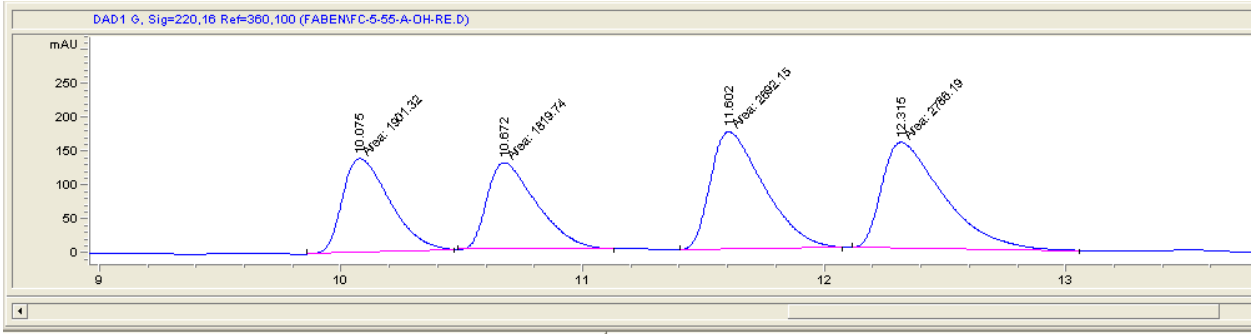
Enantiomerically Pure



File Information	
LC-File	FC-5-104-A-OH-2.D
File Path	C:\CHEM32\1\DATA\FABEN\
Date	25-Feb-16, 14:37:51
Sample	FC-5-104-A-OH-2

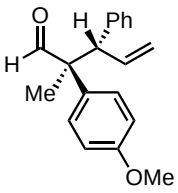
#	Time	Area	Height	Width	Area%	Symmetry
1	7.625	3426.8	338.6	0.1521	81.725	0.462
2	8.382	148.4	15.6	0.1429	3.538	0.872
3	8.707	617.9	60	0.1571	14.737	0.686

Racemic



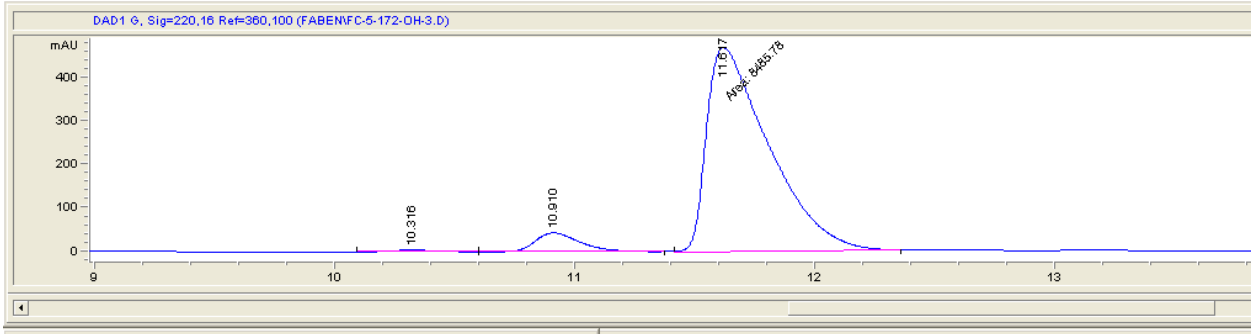
File Information	
LC-File	FC-5-55-A-OH-RE.D
File Path	C:\CHEM32\1\DATA\FABEN\
Date	03-Sep-16, 09:07:14
Sample	FC-5-55-A-OH-RE

#	Time	Area	Height	Width	Area%	Symmetry
1	10.075	1901.3	139.3	0.2274	20.668	0.568
2	10.672	1819.7	128	0.237	19.781	0.508
3	11.602	2692.2	173.9	0.2581	29.264	0.508
4	12.315	2786.2	156.8	0.2962	30.287	0.439



(*S*,*S*)-**3b**

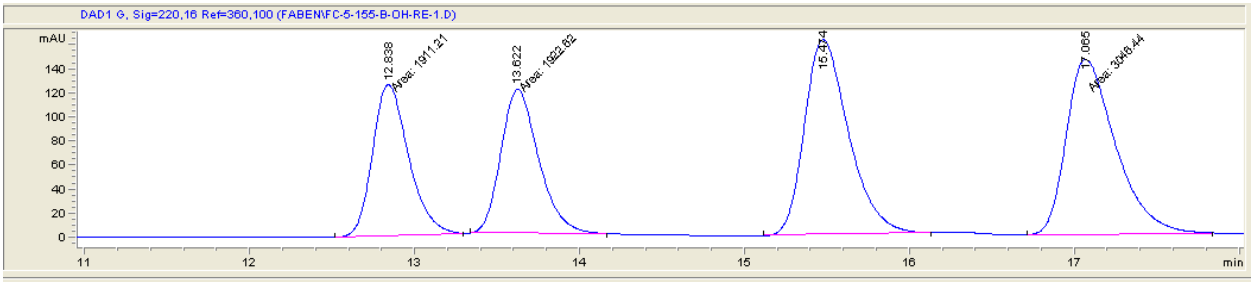
Enantiomerically pure



File Information	
LC-File	FC-5-172-OH-3.D
File Path	C:\CHEM32\1\DATA\FABEN\
Date	02-Sep-16, 15:49:55

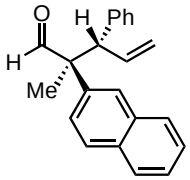
#	Time	Area	Height	Width	Area%	Symmetry
1	10.316	53.6	4.2	0.1875	0.588	0.751
2	10.91	576.1	43.7	0.1987	6.320	0.641
3	11.617	8485.8	470	0.3009	93.092	0.358

Racemic



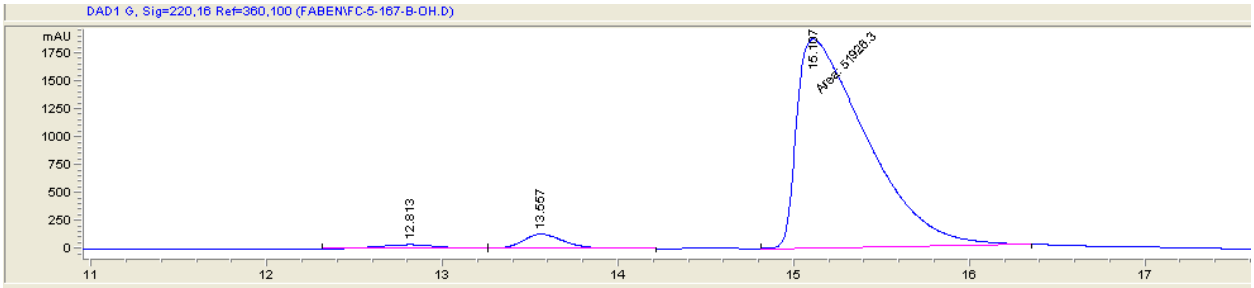
File Information	
LC-File	FC-5-155-B-OH-RE-1.D
File Path	C:\CHEM32\1\DATA\FABEN\
Date	13-May-16, 08:15:38
Sample	FC-5-155-B-OH-RE-1

#	Time	Area	Height	Width	Area%	Symmetry
1	12.838	1911.2	125.6	0.2537	19.286	0.753
2	13.622	1922.6	119.8	0.2674	19.401	0.759
3	15.474	3029.5	162.1	0.284	30.571	0.688
4	17.065	3046.4	145.5	0.3489	30.742	0.615



(*S*,*S*)-**3c**

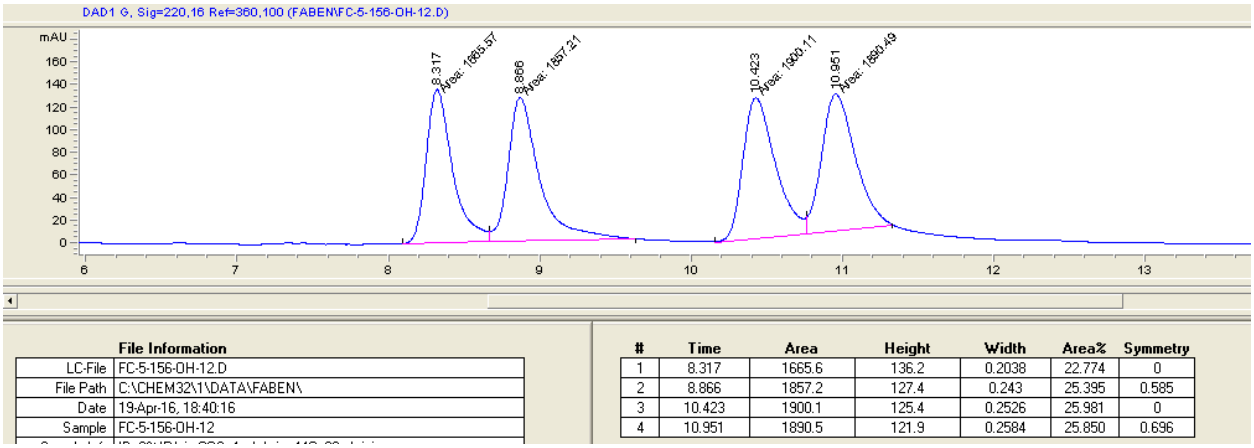
Enantiomerically Pure



File Information	
LC-File	FC-5-167-B-OH.D
File Path	C:\CHEM32\1\DATA\FABEN\
Date	03-Sep-16, 12:11:30

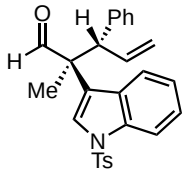
#	Time	Area	Height	Width	Area%	Symmetry
1	12.813	915.8	36.8	0.3601	1.664	1.017
2	13.557	2208.8	131.2	0.2565	4.012	0.729
3	15.107	51926.3	1873.3	0.462	94.324	0.293

Racemic



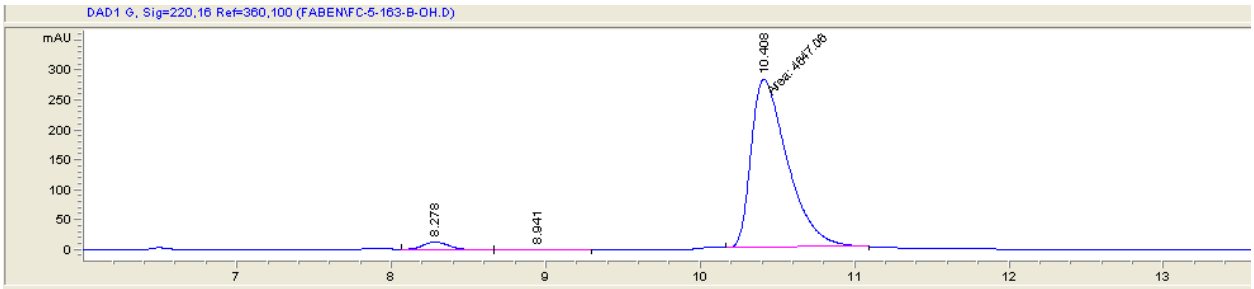
File Information	
LC-File	FC-5-156-OH-12.D
File Path	C:\CHEM32\1\DATA\FABEN\
Date	19-Apr-16, 18:40:16
Sample	FC-5-156-OH-12

#	Time	Area	Height	Width	Area%	Symmetry
1	8.317	1665.6	136.2	0.2038	22.774	0
2	8.866	1857.2	127.4	0.243	25.395	0.585
3	10.423	1900.1	125.4	0.2526	25.981	0
4	10.951	1890.5	121.9	0.2584	25.850	0.696



(*S*,*S*)-**3d**

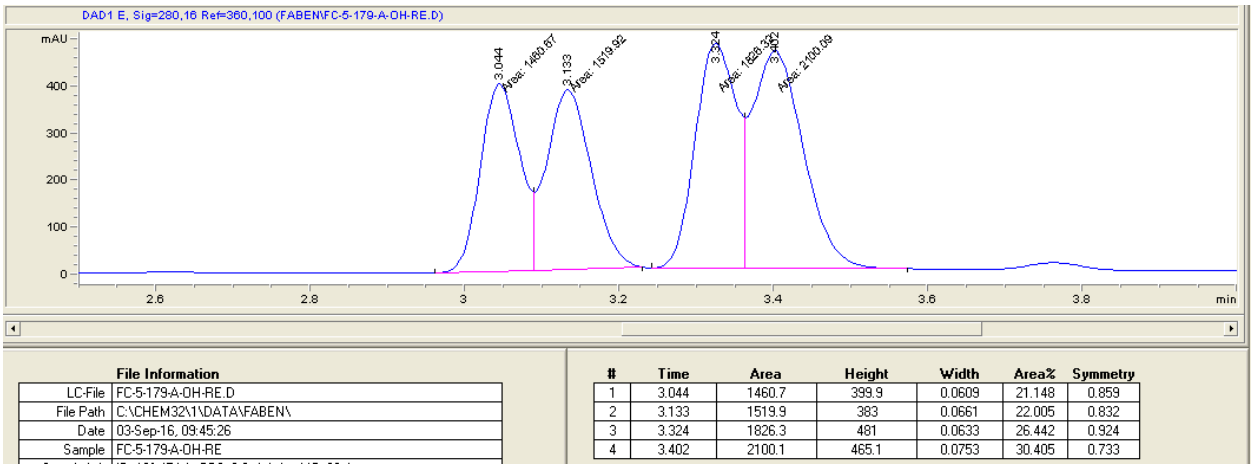
Enantiomerically Pure



File Information	
LC-File	FC-5-163-B-OH.D
File Path	C:\CHEM32\1\DATA\FABEN\
Date	07-Sep-16, 15:33:43

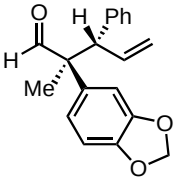
#	Time	Area	Height	Width	Area%	Symmetry
1	8.278	178.4	13.8	0.1903	3.675	0.849
2	8.941	28.2	1.5	0.2326	0.582	1.074
3	10.408	4647.1	282	0.2747	95.743	0.519

Racemic



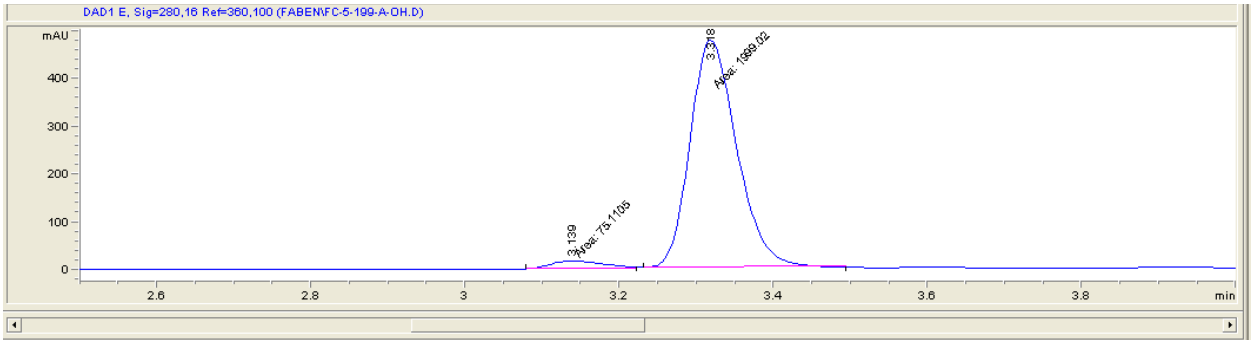
File Information	
LC-File	FC-5-179-A-OH-RE.D
File Path	C:\CHEM32\1\DATA\FABEN\
Date	03-Sep-16, 09:45:26
Sample	FC-5-179-A-OH-RE

#	Time	Area	Height	Width	Area%	Symmetry
1	3.044	1460.7	399.9	0.0609	21.148	0.859
2	3.133	1519.9	383	0.0661	22.005	0.832
3	3.324	1826.3	481	0.0633	26.442	0.924
4	3.402	2100.1	465.1	0.0753	30.405	0.733



(*S*,*S*)-**3e**

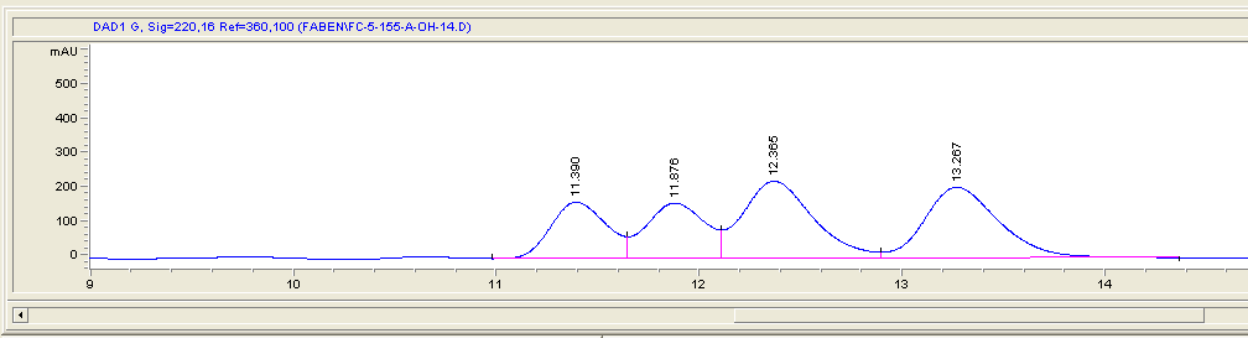
Enantiomerically Pure



File Information	
LC-File	FC-5-199-A-OH.D
File Path	C:\CHEM32\1\DATA\FABEN\
Date	03-Sep-16, 09:35:09

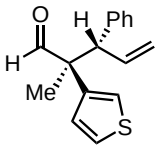
#	Time	Area	Height	Width	Area%	Symmetry
1	3.139	75.1	16.5	0.0758	3.621	0.652
2	3.318	1999	476.8	0.0699	96.379	0.76

Racemic



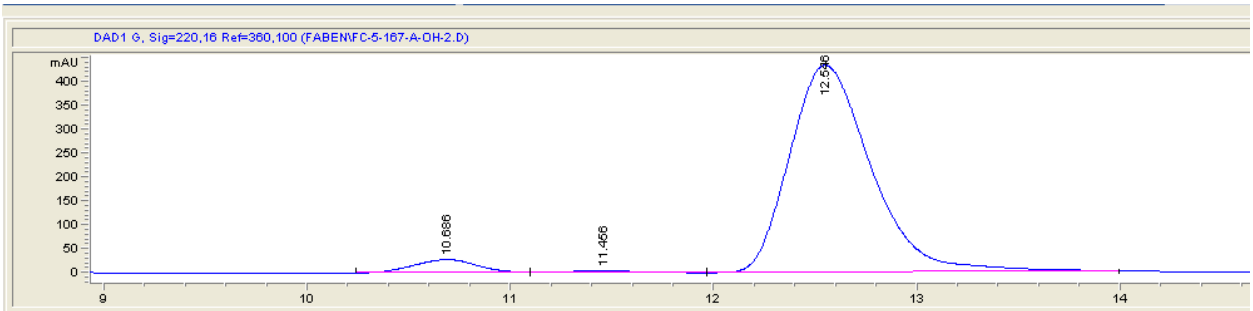
File Information	
LC-File	FC-5-155-A-OH-14.D
File Path	C:\CHEM32\1\DATA\FABEN\
Date	16-Apr-16, 17:36:43
Sample	FC-5-155-A-OH-14
Sample Info	IC, % IPA in CO2, 2.5 mL/min, 44C, 30 uL inj
Barcode	

#	Time	Area	Height	Width	Area%	Symmetry
1	11.39	3162.1	164.9	0.2967	18.373	0.825
2	11.876	3262.3	161.6	0.3035	18.955	0.927
3	12.365	5479.9	225.3	0.3628	31.840	0.744
4	13.267	5306.6	207	0.3852	30.833	0.724



(*S*,*S*)-**3f**

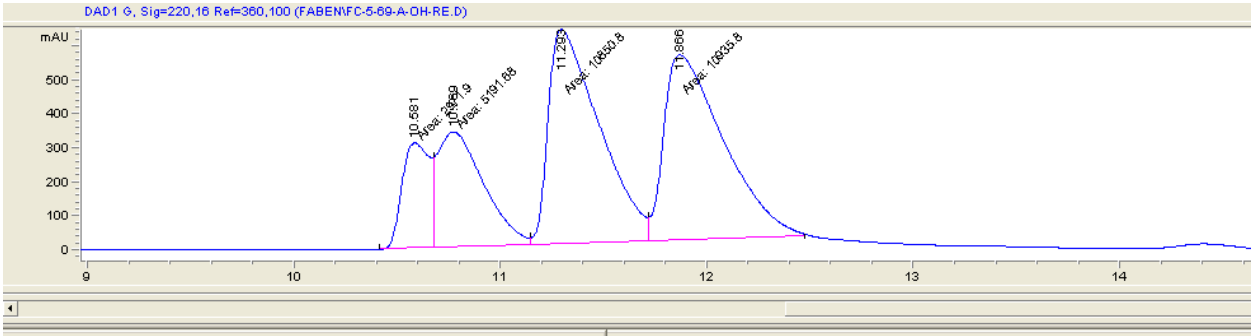
Enantiomerically Pure



File Information	
LC-File	FC-5-167-A-OH-2.D
File Path	C:\CHEM32\1\DATA\FABEN\
Date	03-Sep-16, 10:32:48
Sample	FC-5-167-A-OH-2

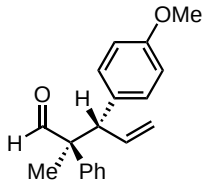
#	Time	Area	Height	Width	Area%	Symmetry
1	10.686	606.3	27.7	0.3283	4.722	1.052
2	11.456	102	3.8	0.3239	0.794	1.152
3	12.546	12132.7	433.8	0.4293	94.484	0.711

Racemic



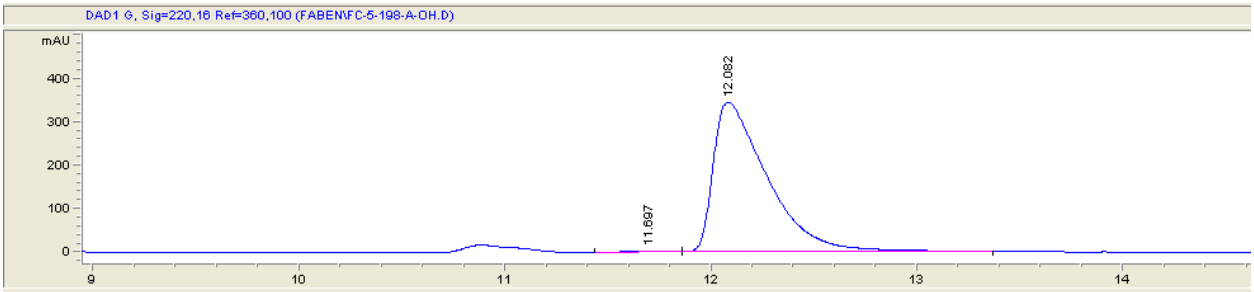
File Information	
LC-File	FC-5-69-A-OH-RE.D
File Path	C:\CHEM32\1\DATA\FABEN\
Date	07-Sep-16, 16:15:05
Sample	FC-5-69-A-OH-RE

#	Time	Area	Height	Width	Area%	Symmetry
1	10.581	2971.9	310.9	0.1593	9.923	0
2	10.769	5191.7	339.9	0.2546	17.334	0.48
3	11.293	10850.8	630.9	0.2866	36.229	0.344
4	11.866	10935.8	544.9	0.3345	36.513	0.355



(*S*,*S*)-**3g**

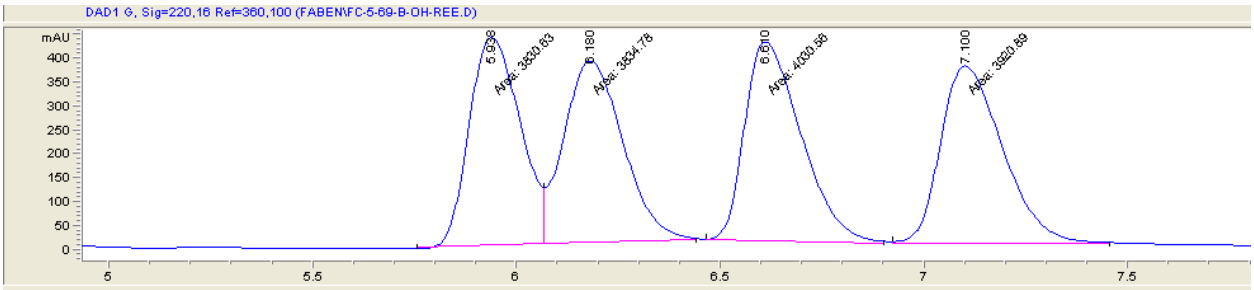
Enantiomerically Pure



File Information	
LC-File	FC-5-198-A-OH.D
File Path	C:\CHEM32\1\DATA\FABEN\

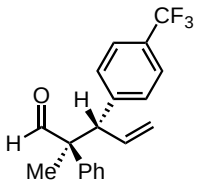
#	Time	Area	Height	Width	Area%	Symmetry
1	11.697	59.2	4	0.2168	0.922	1.09
2	12.082	6359.1	345.9	0.2685	99.078	0.349

Racemic



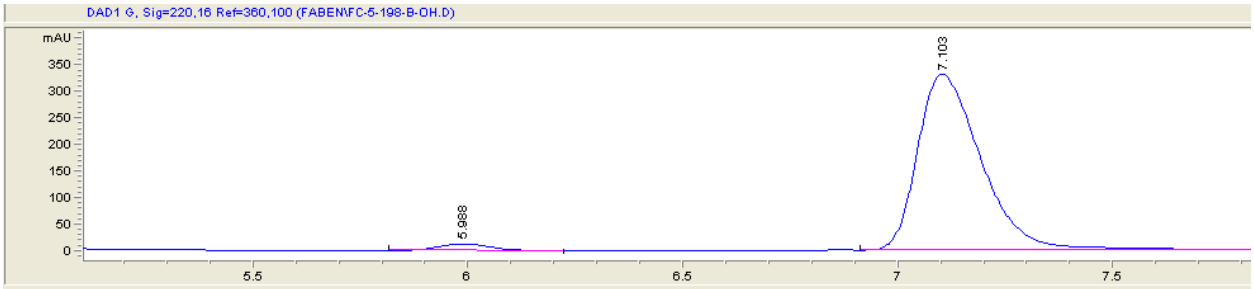
File Information	
LC-File	FC-5-69-B-OH-REE.D
File Path	C:\CHEM32\1\DATA\FABEN\
Date	07-Sep-16, 16:52:58
Sample	FC-5-69-B-OH-REE

#	Time	Area	Height	Width	Area%	Symmetry
1	5.938	3830.6	435.7	0.1465	24.529	0.756
2	6.18	3834.8	380.2	0.1681	24.555	0.785
3	6.61	4030.6	417.4	0.1609	25.809	0.577
4	7.1	3920.9	370.9	0.1762	25.107	0.637



(*S*,*S*)-**3h**

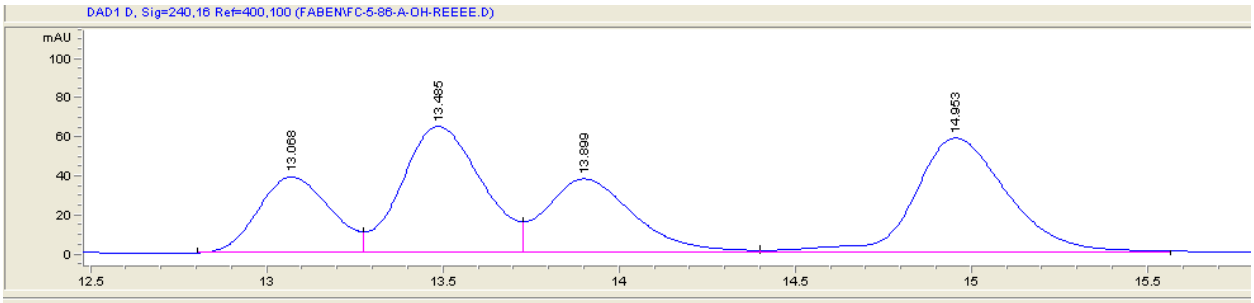
Enantiomerically Pure



File Information	
LC-File	FC-5-198-B-OH.D
File Path	C:\CHEM32\1\DATA\FABEN\

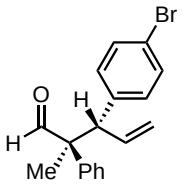
#	Time	Area	Height	Width	Area%	Symmetry
1	5.988	111.6	12.8	0.1358	3.142	0.858
2	7.103	3440.1	331.6	0.159	96.858	0.593

Racemic



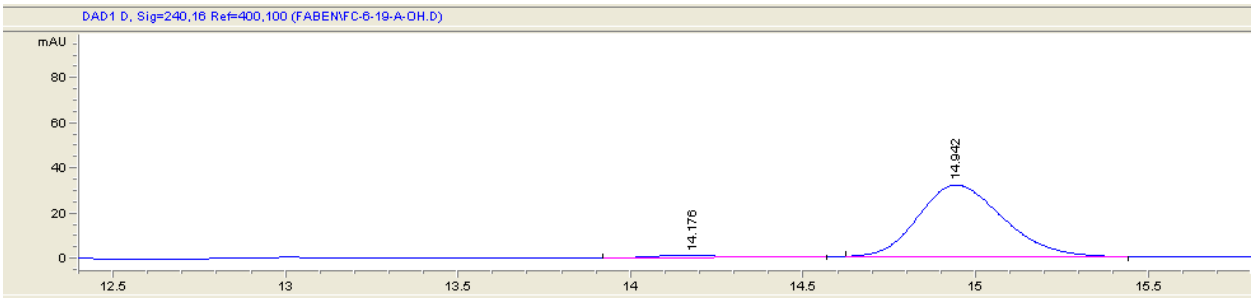
File Information	
LC-File	FC-5-86-A-OH-REEEE.D
File Path	C:\CHEM32\1\DATA\FABEN\
Date	27-Sep-16, 12:51:35
Sample	FC-5-86-A-OH-REEEE

#	Time	Area	Height	Width	Area%	Symmetry
1	13.068	552.2	38.8	0.2201	16.709	0.83
2	13.485	1018.9	64.6	0.2441	30.828	0.812
3	13.899	657.3	37.8	0.2611	19.887	0.706
4	14.953	1076.6	58.5	0.2806	32.576	0.784



(*S*,*S*)-**3i**

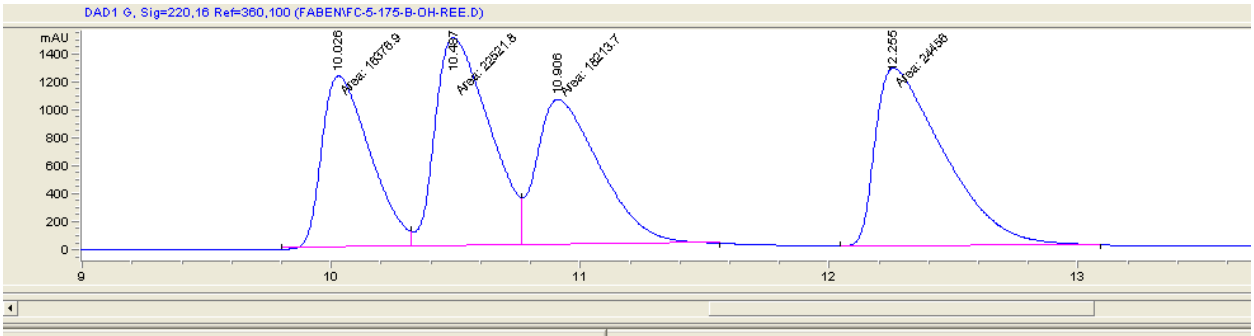
Enantiomerically Pure



File Information	
LC-File	FC-6-19-A-OH.D
File Path	C:\CHEM32\1\DATA\FABEN\

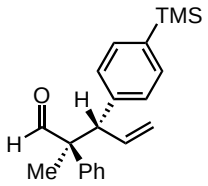
#	Time	Area	Height	Width	Area%	Symmetry
1	14.176	24.1	1.2	0.2391	4.129	0.745
2	14.942	559.9	32.1	0.2663	95.871	0.779

Racemic



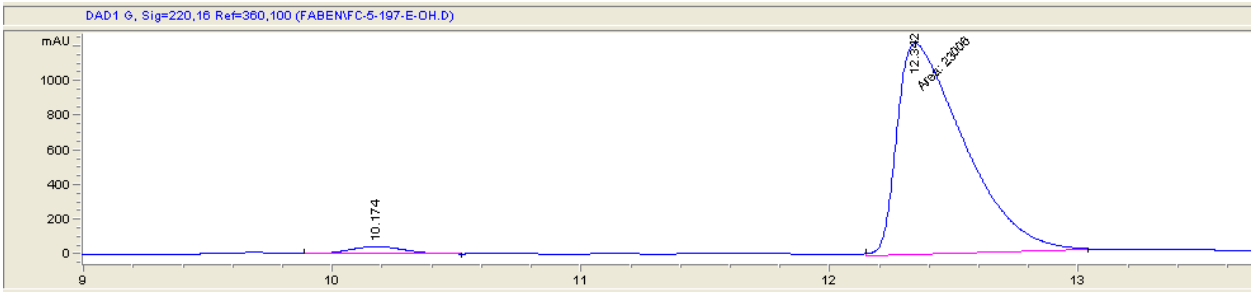
File Information	
LC-File	FC-5-175-B-OH-REE.D
File Path	C:\CHEM32\1\DATA\FABEN\
Date	07-Sep-16, 17:29:29
Sample	FC-5-175-B-OH-REE

#	Time	Area	Height	Width	Area%	Symmetry
1	10.026	16376.9	1221.2	0.2235	20.078	0.512
2	10.487	22521.8	1483.6	0.253	27.611	0.495
3	10.906	18213.7	1036.8	0.2928	22.329	0.487
4	12.255	24456	1275	0.3197	29.982	0.346



(*S*,*S*)-**3j**

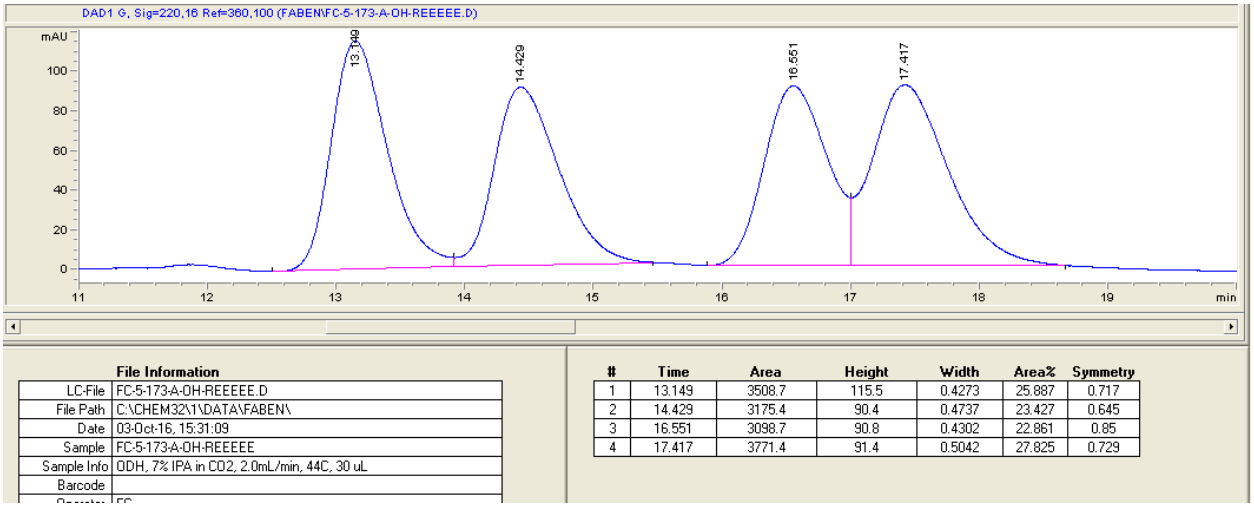
Enantiomerically Pure



File Information	
LC-File	FC-5-197-E-OH.D
File Path	C:\CHEM32\1\DATA\FABEN\

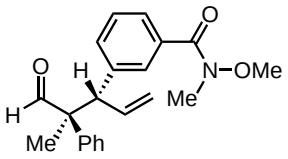
#	Time	Area	Height	Width	Area%	Symmetry
1	10.174	705.2	43.4	0.2516	2.974	0.945
2	12.342	23006	1217.7	0.3149	97.026	0.359

Racemic



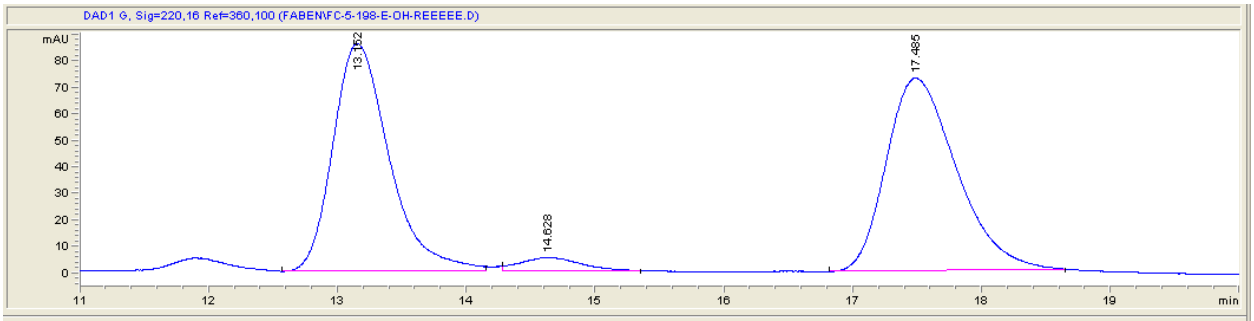
File Information	
LC-File	FC-5-173-A-OH-REEEEE.D
File Path	C:\CHEM32\1\DATA\FABEN\
Date	03-Oct-16, 15:31:09
Sample	FC-5-173-A-OH-REEEEE
Sample Info	ODH, 7% IPA in CO2, 2.0mL/min, 44C, 30 uL
Barcode	

#	Time	Area	Height	Width	Area%	Symmetry
1	13.149	3508.7	115.5	0.4273	25.887	0.717
2	14.429	3175.4	90.4	0.4737	23.427	0.645
3	16.551	3098.7	90.8	0.4302	22.861	0.85
4	17.417	3771.4	91.4	0.5042	27.825	0.729



(*S*,*S*)-**3k**

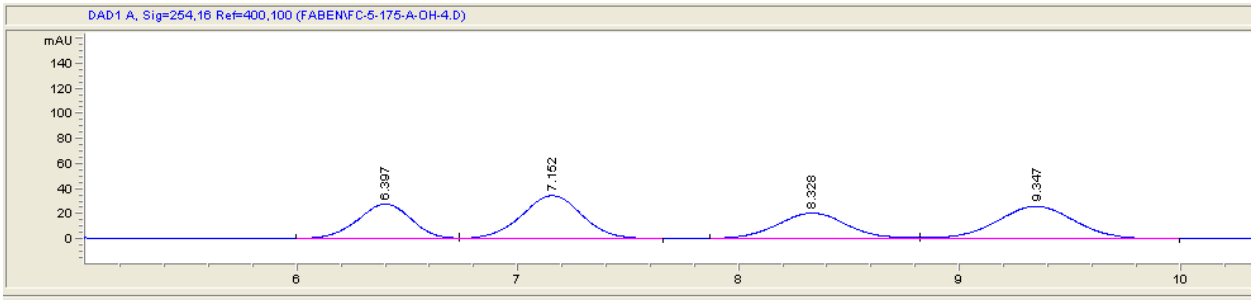
Enantiomerically Pure



File Information	
LC-File	FC-5-198-E-OH-REEEEE.D
File Path	C:\CHEM32\1\DATA\FABEN\
Date	03-Oct-16, 15:06:50

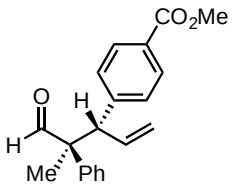
#	Time	Area	Height	Width	Area%	Symmetry
1	13.152	2617.8	86.1	0.4439	47.067	0.722
2	14.628	170.2	5.1	0.393	3.059	0.781
3	17.485	2773.9	72.9	0.51	49.874	0.675

Racemic



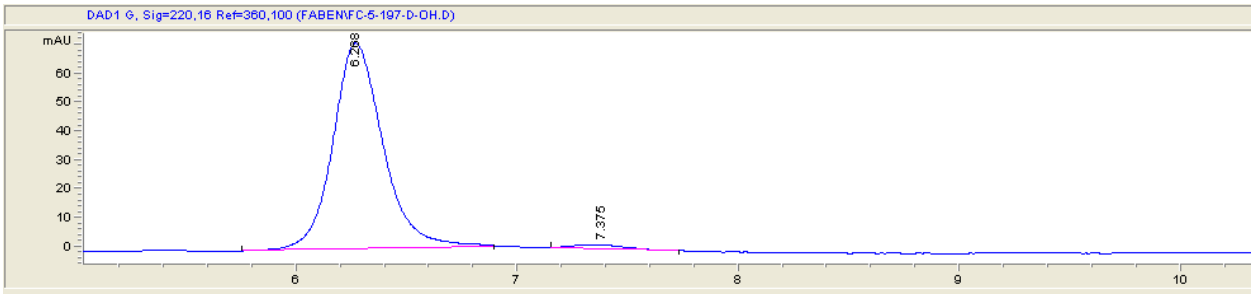
File Information	
LC-File	FC-5-175-A-OH-4.D
File Path	C:\CHEM32\1\DATA\FABEN\
Date	07-May-16, 17:20:00
Sample	FC-5-175-A-OH-4

#	Time	Area	Height	Width	Area%	Symmetry
1	6.397	466.9	27.5	0.2508	20.903	1.062
2	7.152	660.8	34.3	0.2856	29.586	0.987
3	8.328	461.2	20.5	0.2951	20.648	0.927
4	9.347	644.7	25.8	0.307	28.863	1.066



(*S*,*S*)-**3l**

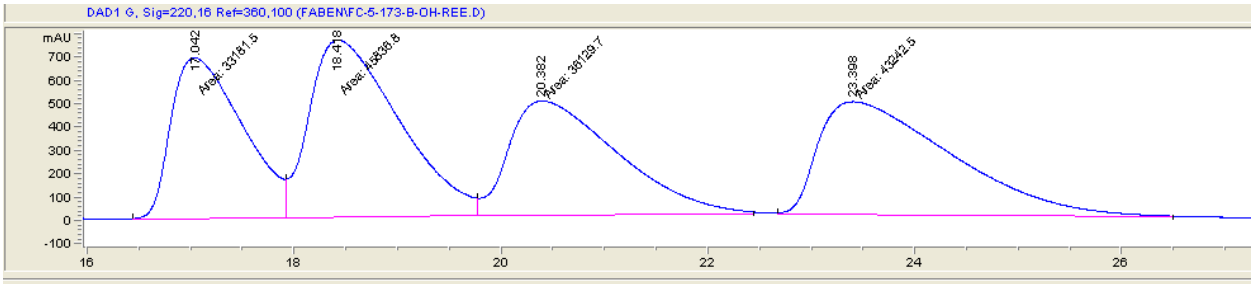
Enantiomerically Pure



File Information	
LC-File	FC-5-197-D-OH.D
File Path	C:\CHEM32\1\DATA\FABEN\

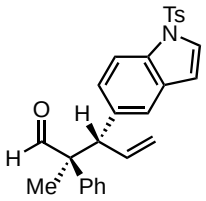
#	Time	Area	Height	Width	Area%	Symmetry
1	6.268	1139.5	71.5	0.242	98.114	0.786
2	7.375	21.9	1.4	0.1835	1.886	0.931

Racemic



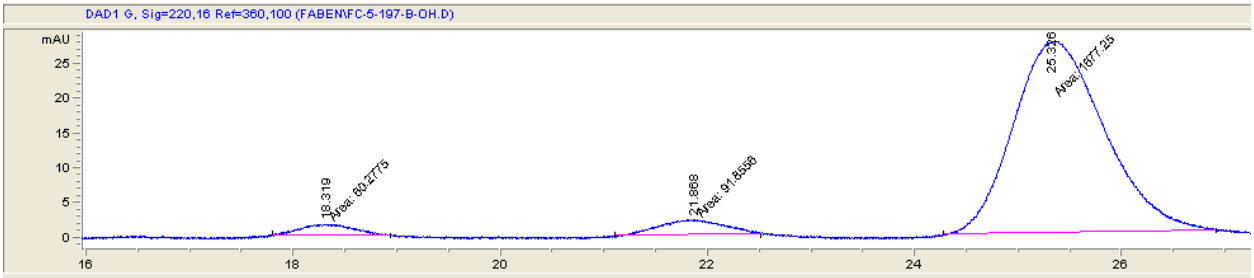
File Information	
LC-File	FC-5-173-B-OH-REE.D
File Path	C:\CHEM32\1\DATA\FABEN\
Date	10-Sep-16, 12:39:53
Sample	FC-5-173-B-OH-REE

#	Time	Area	Height	Width	Area%	Symmetry
1	17.042	33181.5	690.4	0.801	20.949	0
2	18.418	45836.8	761.5	1.0032	28.939	0.465
3	20.382	36129.7	492.1	1.2236	22.811	0.418
4	23.398	43242.5	484.5	1.4874	27.301	0.343



(*S*,*S*)-**3m**

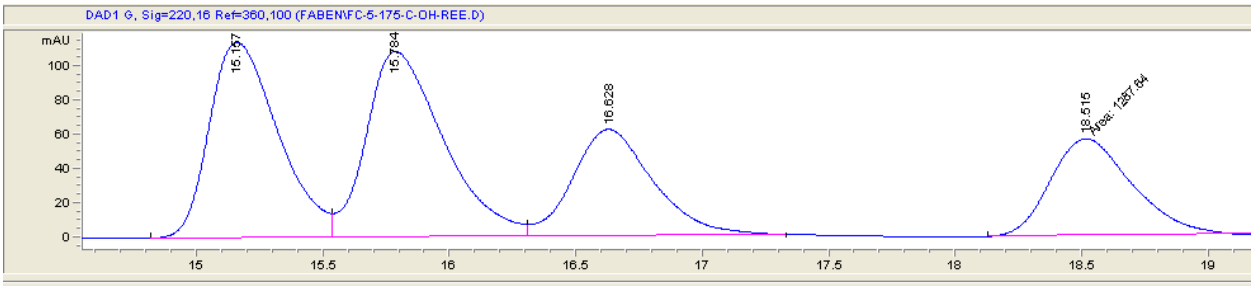
Enantiomerically Pure



File Information	
LC-File	FC-5-197-B-OH.D
File Path	C:\CHEM32\1\DATA\FABEN\
Date	10-Sep-16, 12:06:50

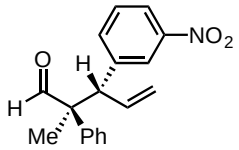
#	Time	Area	Height	Width	Area%	Symmetry
1	18.319	60.3	1.7	0.6074	3.295	0.885
2	21.868	91.9	2.1	0.7281	5.021	1.137
3	25.326	1677.2	27.4	1.0191	91.684	0.739

Racemic



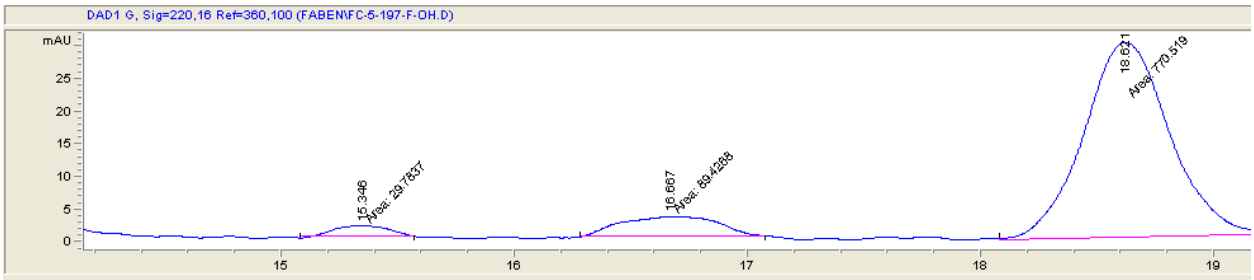
File Information	
LC-File	FC-5-175-C-OH-REE.D
File Path	C:\CHEM32\1\DATA\FABEN\
Date	10-Sep-16, 14:41:05
Sample	FC-5-175-C-OH-REE

#	Time	Area	Height	Width	Area%	Symmetry
1	15.157	2160.1	114.2	0.2946	30.213	0.634
2	15.784	2309.7	108.6	0.3261	32.306	0.57
3	16.628	1392.1	62.4	0.3343	19.471	0.759
4	18.515	1287.6	56.8	0.3777	18.010	0.741



(*S*,*S*)-**3n**

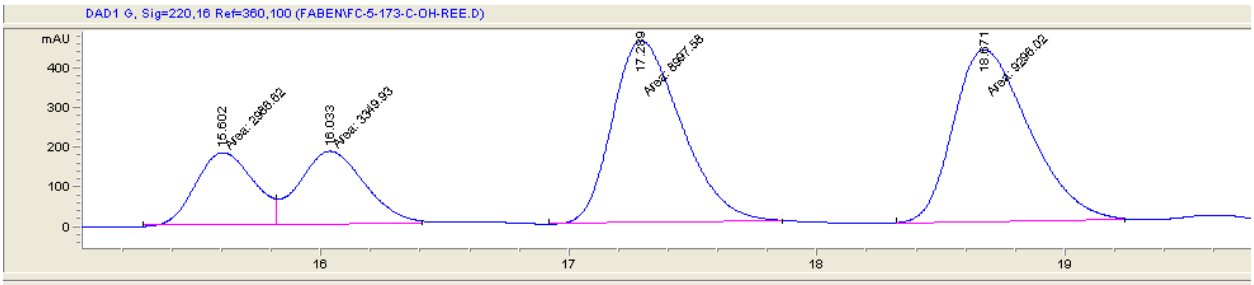
Enantiomerically Pure



File Information	
LC-File	FC-5-197-F-OH.D
File Path	C:\CHEM32\1\DATA\FABEN\
Date	10-Sep-16, 14:15:25

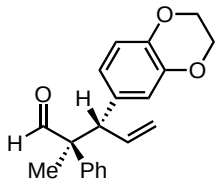
#	Time	Area	Height	Width	Area%	Symmetry
1	15.346	29.8	1.7	0.2864	3.347	1.004
2	16.667	89.4	3	0.4934	10.051	1.059
3	18.621	770.5	29.8	0.4303	86.601	0.921

Racemic



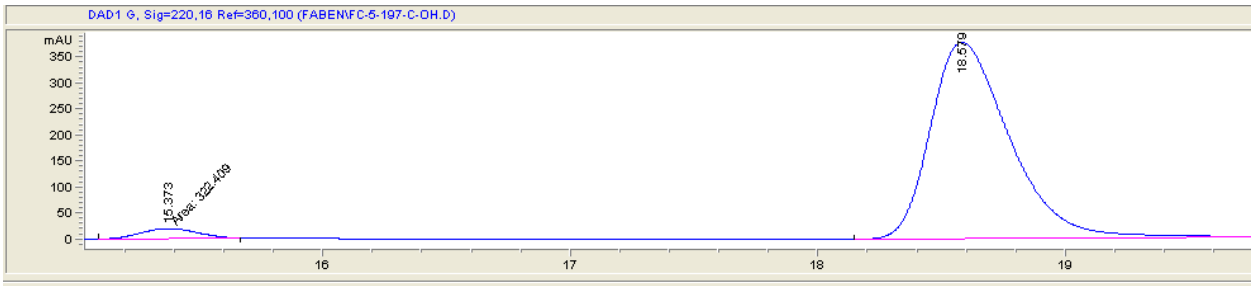
File Information	
LC-File	FC-5-173-C-OH-REE.D
File Path	C:\CHEM32\1\DATA\FABEN\
Date	10-Sep-16, 13:49:53
Sample	FC-5-173-C-OH-REE

#	Time	Area	Height	Width	Area%	Symmetry
1	15.602	2986.6	182.4	0.2729	12.126	0.838
2	16.033	3349.9	183.4	0.3044	13.601	0.851
3	17.289	8997.6	459.9	0.326	36.531	0.694
4	18.671	9296	435.2	0.356	37.742	0.658



(*S*,*S*)-**3o**

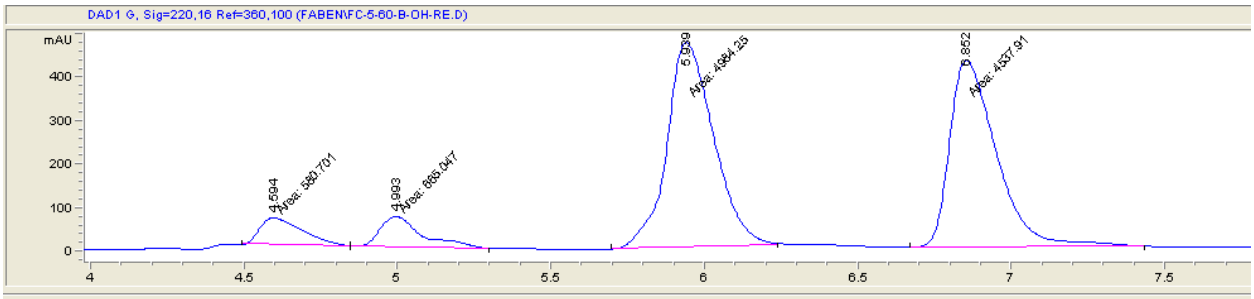
Enantiomerically Pure



File Information	
LC-File	FC-5-197-C-OH.D
File Path	C:\CHEM32\1\DATA\FABEN\

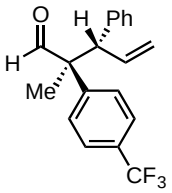
#	Time	Area	Height	Width	Area%	Symmetry
1	15.373	322.4	19.9	0.2694	3.650	0.952
2	18.579	8511.3	378.6	0.3443	96.350	0.607

Racemic



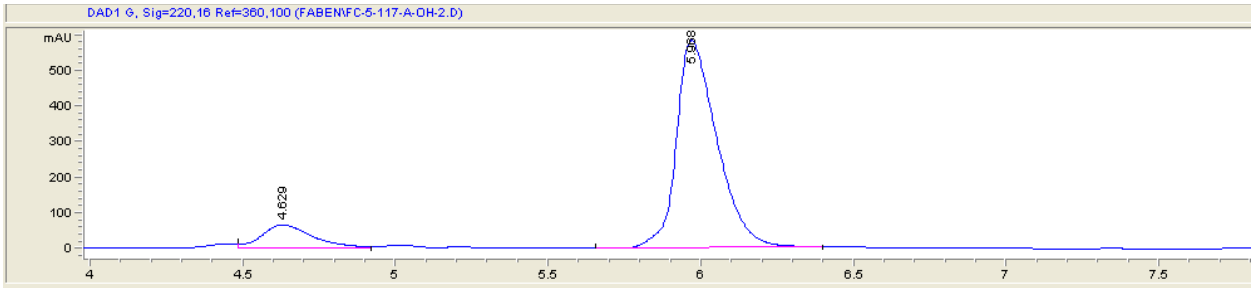
File Information	
LC-File	FC-5-60-B-OH-RE.D
File Path	C:\CHEM32\1\DATA\FABEN\
Date	02-Sep-16, 14:17:38
Sample	FC-5-60-B-OH-RE

#	Time	Area	Height	Width	Area%	Symmetry
1	4.594	580.7	60.9	0.159	5.393	0.458
2	4.993	665	69.4	0.1596	6.176	0.56
3	5.939	4984.2	469.1	0.1771	46.288	0.702
4	6.852	4537.9	428.8	0.1764	42.143	0.54



(*S*,*S*)-**3p**

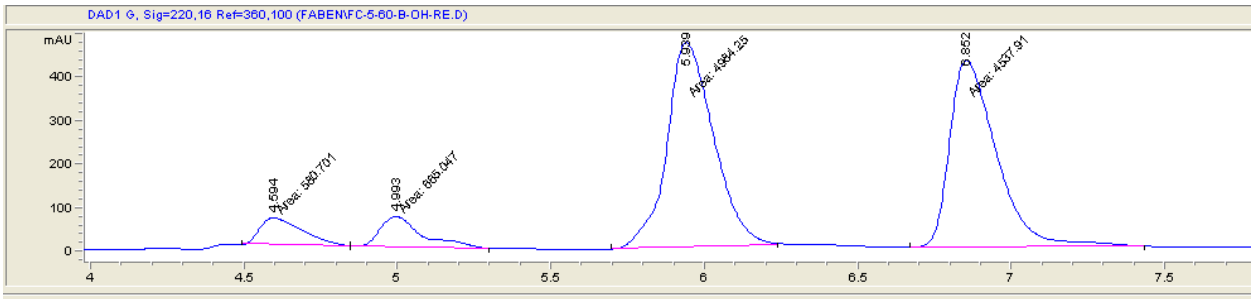
Enantiomerically Pure



File Information	
LC-File	FC-5-117-A-OH-2.D
File Path	C:\CHEM32\1\DATA\FABEN\

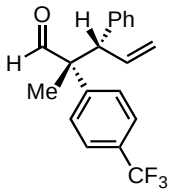
#	Time	Area	Height	Width	Area%	Symmetry
1	4.629	803.3	67	0.1789	12.858	0.654
2	5.968	5444.1	583.2	0.1409	87.142	0.58

Racemic



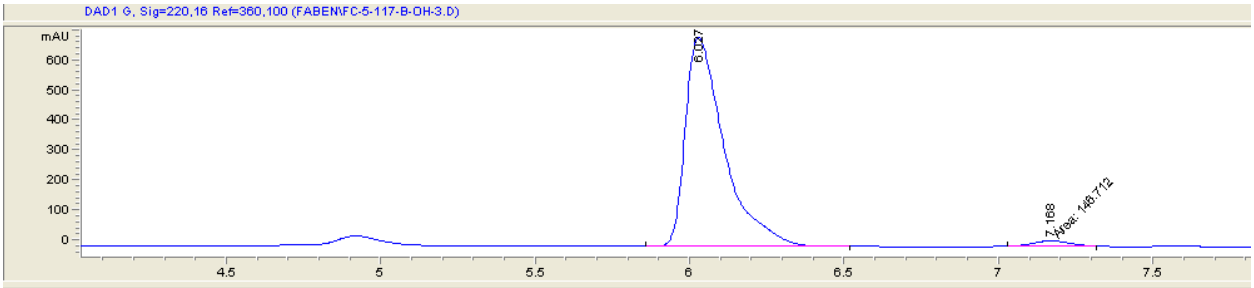
File Information	
LC-File	FC-5-60-B-OH-RE.D
File Path	C:\CHEM32\1\DATA\FABEN\
Date	02-Sep-16, 14:17:38
Sample	FC-5-60-B-OH-RE

#	Time	Area	Height	Width	Area%	Symmetry
1	4.594	580.7	60.9	0.159	5.393	0.458
2	4.993	665	69.4	0.1596	6.176	0.56
3	5.939	4984.2	469.1	0.1771	46.288	0.702
4	6.852	4537.9	428.8	0.1764	42.143	0.54



(*R*,*S*)-**3p**

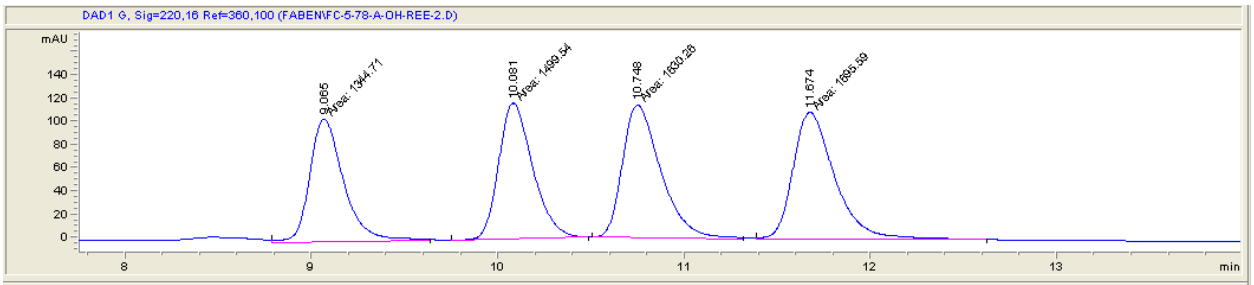
Enantiomerically Pure



File Information	
LC-File	FC-5-117-B-OH-3.D
File Path	C:\CHEM32\1\DATA\FABEN\

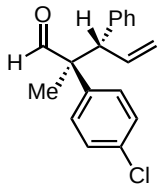
#	Time	Area	Height	Width	Area%	Symmetry
1	6.027	6117.4	695.4	0.1326	97.658	0.466
2	7.168	146.7	17.8	0.1374	2.342	0.941

Racemic



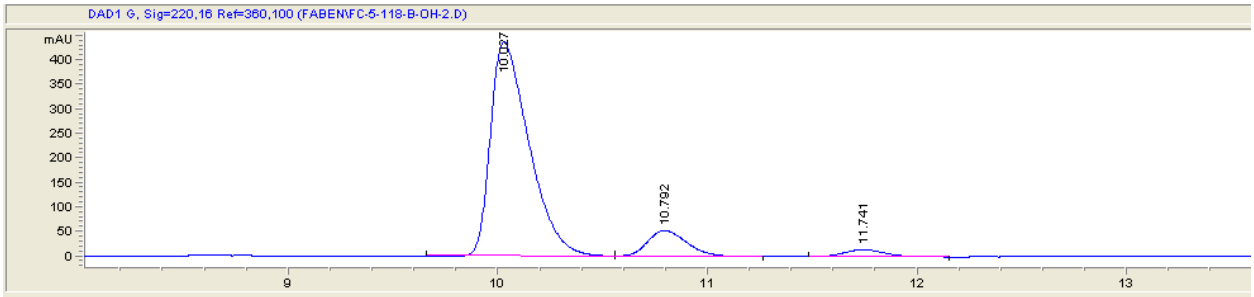
File Information	
LC-File	FC-5-78-A-OH-REE-2.D
File Path	C:\CHEM32\1\DATA\FABEN\
Date	27-Sep-16, 12:04:59
Sample	FC-5-78-A-OH-REE-2

#	Time	Area	Height	Width	Area%	Symmetry
1	9.065	1344.7	105.8	0.2118	21.794	0.701
2	10.081	1499.5	117.1	0.2134	24.303	0.721
3	10.748	1630.3	113.9	0.2386	26.422	0.624
4	11.674	1695.6	109.1	0.259	27.481	0.664



(*S*,*S*)-**3q**

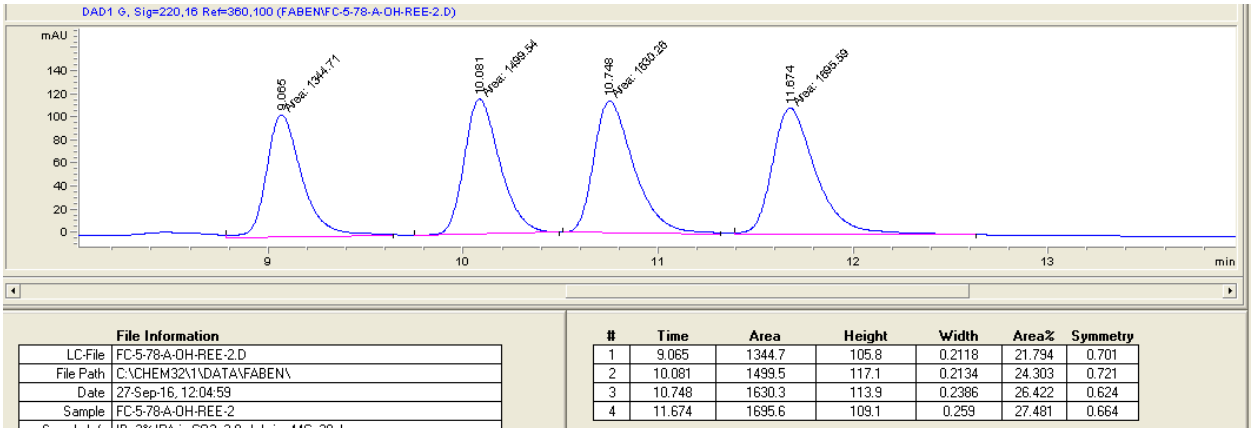
Enantiomerically Pure



File Information	
LC-File	FC-5-118-B-OH-2.D
File Path	C:\CHEM32\1\DATA\FABEN\
Date	27-Sep-16, 11:28:44

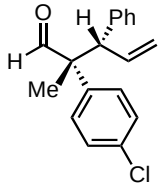
#	Time	Area	Height	Width	Area%	Symmetry
1	10.027	5611.2	436.9	0.1949	86.164	0.508
2	10.792	701.3	53.1	0.2059	10.769	0.724
3	11.741	199.8	14.5	0.2109	3.068	0.866

Racemic



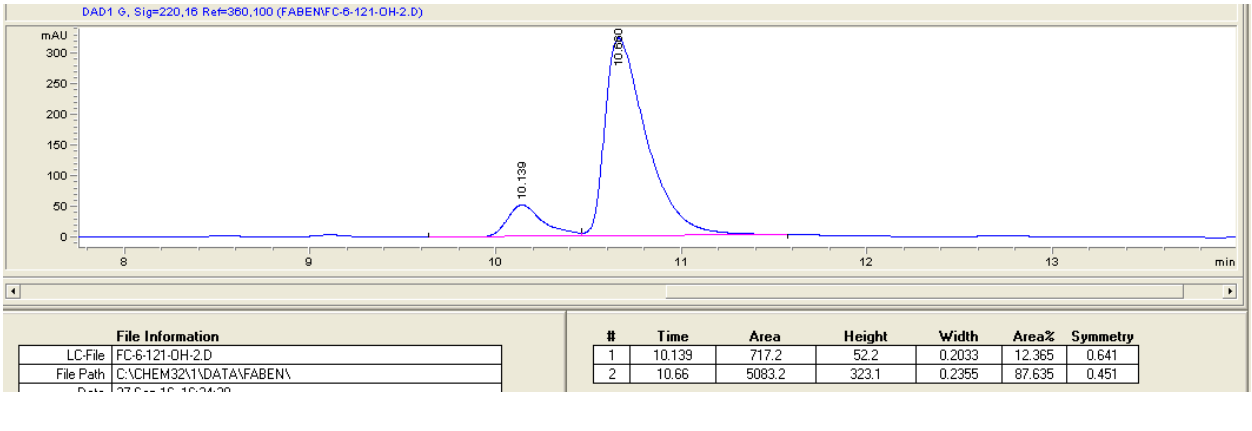
File Information	
LC-File	FC-5-78-A-OH-REE-2.D
File Path	C:\CHEM32\1\DATA\FABEN\
Date	27-Sep-16, 12:04:59
Sample	FC-5-78-A-OH-REE-2

#	Time	Area	Height	Width	Area%	Symmetry
1	9.065	1344.7	105.8	0.2118	21.794	0.701
2	10.081	1499.5	117.1	0.2134	24.303	0.721
3	10.748	1630.3	113.9	0.2386	26.422	0.624
4	11.674	1695.6	109.1	0.259	27.481	0.664



(*R*,*S*)-**3q**

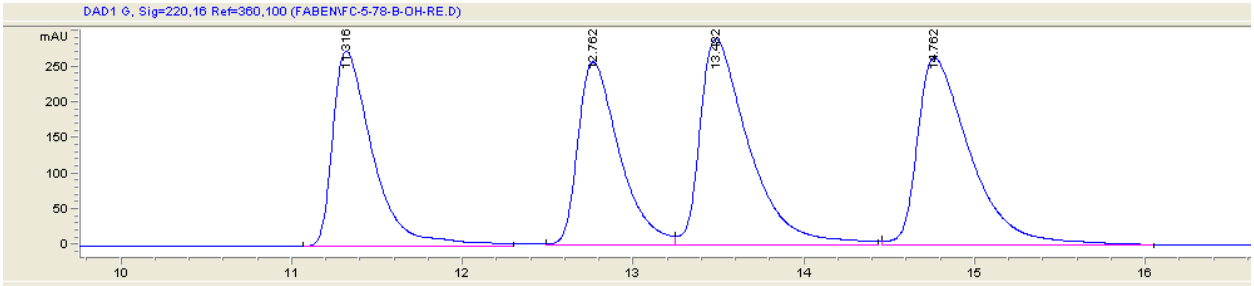
Enantiomerically Pure



File Information	
LC-File	FC-6-121-OH-2.D
File Path	C:\CHEM32\1\DATA\FABEN\

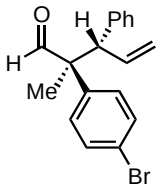
#	Time	Area	Height	Width	Area%	Symmetry
1	10.139	717.2	52.2	0.2033	12.365	0.641
2	10.66	5083.2	323.1	0.2355	87.635	0.451

Racemic



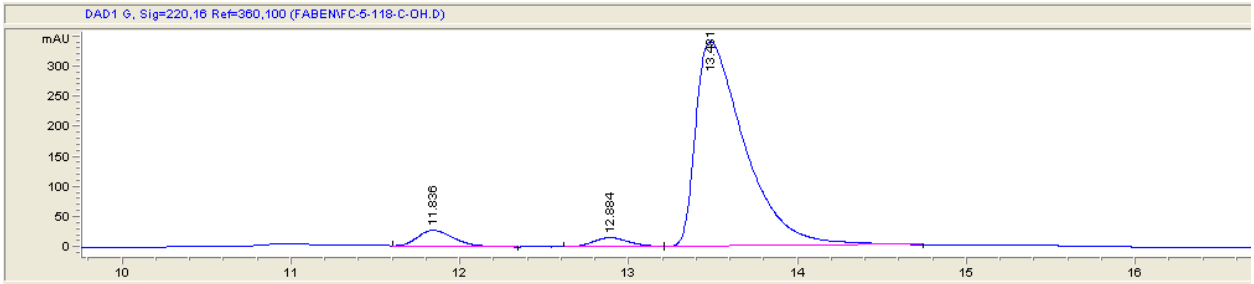
File Information	
LC-File	FC-5-78-B-OH-RE.D
File Path	C:\CHEM32\1\DATA\FABEN\
Date	02-Sep-16, 16:29:24
Sample	FC-5-78-B-OH-RE

#	Time	Area	Height	Width	Area%	Symmetry
1	11.316	4506.4	273.9	0.25	22.047	0.455
2	12.762	4395.4	258.2	0.2586	21.504	0.536
3	13.482	5854.7	289.6	0.2998	28.643	0.439
4	14.762	5683.6	262.9	0.3262	27.806	0.441



(*S*,*S*)-**3r**

Enantiomerically Pure



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File Path	C:\CHEM32\1\DATA\FABEN\
Date	02-Sep-16, 16:07:08

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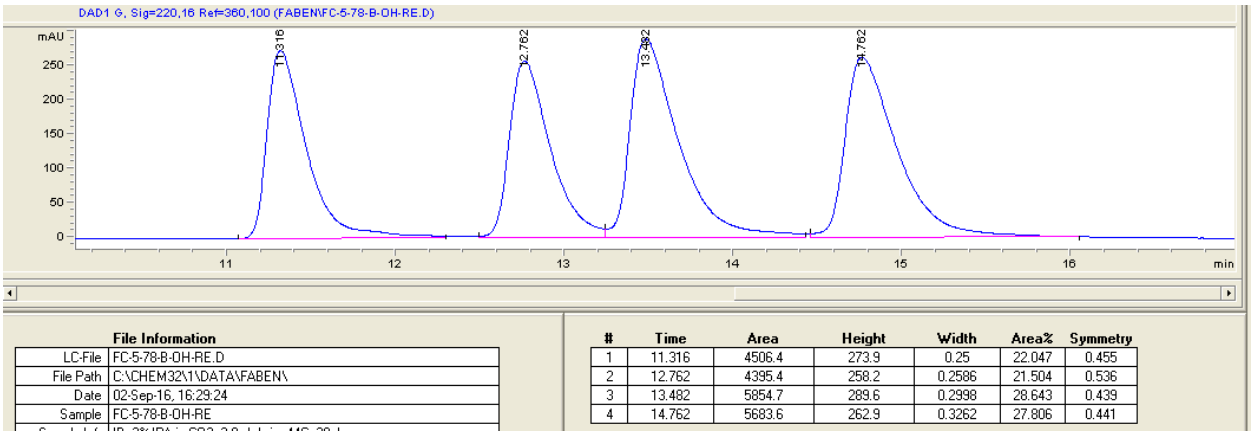
1	11.836	427.7	27.5	0.2371	5.667	0.734
2	12.884	215.8	14.9	0.2235	2.860	0.841
3	13.481	6903.5	339.9	0.3069	91.473	0.388

Racemic



File Information	
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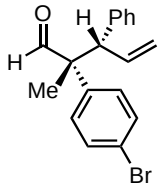
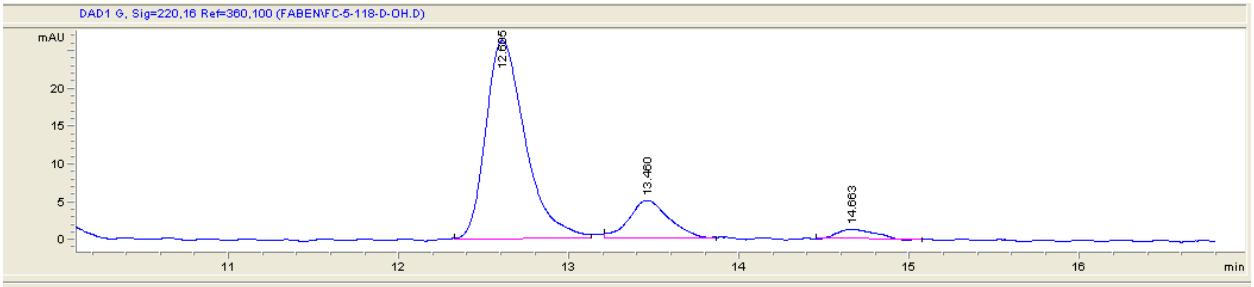
File Path	C:\CHEM32\1\DATA\FABEN\
Date	02-Sep-16, 16:29:24
Sample	FC-5-78-B-OH-RE

#	Time	Area	Height	Width	Area%	Symmetry
1	11.316	4506.4	273.9	0.25	22.047	0.455
2	12.762	4395.4	258.2	0.2586	21.504	0.536
3	13.482	5854.7	289.6	0.2998	28.643	0.439
4	14.762	5683.6	262.9	0.3262	27.806	0.441



(*R*,*S*)-**3r**

Enantiomerically Pure



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LC-File	FC-5-118-D-OH.D
File Path	C:\CHEM32\1\DATA\FABEN\
Date	27-Sep-16, 15:23:46

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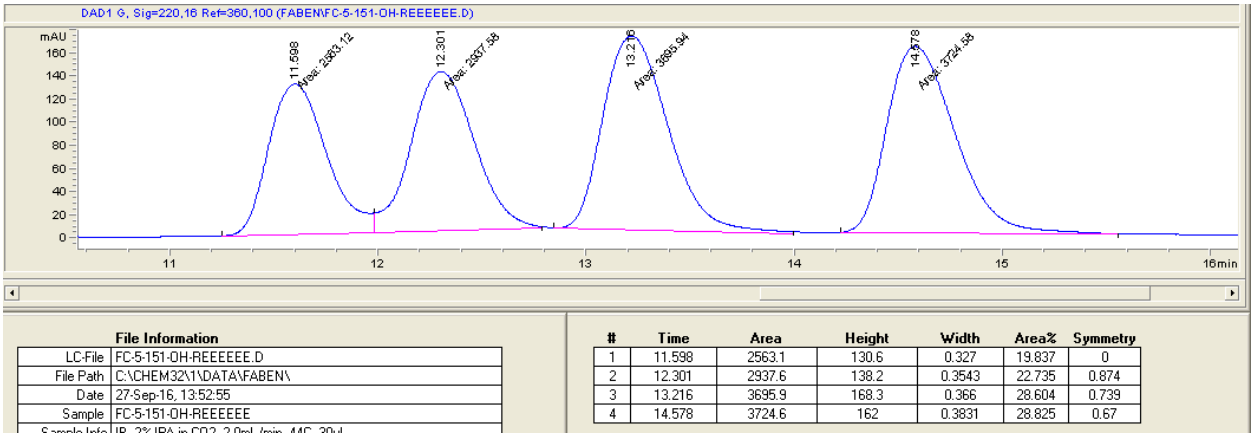
1	12.605	426.2	26.4	0.2455	79.866	0.661
2	13.46	85.7	5.1	0.2436	16.054	0.833
3	14.663	21.8	1.3	0.1975	4.080	0.623

Racemic



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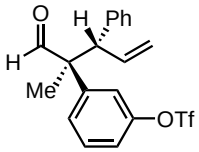
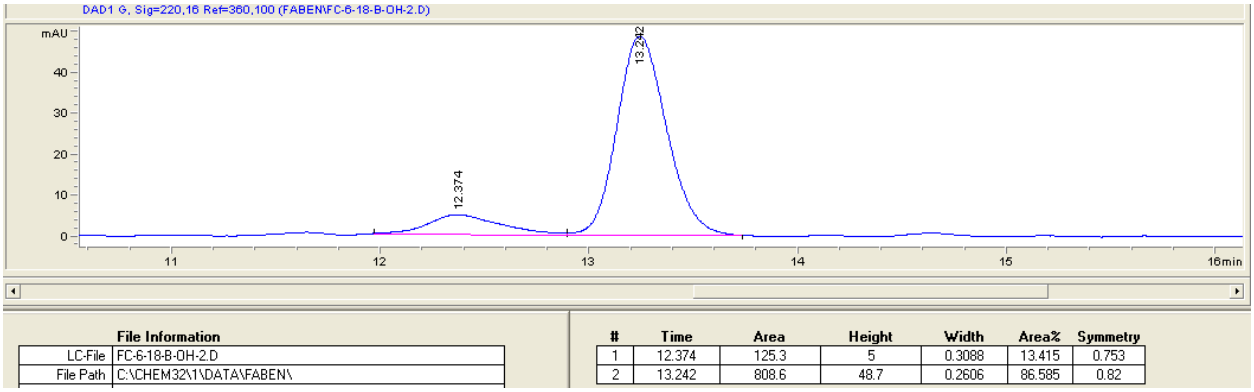
File Path	C:\CHEM32\1\DATA\FABEN\
Date	27-Sep-16, 13:52:55
Sample	FC-5-151-OH-REEEEEE

#	Time	Area	Height	Width	Area%	Symmetry
1	11.598	2563.1	130.6	0.327	19.837	0
2	12.301	2937.6	138.2	0.3543	22.735	0.874
3	13.216	3695.9	168.3	0.366	28.604	0.739
4	14.578	3724.6	162	0.3831	28.825	0.67



(*S*,*S*)-**3s**

Enantiomerically Pure



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#	Time	Area	Height	Width	Area%	Symmetry
1	12.374	125.3	5	0.3088	13.415	0.753
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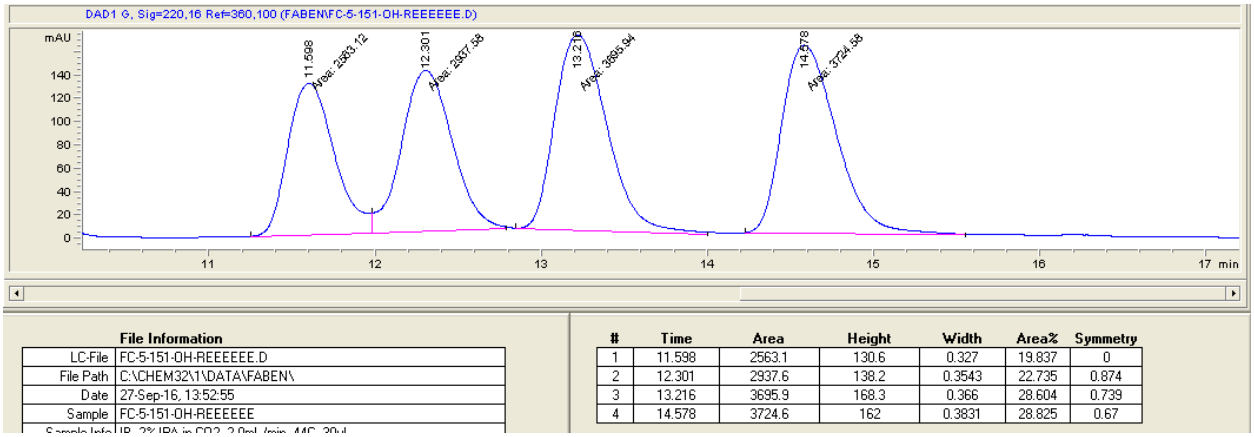
Racemic



File Information	
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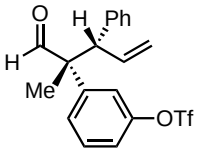
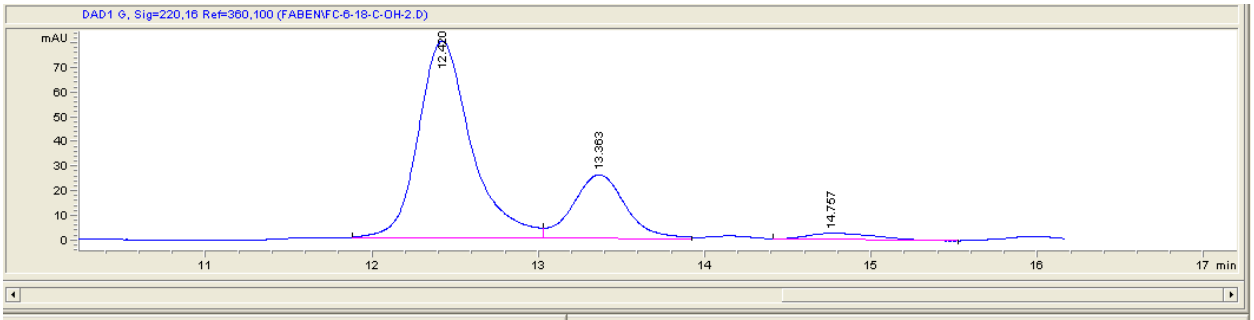
File Path	C:\CHEM32\1\DATA\FABEN\
Date	27-Sep-16, 13:52:55
Sample	FC-5-151-OH-REEEEEE

#	Time	Area	Height	Width	Area%	Symmetry
1	11.598	2563.1	130.6	0.327	19.837	0
2	12.301	2937.6	138.2	0.3543	22.735	0.874
3	13.216	3695.9	168.3	0.366	28.604	0.739
4	14.578	3724.6	162	0.3831	28.825	0.67



(*R*,*S*)-**3s**

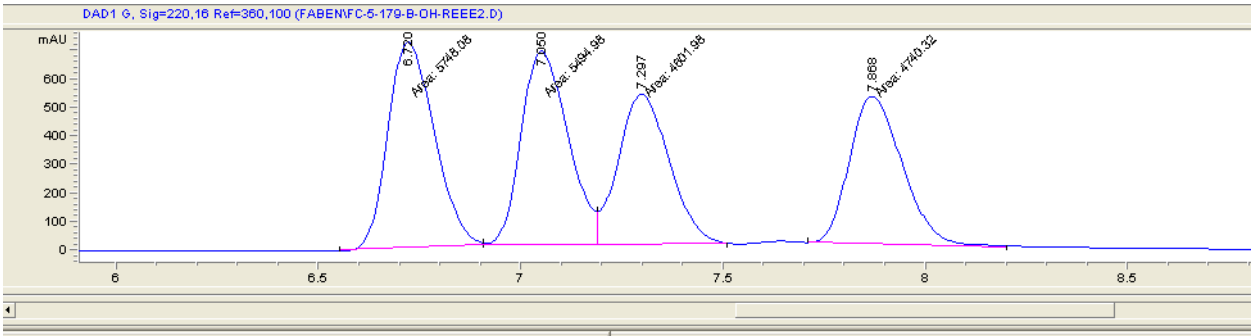
Enantiomerically Pure



File Information	
LC-File	FC-6-18-C-OH-2.D
File Path	C:\CHEM32\1\DATA\FABEN\
Date	27-Sep-16, 13:33:45

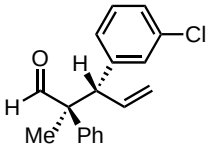
#	Time	Area	Height	Width	Area%	Symmetry
1	12.42	1775.5	80.2	0.3353	72.741	0.772
2	13.363	579.4	26.1	0.336	23.738	0.939
3	14.757	85.9	2.8	0.36	3.521	0.58

Racemic



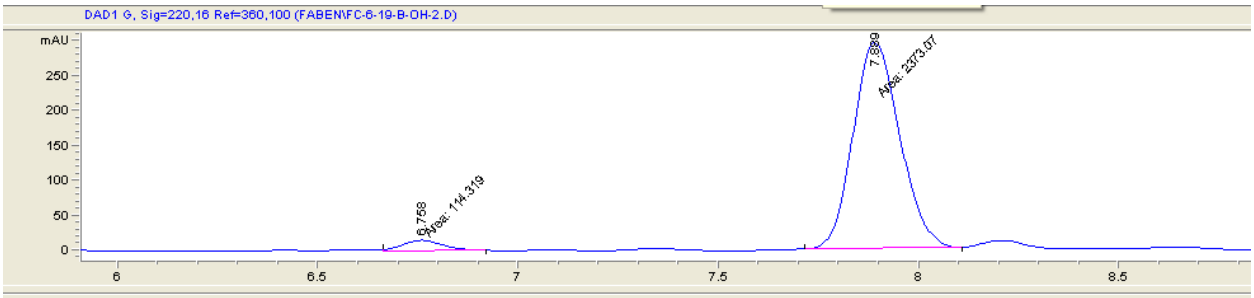
File Information	
LC-File	FC-5-179-B-OH-REEE2.D
File Path	C:\CHEM32\1\DATA\FABEN\
Date	19-Sep-16, 09:24:45
Sample	FC-5-179-B-OH-REEE2

#	Time	Area	Height	Width	Area%	Symmetry
1	6.72	5748.1	721.2	0.1328	27.923	0.75
2	7.05	5495	679.4	0.1348	26.694	0.732
3	7.297	4602	525.3	0.146	22.356	0.811
4	7.868	4740.3	516.7	0.1529	23.028	0.722



(*S*,*S*)-**3t**

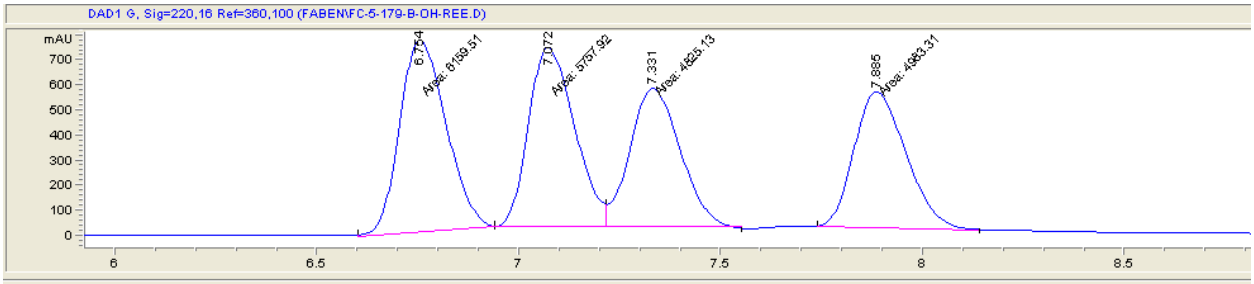
Enantiomerically Pure



File Information	
LC-File	FC-6-19-B-OH-2.D
File Path	C:\CHEM32\1\DATA\FABEN\

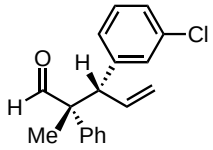
#	Time	Area	Height	Width	Area%	Symmetry
1	6.758	114.3	16	0.1188	4.596	0.98
2	7.889	2373.1	293.9	0.1346	95.404	0.829

Racemic



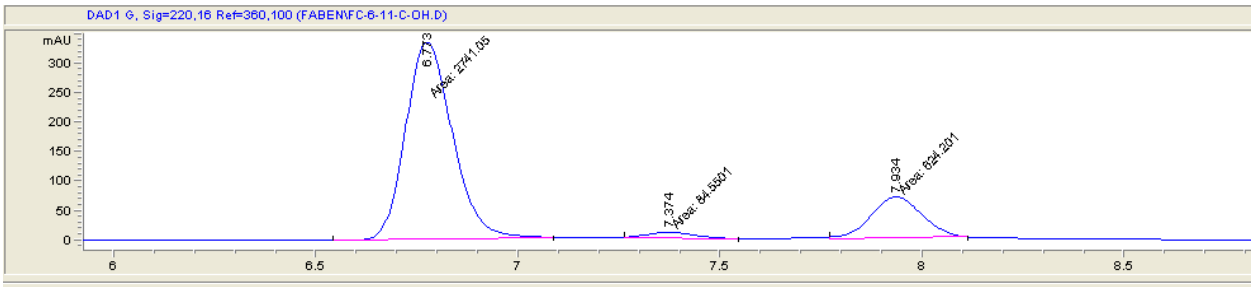
File Information	
LC-File	FC-5-179-B-OH-REE.D
File Path	C:\CHEM32\1\DATA\FABEN\
Date	10-Sep-16, 11:47:33
Sample	FC-5-179-B-OH-REE

#	Time	Area	Height	Width	Area%	Symmetry
1	6.754	6159.5	769.1	0.1335	28.351	0.759
2	7.072	5757.9	718.1	0.1336	26.503	0.723
3	7.331	4825.1	555.6	0.1447	22.209	0.806
4	7.885	4983.3	545.7	0.1522	22.937	0.736



(*R*,*S*)-**3t**

Enantiomerically Pure



File Information	
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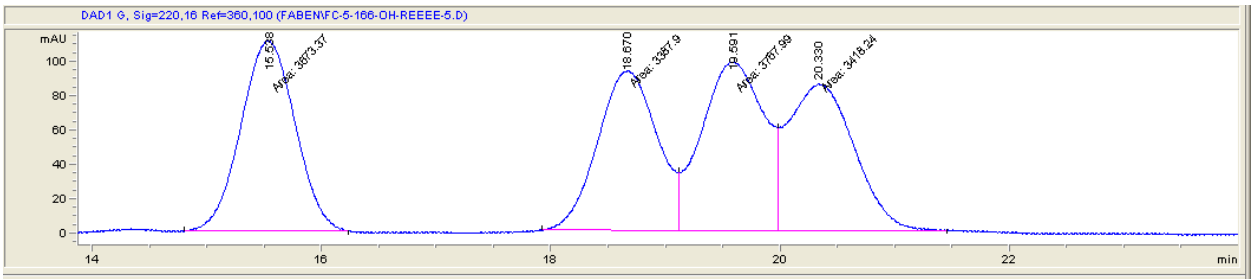
File Path	C:\CHEM32\1\DATA\FABEN\
Date	10-Sep-16, 11:33:40

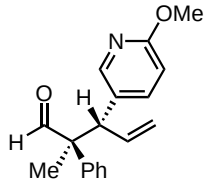
#	Time	Area	Height	Width	Area%	Symmetry
1	6.773	2741.1	335.6	0.1361	79.455	0.799
2	7.374	84.6	9.9	0.1417	2.451	0.772
3	7.934	624.2	70.1	0.1483	18.094	0.934

Racemic



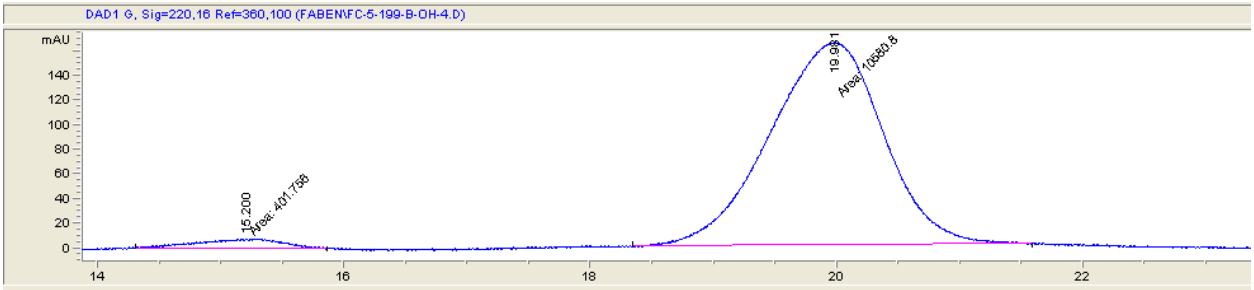
File Information	
LC-File	FC-5-166-OH-REEEE-5.D
File Path	C:\CHEM32\1\DATA\FABEN\
Date	16-Sep-16, 11:53:43
Sample	FC-5-166-OH-REEEE-5

#	Time	Area	Height	Width	Area%	Symmetry
1	15.538	3673.4	110.9	0.5521	25.783	1.06
2	18.67	3387.9	93.2	0.6056	23.779	0
3	19.591	3768	98.6	0.6371	26.447	0
4	20.33	3418.2	85.7	0.6645	23.992	0.774



(*S*,*S*)-**3u**

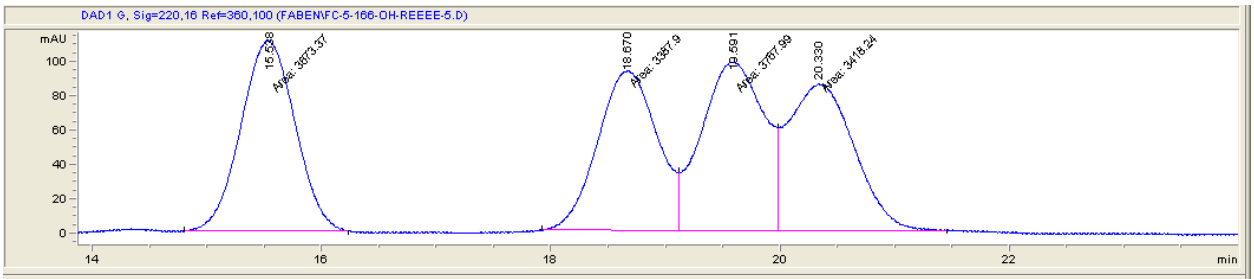
Enantiomerically Pure



File Information	
LC-File	FC-5-199-B-OH-4.D
File Path	C:\CHEM32\1\DATA\FABEN\

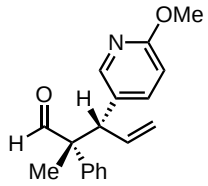
#	Time	Area	Height	Width	Area%	Symmetry
1	15.2	401.8	8.2	0.8198	3.658	1.369
2	19.981	10580.8	165	1.0691	96.342	1.271

Racemic



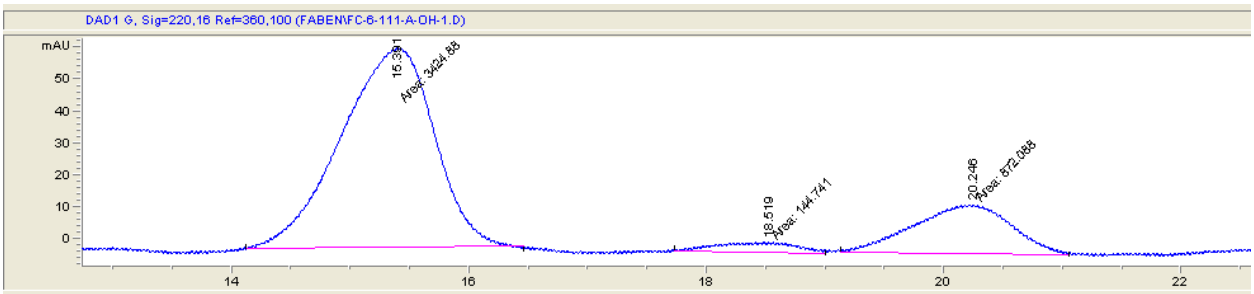
File Information	
LC-File	FC-5-166-OH-REEEE-5.D
File Path	C:\CHEM32\1\DATA\FABEN\
Date	16-Sep-16, 11:53:43
Sample	FC-5-166-OH-REEEE-5

#	Time	Area	Height	Width	Area%	Symmetry
1	15.538	3673.4	110.9	0.5521	25.783	1.06
2	18.67	3387.9	93.2	0.6056	23.779	0
3	19.591	3768	98.6	0.6371	26.447	0
4	20.33	3418.2	85.7	0.6645	23.992	0.774



(*R*,*S*)-**3u**

Enantiomerically Pure



File Information	
LC-File	FC-6-111-A-OH-1.D
File Path	C:\CHEM32\1\DATA\FABEN\
Date	16-Sep-16, 14:05:07

#	Time	Area	Height	Width	Area%	Symmetry
1	15.391	3424.9	62.7	0.9108	77.107	1.442
2	18.519	144.7	3.2	0.7516	3.259	1.539
3	20.246	872.1	15.3	0.9507	19.634	1.276

Appendix 2.4: Supporting Information for Chapter 2.4

Alkyne Hydroheteroarylation: Enantioselective Coupling of Indoles and Alkynes via Rh-Hydride Catalysis

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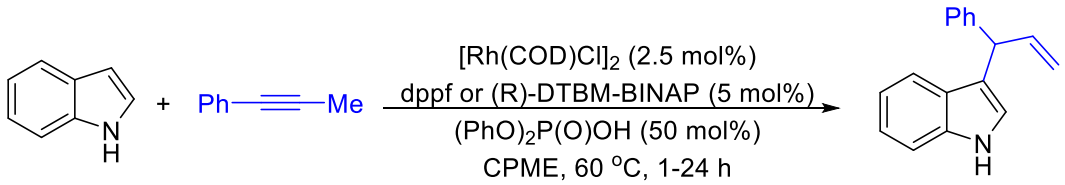
1. Materials and Methods

All syntheses were performed in oven-dried or flame-dried glassware under an atmosphere of N_2. Tetrahydrofuran, dichloromethane, toluene and diethyl ether were purified using an Innovative Technologies Pure Solv system, degassed by three freeze-pump-thaw cycles, and stored over 3 Å MS within an N_2 filled glove box. 1,4-Dioxane, 1,2-dimethoxyethane and dimethylsulfoxide were refluxed with CaH_2 and distilled prior to use. The molarity of organolithium reagents was determined by titration with *iso*-propanol/1,10-phenanthroline. Reactions were monitored either *via* gas chromatography using an Agilent Technologies 7890A GC system equipped with an Agilent Technologies 5975C inert XL EI/CI MSD or by analytical thin-layer chromatography on EMD Silica Gel 60 F_{254} plates. Visualization of the developed plates was performed under UV light (254 nm) or using either $KMnO_4$ or *p*-anisaldehyde stain. Column chromatography was performed with Silicycle Silia-P Flash Silica Gel using glass columns. Automated column chromatography was performed using either a Biotage SP1 or Teledyne Isco CombiFlash Rf 200 purification system. ^1H, ^{13}C, ^{19}F, and ^{31}P NMR spectra were recorded on a Bruker DRX-400 (400 MHz ^1H, 100 MHz ^{13}C, 376.5 MHz ^{19}F, 161.9 MHz ^{31}P), GN-500 (500 MHz ^1H, 125.7 MHz ^{13}C) or CRYO-500 (500 MHz ^1H, 125.7 MHz ^{13}C) spectrometer. ^1H NMR spectra were internally referenced to the residual solvent signal or TMS. ^{13}C NMR spectra were internally referenced to the residual solvent signal. Data for ^1H NMR are reported as follows: chemical shift (δ ppm), multiplicity (s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet, br = broad), coupling constant (Hz), integration. Data for ^{13}C NMR are reported in terms of chemical shift (□, ppm). Infrared spectra were obtained on a Thermo Scientific Nicolet iS5 FT-IR spectrometer equipped with an iD5 ATR accessory. High resolution mass spectra (HRMS) was performed by the University of California, Irvine Mass Spectrometry Center. All new compounds were characterized by ^1H NMR, ^{13}C NMR, HRMS, and optical rotation. For known compounds, we have cited the published characterization data that we used to compare to our synthesized compounds and we have included a ^1H NMR spectrum to establish purity of the isolated material.

2. Typical Procedure for Indole-Alkyne Coupling

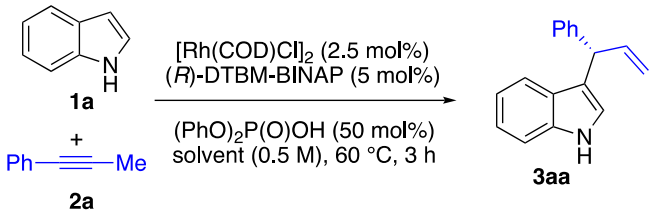


1a **2a** **3aa**

In a N_2-filled glovebox, $[Rh(COD)Cl]_2$ (1.2 mg, 0.0025 mmol), dppf (2.8 mg, 0.005 mmol) or (*R*)-DTBM-BINAP (6.0 mg, 0.005 mmol), diphenyl hydrogen phosphate (12.5 mg, 0.05 mmol), indole **1** (0.10 mmol), alkyne **2** (0.12 mmol) and CPME (0.2 mL) were added to a 1 dram vial. After heating the reaction mixture at 60 °C for 1-24 hours, the resulting solution was cooled to rt. The selectivity was determined by ^{1}H NMR analysis of the crude reaction mixture. The product **3** was isolated by flash column chromatography or preparatory TLC using hexanes/EtOAc.

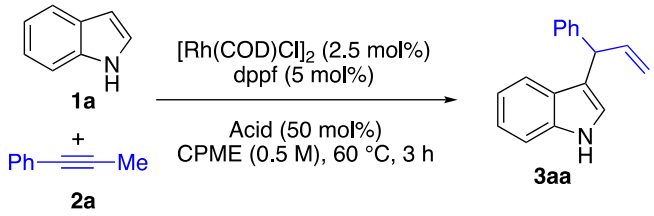
Preparative Scale Reaction: In a N_2-filled glovebox, $[Rh(COD)Cl]_2$ (12.3 mg, 0.025 mmol), (*R*)-DTBM-BINAP (59.6 mg, 0.05 mmol), diphenyl hydrogen phosphate (125.1 mg, 0.5 mmol), *N*-methyl indole **1b** (131.2 mg, 1.0 mmol), alkyne **2a** (151 μL, 0.12 mmol) and CPME (2 mL) were added to a 1 dram vial. After heating the reaction mixture at 60 °C for 24 hours, the resulting solution was cooled to rt. The selectivity was determined by ^{1}H NMR analysis of the crude reaction mixture. The product **3ba** was isolated by flash column chromatography using 2% ethyl acetate in hexanes as a yellow oil (228.8 mg, 0.93 mmol, 93% yield, 91% *ee*).

3. Evaluation of Solvents



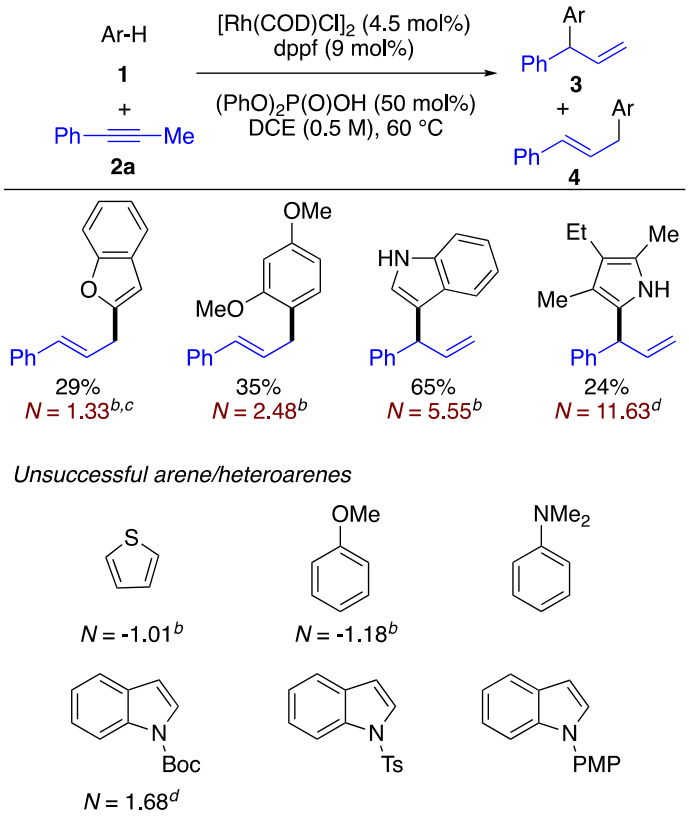
Solvent	NMR yield	*ee*	Solvent	NMR yield	*ee*
1,2-DCE	24%	nd	Ethyl acetate	74%	91%
Toluene	11%	nd	THF	52%	91%
Acetone	16%	nd	1,4-dioxane	73%	90%
MeOH	28%	nd	2-Me-THF	80%	92%
MeCN	24%	nd	1,2-DME	50%	92%
$MeNO_2$	42%	nd	**CPME**	**92%**	**91%**

Evaluation of Acids



Acid	NMR yield
TFA	6%
Benzoic Acid	< 5%
PTSA	60%
$(PhO)_2P(O)OH$	**90%**
$(BuO)_2P(O)OH$	27%

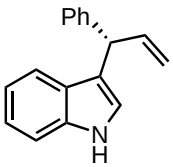
4. Alkyne Hydroarylation with Arenes of Various Nucleophilicities[a]



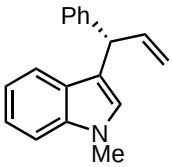
[a]**1** (0.1 mmol), **2a** (0.12 mmol), $[Rh(COD)Cl]_2$ (4.5 mol%), dppf (9.0 mol%), $(PhO)_2P(O)OH$ (50 mol%), DCE (0.2 mL), 60 °C, [b]Nucleophilicity in DCM. [c]Nucleophilicity of furan. [d]Nucleophilicity in MeCN.

In a N_2-filled glovebox, $[Rh(COD)Cl]_2$ (2.2 mg, 0.0045 mmol), dppf (5.0 mg, 0.009 mmol), diphenyl hydrogen phosphate (12.5 mg, 0.05 mmol), arene/heteroarene **1** (0.10 mmol), alkyne **2a** (25 μL, 0.12 mmol) and DCE (0.2 mL) were added to a 1 dram vial. After heating the reaction mixture at 60 °C, the resulting solution was cooled to rt. The selectivity was determined by ^1H NMR analysis of the crude reaction mixture. The product **3** was isolated by flash column chromatography or preparatory TLC using hexanes/EtOAc.

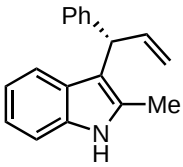
5. Characterization data



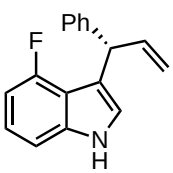
(*S*)-3-(1-Phenylallyl)-1H-indole (3aa): yellow oil, isolated *via* preparatory TLC using 8% ethyl acetate in hexanes, R_f = 0.15, 19.7 mg, 86% yield, 91% ee, $[\alpha]^{25}_D$ = -16.8 (c = 0.42, $CHCl_3$). The ^{1}H NMR spectrum is in accordance with literature.[1] **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.93 (s, 1H), 7.41 – 7.09 (m, 8H), 7.00 (t, *J* = 6.4 Hz, 1H), 6.85 (s, 1H), 6.32 (ddd, *J* = 16.8, 9.2, 6.8 Hz, 1H), 5.17 (d, *J* = 9.2 Hz, 1H), 5.05 (d, *J* = 16.8 Hz, 1H), 4.94 (d, *J* = 6.8 Hz, 1H). **Chiral SFC**: 91% ee, AD-H column, 220 nm, 2% 2-propanol in CO_2, 2 mL/min, retention time 30.7 min and 33.6 min (major).



(*S*)-1-Methyl-3-(1-phenylallyl)-1H-indole (3ba): yellow oil, isolated *via* preparatory TLC using 2% ethyl acetate in hexanes, R_f = 0.1, 22.2 mg, 90% yield, 92% ee, $[\alpha]^{25}_D$ = -0.5 (c = 0.76, $CHCl_3$). This compound was also prepared on a 1 mmol scale to afford **3ba** in 93% yield and 91% *ee* (see Preparative Scale Reaction). The ^{1}H NMR spectrum is in accordance with literature.[2] **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.41 (dt, *J* = 8.0, 0.8 Hz, 1H), 7.31 – 7.28 (m, 5H), 7.27 – 7.18 (m, 2H), 7.07 – 6.99 (m, 1H), 6.73 (s, 1H), 6.36 (ddd, *J* = 17.2, 10.0, 6.8 Hz, 1H), 5.20 (dt, J = 10.0, 1.6 Hz, 1H), 5.09 (dt, *J* = 17.2, 1.6 Hz, 1H), 4.97 (d, *J* = 6.8 Hz, 1H), 3.75 (s, 3H). **Chiral SFC**: 92% ee, AD-H column, 220 nm, 2% 2-propanol in CO_2, 2 mL/min, retention time 4.7 min and 5.0 min (major).

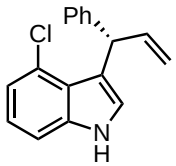


(*S*)-2-Methyl-3-(1-phenylallyl)-1H-indole (3ca): yellow oil, isolated *via* preparatory TLC using 8% ethyl acetate in hexanes, R_f = 0.25, 23.4 mg, 95% yield, 69% ee, $[\alpha]^{24}_D$ = +76.5 (c = 0.68, $CHCl_3$). The ^{1}H NMR spectrum is in accordance with literature.[2] **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.80 (s, 1H), 7.38 – 7.24 (m, 6H), 7.22 – 7.15 (m, 1H), 7.08 (ddd, *J* = 8.0, 7.2, 1.2 Hz, 1H), 6.97 (ddd, *J* = 8.0, 7.2, 1.2 Hz, 1H), 6.46 (ddd, *J* = 17.2, 10.0, 7.2 Hz, 1H), 5.21 (dt, *J* = 10.0, 1.6 Hz, 1H), 5.07 (dt, *J* = 17.2, 1.6 Hz, 1H), 4.99 (d, *J* = 7.2 Hz, 1H), 2.34 (s, 3H). Impurities at approx.. δ 1.50 (s), 1.30 (s), and 1.10 (s) could not be removed after several attempts at purification. **Chiral SFC**: 69% ee, OJ-H column, 220 nm, 9% 2-propanol in CO_2, 2 mL/min, retention time 11.1 min (major) and 12.1 min.

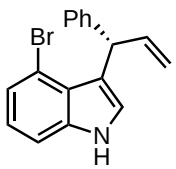


(*S*)-4-Fluoro-3-(1-phenylallyl)-1H-indole (3da): yellow oil, isolated *via* preparatory TLC using 10% ethyl acetate in hexanes, R_f = 0.4, 20.0mg, 80% yield, 90% ee, $[\alpha]^{25}_D$ = -17.4 (c = 0.33, $CHCl_3$). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.07 (s, 1H), 7.32 – 7.26 (m, 4H), 7.23 – 7.17 (m, 1H), 7.15 – 7.02 (m, 2H), 6.85 (d, *J* = 2.4 Hz, 1H), 6.69 (ddd, *J* = 11.2, 7.6, 0.8 Hz, 1H), 6.37 (ddd, *J* = 17.2, 10.0, 7.2 Hz, 1H), 5.21 – 5.15 (m, 2H), 5.00 (dt, *J* = 17.2, 1.6 Hz,

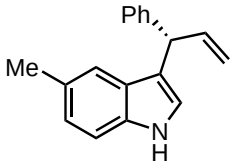
1H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 143.4, 140.8, 128.4, 128.2, 126.2, 122.7, 122.6, 122.4, 122.4, 115.3, 107.1, 107.1, 105.0, 104.8, 47.0. **^{19}F NMR** (565 MHz, $CDCl_3$) δ -121.3. **IR** (ATR): 1503, 1345, 1223, 1031, 917, 776, 731, 699, 684, 608 cm^{-1}. **HRMS** calculated for $C_{17}H_{14}NF$ $[M]^+$ 251.1110, found 251.1115. **Chiral SFC**: 90% ee, OJ-H column, 220 nm, 10% 2-propanol in CO_2, 3 mL/min, retention time 10.3 min and 11.3 min (major).



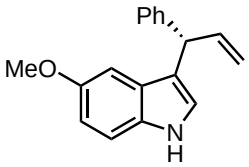
(*S*)-4-Chloro-3-(1-phenylallyl)-1H-indole (3ea): yellow oil, isolated *via* preparatory TLC using 10% ethyl acetate in hexanes, R_f = 0.2, 27.0 mg, 99% yield, 93% ee, $[\alpha]^{25}_D$ = -8.6 (c = 0.47, $CHCl_3$). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.12 (s, 1H), 7.32 – 7.17 (m, 6H), 7.10 – 7.01 (m, 2H), 6.90 (dd, *J* = 2.4, 0.8 Hz, 1H), 6.36 (ddd, *J* = 17.2, 10.0, 6.4 Hz, 1H), 5.63 (d, *J* = 6.4 Hz, 1H), 5.20 (dt, *J* = 10.0, 1.6 Hz, 1H), 4.88 (dt, *J* = 17.2, 1.6 Hz, 1H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 143.6, 141.5, 137.9, 128.8, 128.1, 126.1, 124.3, 122.6, 118.7, 115.5, 109.8, 46.0. **IR** (ATR): 1337, 1190, 925,776, 757, 738, 705, 625, 587, 578, 572 cm^{-1}. **HRMS** calculated for $C_{17}H_{14}NCl$ $[M]^+$ 267.0815, found 267.0808. **Chiral SFC**: 93% ee, AD-H column, 220 nm, 10% 2-propanol in CO_2, 2 mL/min, retention time 10.2 min (major) and 11.4 min.



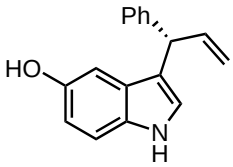
(*S*)-4-Bromo-3-(1-phenylallyl)-1H-indole (3fa): yellow oil, isolated *via* preparatory TLC using 10% ethyl acetate in hexanes, R_f = 0.2, 29.1 mg, 93% yield, 89% ee, $[\alpha]^{25}_D$ = -15.0 (c = 0.88, $CHCl_3$). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.13 (s, 1H), 7.33 – 7.18 (m, 7H), 7.00 (t, *J* = 8.0 Hz, 1H), 6.92 (d, *J* = 2.4 Hz, 1H), 6.37 (ddd, *J* = 17.2, 10.0, 6.0 Hz, 1H), 5.76 (d, *J* = 6.0 Hz, 1H), 5.21 (dt, *J* = 10.0, 1.6 Hz, 1H), 4.87 (dt, *J* = 17.2, 1.6 Hz, 1H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 143.6, 141.5, 137.8, 128.9, 128.1, 126.1, 124.9, 124.8, 124.4, 122.9, 119.0, 115.7, 114.4, 110.4, 45.5. IR (ATR): 1418, 1332, 1183, 1030, 995, 909, 811, 792, 735, 699, 674, 623, 574 cm^{-1}. **HRMS** calculated for $C_{17}H_{14}NBr$ $[M]^+$ 311.0310, found 311.0312. **Chiral SFC**: 89% ee, OJ-H column, 220 nm, 10% 2-propanol in CO_2, 3 mL/min, retention time 16.1 min and 18.5 min (major).



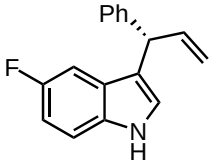
(*S*)-5-Methyl-3-(1-phenylallyl)-1H-indole (3ga)[3]: yellow oil, isolated *via* preparatory TLC using 10% ethyl acetate in hexanes, R_f = 0.4, 21.9 mg, 87% yield, 89% ee, $[\alpha]^{25}_D$ = -17.1 (c = 1.05, $CHCl_3$). The ^{1}H NMR spectrum is in accordance with literature.[3] **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.89 (s, 1H), 7.34 – 7.18 (m, 7H), 7.00 (d, *J* = 8.4 Hz, 1H), 6.83 (s, 1H), 6.36 (ddd, *J* = 17.2, 10.0, 7.0 Hz, 1H), 5.19 (dt, *J* = 10.0, 1.6 Hz, 1H), 5.07 (dt, *J* = 17.2, 1.6 Hz, 1H), 4.95 (d, *J* = 7.0 Hz, 1H), 2.39 (s, 3H). **Chiral SFC**: 89% ee, OJ-H column, 220 nm, 15% 2-propanol in CO_2, 3 mL/min, retention time 5.0 min and 13.5 min (major).



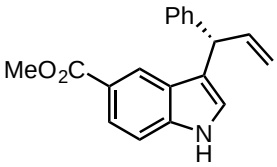
(*S*)-5-Methoxy-3-(1-phenylallyl)-1H-indole (3ha): yellow oil, isolated *via* preparatory TLC using 10% ethyl acetate in hexanes, R_f = 0.2, 21.3 mg, 81% yield, 90% ee, $[\alpha]^{25}_D$ = -18.0 (c = 0.42, $CHCl_3$). The ^{1}H NMR spectrum is in accordance with literature.[1] **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.89 (s, 1H), 7.34 – 7.18 (m, 6H), 6.84 (d, *J* = 7.6 Hz, 3H), 6.35 (ddd, *J* = 17.0, 10.0, 7.2 Hz, 1H), 5.21 (dd, *J* = 10.0, 0.8 Hz, 1H), 5.09 (dd, *J* = 17.0, 0.8 Hz, 1H), 4.92 (d, *J* = 7.2 Hz, 1H), 3.75 (s, 3H). **Chiral SFC**: 90% ee, OJ-H column, 220 nm, 15% 2-propanol in CO_2, 3 mL/min, retention time 5.8 min and 13.2 min (major).



(*S*)-3-(1-Phenylallyl)-1H-indol-5-ol (3ia): yellow oil, isolated *via* preparatory TLC using 20% ethyl acetate in hexanes, R_f = 0.25, 22.4 mg, 90% yield, 90% ee, $[\alpha]^{26}_D$ = -12.1 (c = 0.25, $CHCl_3$). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.89 (s, 1H), 7.34 – 7.18 (m, 6H), 6.88 (d, *J* = 2.4 Hz, 1H), 6.80 – 6.72 (m, 2H), 6.34 (ddd, *J* = 17.2, 10.0, 7.2 Hz, 1H), 5.2 (dt, *J* = 10.0, 1.6 Hz, 1H), 5.07 (dt, *J* = 17.2, 1.6 Hz, 1H), 4.88 (d, *J* = 7.2 Hz, 1H), 4.52 (s, 1H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 149.1, 143.0, 140.3, 131.9, 128.4, 128.3, 127.5, 126.3, 123.6, 117.8, 115.5, 111.8, 111.7, 104.4, 47.0. **IR** (ATR): 1488, 1452, 1217, 1178, 917, 846, 796, 751, 728, 699, 673, 600 cm^{-1}. **HRMS** calculated for $C_{17}H_{15}NO$ $[M]^+$ 249.1154, found 249.1149. **Chiral SFC**: 90% ee, OJ-H column, 220 nm, 20% 2-propanol in CO_2, 3 mL/min, retention time 9.8 min (major) and 10.5 min.

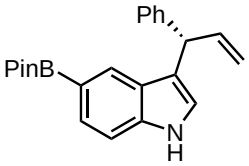


(*S*)-5-Fluoro-3-(1-phenylallyl)-1H-indole (3ja): yellow oil, isolated *via* preparatory TLC using 10% ethyl acetate in hexanes, R_f = 0.4, 17.9 mg, 71% yield, 85% ee, $[\alpha]^{25}_D$ = +1.1 (c = 0.71, $CHCl_3$). The ^{1}H NMR spectrum is in accordance with literature.[3] **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.99 (s, 1H), 7.33 – 7.19 (m, 6H), 7.03 (dd, *J* = 10.0, 2.4 Hz, 1H), 6.95 – 6.84 (m, 2H), 6.33 (ddd, *J* = 17.2, 10.0, 7.2 Hz, 1H), 5.21 (dt, *J* = 10.0, 1.6 Hz, 1H), 5.07 (dt, *J* = 17.2, 1.6 Hz, 1H), 4.89 (d, *J* = 7.2 Hz, 1H). **Chiral SFC**: 85% ee, OJ-H column, 220 nm, 20% 2-propanol in CO_2, 3 mL/min, retention time 4.3 min and 7.4 min (major).

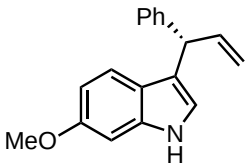


(*S*)-Methyl 3-(1-phenylallyl)-1H-indole-5-carboxylate (3ka): yellow oil, isolated *via* preparatory TLC using 20% ethyl acetate in hexanes, R_f = 0.3, 18.7 mg, 64% yield, 96% ee, $[\alpha]^{25}_D$ = -55.3 (c = 0.58, $CHCl_3$). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.25 (s, 1H), 8.2 (s, 1H), 7.88 (dd, *J* = 8.8, 1.6 Hz, 1H), 7.35 (dd, *J* = 8.8, 0.4 Hz, 1H), 7.33 – 7.20 (m, 5H), 6.91 (dd, *J* = 2.4, 0.8 Hz, 1H), 6.35 (ddd, *J* = 17.2, 10.0, 7.2 Hz, 1H), 5.22 (dt, *J* = 10.0, 1.6 Hz, 1H), 5.06 (dt, *J* = 17.0, 1.6 Hz, 1H), 5.01 (dd, *J* = 7.2, 0.8 Hz, 1H), 3.89 (s, 3H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 168.1, 142.7, 140.1, 139.2, 128.4, 128.4, 126.5, 126.5, 123.8, 123.5, 122.7, 121.5, 120.0, 115.8, 110.8, 51.8, 46.5. **IR** (ATR): 1687, 1611, 1434, 1260, 1243, 1216, 1111, 988, 917,

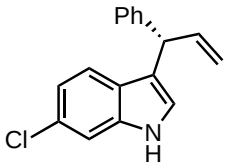
766, 753, 748, 700 cm^{-1}. **HRMS** calculated for $C_{19}H_{17}NO_2$ $[M]^+$ 291.1259, found 291.1254. **Chiral SFC**: 86% ee, OJ-H column, 220 nm, 15% 2-propanol in CO_2, 3 mL/min, retention time 5.4 min and 13.2 min (major).



(*S*)-3-(1-Phenylallyl)-5-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)-1H-indole (3la): yellow oil, isolated *via* preparatory TLC using 10% ethyl acetate in hexanes, R_f = 0.4, 24.6 mg, 69% yield, 94% ee, $[\alpha]^{23}_D$ = -35.7 (c = 0.28, $CHCl_3$). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.07 (s, 1H), 8.03 (d, *J* = 0.8 Hz, 1H), 7.65 (dd, *J* = 8.2, 0.8 Hz, 1H), 7.34 (dd, *J* = 8.2, 0.8 Hz, 1H), 7.30 (d, *J* = 4.4 Hz, 4H), 7.25 – 7.18 (m, 1H), 6.81 (dd, *J* = 2.4, 0.8 Hz, 1H), 6.35 (ddd, *J* = 17.2, 10.0, 7.2 Hz, 1H), 5.19 (dt, *J* = 10.0, 1.6 Hz, 1H), 5.06 (d, *J* = 7.2 Hz, 1H), 5.03 (dt, *J* = 17.2, 1.6 Hz, 1H), 1.35 (s, 12H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 143.2, 140.5, 138.5, 128.4, 128.4, 128.3, 127.1, 126.7, 126.2, 122.6, 119.1, 115.5, 110.5, 83.4, 46.1, 24.9. **IR** (ATR): 1371, 1351, 1142, 1097, 908, 856, 730, 690 cm^{-1}. **HRMS** calculated for calculated for $C_{23}H_{27}BNO_2$ $[M+H]^+$ 360.2139, found 360.2155. **Chiral SFC**: 94% ee, OJ-H column, 220 nm, 10% 2-propanol in CO_2, 3 mL/min, retention time 12.6 min and 14.5 min (major).

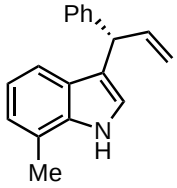


(*S*)-6-Methoxy-3-(1-phenylallyl)-1H-indole (3ma): yellow oil, isolated *via* preparatory TLC using 10% ethyl acetate in hexanes, R_f = 0.2, 14.0 mg, 53% yield, 91% ee, $[\alpha]^{24}_D$ = -2.5 (c 0.24, $CHCl_3$). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.86 (s, 1H), 7.32 – 7.19 (m, 6H), 6.84 (d, *J* = 2.4 Hz, 1H), 6.77 (dd, *J* = 2.4, 1.2 Hz, 1H), 6.70 (dd, *J* = 8.8, 2.4 Hz, 1H), 6.34 (ddd, *J* = 17.2, 10.0, 7.2 Hz, 1H), 5.19 (dt, *J* = 10.0, 1.6 Hz, 1H), 5.07 (dt, *J* = 17.2, 1.6 Hz, 1H), 4.91 (dd, *J* = 7.2, 1.2 Hz, 1H), 3.82 (s, 3H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 156.5, 143.2, 140.5, 137.4, 128.4, 128.3, 126.2, 121.2, 121.2, 120.4, 118.4, 115.4, 109.2, 94.6, 55.6, 47.0. **IR** (ATR): 1451, 1154, 1013, 925, 839, 888, 756, 749, 700, 629, 612 cm^{-1}. **HRMS** calculated for $C_{18}H_{17}NO$ $[M]^+$ 263.1310, found 263.1302. **Chiral SFC**: 91% ee, OJ-H column, 220 nm, 15% 2-propanol in CO_2, 3 mL/min, retention time 9.8 min (major) and 10.7 min.

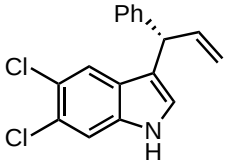


(*S*)-6-Chloro-3-(1-phenylallyl)-1H-indole (3na): yellow oil, isolated *via* preparatory TLC using 10% ethyl acetate in hexanes, R_f = 0.5, 19.1 mg, 72% yield, 92% ee, $[\alpha]^{25}_D$ = -1.4 (c = 0.28, $CHCl_3$). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.00 (s, 1H), 7.35 – 7.21 (m, 7H), 7.00 (dd, *J* = 8.4, 1.6 Hz, 1H), 6.89 (dd, *J* = 2.4, 0.8 Hz, 1H), 6.33 (ddd, *J* = 17.2, 10.0, 7.2 Hz, 1H), 5.2 (dt, *J* = 10.0, 1.6 Hz, 1H), 5.07 (dt, *J* = 17.2, 1.6 Hz, 1H), 4.93 (d, *J* = 7.2 Hz, 1H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 142.8, 140.1, 134.0, 128.4, 128.3, 128.0, 126.4, 125.4, 123.1, 120.7, 120.1, 118.7, 115.7, 111.0, 46.8. **IR** (ATR): 1450, 1095, 1060, 905, 844, 804, 753, 699, 591

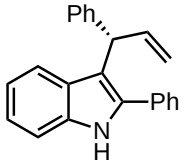
cm^{-1}. **HRMS** calculated for $C_{17}H_{14}NCl$ $[M]^+$ 267.0815, found 267.0813. **Chiral SFC**: 92% ee, OJ-H column, 220 nm, 15% 2-propanol in CO_2, 3 mL/min, retention time 6.6 min and 9.3 min (major).



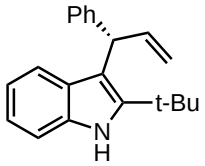
(*S*)-7-Methyl-3-(1-phenylallyl)-1H-indole (3oa): yellow oil, isolated *via* preparatory TLC using 10% ethyl acetate in hexanes, R_f = 0.3, 23.6 mg, 96% yield, 91% ee, $[\alpha]^{25}_D$ = -16.8 (c = 0.73, $CHCl_3$). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.93 (s, 1H), 7.32 – 7.20 (m, 6H), 7.01 – 6.94 (m, 2H), 6.90 (dd, *J* = 2.4, 0.8 Hz, 1H), 6.37 (ddd, *J* = 17.2, 10.0, 7.2, 1H), 5.21 (d, *J* = 10.0 Hz, 1H), 5.09 (dd, *J* = 17.2, 0.8 Hz, 1H), 4.97 (d, *J* = 7.2 Hz, 1H), 2.48 (s, 3H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 143.2, 140.5, 136.2, 128.4, 128.3, 126.3, 126.2, 122.6, 122.1, 120.2, 119.5, 119.0, 117.6, 115.4, 47.0, 16.6. **IR** (ATR): 1450, 1429, 1063, 994, 916, 779, 744, 699, 665, 611, 600 cm^{-1}. **HRMS** calculated for $C_{18}H_{17}N$ $[M]^+$ 247.1361, found 247.1355. **Chiral SFC**: 91% ee, OJ-H column, 220 nm, 15% 2-propanol in CO_2, 3 mL/min, retention time 9.0 min and 16.7 min (major).



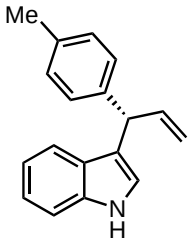
(*S*)-5, 6-Dichloro-3-(1-phenylallyl)-1H-indole (3pa): yellow oil, isolated *via* preparatory TLC using 10% ethyl acetate in hexanes, R_f = 0.3, 16.2mg, 54% yield, 85% ee, $[\alpha]^{25}_D$ = -21.1 (c = 0.34, $CHCl_3$). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.02 (s, 1H), 7.45 (s, 2H), 7.35 – 7.28 (m, 2H), 7.24-7.22 (m, 3H), 6.90 (d, *J* = 2.4 Hz, 1H), 6.30 (ddd, *J* = 17.2, 10.0, 7.2 Hz, 1H), 5.22 (d, *J* = 10.0 Hz, 1H), 5.05 (d, *J* = 17.2 Hz, 1H), 4.87 (d, *J* = 7.2 Hz, 1H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 142.4, 139.8, 135.4, 128.5, 128.3, 126.6, 126.0, 124.4, 123.5, 120.8, 118.4, 116.0, 112.5, 46.6. **IR** (ATR): 1449, 1098, 919, 865, 845, 758, 743, 699, 657 cm^{-1}. **HRMS** calculated for $C_{17}H_{13}NCl_2$ $[M]^+$ 301.0425, found 301.0419. **Chiral SFC**: 91% ee, OJ-H column, 220 nm, 15% 2-propanol in CO_2, 3 mL/min, retention time 5.6 min and 11.6 min (major).



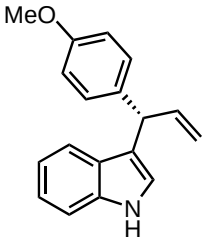
(*S*)-2-phenyl-3-(1-phenylallyl)-1*H*-indole (3qa): yellow oil, isolated *via* preparatory TLC using 5% ethyl acetate in hexanes, R_f = 0.25, 22.2 mg, 72% yield, 92% ee, $[\alpha]^{22}_D$ = -14.9 (c = 2.22, $CHCl_3$). **^{1}H NMR** (400 MHz, $CDCl_3$): δ 8.07 (bs, 1H), 7.55-7.52 (m, 2H), 7.49-7.44 (m, 2H), 7.44-7.38 (m, 3H), 7.38-7.34 (m, 2H), 7.32-7.25 (m, 2H), 7.23-7.17 (m, 2H), 7.02 (ddd, *J* = 8.0, 7.1, 1.0 Hz, 1H), 6.59-6.51 (m, 1H), 5.26 (dt, *J* = 10.1, 1.5 Hz, 1H), 5.15 (d, *J* = 6.8 Hz, 1H), 5.10 (dt, *J* = 17.1, 1.6 Hz, 1H). The ^{1}H NMR is in accordance with the literature (Chen, S.-J.; Lu, G-.P.; Cai, C. *Synthesis* **2014,** *46*, 1717). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 143.3, 140.2, 136.4, 135.6, 133.1, 128.9, 128.7, 128.37, 128.31, 128.13, 128.01, 126.1, 122.2, 121.5, 119.7, 116.2, 113.9, 111.0, 46.0. **IR** (ATR): 3400, 1682, 1619, 1487, 1459, 1299, 1244, 1089, 1013, 911, 917, 740 cm^{-1} **Chiral SFC**: 92% ee, AD-H column, 220 nm, 25% 2-propanol in CO_2, 2 mL/min, retention time 5.1 min (major) and 9.7 min (minor).



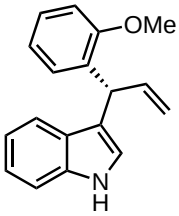
(*S*)-2-(*tert*-butyl)-3-(1-phenylallyl)-1*H*-indole (3ra): yellow oil, isolated *via* preparatory TLC using 10% ethyl acetate in hexanes, R_f = 0.3, 19.8 mg, 69% yield, 86% ee, $[\alpha]^{22}_D$ = -10.9 (c = 1.98, $CHCl_3$). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.99 (d, *J* = 0.3 Hz, 1H), 7.37-7.34 (m, 3H), 7.32-7.26 (m, 3H), 7.23-7.16 (m, 2H), 7.09 (ddd, *J* = 8.1, 7.0, 1.1 Hz, 1H), 6.91 (ddd, *J* = 8.0, 7.1, 1.0 Hz, 1H), 6.55 (ddd, *J* = 17.1, 10.0, 7.6 Hz, 1H), 5.36 (dd, *J* = 7.7, 0.2 Hz, 1H), 5.26 (ddd, *J* = 10.1, 1.6, 1.1 Hz, 1H), 5.16 (dt, *J* = 17.1, 1.5 Hz, 1H), 1.53 (s, 9H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 143.2, 142.7, 140.0, 134.4, 128.4, 128.20, 128.18, 126.0, 120.99, 120.93, 119.0, 116.0, 111.5, 110.6, 46.4, 32.8, 30.7. **IR** (ATR): 3445, 1470, 1458, 1302, 1244, 909, 740, 726, 697 cm^{-1}. **HRMS** calculated for $C_{21}H_{23}N$ $[M]^+$ 289.1830, found 289.1835. **Chiral SFC**: 86% ee, OD-H column, 220 nm, 3% 2-propanol in CO_2, 2 mL/min, retention time 7.9 min (major) and 8.8 min (minor).



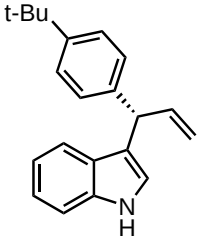
(*S*)-3-(1-(*p*-Tolyl)allyl)-1H-indole (3ab): yellow oil, isolated *via* preparatory TLC using 10% ethyl acetate in hexanes, R_f = 0.2, 18.7 mg, 76% yield, 89% ee, $[\alpha]^{26}_D$ = -3.1 (c = 0.77, $CHCl_3$). The ^{1}H NMR spectrum is in accordance with literature.[3] **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.07 (s, 1H), 7.50 (d, *J* = 8.0 Hz, 1H), 7.43 (d, *J* = 8.0 Hz, 1H), 7.30 – 7.23 (m, 3H), 7.20 (d, *J* = 8.0 Hz, 2H), 7.15 – 7.08 (m, 1H), 6.96 (d, *J* = 1.6 Hz, 1H), 6.43 (ddd, *J* = 17.2, 10.0, 7.2 Hz, 1H), 5.27 (dt, *J* = 10.0, 1.6 Hz, 1H), 5.16 (dt, *J* = 17.2, 1.6 Hz, 1H), 5.02 (d, *J* = 7.2 Hz, 1H), 2.41 (s, 3H). **Chiral SFC**: 89% ee, OJ-H column, 220 nm, 15% 2-propanol in CO_2, 3 mL/min, retention time 10.3 min and 14.8 min (major).



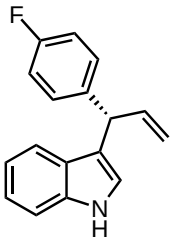
(*S*)-3-(1-(4-Methoxyphenyl)allyl)-1H-indole (3ac): yellow oil, isolated *via* preparatory TLC using 10% ethyl acetate in hexanes, R_f = 0.2, 18.4 mg, 70% yield, 82% ee, $[\alpha]^{26}_D$ = -4.2 (c = 0.29, $CHCl_3$). The ^{1}H NMR spectrum is in accordance with literature.[1] **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.99 (s, 1H), 7.42 – 7.31 (m, 2H), 7.22 – 7.14 (m, 3H), 7.06 – 7.00 (m, 1H), 6.88 (dd, *J* = 2.4, 0.8 Hz, 1H), 6.85 – 6.78 (m, 2H), 6.33 (ddd, *J* = 17.2, 10.0, 7.2 Hz, 1H), 5.17 (dt, *J* = 10.0, 1.6 Hz, 1H), 5.05 (dt, *J* = 17.2, 1.6 Hz, 1H), 4.91 (d, *J* = 7.2 Hz, 1H), 3.79 (s, 3H). **Chiral SFC**: 82% ee, OJ-H column, 220 nm, 20% 2-propanol in CO_2, 3 mL/min, retention time 7.0 min and 9.6 min (major).



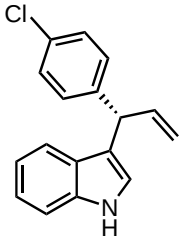
(*S*)-3-(1-(2-Methoxyphenyl)allyl)-1H-indole (3ad): yellow oil, isolated *via* preparatory TLC using 10% ethyl acetate in hexanes, R_f = 0.2, 76% yield, 93% ee, $[\alpha]^{26}_D$ = +4.1 (c = 0.30, $CHCl_3$). The ^{1}H NMR spectrum is in accordance with literature.[1] **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.94 (s, 1H), 7.46 (d, *J* = 8.0 Hz, 1H), 7.33 (d, *J* = 8.0 Hz, 1H), 7.23 – 7.14 (m, 3H), 7.06 – 7.00 (m, 1H), 6.95 – 6.84 (m, 3H), 6.33 (ddd, *J* = 17.2, 10.2, 7.2 Hz, 1H), 5.46 (d, *J* = 7.2 Hz, 1H), 5.17 (dt, *J* = 10.2, 1.6 Hz, 1H), 5.01 (dt, *J* = 17.2, 1.6 Hz, 1H), 3.85 (s, 3H). **Chiral SFC**: 93% ee, OJ-H column, 220 nm, 15% 2-propanol in CO_2, 3 mL/min, retention time 9.2 min and 13.4 min (major).



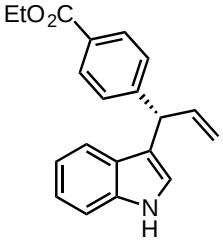
(*S*)-3-(1-(4-(*tert*-Butyl)phenyl)allyl)-1H-indole (3ae): yellow oil, isolated *via* preparatory TLC using 10% ethyl acetate in hexanes, R_f = 0.15, 25.5 mg, 88% yield, 89% ee, $[\alpha]^{25}_D$ = -3.6 (c = 0.45, $CHCl_3$). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.99 (s, 1H), 7.45 (d, *J* = 8.0 Hz, 1H), 7.33 (dd, *J* = 14.8, 8.0 Hz, 3H), 7.22 (d, *J* = 8.0 Hz, 2H), 7.17 (t, *J* = 7.6 Hz, 1H), 7.04 (t, *J* = 7.6 Hz, 1H), 6.88 (s, 1H), 6.35 (ddd, *J* = 17.2, 10.0, 6.8 Hz, 1H), 5.17 (d, *J* = 10.0 Hz, 1H), 5.08 (d, *J* = 17.2 Hz, 1H), 4.94 (d, *J* = 6.8 Hz, 1H), 1.30 (s, 9H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 149.0, 140.620, 140.1, 136.6, 127.9, 126.9, 125.2, 122.4, 122.0, 119.9, 119.2, 118.7, 115.2, 111.0, 46.5, 34.4, 31.4. **IR** (ATR): 2961, 1456, 1094, 1010, 915, 816, 794, 764, 739 cm^{-1}. **HRMS** calculated for $C_{21}H_{23}N$ $[M]^+$ 289.1830, found 289.1828. **Chiral SFC**: 89% ee, OJ-H column, 220 nm, 15% 2-propanol in CO_2, 3 mL/min, retention time 3.3 min and 9.9 min (major).



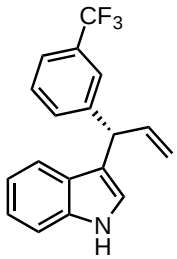
(*S*)-3-(1-(4-Fluorophenyl)allyl)-1H-indole (3af): yellow oil, isolated *via* preparatory TLC using 10% ethyl acetate in hexanes, R_f = 0.4, 23.3 mg, 93% yield, 90% ee, $[\alpha]^{26}_D$ = +7.5 (c = 0.72, $CHCl_3$). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.00 (s, 1H), 7.40 – 7.34 (m, 2H), 7.24 (dd, *J* = 6.0, 2.8 Hz, 2H), 7.19 (t, *J* = 7.6 Hz, 1H), 7.07 – 6.95 (m, 3H), 6.91 – 6.87 (m, 1H), 6.33 (ddd, *J* = 17.2, 10.0, 7.2 Hz, 1H), 5.21 (d, *J* = 10.0 Hz, 1H), 5.06 (d, *J* = 17.2 Hz, 1H), 4.96 (d, *J* = 7.2 Hz, 1H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 162.7, 160.3, 140.3, 138.8, 138.8, 136.7, 129.8, 129.7, 126.6, 122.4, 122.2, 119.7, 119.4, 118.3, 115.6, 115.2, 114.9, 111.1, 46.1. **^{19}F NMR** (565 MHz, $CDCl_3$) δ -117.1. **IR** (ATR): 1504, 1216, 1092, 925, 822, 808, 740, 652, 601, 570 cm^{-1}. **HRMS** calculated for $C_{17}H_{14}NF$ $[M]^+$ 251.1110, found 251.1105. **Chiral SFC**: 90% ee, OJ-H column, 220 nm, 15% 2-propanol in CO_2, 3 mL/min, retention time 4.4 min and 6.1 min (major).



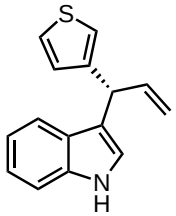
(*S*)-3-(1-(4-Chlorophenyl)allyl)-1H-indole (3ag): yellow oil, isolated *via* preparatory TLC using 10% ethyl acetate in hexanes, R_f = 0.2, 22.0 mg, 82% yield, 88% ee, $[\alpha]^{26}_D$ = -4.1 (c = 0.25, $CHCl_3$). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.01 (s, 1H), 7.36 (d, *J* = 8.8 Hz, 2H), 7.26 (dt, *J* = 4.4, 2.0 Hz, 2H), 7.23 – 7.15 (m, 3H), 7.04 (t, *J* = 8.0 Hz, 1H), 6.90 (d, *J* = 2.4 Hz, 1H), 6.32 (ddd, *J* = 17.2, 10.0, 7.2 Hz, 1H), 5.21 (dt, *J* = 10.0, 1.2 Hz, 1H), 5.06 (dt, *J* = 17.2, 1.2 Hz, 1H), 4.94 (d, *J* = 7.2 Hz, 1H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 141.6, 140.0, 136.6, 132.0, 129.8, 128.4, 126.6, 122.4, 122.2, 119.7, 119.4, 118.0, 115.8, 111.1, 46.3. **IR** (ATR): 1487, 1454, 1087, 1014, 998, 919, 846, 811, 795, 764, 753, 740, 726, 577 cm^{-1}. **HRMS** calculated for $C_{17}H_{14}NCl$ $[M]^+$ 267.0815, found 267.0817. **Chiral SFC**: 88% ee, OJ-H column, 220 nm, 15% 2-propanol in CO_2, 3 mL/min, retention time 5.6 min and 8.0 min (major).



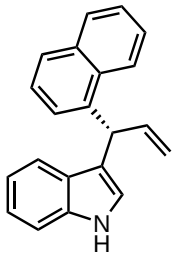
(*S*)-Ethyl 4-(1-(1H-indol-3-yl)allyl)benzoate (3ah): yellow oil, isolated *via* preparatory TLC using 20% ethyl acetate in hexanes, R_f = 0.3, 28.1 mg, 92% yield, 93% ee, $[\alpha]^{25}_D$ = -1.3 (c = 0.48, $CHCl_3$). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.10 (s, 1H), 7.98 (d, *J* = 8.4 Hz, 2H), 7.35 (t, *J* = 7.2 Hz, 4H), 7.21 – 7.13 (m, 1H), 7.02 (ddd, *J* = 8.4, 7.2, 0.8 Hz, 1H), 6.90 (d, *J* = 1.6 Hz, 1H), 6.34 (ddd, *J* = 17.2, 10.0, 7.2 Hz, 1H), 5.23 (dt, *J* = 10.0, 1.6 Hz, 1H), 5.07 (dt, *J* = 17.2, 1.6 Hz, 1H), 5.02 (d, *J* = 7.2 Hz, 1H), 4.36 (q, *J* = 7.2 Hz, 2H), 1.38 (t, *J* = 7.2 Hz, 3H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 166.7, 148.5, 139.6, 136.6, 129.7, 128.6, 128.4, 126.6, 122.5, 122.2, 119.6, 119.4, 117.7, 116.1, 111.1, 60.8, 46.9, 14.3. **IR** (ATR): 1698, 1607, 1366, 1273, 1220, 1176, 1101, 1019, 918, 762, 739, 708, 643 cm^{-1}. **HRMS** calculated for $C_{20}H_{19}NO_2$ $[M]^+$ 305.1416, found 305.1427. **Chiral SFC**: 81% ee, OJ-H column, 220 nm, 15% 2-propanol in CO_2, 3 mL/min, retention time 4.0 min and 4.8 min (major).



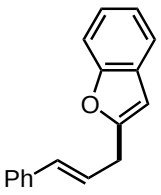
(*S*)-3-(1-(3-(Trifluoromethyl)phenyl)allyl)-1H-indole (3ai): yellow oil, isolated *via* preparatory TLC using 10% ethyl acetate in hexanes, R_f = 0.4, 29.1 mg, 97% yield, 92% ee, $[\alpha]^{26}_D$ = +4.1 (c = 0.58, $CHCl_3$). The ^{1}H NMR spectrum is in accordance with literature.[3] **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.07 (s, 1H), 7.58 (s, 1H), 7.52 – 7.43 (m, 2H), 7.42 – 7.35 (m, 3H), 7.19 (t, *J* = 8.0 Hz, 1H), 7.05 (t, *J* = 8.0 Hz, 1H), 6.88 (d, *J* = 2.4 Hz, 1H), 6.34 (ddd, *J* = 17.2, 10.0, 7.2 Hz, 1H), 5.25 (dt, *J* = 10.0, 1.6 Hz, 1H), 5.08 (dt, *J* = 17.2, 1.6 Hz, 1H), 5.03 (d, *J* = 7.2 Hz, 1H). **Chiral SFC**: 92% ee, OJ-H column, 220 nm, 12% 2-propanol in CO_2, 3 mL/min, retention time 2.1 min and 3.1 min (major).



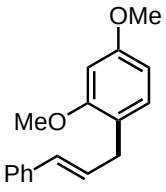
(*S*)-3-(1-(Thiophen-3-yl)allyl)-1H-indole (3aj): yellow oil, isolated *via* preparatory TLC using 10% ethyl acetate in hexanes, R_f = 0.25, 19.4 mg, 81% yield, 88% ee, $[\alpha]^{26}_D$ = -7.1 (c = 0.17, $CHCl_3$). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.99 (s, 1H), 7.47 (d, *J* = 8.0 Hz, 1H), 7.36 (d, *J* = 8.0 Hz, 1H), 7.27 – 7.24 (m, 1H), 7.19 (ddd, *J* = 8.2, 7.2, 1.2 Hz, 1H), 7.06 (ddd, *J* = 8.2, 7.2, 1.2 Hz, 1H), 7.03 – 6.97 (m, 2H), 6.91 (d, *J* = 2.0 Hz, 1H), 6.34 (ddd, *J* = 17.2, 10.0, 7.2 Hz, 1H), 5.19 ((dt, *J* = 10.0, 1.6 Hz, 1H), 5.12 (dt, *J* = 17.2, 1.6 Hz, 1H), 5.03 (d, *J* = 7.2 Hz, 1H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 144.1, 140.0, 136.6, 128.2, 126.7, 125.2, 122.1, 122.1, 121.2, 119.7, 119.4, 118.2, 115.2, 111.1, 42.4. **IR** (ATR): 1455, 917, 836, 766, 739, 664, 596, 586 cm^{-1}. **HRMS** calculated for $C_{15}H_{13}NS$ $[M]^+$ 239.0769, found 239.0765. **Chiral SFC**: 88% ee, OJ-H column, 220 nm, 15% 2-propanol in CO_2, 3 mL/min, retention time 9.4 min and 10.2 min (major).



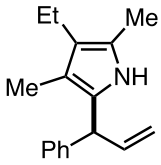
(-)-3-(1-(Naphthalen-1-yl)allyl)-1H-indole (3ak): yellow oil, isolated *via* preparatory TLC using 10% ethyl acetate in hexanes, R_f = 0.2, 27.2 mg, 96% yield, 94% ee, $[\alpha]^{25}_D$ = -36.0 (c = 0.54, $CHCl_3$). The ^{1}H NMR spectrum is in accordance with literature.[3] **^{1}H NMR** (400 MHz, $CDCl_3$) δ 8.14 (d, *J* = 7.6 Hz, 1H), 7.95 (s, 1H), 7.89 (d, *J* = 7.6 Hz, 1H), 7.78 (dd, *J* = 6.4, 3.2 Hz, 1H), 7.52 – 7.38 (m, 5H), 7.36 (d, *J* = 8.0 Hz, 1H), 7.21 (t, *J* = 8.0 Hz, 1H), 7.07 (t, *J* = 8.0 Hz, 1H), 6.75 (d, *J* = 2.4 Hz, 1H), 6.47 (ddd, *J* = 17.2, 10.0, 6.4 Hz, 1H), 5.78 (d, *J* = 6.4 Hz, 1H), 5.29 (dt, *J* = 10.0, 1.6 Hz, 1H), 5.05 (dt, *J* = 17.2, 1.6 Hz, 1H). Impurities at approx.. δ 4.10 (q), 2.05 (s), and 1.30 (t) appears to be ethyl acetate but could not be removed after several attempts at purification and prolonged periods on hi-vac. **Chiral SFC**: 94% ee, OJ-H column, 220 nm, 20% 2-propanol in CO_2, 3 mL/min, retention time 9.3 min and 17.9 min (major).



1-phenyl-3-(benzofuran-2-yl)-1-propene: yellow oil, isolated *via* preparatory TLC using 2% ethyl acetate in hexanes, R_f = 0.2, 6.8 mg, 29% yield. The ^{1}H NMR spectrum is in accordance with literature.[4] **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.51 – 7.48 (m, 1H), 7.45 – 7.38 (m, 3H), 7.34 – 7.30 (m, 2H), 7.25 – 7.17 (m, 3H), 6.58 (d, *J* = 15.8 Hz, 1H), 6.48 (q, *J* = 0.9 Hz, 1H), 6.39 (dt, *J* = 15.8, 6.8 Hz, 1H), 3.71 (dt, *J* = 6.8, 1.1 Hz, 2H).



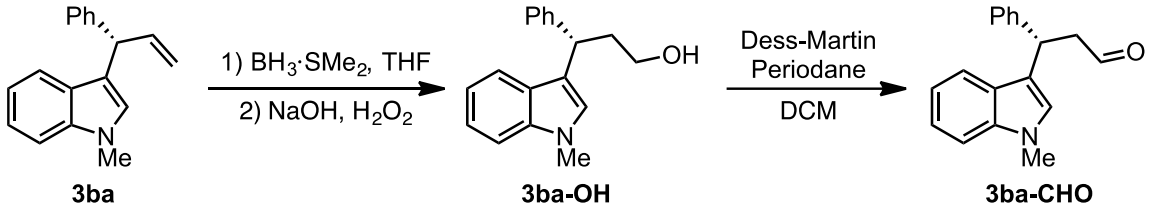
1-phenyl-3-(2,4-dimethoxyphenyl)-1-propene: colorless oil, isolated *via* preparatory TLC using 5% ethyl acetate in hexanes, R_f = 0.35, 8.9 mg, 35% yield. The ^{1}H NMR spectrum is in accordance with literature.[5] **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.41 – 7.39 (m, 2H), 7.34 (dd, *J* = 7.1, 1.6 Hz, 2H), 7.25 – 7.21 (m, 1H), 7.13 (d, *J* = 8.2 Hz, 1H), 6.53-6.48 (m, 2H), 6.44 – 6.38 (m, 2H), 3.88 (s, 3H), 3.86 (s, 3H), 3.52 (d, *J* = 5.6 Hz, 2H).



3-ethyl-2,4-dimethyl-5-(1-phenylallyl)-1*H*-pyrrole: green oil, isolated *via* preparatory TLC using 10% ethyl acetate in hexanes, R_f = 0.55, 5.7 mg, 24% yield, **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.34 – 7.30 (m, 2H), 7.25 – 7.20 (m, 3H), 7.14 – 7.12 (bs, 1H), 6.21 (ddd, *J* = 17.0, 10.2, 6.7 Hz, 1H), 5.22 (dt, *J* = 10.1, 1.5 Hz, 1H), 4.98 (dt, *J* = 17.1, 1.6 Hz, 1H), 4.79 (d, *J* = 6.6 Hz, 1H), 2.38 (q, *J* = 7.5 Hz, 2H), 2.12 (d, *J* = 5.1 Hz, 3H), 1.08 (t, *J* = 7.5 Hz, 3H); **^{13}C NMR** (126 MHz, $CDCl_3$): δ 142.3, 139.3, 128.63, 128.49, 126.6, 124.7, 121.19, 121.11, 116.4, 114.0, 46.7, 17.9, 15.9, 11.2, 9.3. **IR** (ATR): 3462, 2958, 2922, 2856, 1634, 1600, 1491, 1382, 1310, 1220, 1062, 1029, 996, 919, 839, 745, 699, 667, 636 cm^{-1}. **HRMS** calculated for $C_{17}H_{22}N$ $[M+H]^+$ 240.1752, found 239.1702.

6. Determination of Absolute Configuration

Absolute configuration was determined by analogy to a compound with known absolute configuration and reported optical rotation.[6] Indole **3ba** obtained from the described Rh-catalyzed alkyne hydroarylation was derivatized to literature reported aldehyde **3ba-CHO**. The measured optical rotation of **3ba-CHO** ($[\alpha]^{22}_D$ = +29.4°, *c* = 0.62, $CHCl_3$) was compared to the literature reported value ($[\alpha]_D$ = +30.9°, *c* = 1.0, $CHCl_3$) to assign the absolute configuration as (*S*).



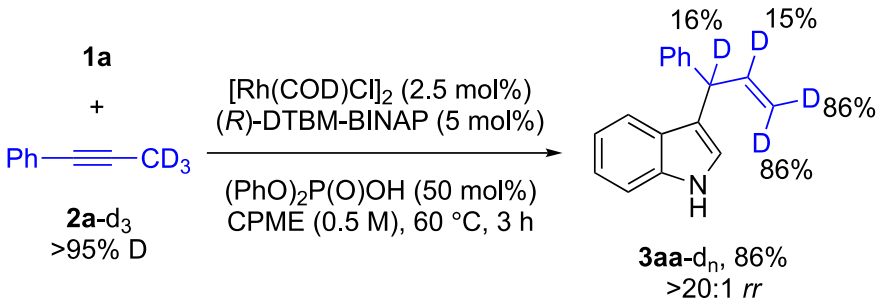
Reported $[\alpha]_D$ *= +30.9° (c = 1.0,* $CHCl_3$*)*
Measured $[\alpha]_D$ *= +29.4° (c = 0.62,* $CHCl_3$*)*

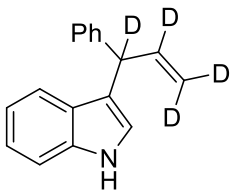
To a flame-dried round bottom was added **3ba** (100 mg, 0.4 mmol, 1 equiv.). After addition of 2 mL of THF, the reaction mixture was cooled to 0 °C. A 2 M BH_3•SMe_2 solution in THF (1 mL, 2.0 mmol, 5 equiv.) was slowly added at 0 °C. After addition, the reaction mixture was warmed to room temperature and allowed to stir for 1 hour. Next, the reaction mixture was cooled to 0 °C and aqueous NaOH (80 mg, 5 equiv.) was slowly added, followed by H_2O_2 (1 mL). The reaction was heated to 60 °C for 2 hours. After cooling to room temperature, the reaction mixture was extracted with Et_2O. The combined organic layers were dried using anhydrous $MgSO_4$, filtered, and concentrated *in vacuo*. The crude residue was purified *via* column chromatography to afford alcohol **3ba-OH** (45.4 mg, 43% yield). The ^{1}H NMR is in accordance with the literature.[7] ^{1}H NMR (400 MHz; CD_2Cl_2): δ 7.44 (ddd, *J* = 8.0, 1.1, 0.8 Hz, 1H), 7.36-7.33 (m, 2H), 7.31-7.26 (m, 3H), 7.20-7.15 (m, 2H), 7.01-6.97 (m, 2H), 4.38 (t, *J* = 7.7 Hz, 1H), 3.62 (tt, *J* = 6.7, 3.4 Hz, 2H), 2.48-2.40 (m, 1H), 2.30-2.23 (m, 1H).

To a flame-dried round bottom was added **3ba-OH** (45 mg, 0.17 mmol, 1 equiv.). After addition of 2 mL of DCM, the reaction mixture was cooled to 0 °C. Dess-Martin Periodane (87 mg, 0.20 mmol, 1.2 equiv.) was added at 0 °C. The reaction was warmed to room temperature and allowed to stir for 15 minutes. The reaction was quenched with saturated aqueous $Na_2S_2O_3$ and $NaHCO_3$ and extracted with DCM. The organic layers were dried with anhydrous $MgSO_4$, filtered, and concentrated *in vacuo*. The crude residue was purified *via* column chromatography to afford aldehyde **3ba-CHO** (12.3 mg, 28% yield). The ^{1}H NMR is in accordance with the literature.[6] ^{1}H NMR (400 MHz; CD_2Cl_2): δ 9.74 (t, *J* = 2.1 Hz, 1H), 7.38 (d, *J* = 8.0 Hz, 1H), 7.33-7.26 (m, 5H), 7.20-7.14 (m, 2H), 7.00-6.96 (m, 1H), 6.92 (s, 1H), 4.84 (t, *J* = 7.8 Hz, 1H), 3.74 (s, 3H), 3.20 (ddd, *J* = 16.6, 8.2, 2.5 Hz, 1H), 3.08 (ddd, *J* = 16.6, 7.3, 1.8 Hz, 1H).

7. Use of Deuterium Labeled Alkyne

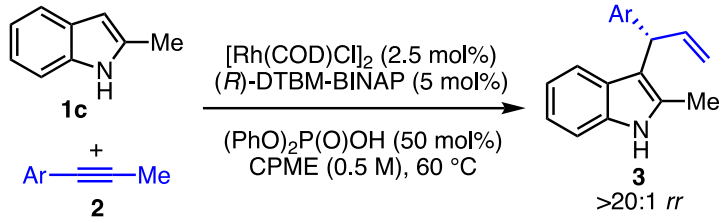
Similar to our previous studies,[8-10] use of a deuterated alkyne (**2a**-d_3) resulted in deuterium incorporation throughout the allyl fragment. This deuterium-scrambling suggests that β-hydride elimination to generate the corresponding allene is reversible.

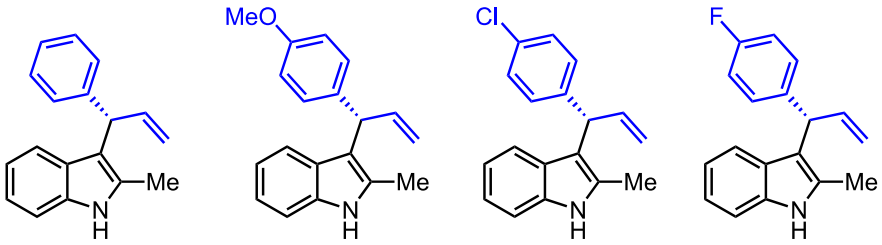




3-(1-Phenylallyl-1,2,3,3-D$_4$)-1H-indole (3aa-d_n): yellow oil, 20.0 mg, 86% yield. **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.98 (s, 1H), 7.41 (d, *J* = 8.0 Hz, 1H), 7.35 (d, *J* = 8.0 Hz, 1H), 7.33 – 7.27 (m, 4H), 7.25 – 7.15 (m, 2H), 7.04 (ddd, *J* = 8.0, 7.2, 1.2 Hz, 1H), 6.89 (d, *J* = 2.4 Hz, 1H), 6.36-6.34 (m, 0.85H), 5.19 (dd, *J* = 10.2, 1.6 Hz, 0.14H), 5.07 (dd, *J* = 17.2, 1.6 Hz, 0.14H), 4.99 – 4.96 (m, 0.84H). **^{13}C NMR** (101 MHz, $CDCl_3$) δ 143.2, 140.2, 136.6, 128.4, 128.3, 126.8, 126.3, 122.4, 122.0, 119.8, 119.3, 118.5, 111.0, 46.8. **IR** (ATR): 1455, 1416, 1335, 1218, 1093, 1009, 938, 738, 698, 602, 579 cm^{-1}.

8. Coupling of 2-Methyl Indole and Various Aryl-Alkynes: Observed Lower Enantioselectivity





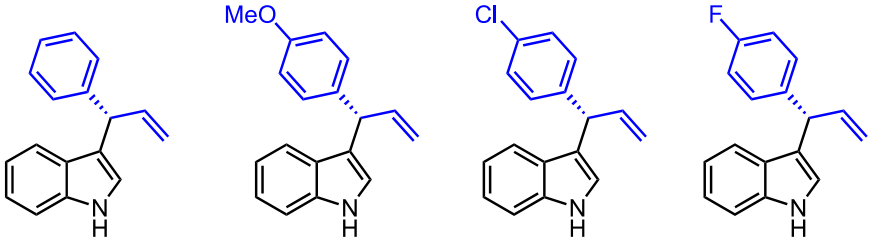
3ca
95%
69% *ee*

3cc
72%
51% *ee*

3cg
76%
70% *ee*

3cf
83%
68% *ee*

In contrast, higher enantioselectivities are observed when using the same alkynes when indole is used:

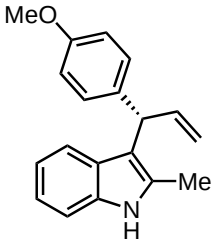


3aa
86%
91% *ee*

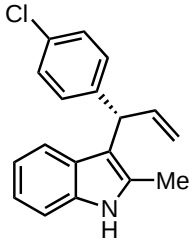
3ac
70%
82% *ee*

3ag
82%
88% *ee*

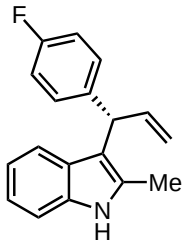
3af
93%
90% *ee*



(*S*)-3-(1-(4-methoxyphenyl)allyl)-2-methyl-1*H*-indole (3cc): yellow oil, isolated *via* preparatory TLC using 5% ethyl acetate in hexanes, R_f = 0.05, 20.0 mg, 72% yield, 51% ee, $[\alpha]^{22}_D$ = +3.6 (c = 0.67, $CHCl_3$). **^{1}H NMR** (400 MHz, $CDCl_3$) δ 7.77 (s, 1H), 7.36-7.34 (m, 1H), 7.28-7.21 (m, 3H), 7.09 (ddd, *J* = 8.1, 7.1, 1.1 Hz, 1H), 6.98 (ddd, *J* = 8.0, 7.0, 1.0 Hz, 1H), 6.83-6.81 (m, 2H), 6.44 (ddd, *J* = 17.1, 10.1, 7.0 Hz, 1H), 5.19 (dt, *J* = 10.1, 1.6 Hz, 1H), 5.07 (dt, *J* = 17.0, 1.6 Hz, 1H), 4.94 (d, *J* = 7.0 Hz, 1H), 3.78 (s, 3H), 2.34 (s, 3H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ158.0, 140.4, 135.47, 135.39, 131.5, 129.3, 128.1, 121.0, 119.6, 119.2, 115.4, 113.7, 113.1, 110.3, 55.4, 45.2, 12.5. **IR** (ATR): 3400, 1682, 1608, 1507, 1459, 1299, 1241, 1175, 1031, 910, 825, 740, 644 cm^{-1}. **HRMS** $C_{19}H_{19}NO$ $[M]^+$ 277.1466, found 277.1463. **Chiral SFC**: 51% ee, OJ-H column, 220 nm, 10% 2-propanol in CO_2, 3 mL/min, retention time 7.7 min and 9.11 min (major).



(*S*)-3-(1-(4-chlorophenyl)allyl)-2-methyl-1*H*-indole (3cg): yellow oil, isolated *via* preparatory TLC using 5% ethyl acetate in hexanes, R_f = 0.1, 21.4 mg, 76% yield, 70% ee, $[\alpha]^{22}_D$ = +46.4 (c = 2.14, $CHCl_3$). **^{1}H NMR** (400 MHz, $CDCl_3$) δ7.87 (s, 1H), 7.37-7.32 (m, 2H), 7.28 (m, 4H), 7.15 (ddd, *J* = 8.1, 7.1, 1.1 Hz, 1H), 7.04 (ddd, *J* = 8.0, 7.0, 1.0 Hz, 1H), 6.46 (ddd, *J* = 17.1, 10.1, 7.0 Hz, 1H), 5.27 (dt, *J* = 10.1, 1.5 Hz, 1H), 5.12 (dt, *J* = 17.1, 1.6 Hz, 1H), 4.99 (dt, *J* = 7.0, 1.3 Hz, 1H), 2.40 (s, 3H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ141.8, 139.6, 135.5, 131.9, 130.2, 129.7, 128.8, 128.4, 127.9, 121.2, 119.4, 116.0, 112.4, 110.4, 45.4, 12.5. **IR** (ATR): 3400, 1682, 1618, 1487, 1459, 1299, 1244, 1089, 1013, 911, 817, 740 cm^{-1}. **HRMS** $C_{18}H_{16}NCl$ $[M]^+$ 281.0971, found 281.0977. **Chiral SFC**: 70% ee, AD-H column, 220 nm, 12% 2-propanol in CO_2, 2 mL/min, retention time 7.2 min (major) and 8.7 min.



(*S*)-3-(1-(4-fluorophenyl)allyl)-2-methyl-1*H*-indole (3cf): yellow oil, isolated *via* preparatory TLC using 5% ethyl acetate in hexanes, R_f = 0.1, 22.1 mg, 83% yield, 68% ee, $[\alpha]^{22}_D$ = +45.5 (c = 2.21, $CHCl_3$). **^{1}H NMR** (400 MHz, $CDCl_3$) δ7.79 (bs, 1H), 7.33-7.31 (m, 1H), 7.29-7.25 (m, 3H), 7.11 (ddd, *J* = 8.1, 7.1, 1.1 Hz, 1H), 7.02-6.94 (m, 3H), 6.44 (ddd, *J* = 17.1, 10.1, 7.0 Hz, 1H), 5.22 (dt, *J* = 10.1, 1.5 Hz, 1H), 5.08 (dt, *J* = 17.0, 1.6 Hz, 1H), 4.97-4.95 (m, 1H), 2.35 (s, 3H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ162.4, 160.5, 139.9, 138.89, 138.87, 135.5, 131.6, 129.77, 129.71, 127.9, 121.1, 119.41, 119.33, 115.8, 115.06, 114.89, 112.6, 110.4, 45.3, 12.4. **^{19}F NMR** (376 MHz, $CDCl_3$) δ δ -118.0. **IR** (ATR): 3400, 1682, 119, 1487, 1459, 1299, 1244, 1089, 1013, 911, 818, 740, 637 cm^{-1}. **HRMS** calculated for $C_{18}H_{16}NF$ $[M]^+$ 265.1267, found 265.1279. **Chiral SFC**: 68% ee, AD-H column, 220 nm, 10% 2-propanol in CO_2, 2 mL/min, retention time 5.6 min (major) and 6.8 min.

9. References

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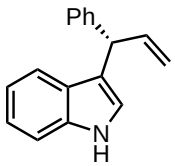
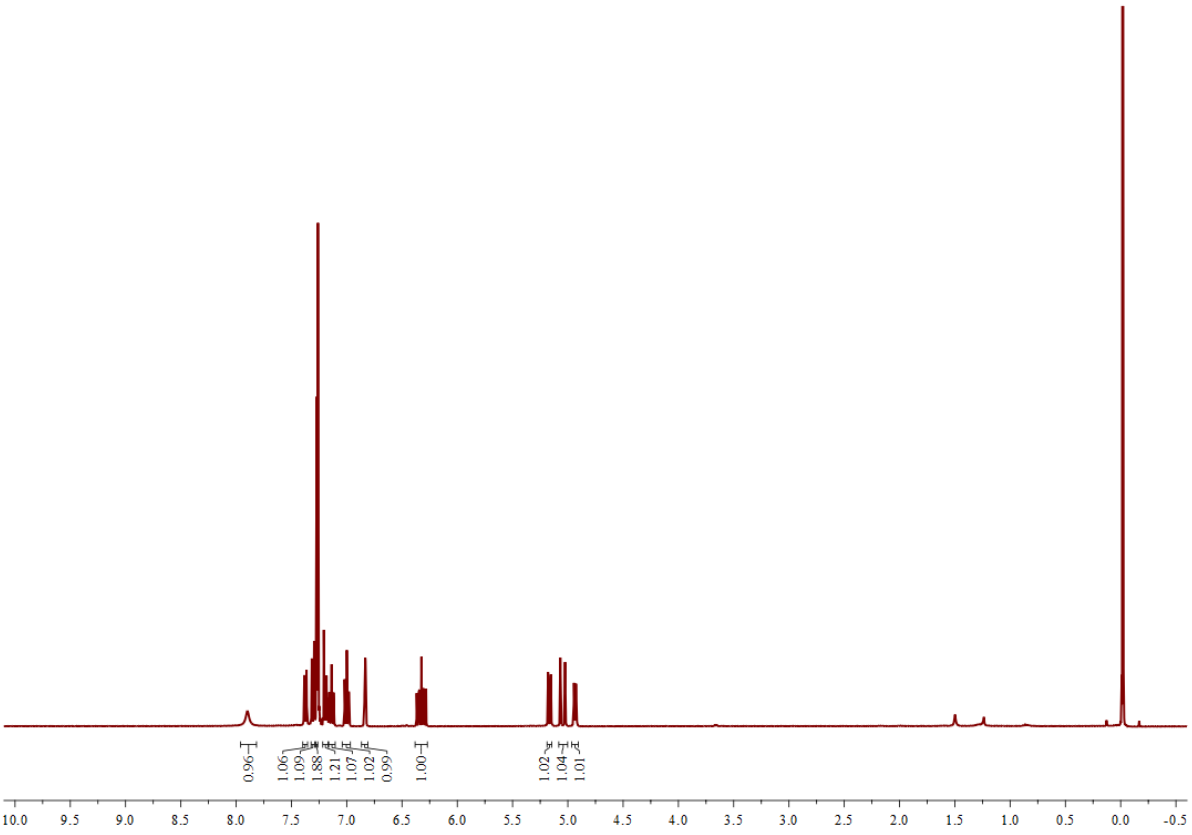
(9) Q.-A. Chen, Z. Chen, V. M. Dong, *J. Am. Chem. Soc.* **2015**, *137*, 8392;

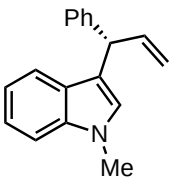
(10) F. A. Cruz, Z. Chen, S. I. Kurtoic, V. M. Dong, *Chem. Commun.* **2016**, *52*, 5836

10. NMR Spectra

(3aa)



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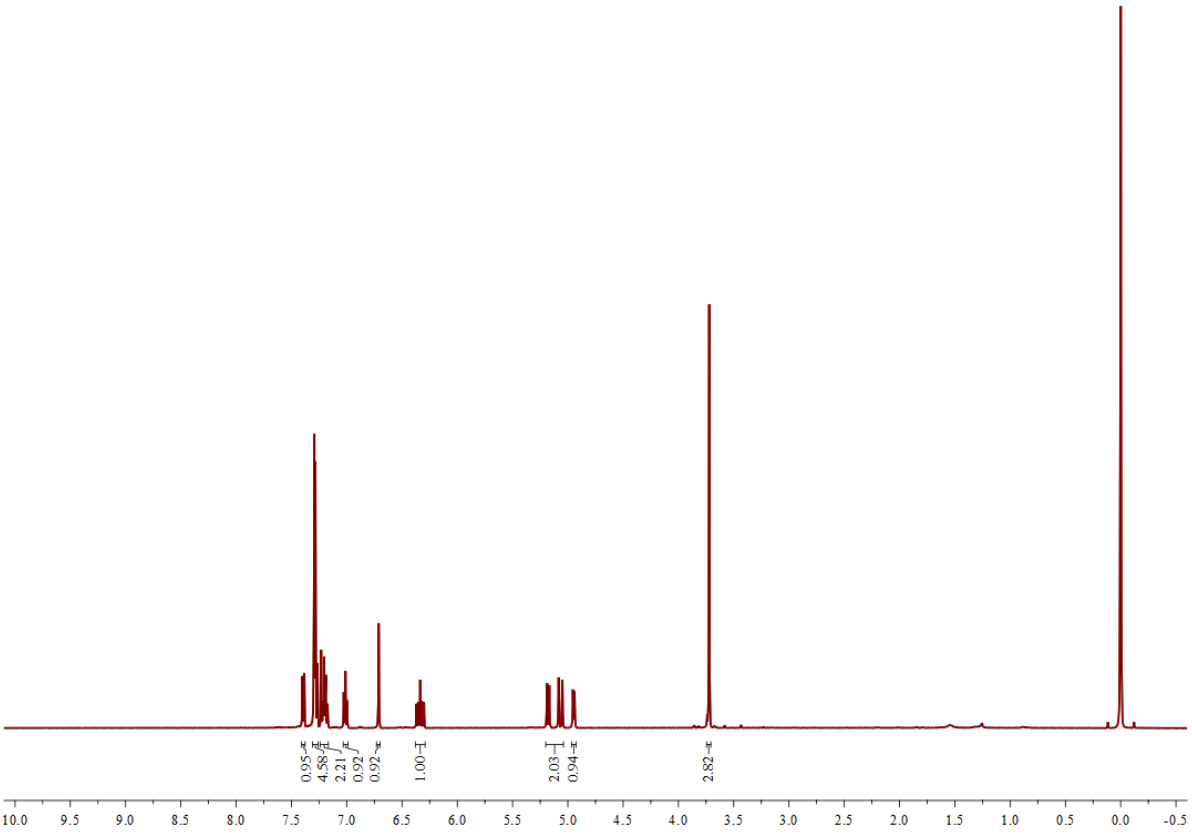
Me

(3ba)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8.0
7.5
7.0
6.5
6.0
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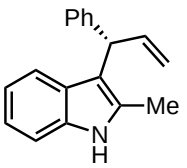
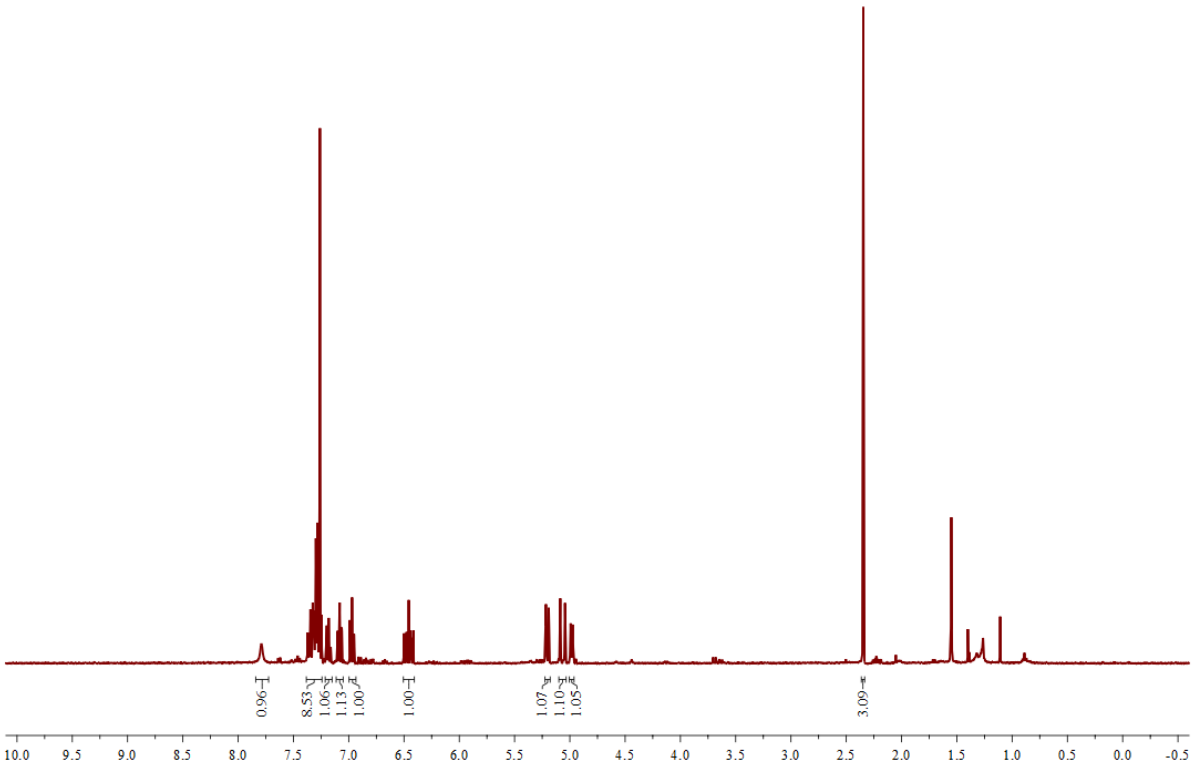

Ph
Me
N
H

(3ca)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9.0
8.5
8.0
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7.0
6.5
6.0
5.5
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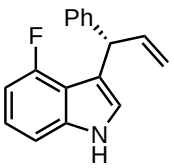
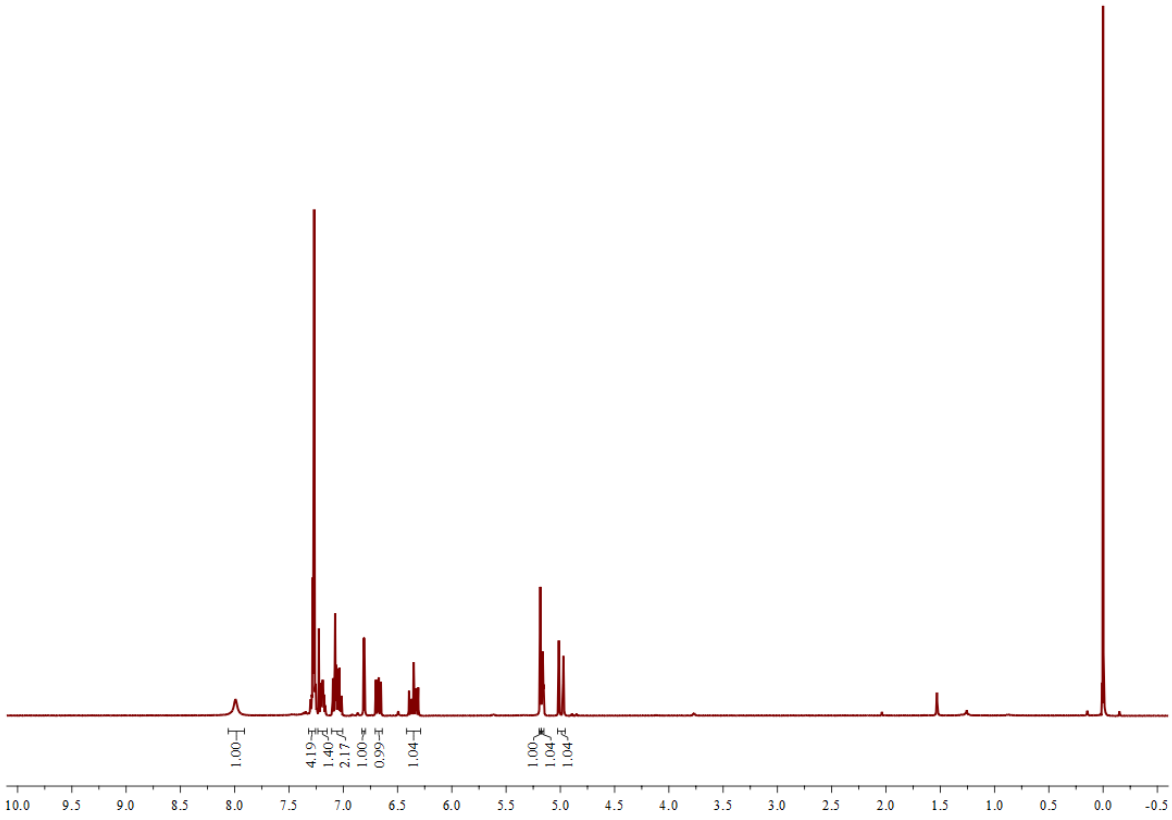

Ph
F
N
H

(3da)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7.5
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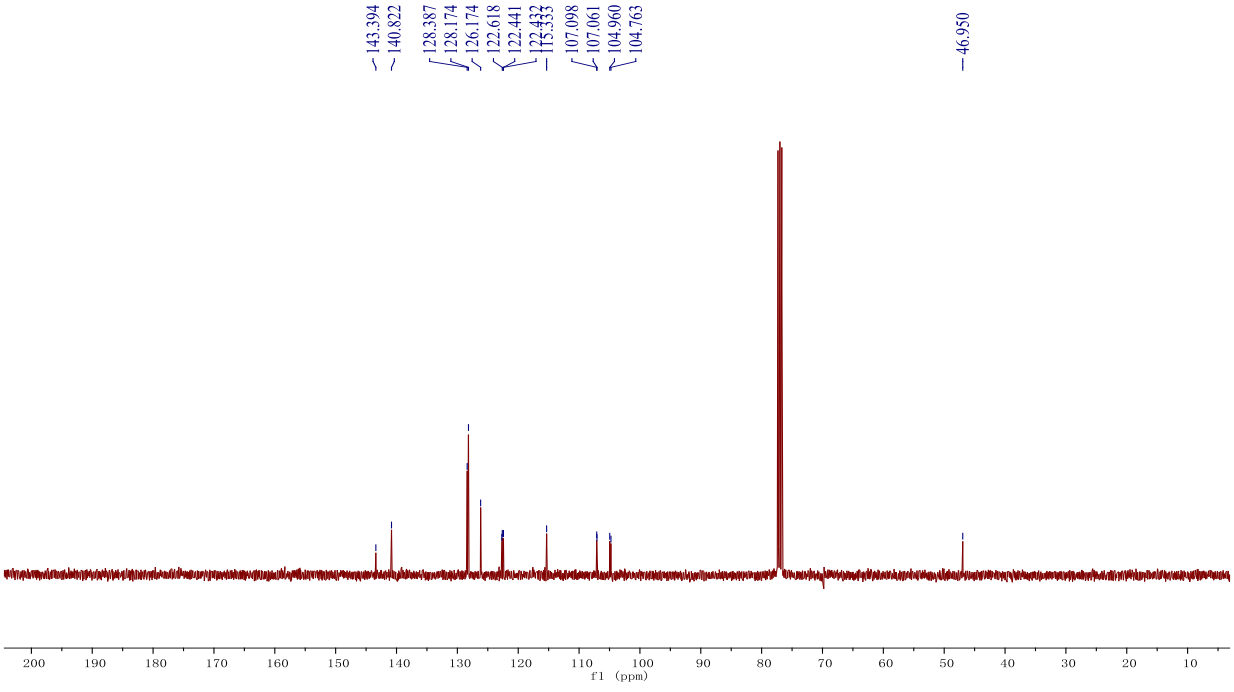
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107.061
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46.950
200
190
180
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140
130
120
110
100
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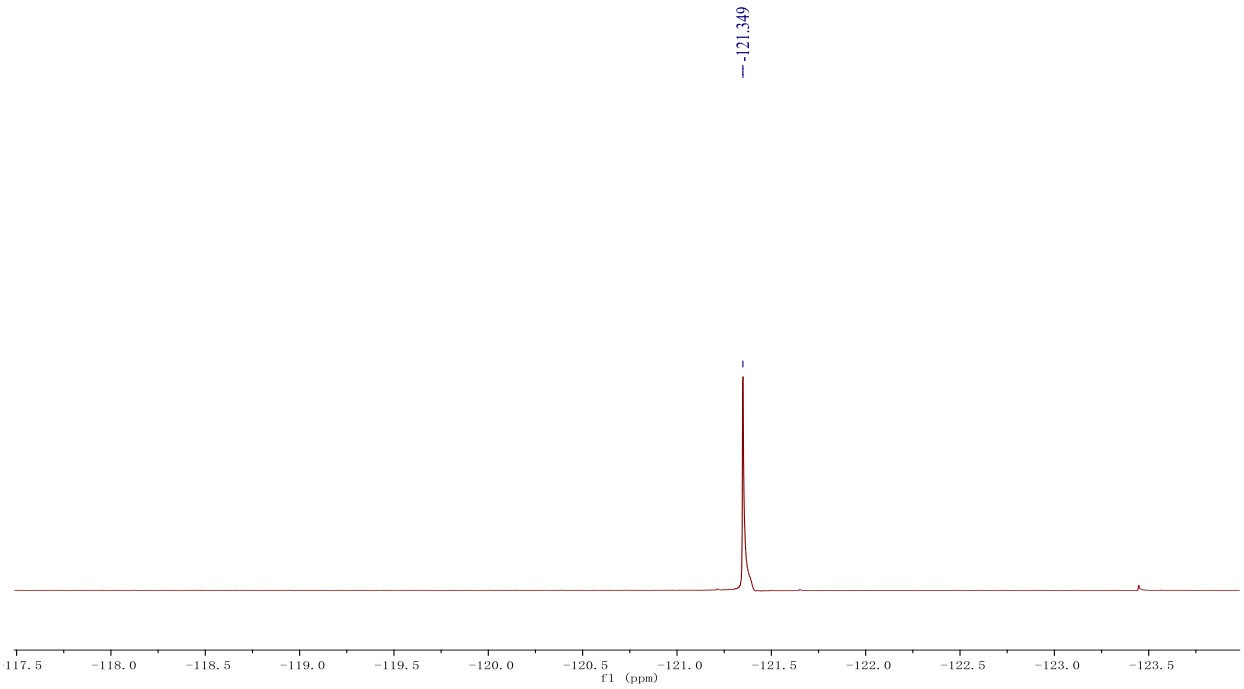
70
60
50
40
30
20
10
f1 (ppm)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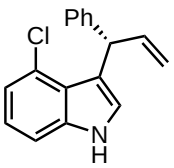
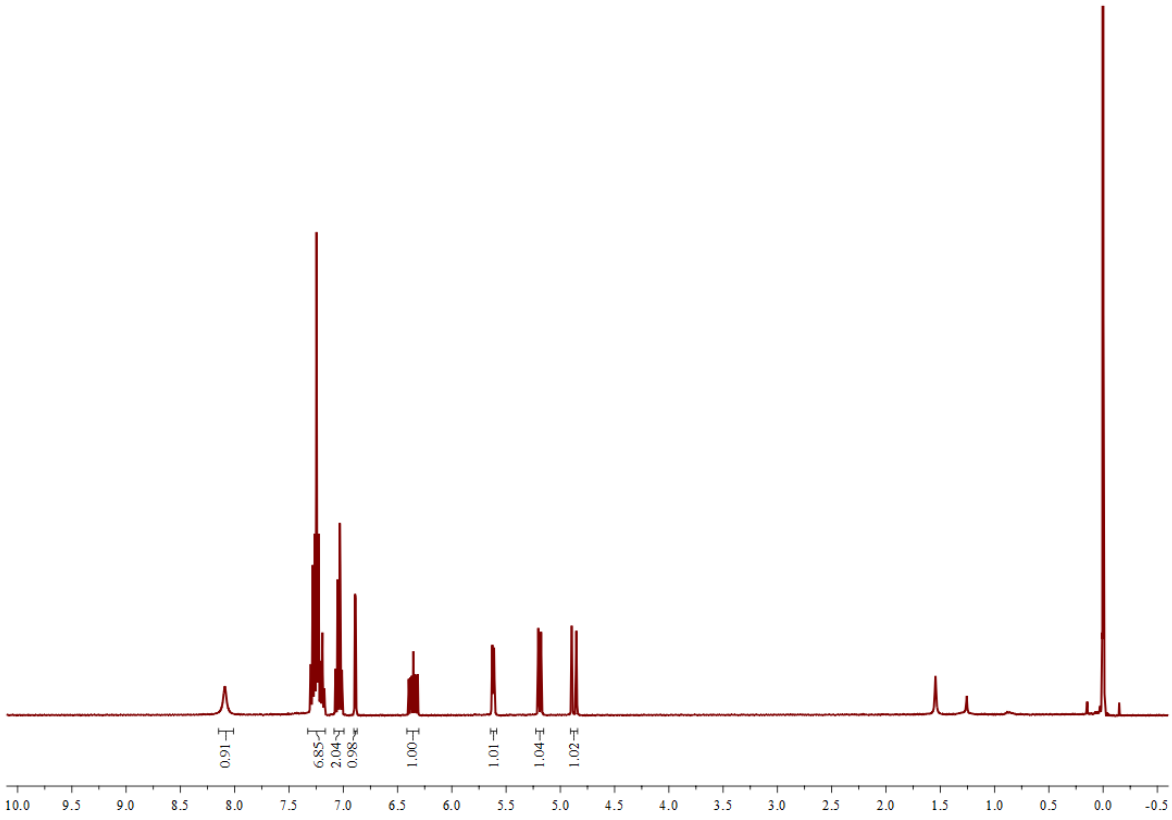
-118.0
-118.5
-119.0
-119.5
-120.0
-120.5
-121.0
-121.5
-122.0
-122.5
-123.0
-123.5
f1 (ppm)


Ph
Cl
N
H

(3ea)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6.0
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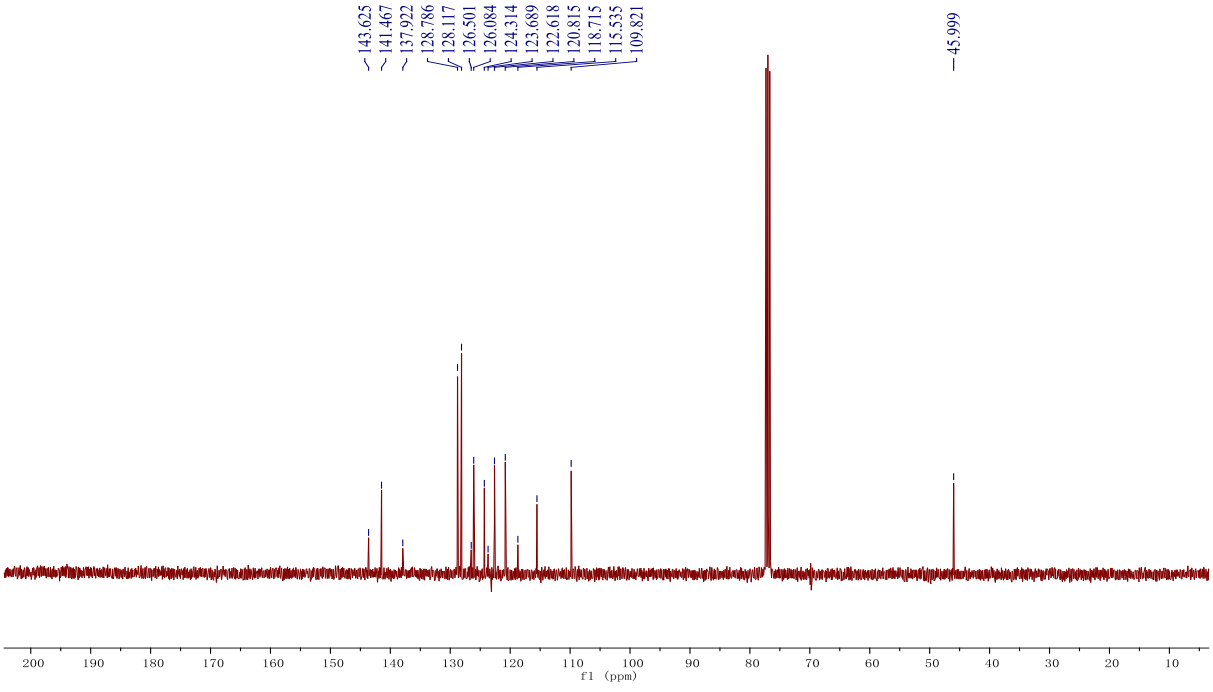
-0.5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115.535
109.821
45.999
200
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50
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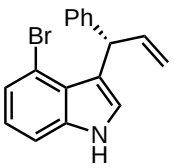
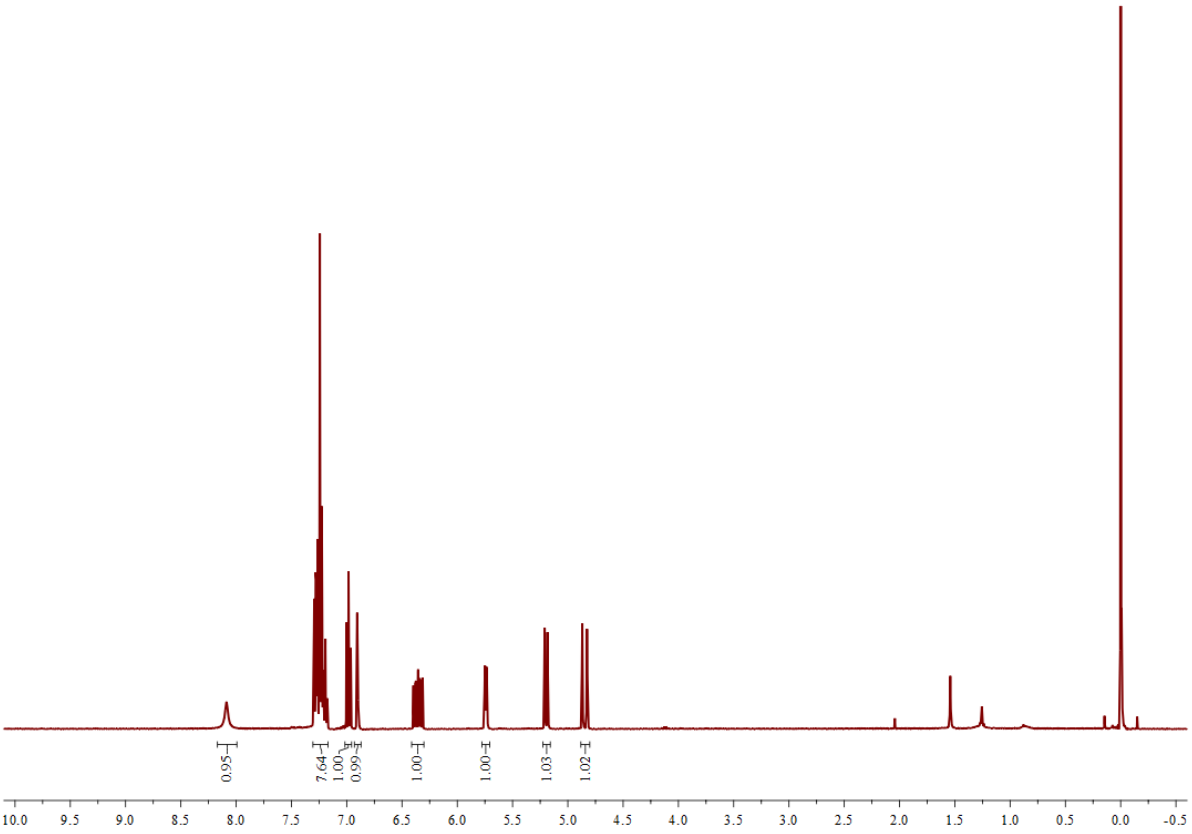
10
f1 (ppm)


Ph
Br
N
H

(3fa)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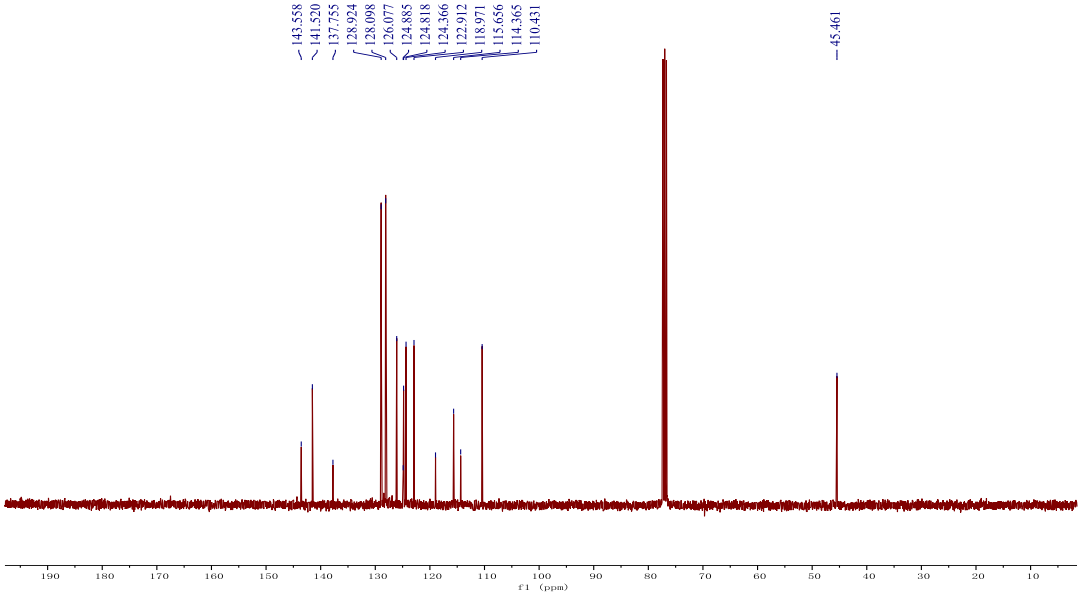
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110.431
45.461
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100
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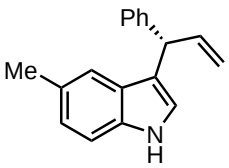
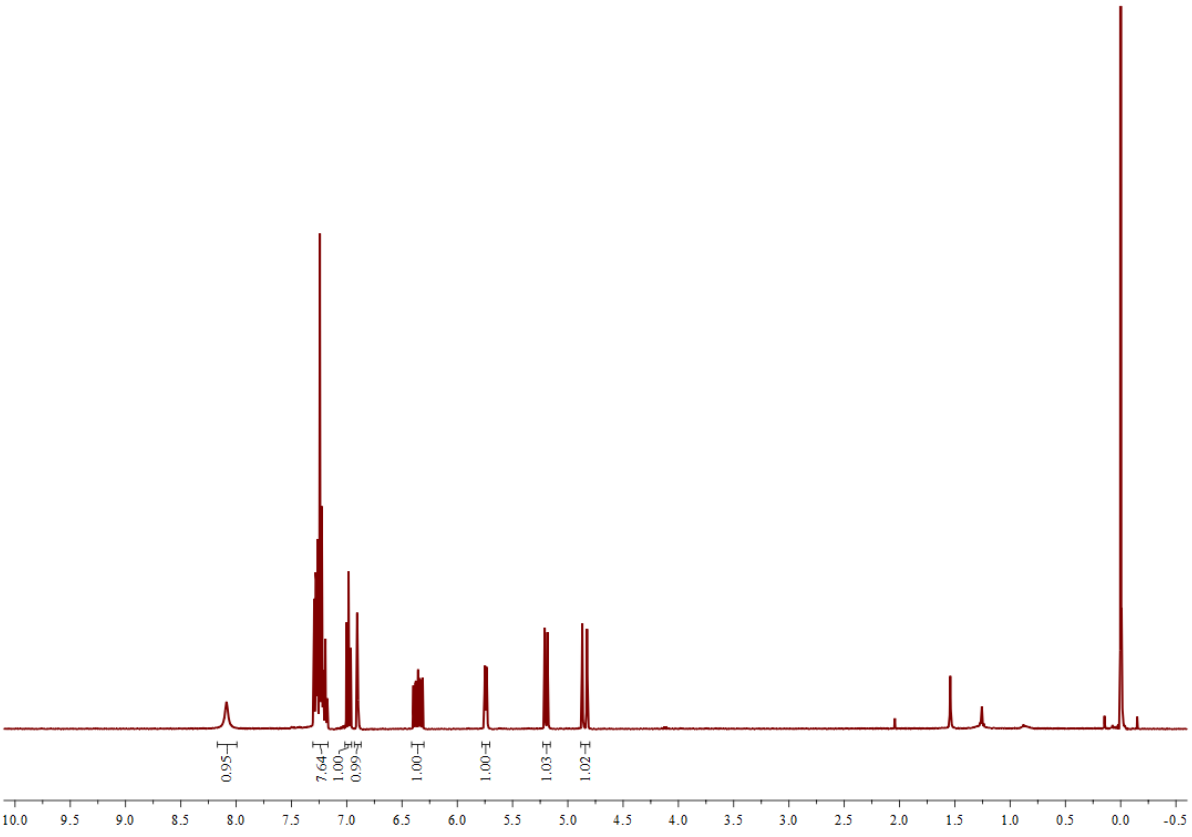
60
50
40
30
20
10
f1 (ppm)


Ph
Me
N
H

(3ga)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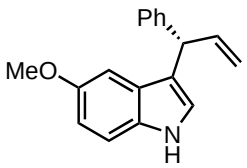
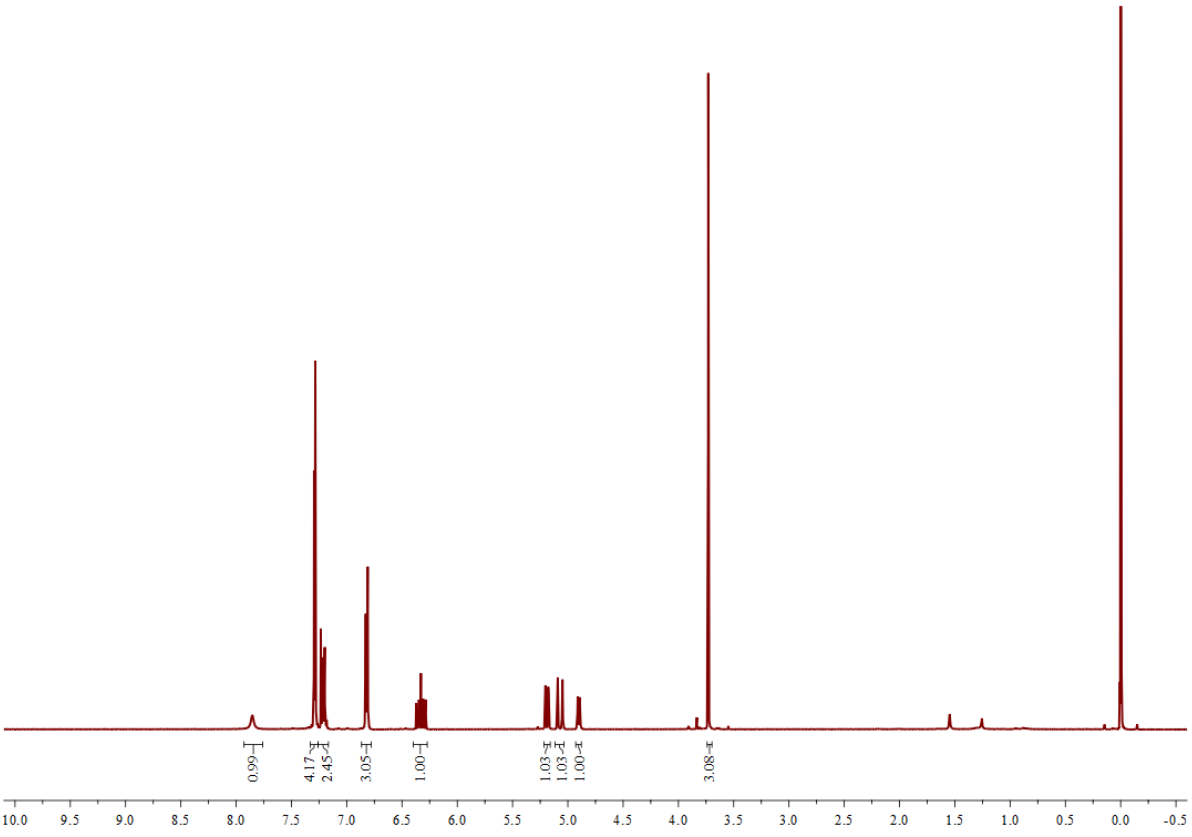

Ph
MeO
N
H

(3ha)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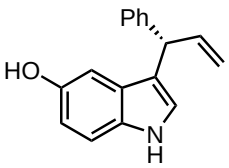
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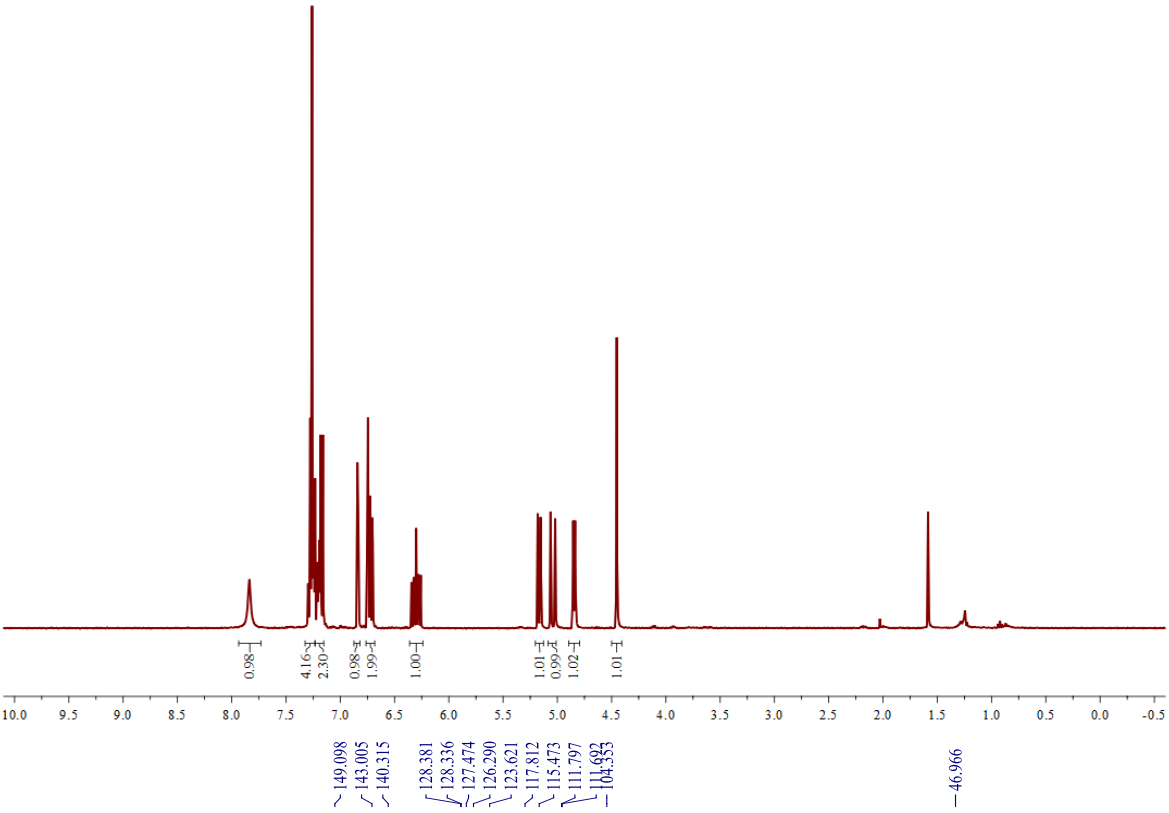
H

(3ia)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143.005
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111.692
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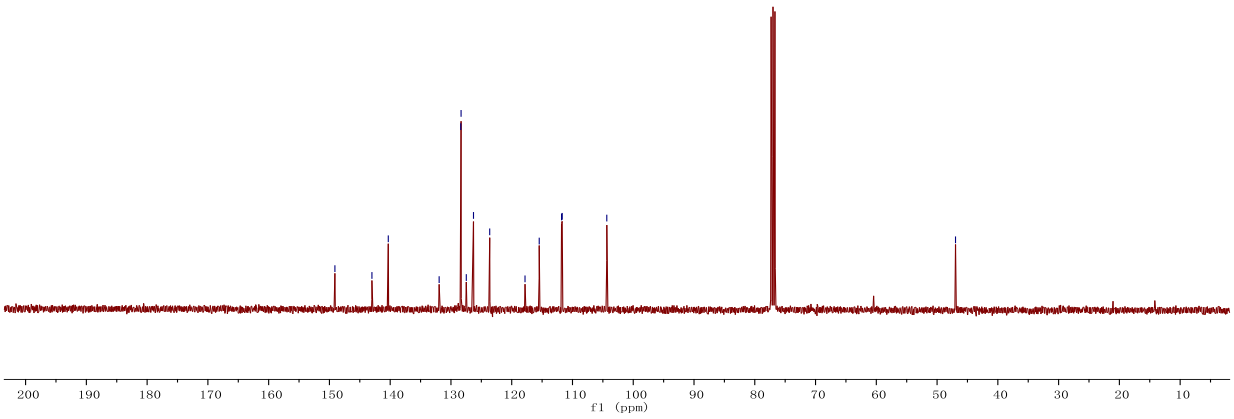
46.966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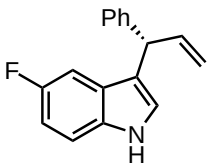
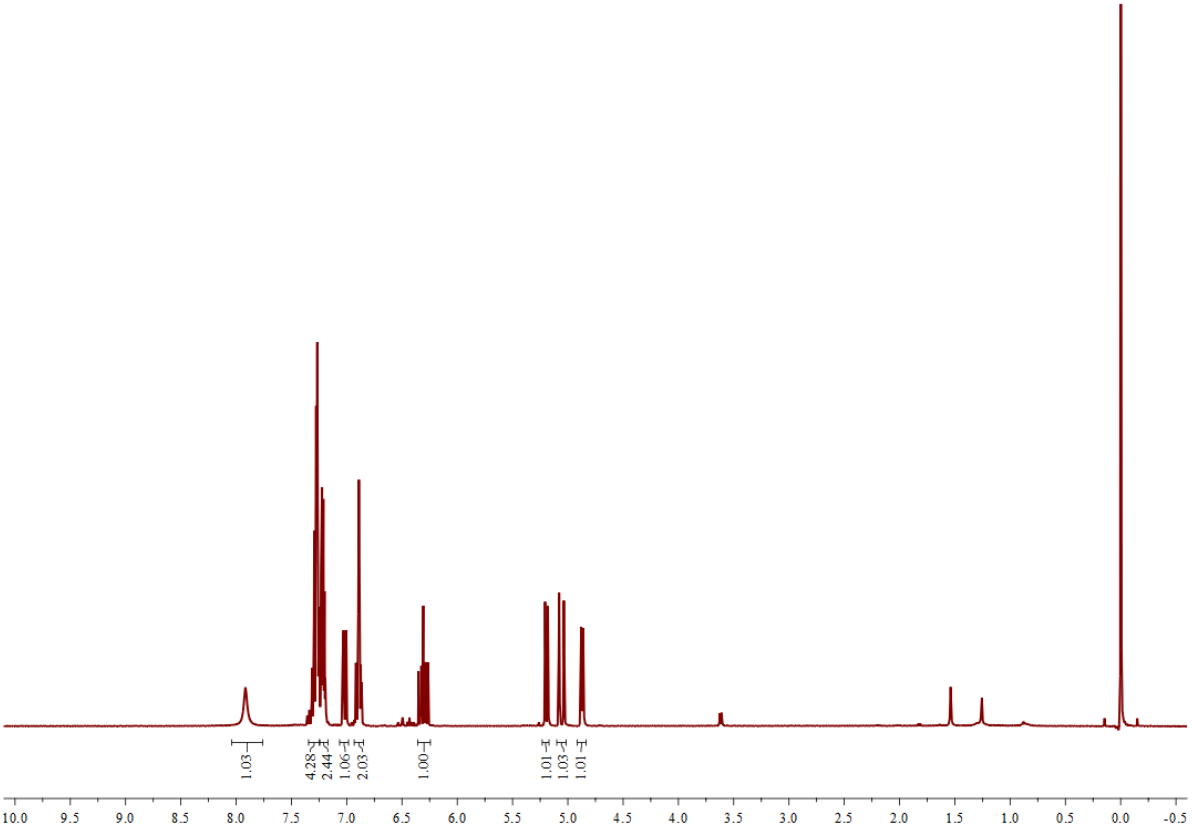

Ph
F
N
H

(3ja)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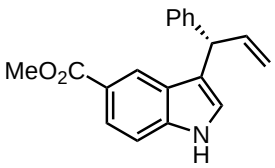
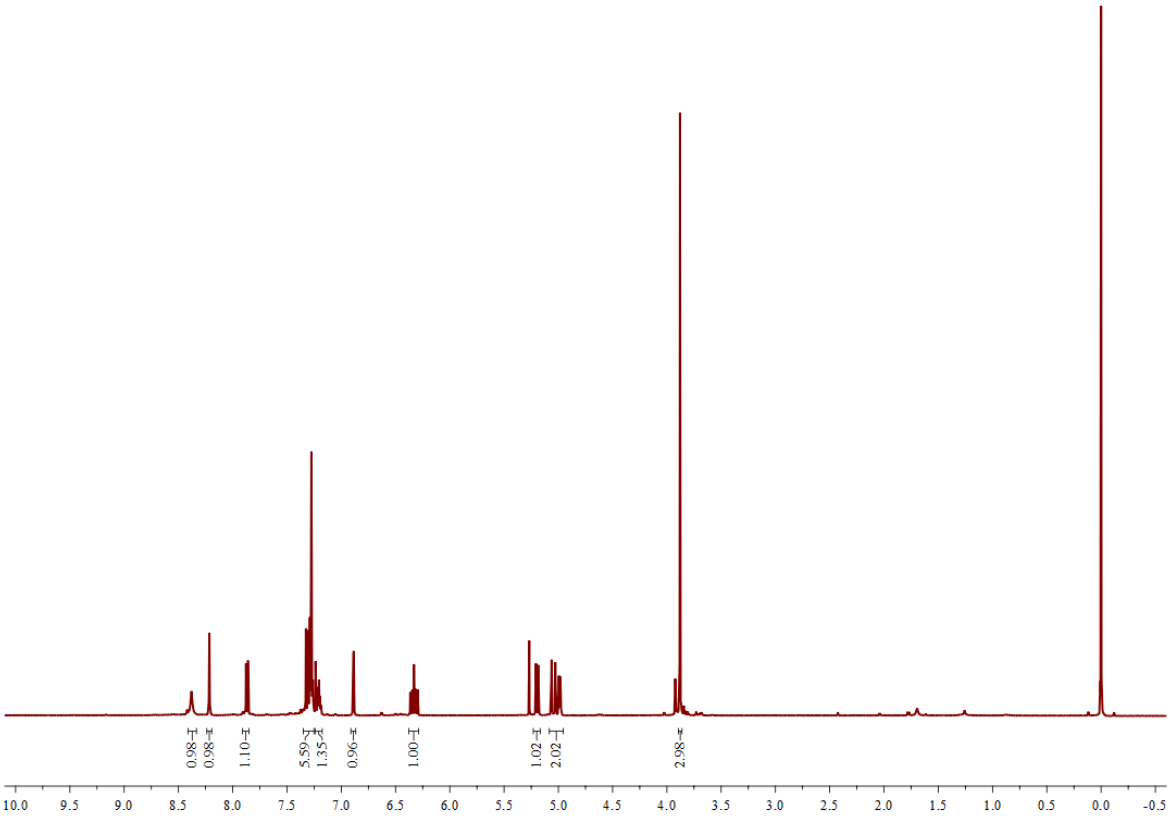
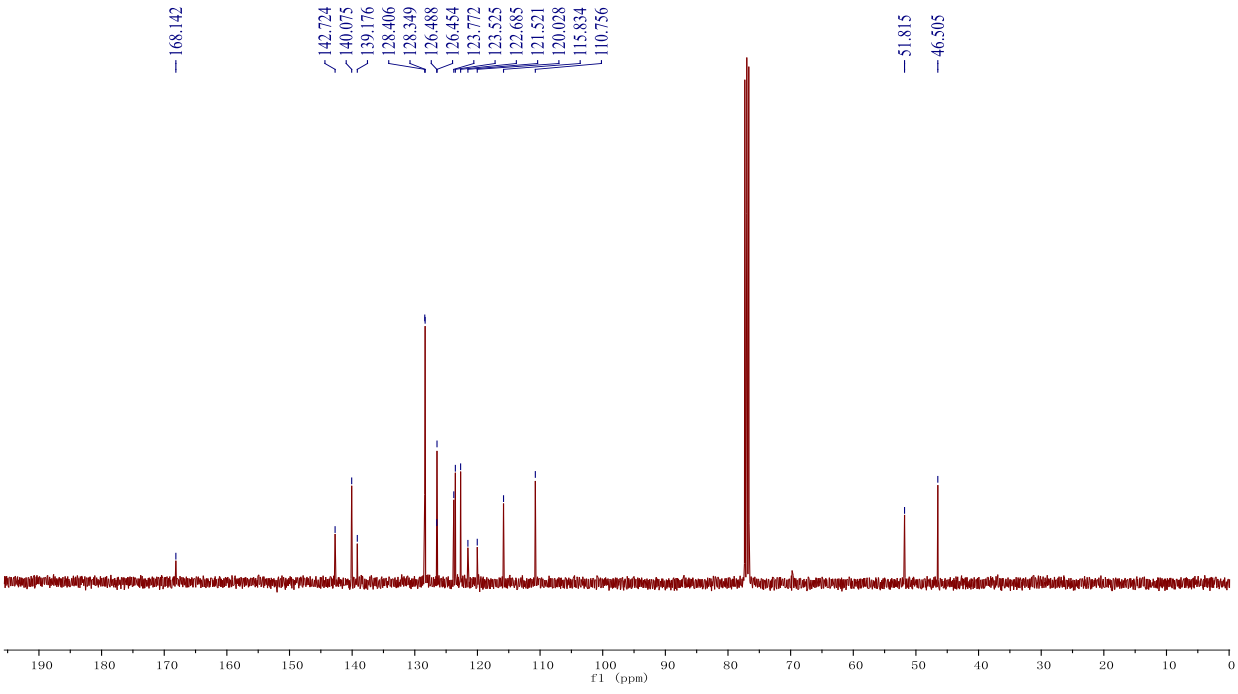
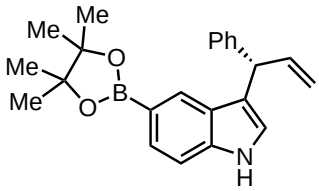
2.03
1.00
1.01
1.03
1.01
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5


Ph
MeO2C
N
H

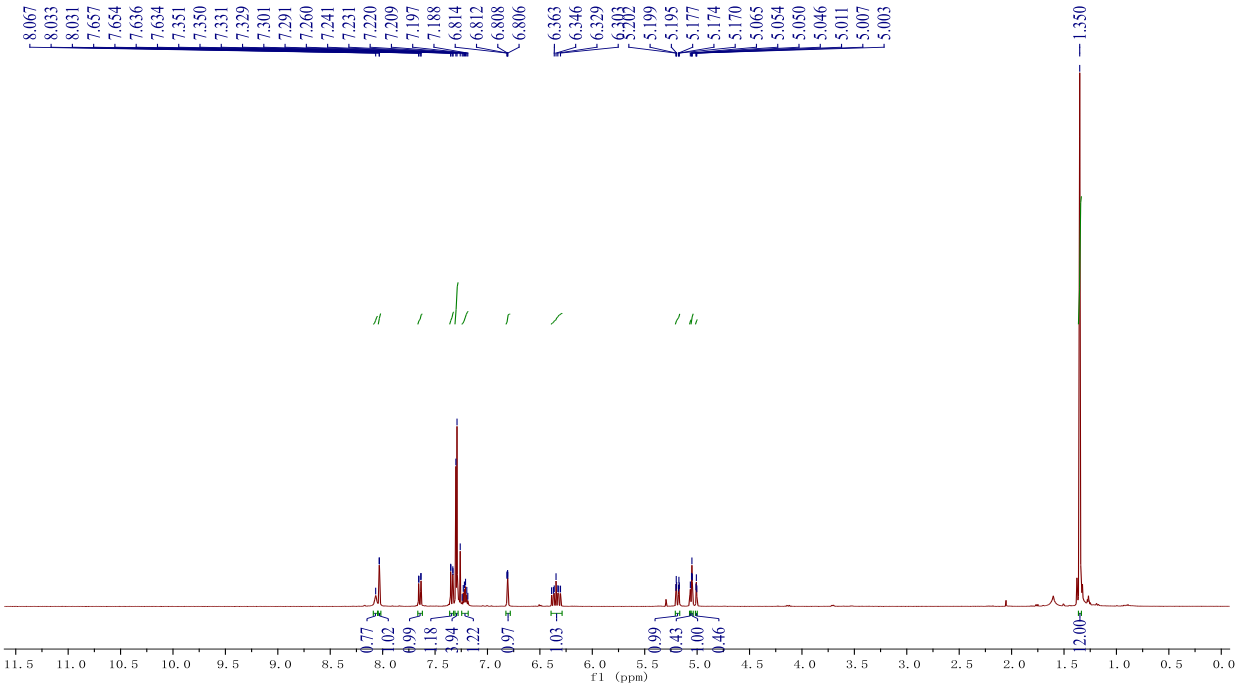
(3ka)

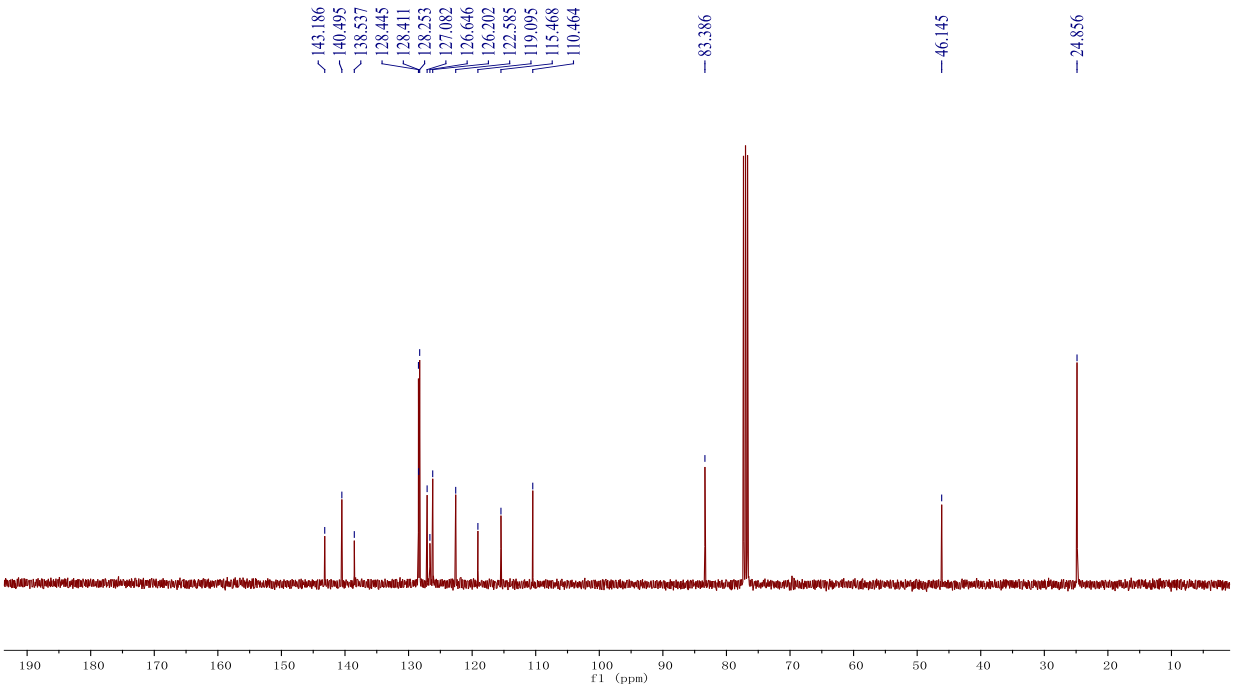

0.98
0.98
1.10
5.59
1.35
0.96
1.00
1.02
2.02
2.98
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5

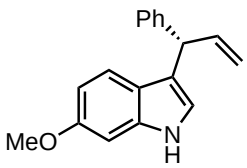

168.142
142.724
140.075
139.176
128.406
128.349
126.488
126.454
123.772
123.525
122.685
121.521
120.028
115.834
110.756
51.815
46.505
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)


Me
Me
Me
Me
O
O
B
Ph
N
H

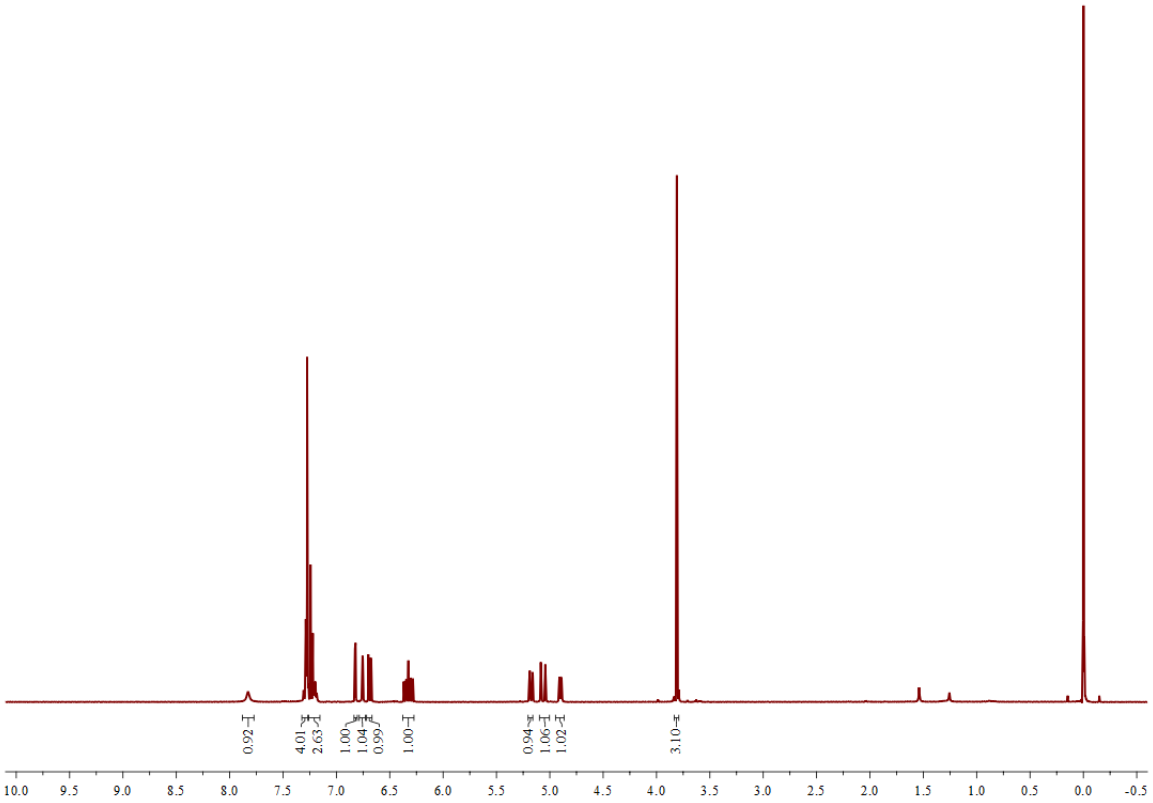
(3la)

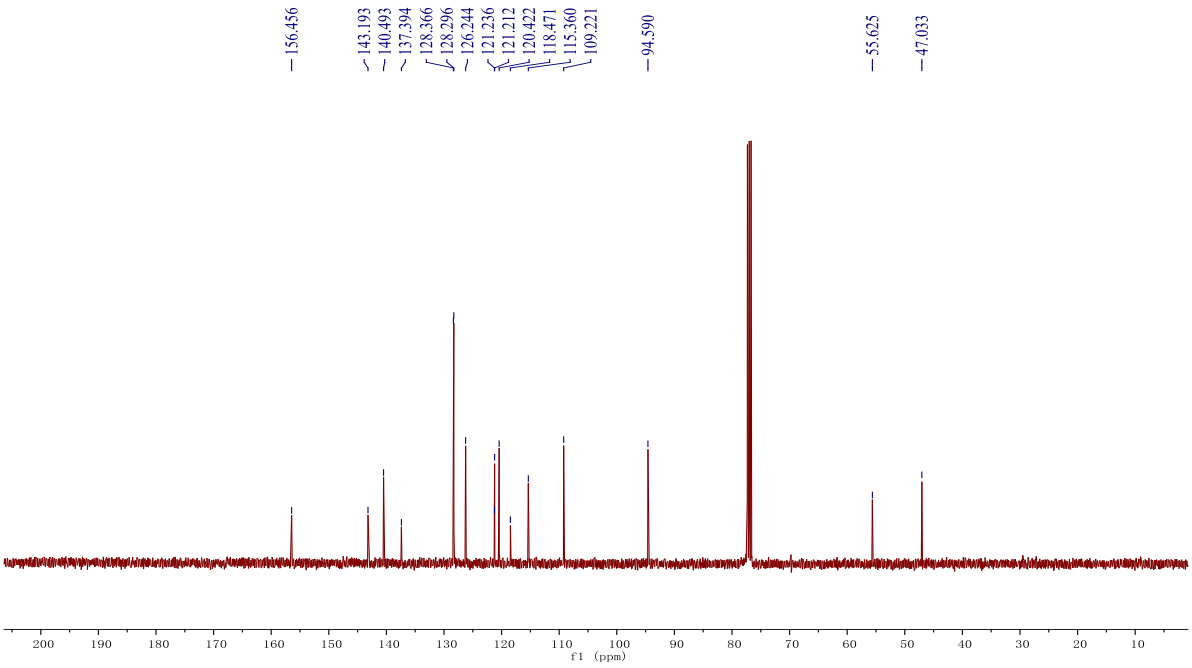

8.067
8.033
8.031
7.657
7.654
7.636
7.634
7.351
7.350
7.331
7.329
7.301
7.291
7.260
7.241
7.231
7.220
7.209
7.197
7.188
6.814
6.812
6.808
6.806
6.363
6.346
6.329
5.202
5.199
5.195
5.177
5.174
5.170
5.065
5.054
5.050
5.046
5.011
5.007
5.003
1.350
0.77
1.02
0.99
1.18
3.94
1.22
0.97
1.03
0.99
0.43
1.00
0.46
12.00
f1 (ppm)

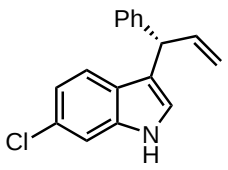

143.186
140.495
138.537
128.445
128.411
128.253
127.082
126.646
126.202
122.585
119.095
115.468
110.464
83.386
46.145
24.856
f1 (ppm)


Ph
MeO
N
H

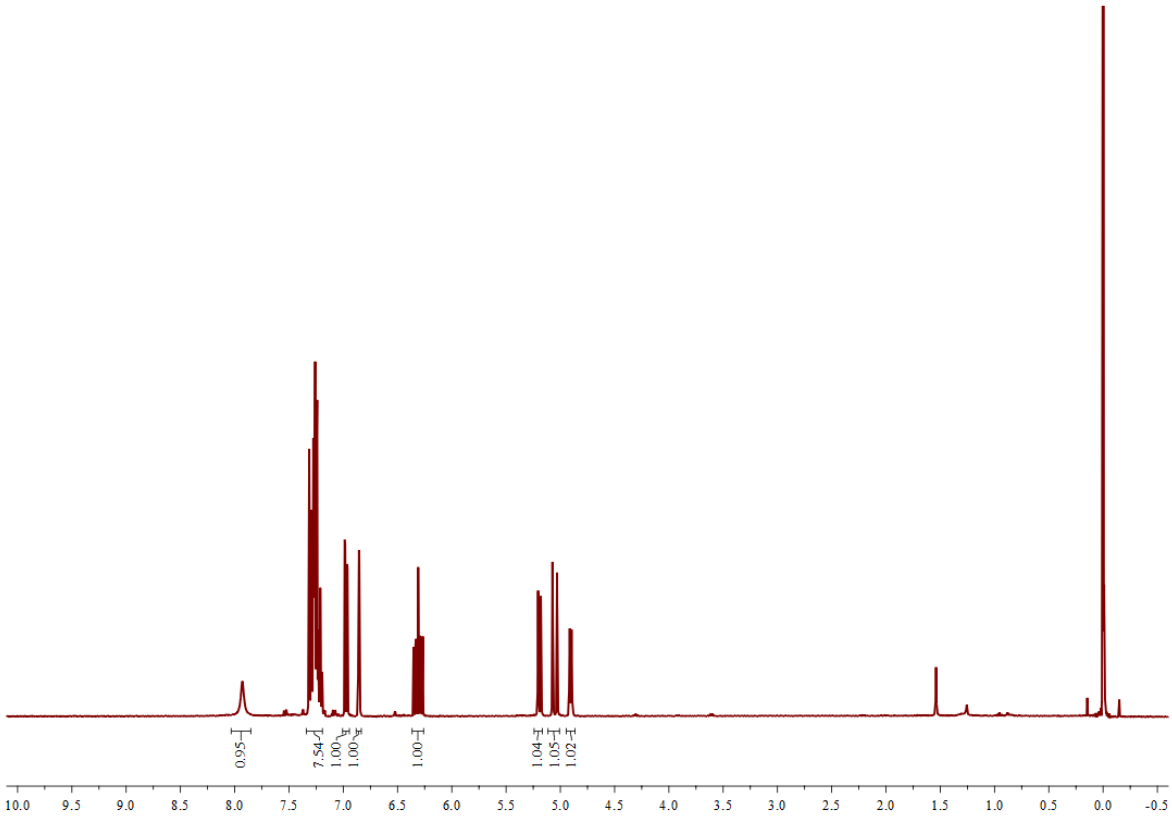
(3ma)

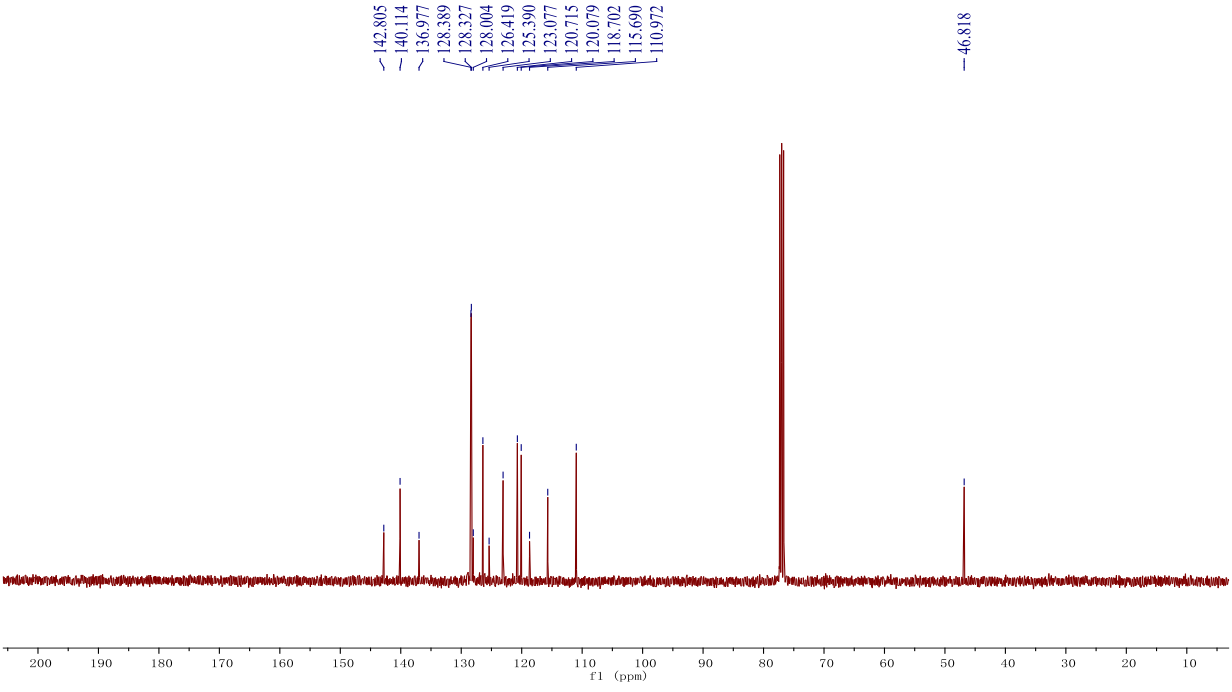

0.92
4.01
2.63
1.00
1.04
0.99
1.00
0.94
1.06
1.02
3.10
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5

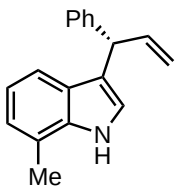

156.456
143.193
140.493
137.394
128.366
128.296
126.244
121.236
121.212
120.422
118.471
115.360
109.221
94.590
55.625
47.033
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10
f1 (ppm)


Ph
Cl
N
H

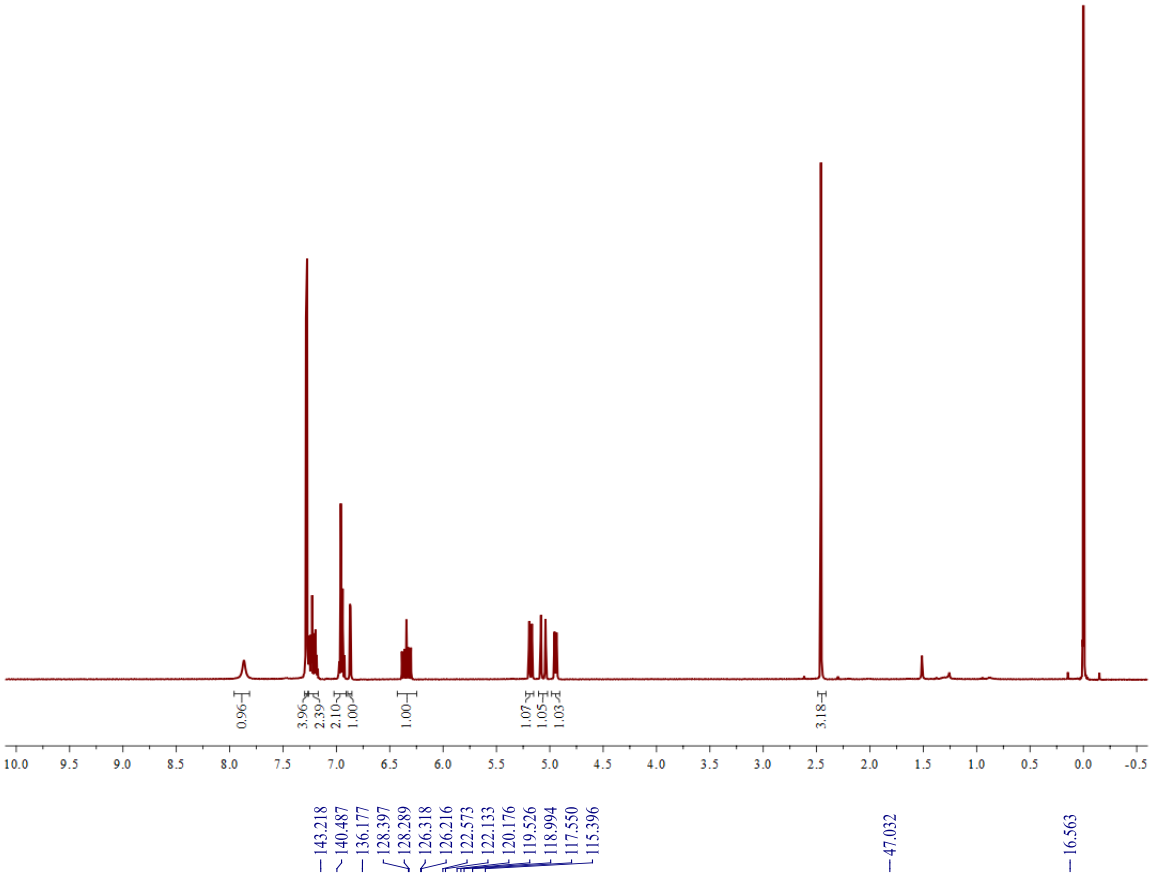
(3na)


0.95
7.54
1.00
1.00
1.00
1.04
1.05
1.02
10.0 9.5 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

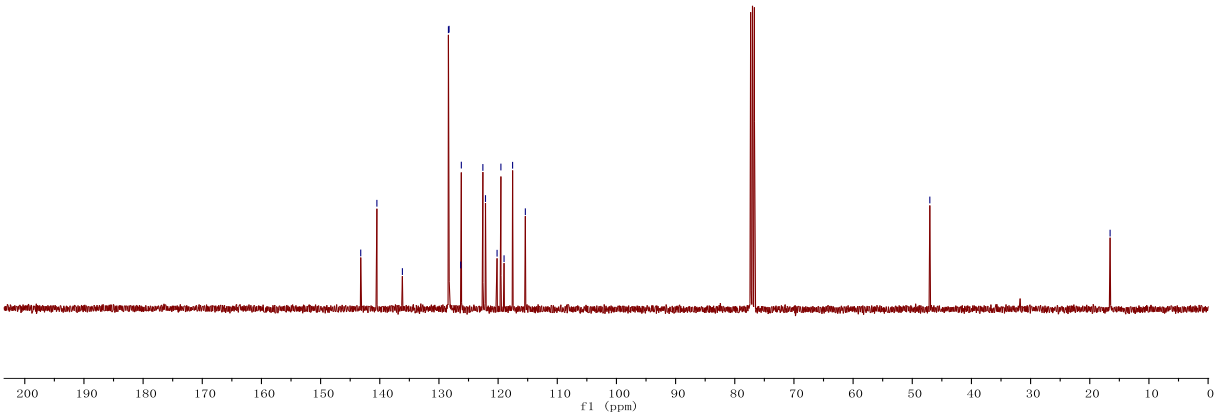

142.805
140.114
136.977
128.389
128.327
128.004
126.419
125.390
123.077
120.715
120.079
118.702
115.690
110.972
46.818
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10
f1 (ppm)

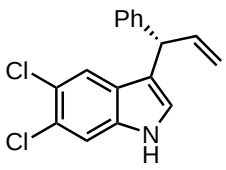

Ph
N
H
Me

(3oa)

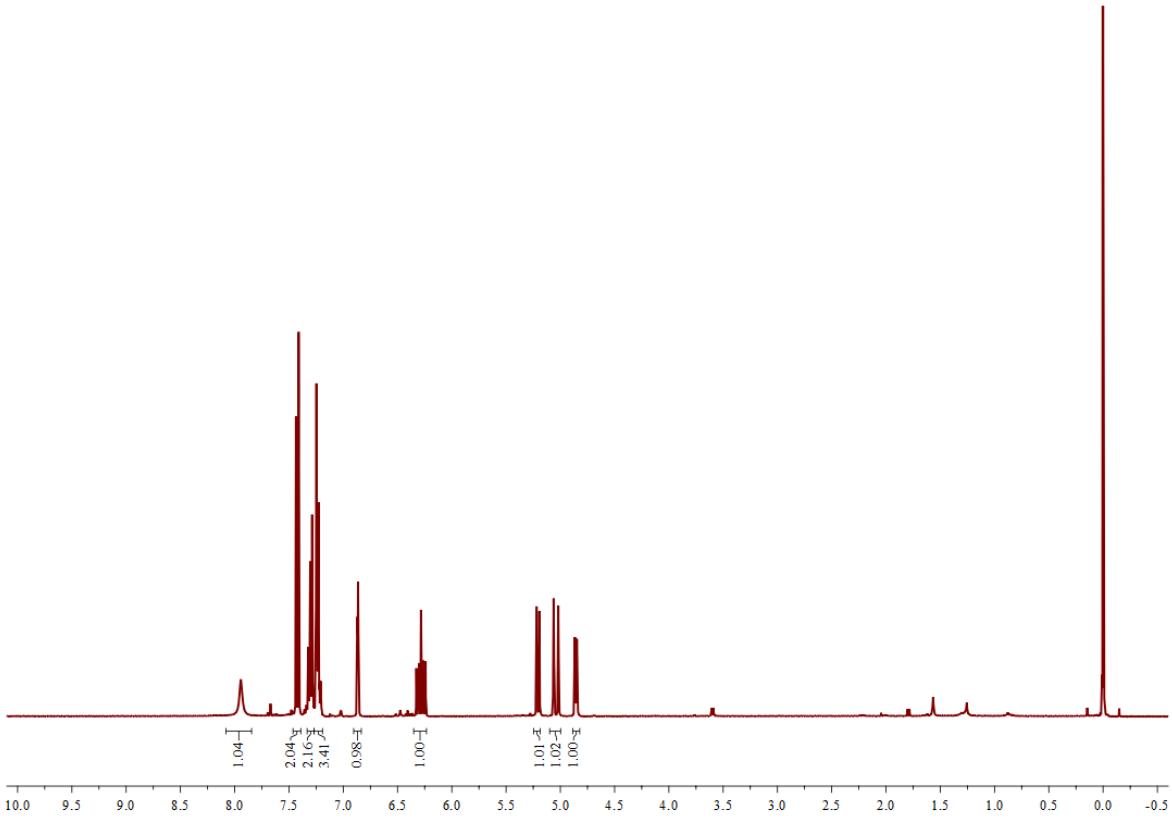

0.96
3.96
2.39
2.10
1.00
1.00
1.07
1.05
1.03
3.18
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5

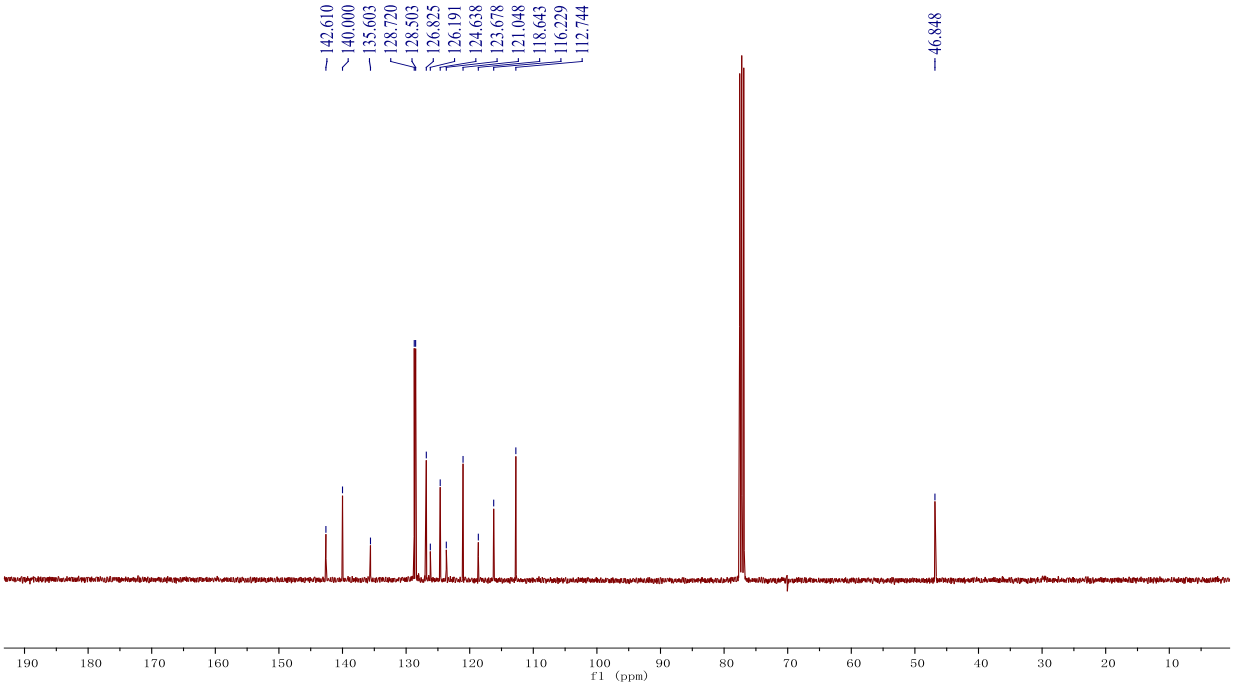
143.218
140.487
136.177
128.397
128.289
126.318
126.216
122.573
122.133
120.176
119.526
118.994
117.550
115.396
47.032
16.563

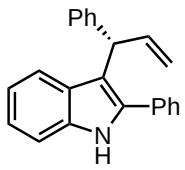

200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
f1 (ppm)


Ph
Cl
Cl
N
H

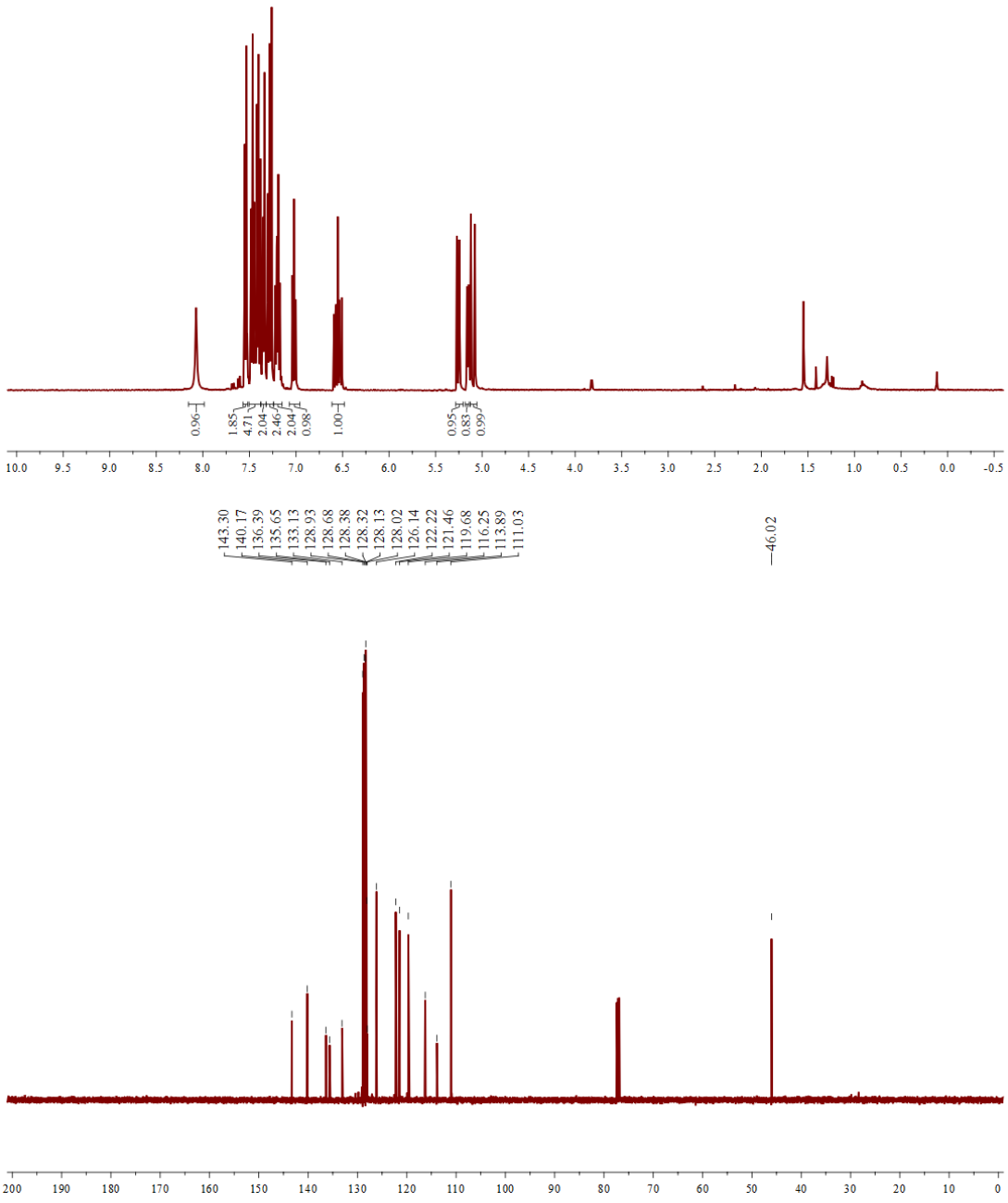
(3pa)

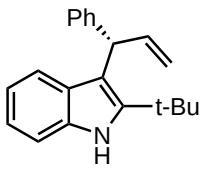

1.04
2.04
2.16
3.41
0.98
1.00
1.01
1.02
1.00
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5


142.610
140.000
135.603
128.720
128.503
126.825
126.191
124.638
123.678
121.048
118.643
116.229
112.744
46.848
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10
f1 (ppm)

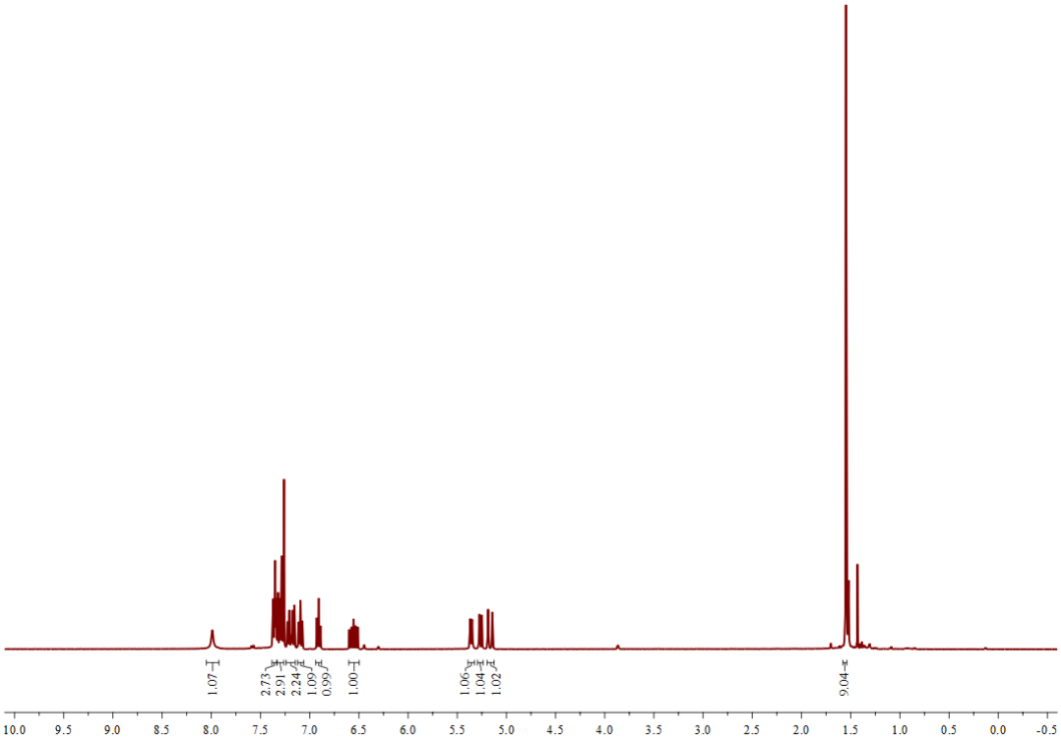

Ph
Ph
N
H

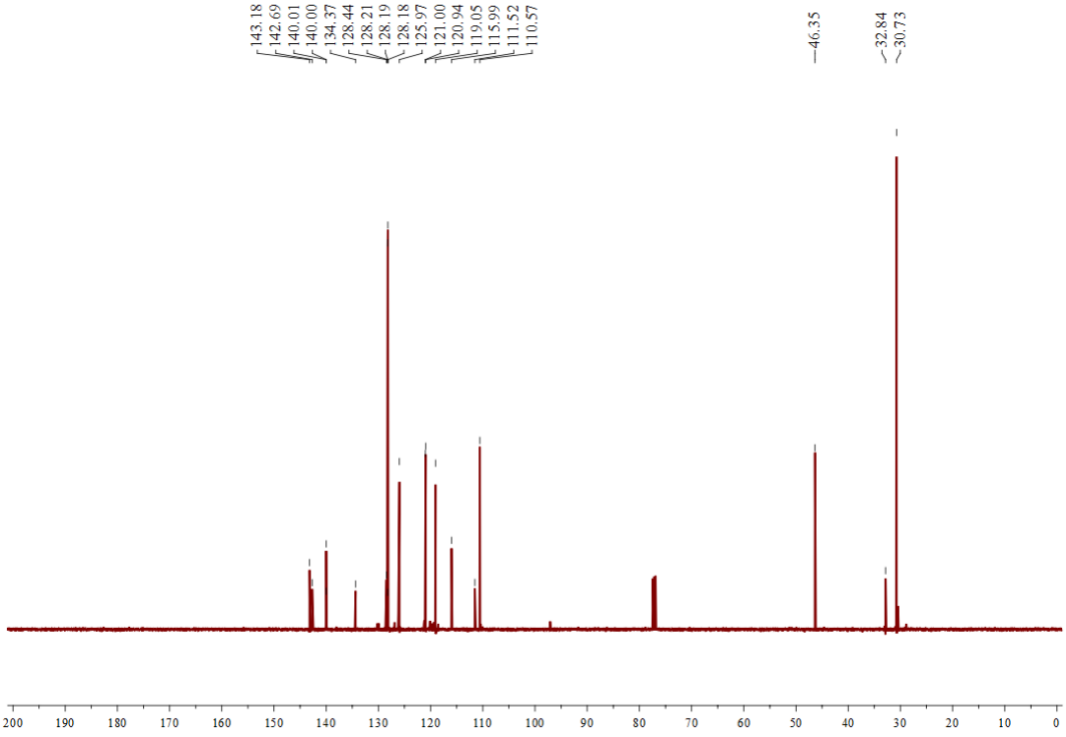
(3qa)

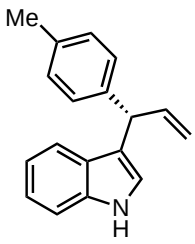

0.96
1.85
4.71
2.04
2.46
2.04
0.98
1.00
0.95
0.83
0.99
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
143.30
140.17
136.39
135.65
133.13
128.93
128.68
128.38
128.32
128.13
128.02
126.14
122.22
121.46
119.68
116.25
113.89
111.03
46.02
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0


Ph
t-Bu
N
H

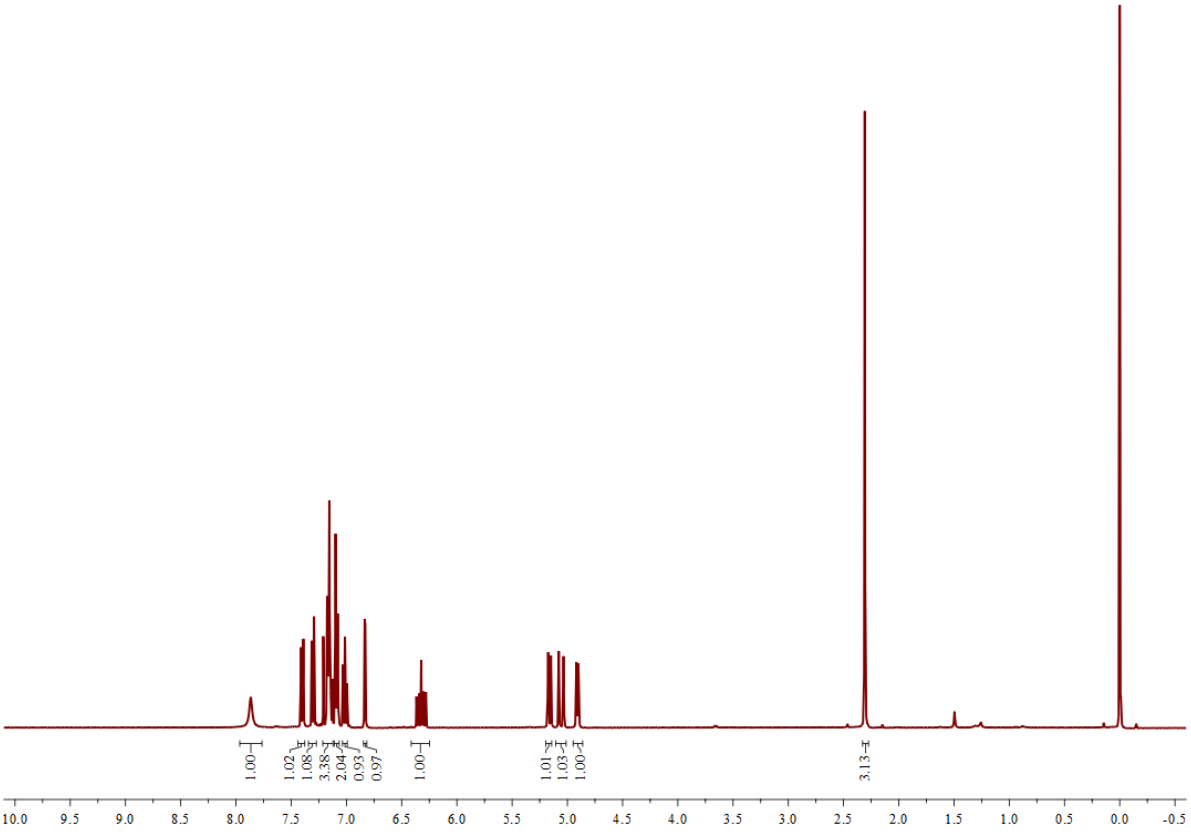
(3ra)

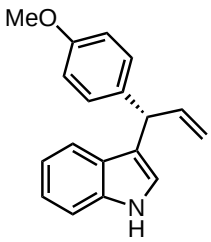

1.07
2.73
2.91
2.24
1.09
0.99
1.00
1.06
1.04
1.02
9.04
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5


143.18
142.69
140.01
140.00
134.37
128.44
128.21
128.19
128.18
125.97
121.00
120.94
119.05
115.99
111.52
110.57
46.35
32.84
30.73
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0

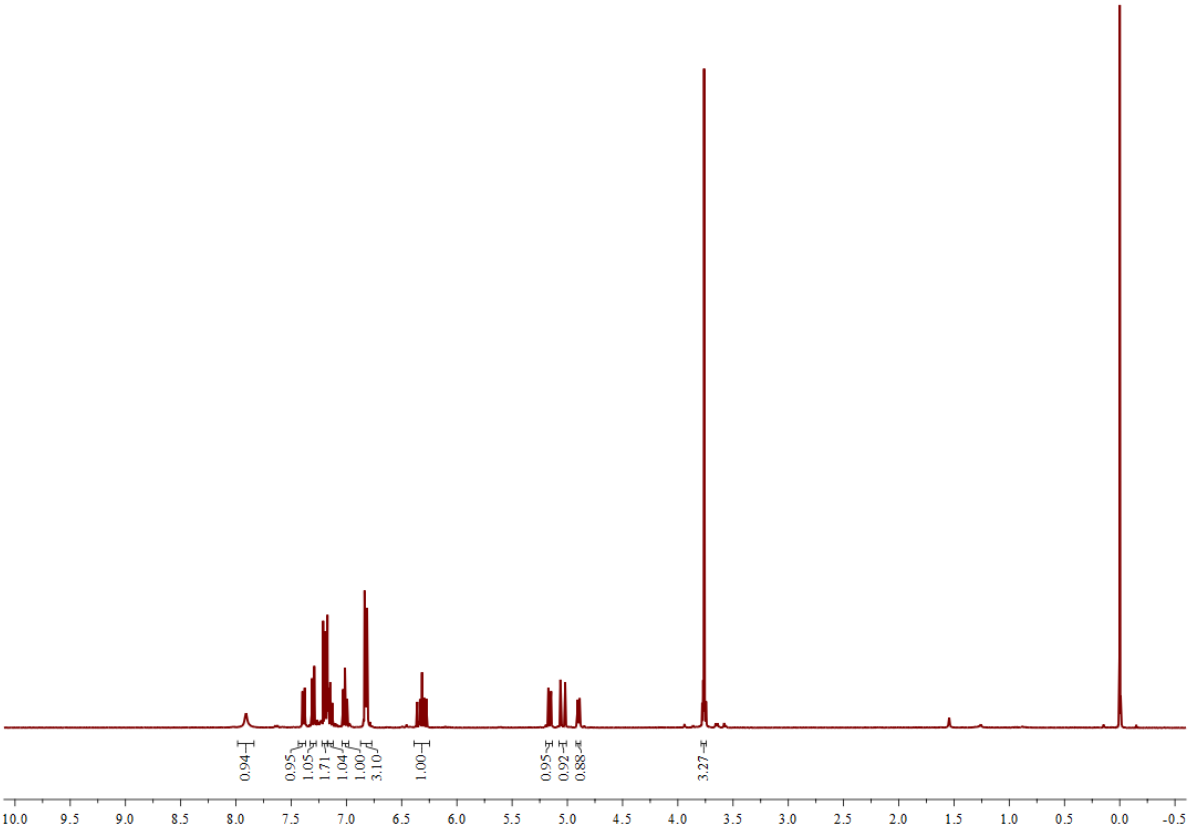

Me
N
H

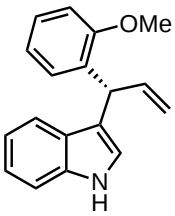
(3ab)


1.00
1.02
1.08
3.38
2.04
0.93
0.97
1.00
1.01
1.03
1.00
3.13
10.0
9.5
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

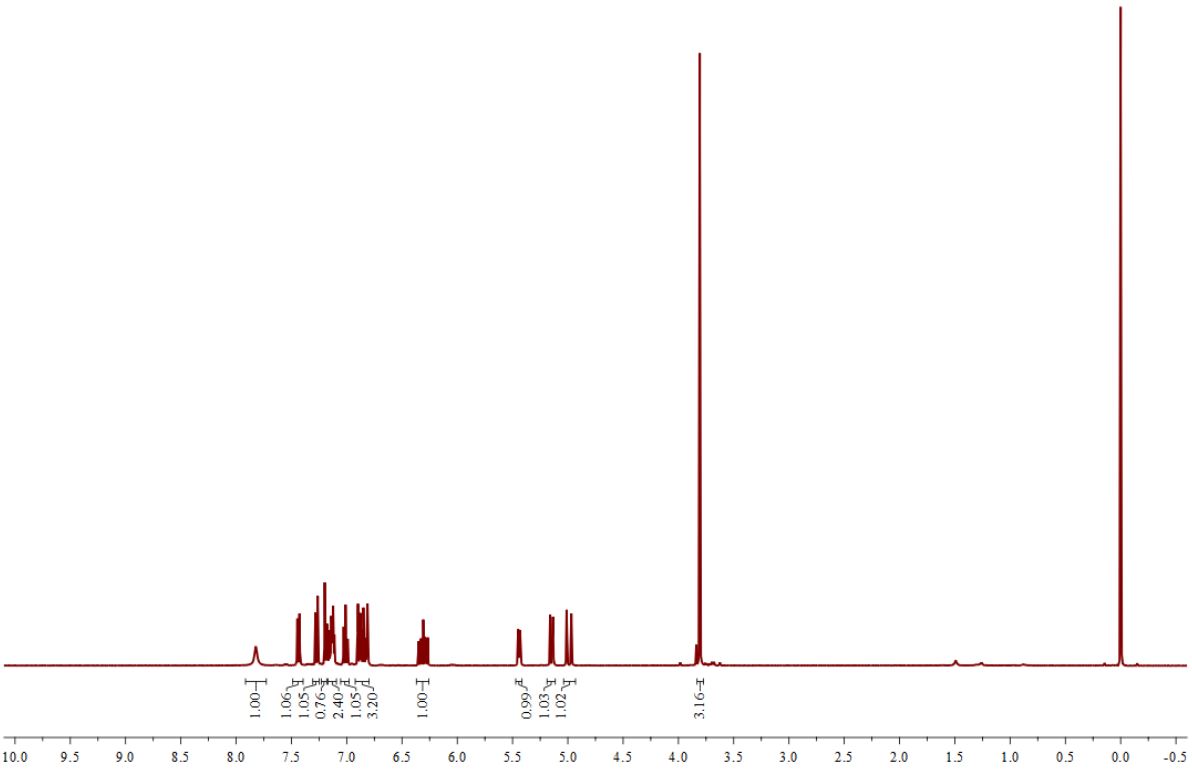

MeO
N
H

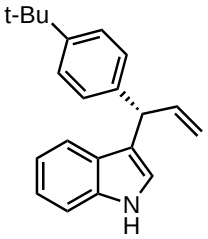
(3ac)


0.94
0.95
1.05
1.71
1.04
1.00
3.10
1.00
0.95
0.92
0.88
3.27
10.0
9.5
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

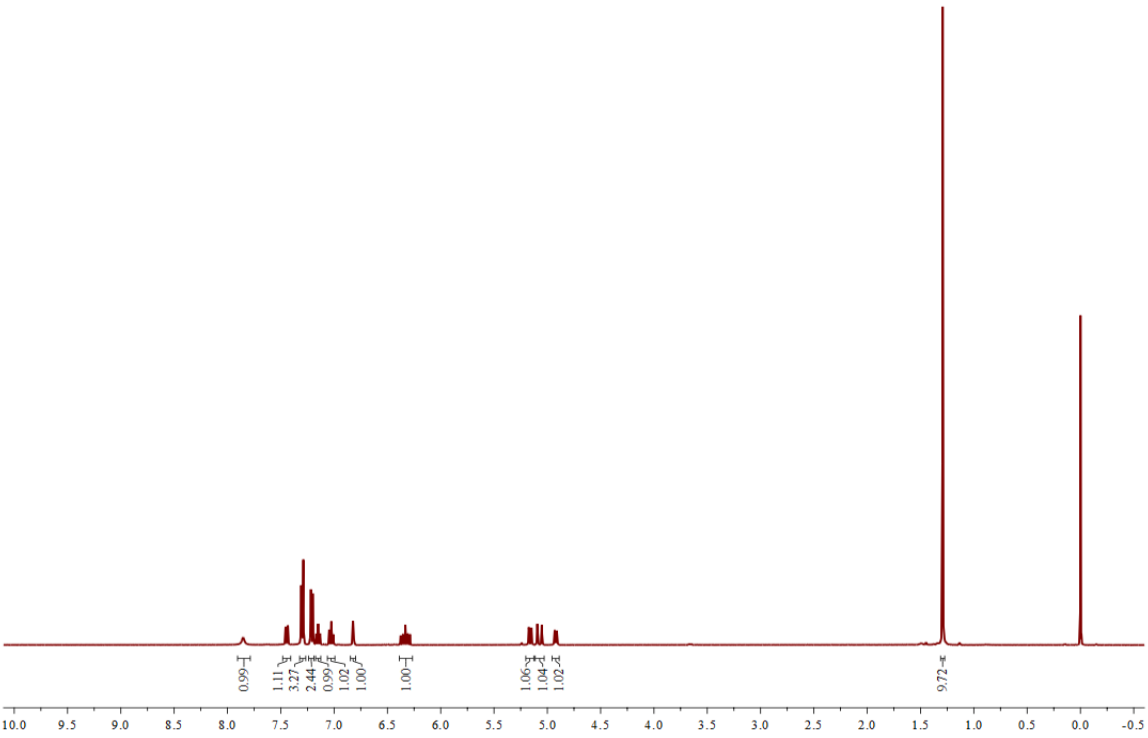

OMe
N
H

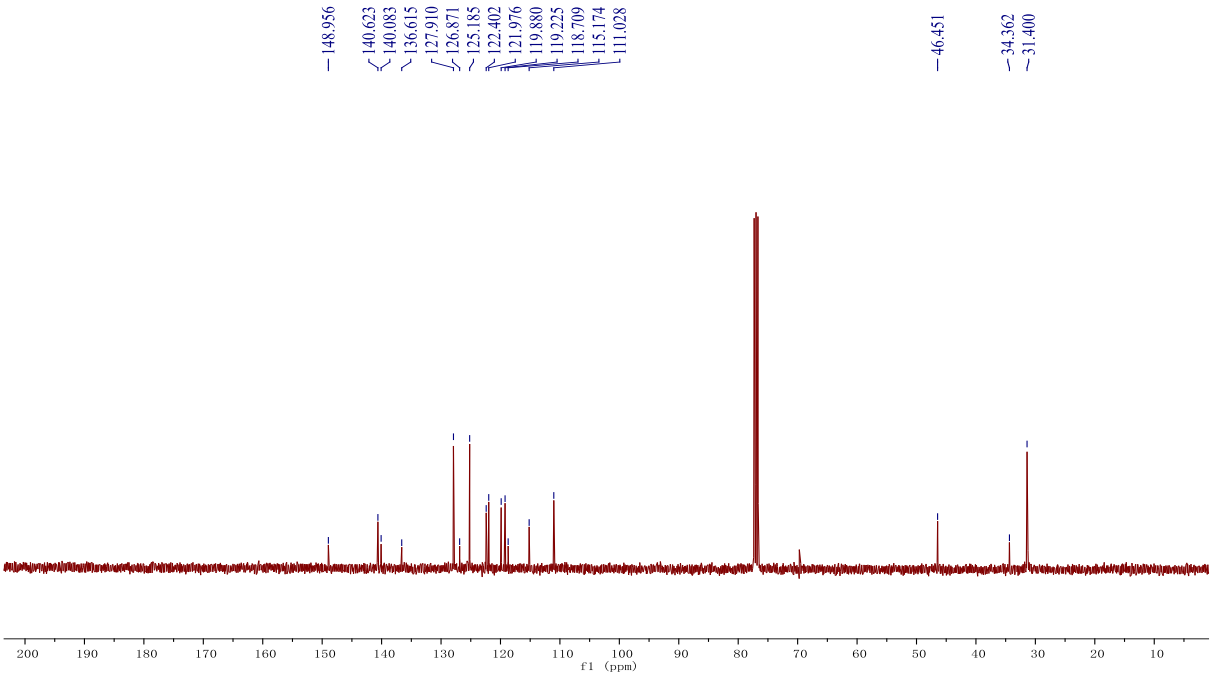
(3ad)

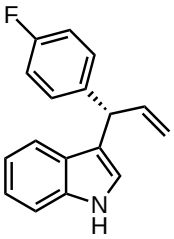

1.00
1.06
1.05
0.76
2.40
1.05
3.20
1.00
0.99
1.03
1.02
3.16
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5


t-Bu
N
H

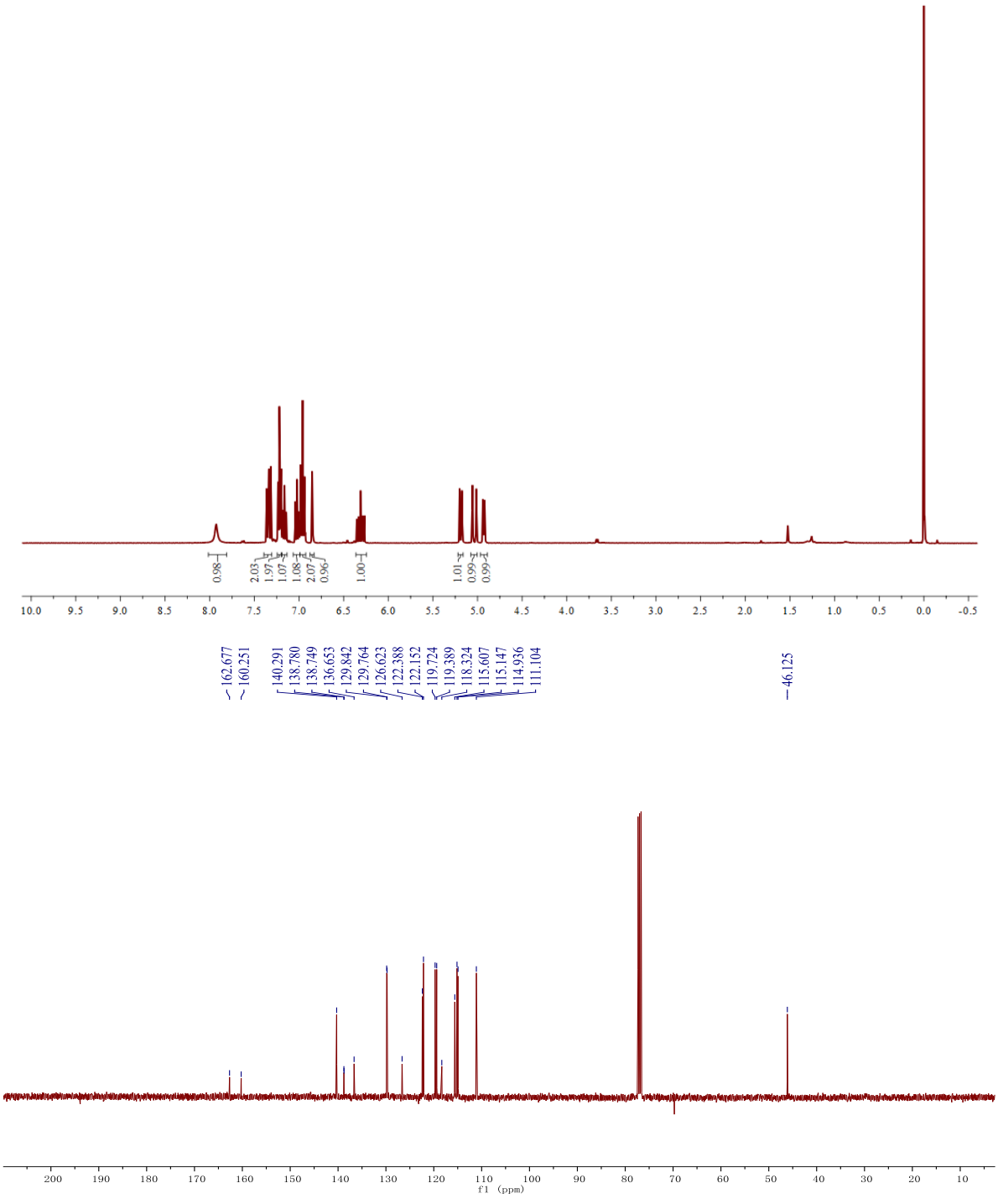
(3ae)


0.99
1.11
3.27
2.44
0.99
1.02
1.00
1.00
1.06
1.04
1.02
9.72
10.0 9.5 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


148.956
140.623
140.083
136.615
127.910
126.871
125.185
122.402
121.976
119.880
119.225
118.709
115.174
111.028
46.451
34.362
31.400
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10
f1 (ppm)


F
N
H

(3af)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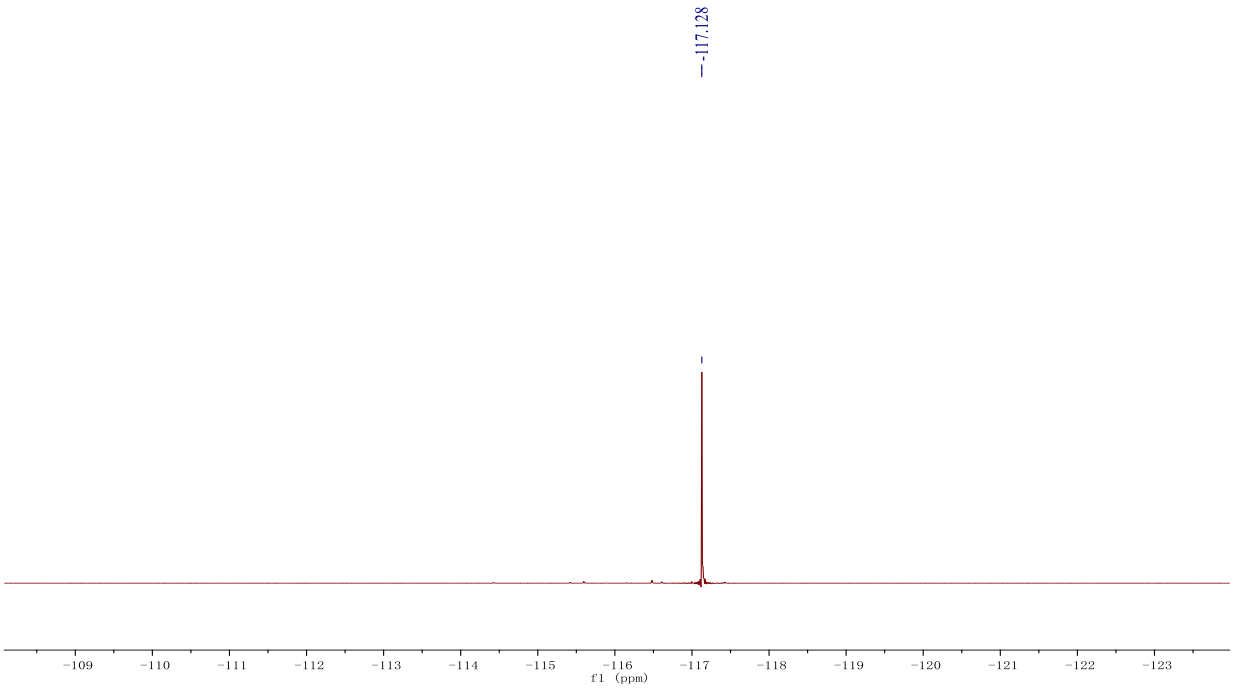
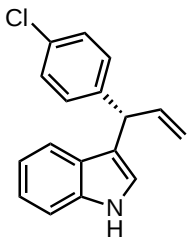
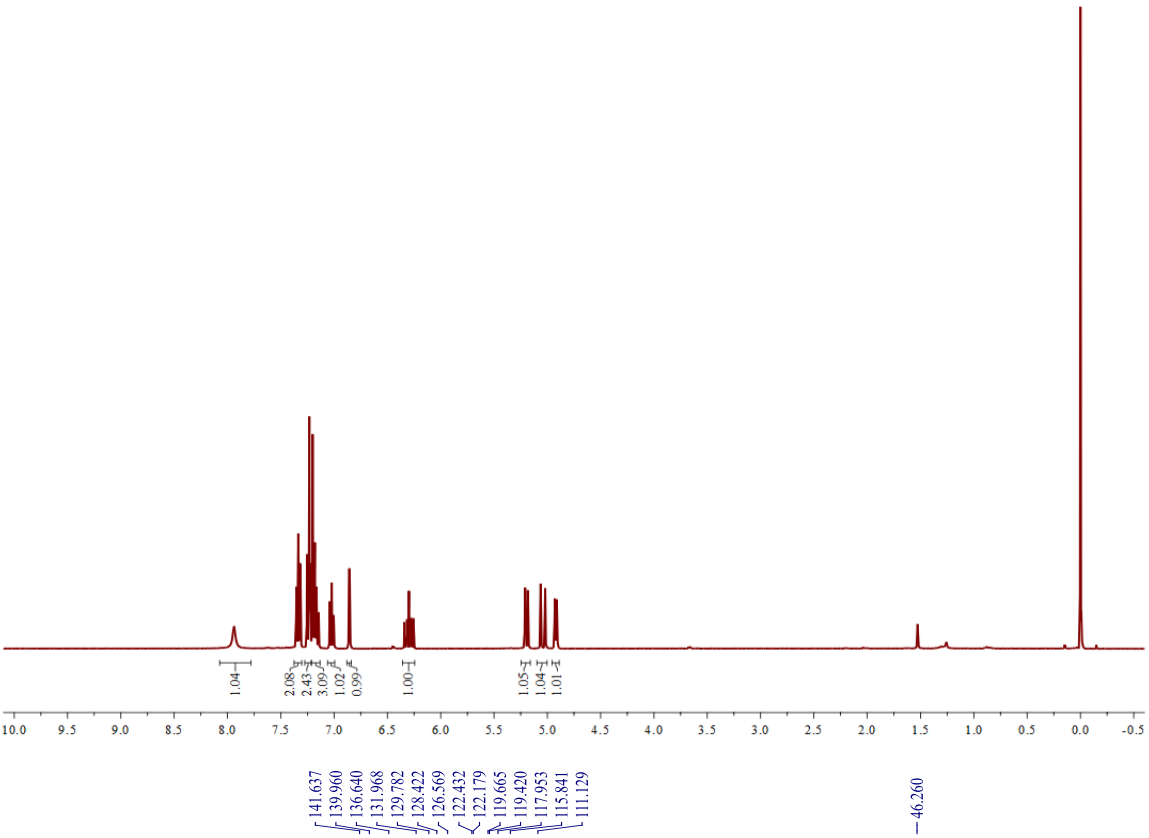
2.03
1.97
1.07
1.08
2.07
0.96
1.00
1.01
0.99
0.99
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5
162.677
160.251
140.291
138.780
138.749
136.653
129.842
129.764
126.623
122.388
122.152
119.724
119.389
118.324
115.607
115.147
114.936
111.104
46.125
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10
f1 (ppm)


-117.128
-109
-110
-111
-112
-113
-114
-115
-116
-117
-118
-119
-120
-121
-122
-123
f1 (ppm)


Cl
N
H

(3ag)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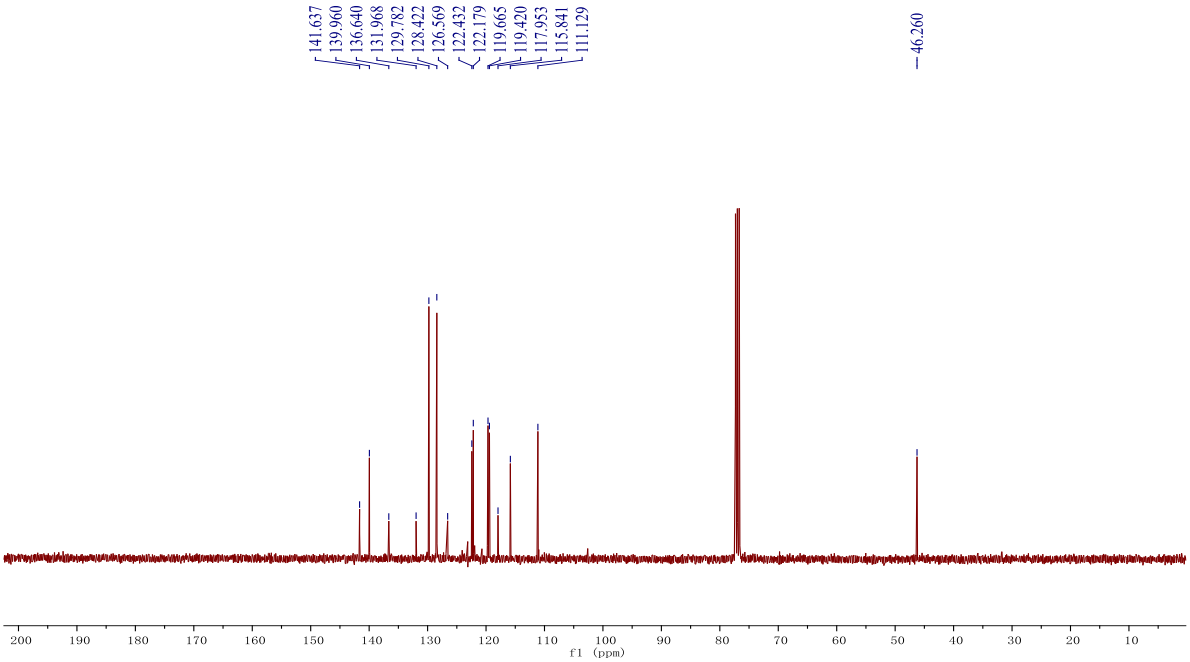
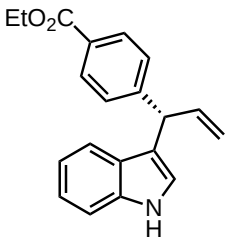
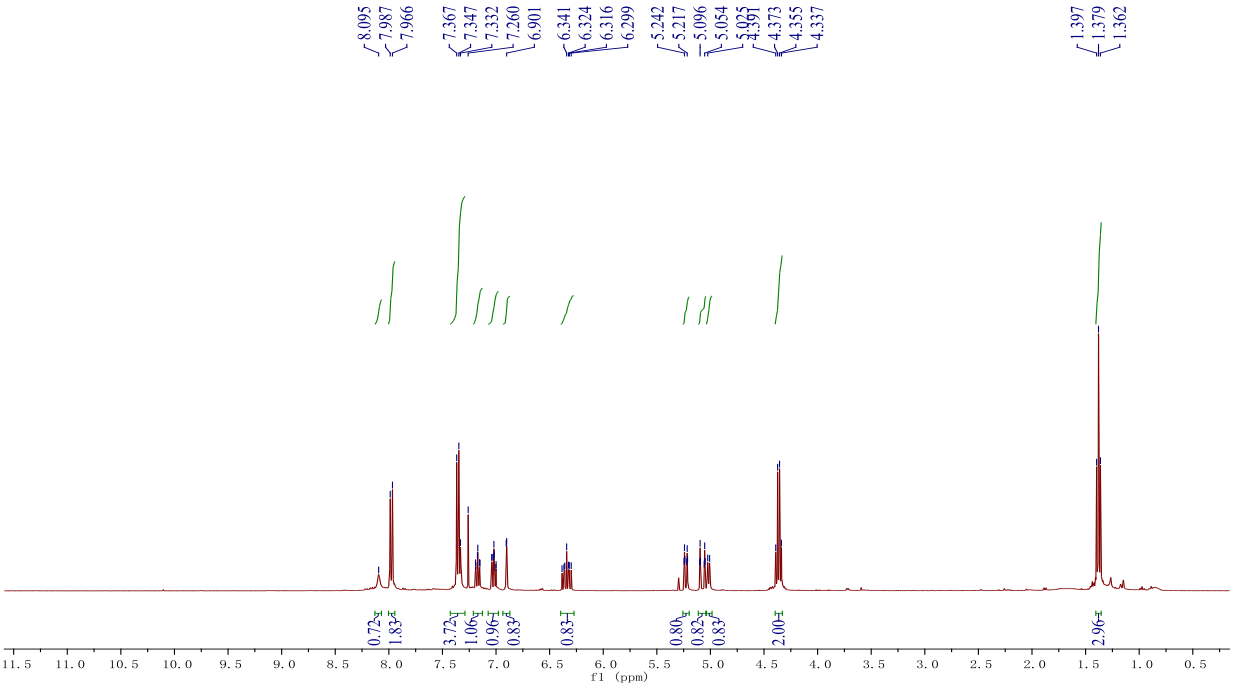
2.08
2.43
3.09
1.02
0.99
1.00
1.05
1.04
1.01
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5


141.637
139.960
136.640
131.968
129.782
128.422
126.569
122.432
122.179
119.665
119.420
117.953
115.841
111.129
46.260
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
f1 (ppm)


EtO2C
N
H

(3ah)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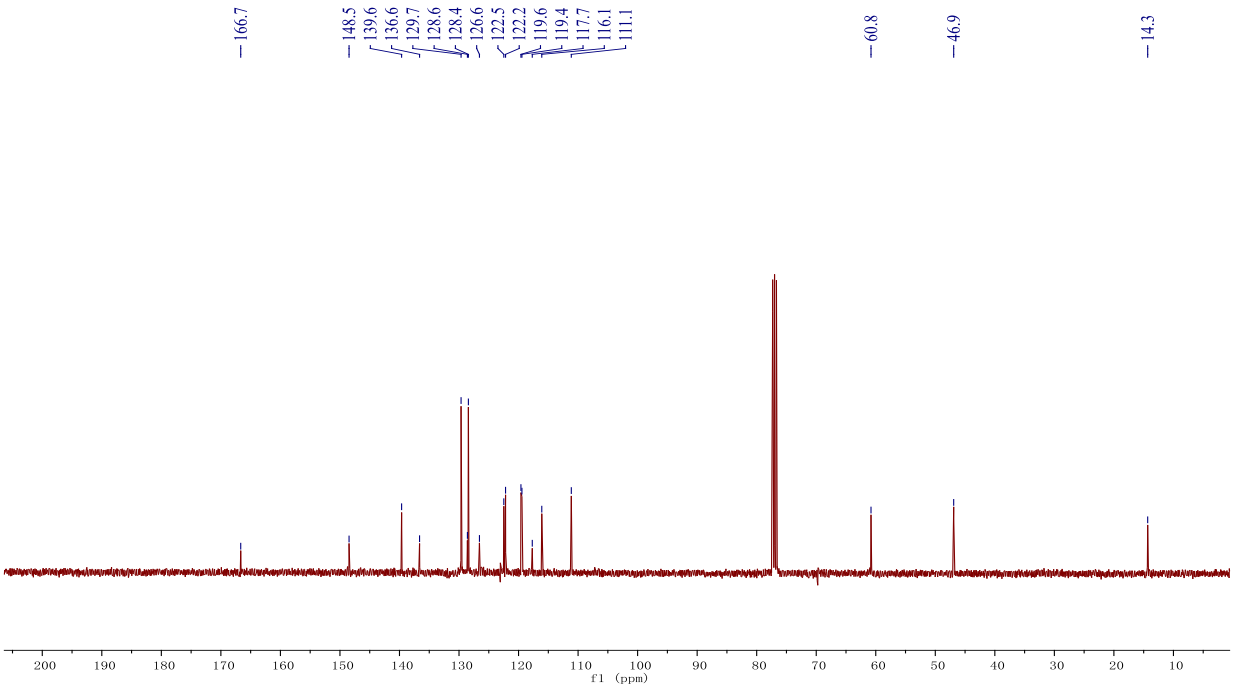
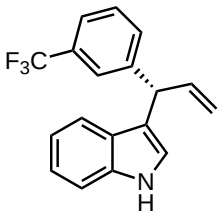
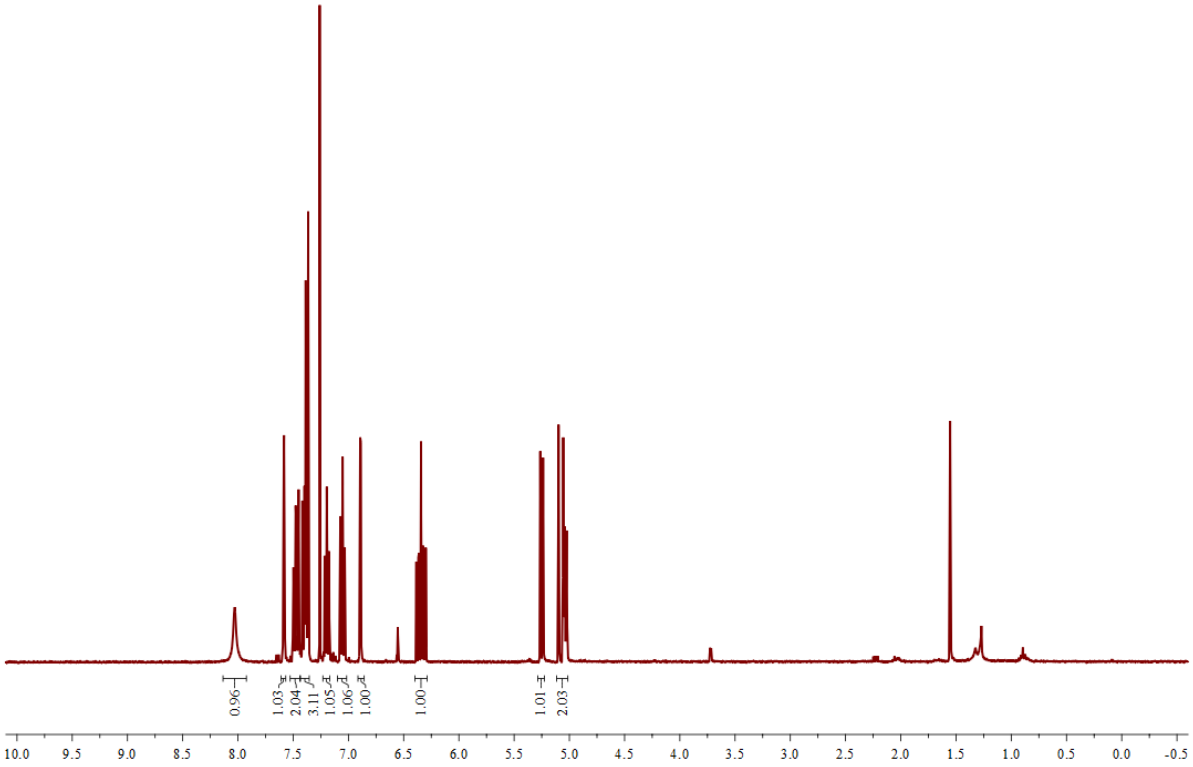
7.987
7.966
7.367
7.347
7.332
7.260
6.901
6.341
6.324
6.316
6.299
5.242
5.217
5.096
5.054
4.391
4.373
4.355
4.337
1.397
1.379
1.362
0.72
1.83
3.72
1.06
0.96
0.83
0.83
0.80
0.82
0.83
2.00
2.96
f1 (ppm)

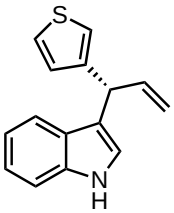

166.7
148.5
139.6
136.6
129.7
128.6
128.4
126.6
122.5
122.2
119.6
119.4
117.7
116.1
111.1
60.8
46.9
14.3
f1 (ppm)

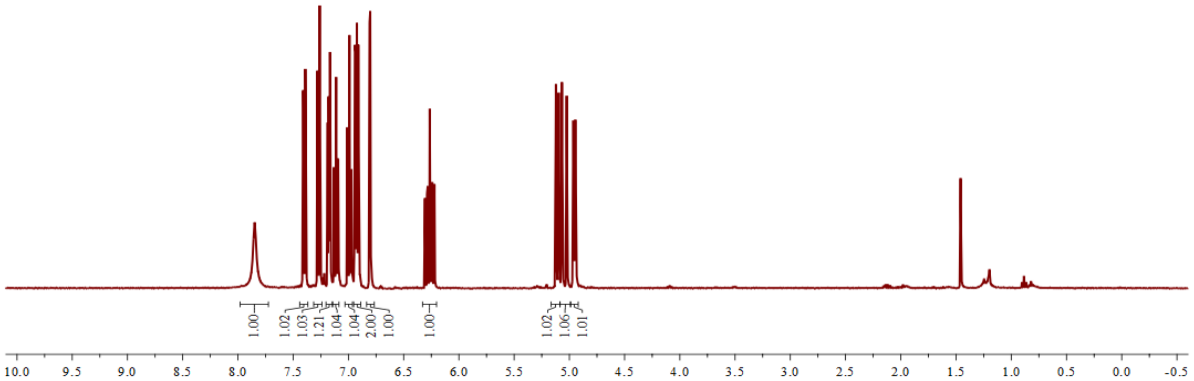
(3ai)

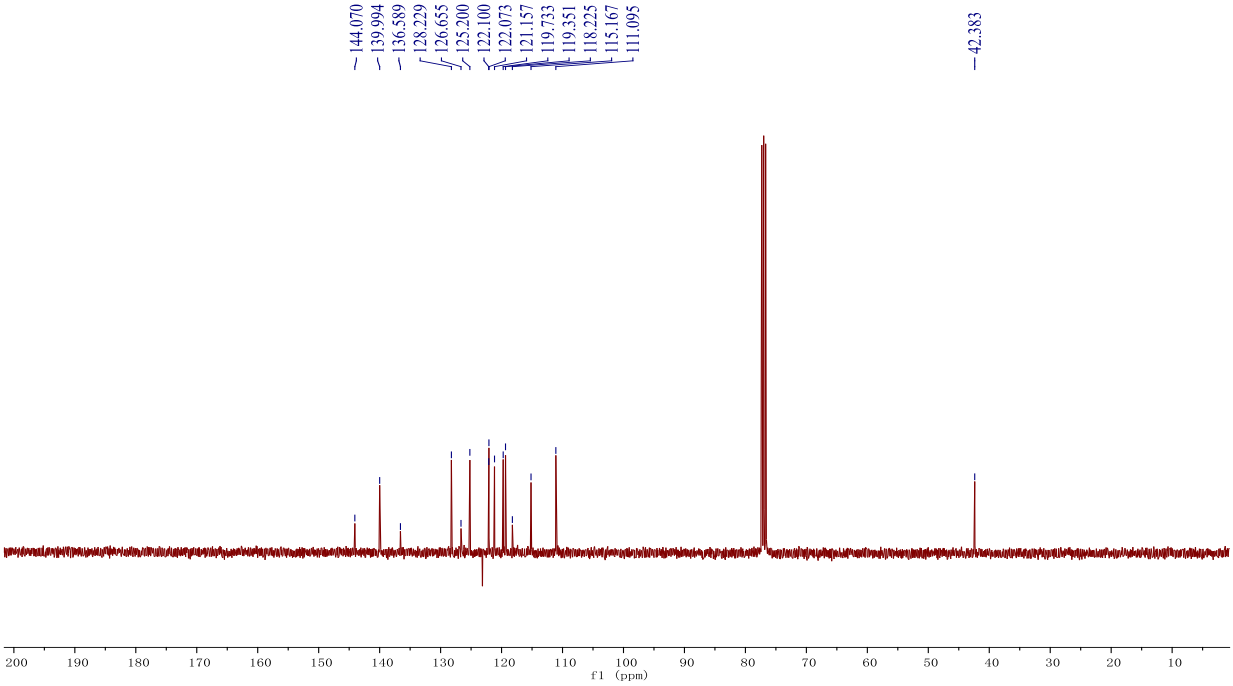

F3C
N
H


0.96
1.03
2.04
3.11
1.05
1.06
1.00
1.00
1.01
2.03
10.0
9.5
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

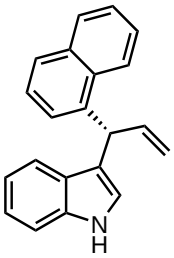
(3aj)

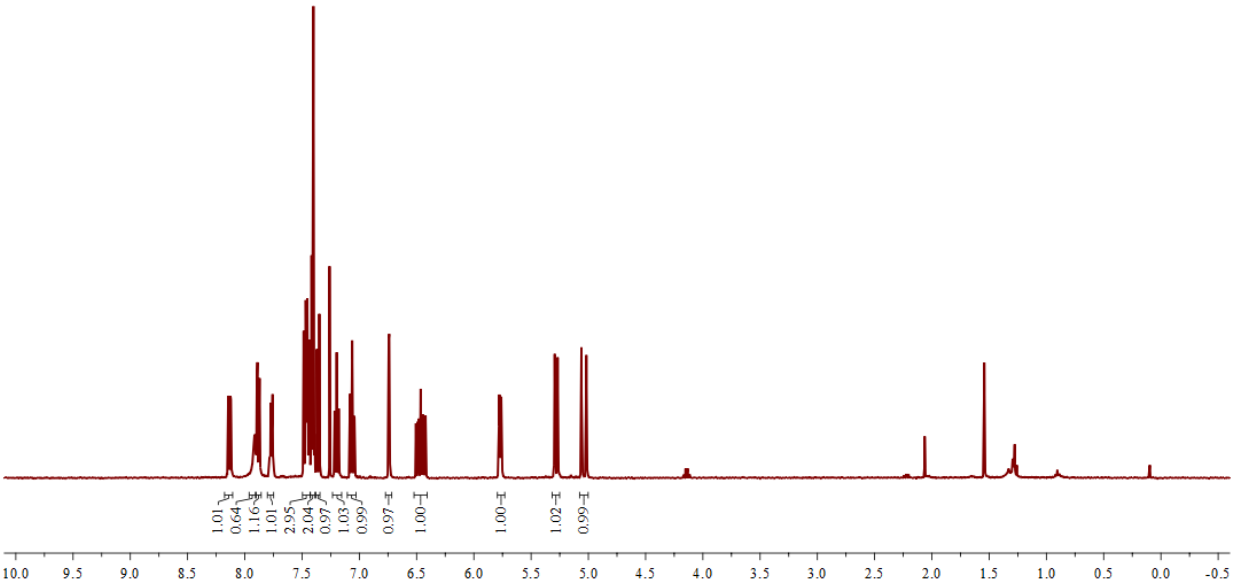

S
N
H

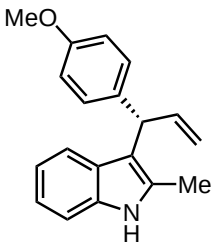

1.00
1.02
1.03
1.21
1.04
1.04
2.00
1.00
1.00
1.02
1.06
1.01
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5


144.070
139.994
136.589
128.229
126.655
125.200
122.100
122.073
121.157
119.733
119.351
118.225
115.167
111.095
42.383
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
f1 (ppm)

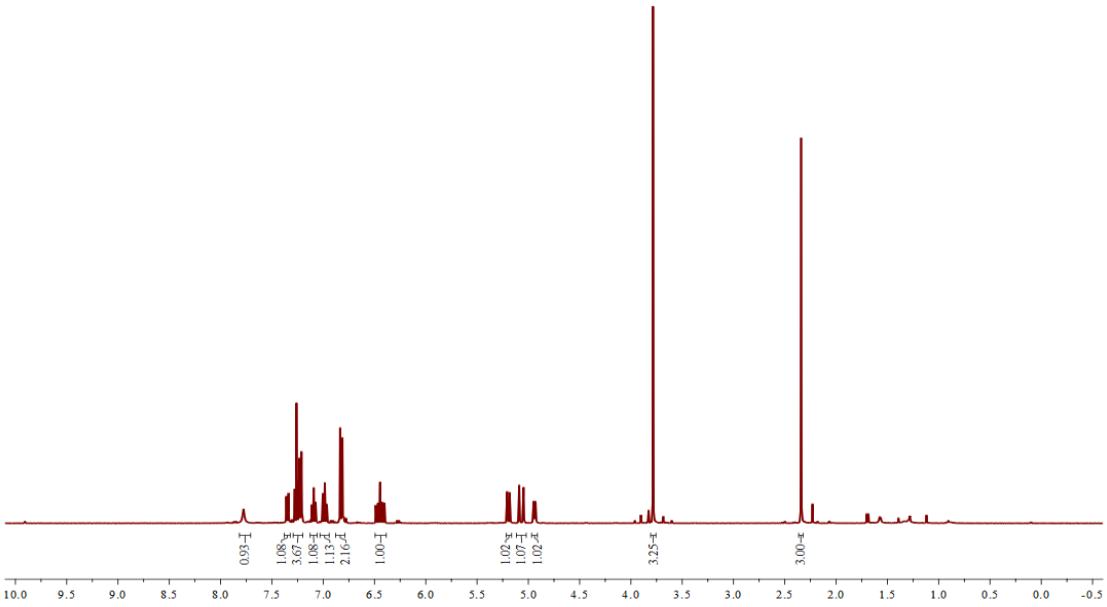
(3ak)

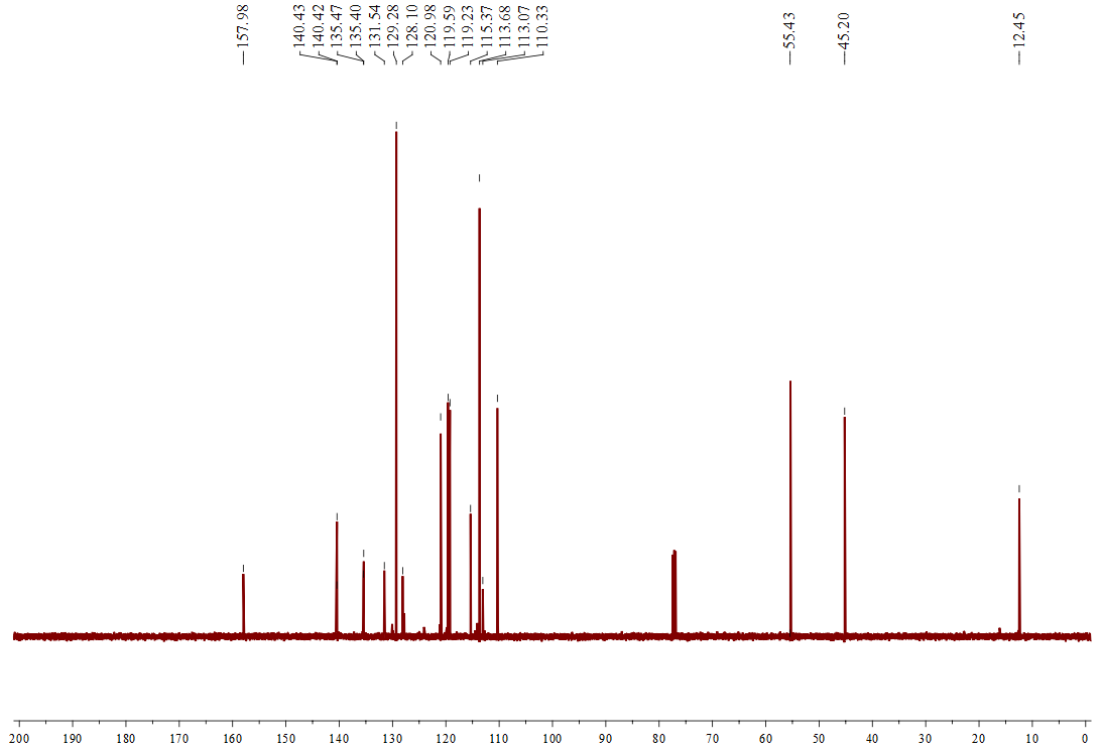

N
H

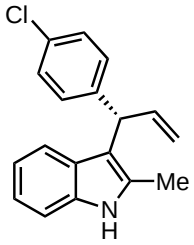

1.01
0.64
1.16
1.01
2.95
2.04
0.97
1.03
0.99
0.97
1.00
1.00
1.02
0.99
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5


MeO
Me
N
H

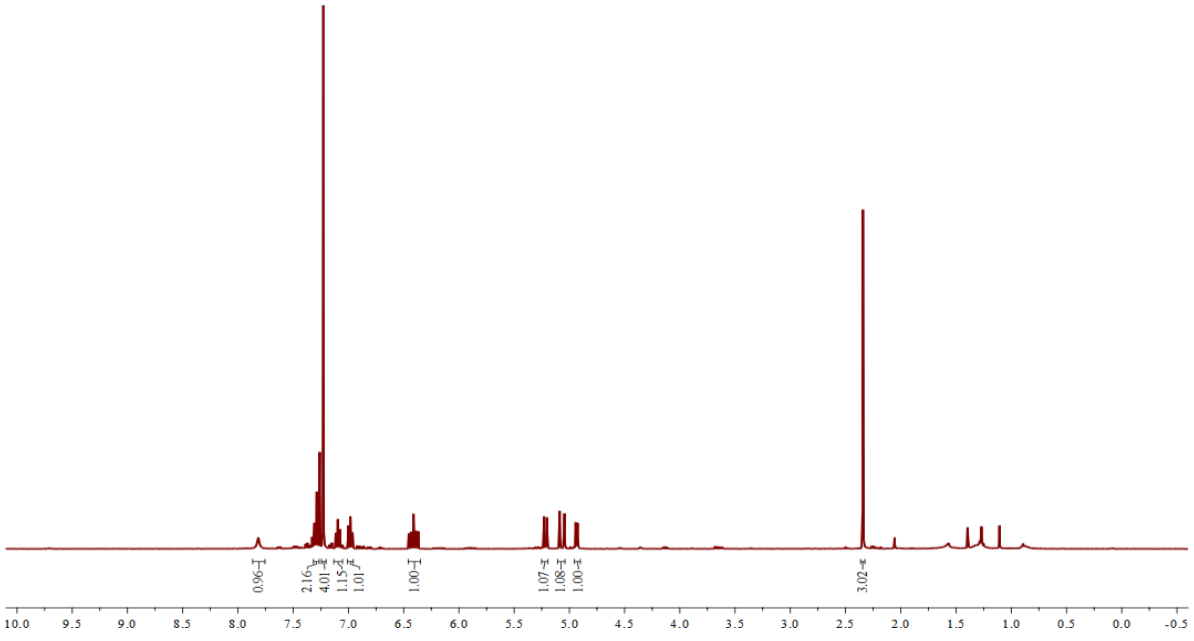
(3cc)

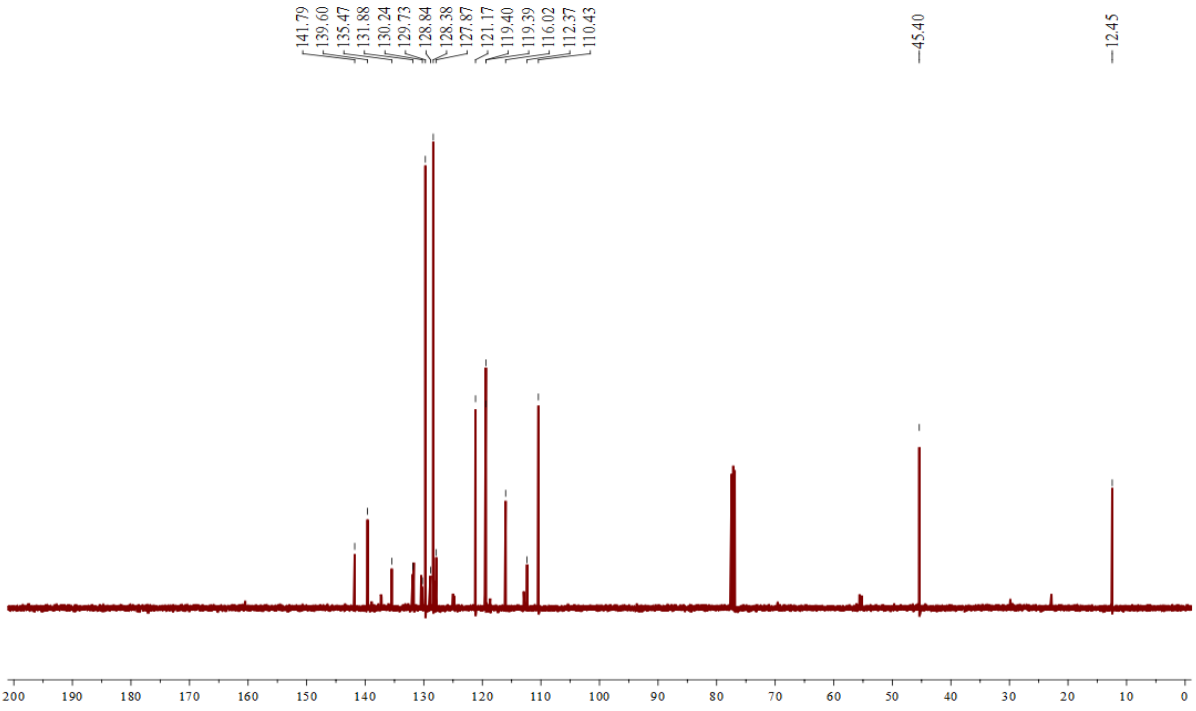

0.93
1.08
3.67
1.08
1.13
2.16
1.00
1.02
1.07
1.02
3.25
3.00
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 -0.5


157.98
140.43
140.42
135.47
135.40
131.54
129.28
128.10
120.98
119.59
119.23
115.37
113.68
113.07
110.33
55.43
45.20
12.45
200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0


Cl
Me
N
H

(3cg)


0.96
2.16
4.01
1.15
1.01
1.00
1.07
1.08
1.00
3.02
10.0
9.5
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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131.88
130.24
129.73
128.84
128.38
127.87
121.17
119.40
119.39
116.02
112.37
110.43
45.40
12.45
200
190
180
170
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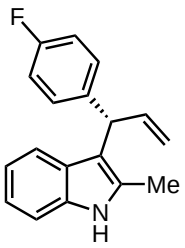
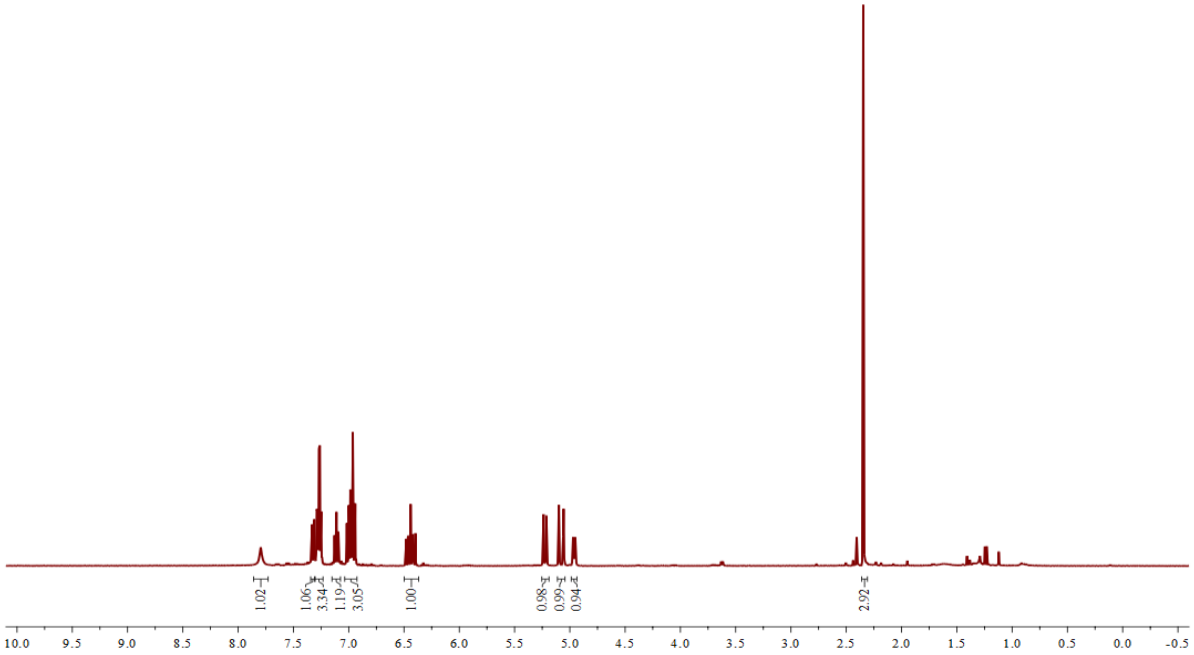
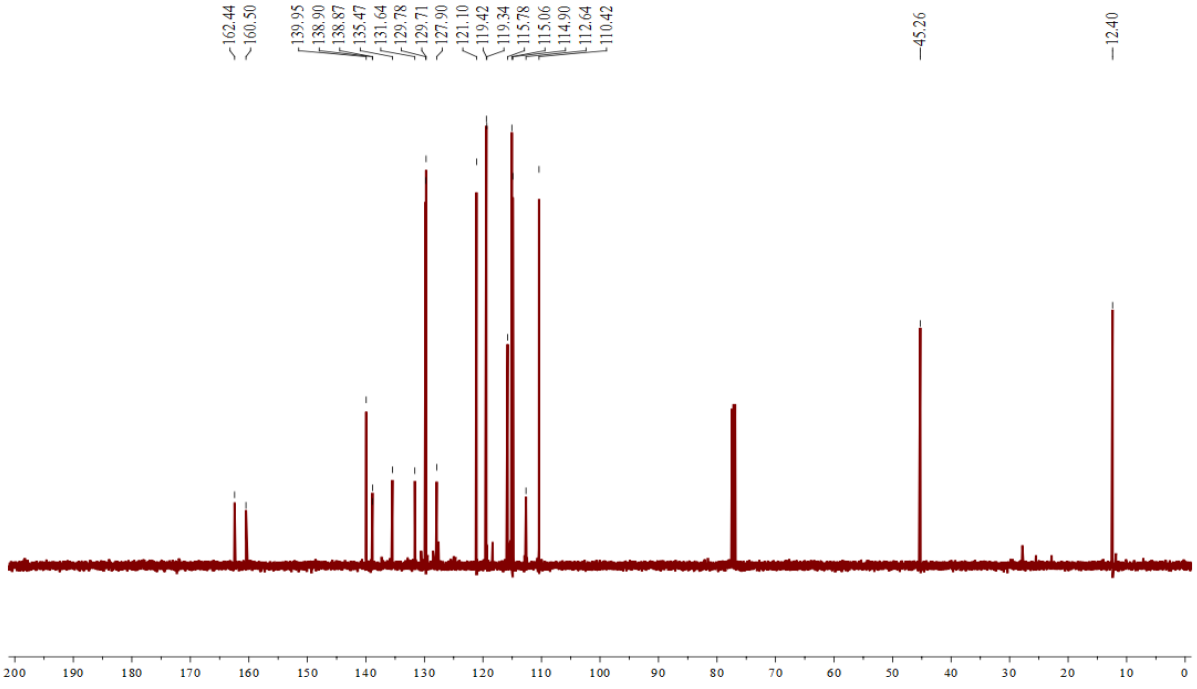
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0


F
Me
N
H

(3cf)


1.02
1.06
3.34
1.19
3.05
1.00
0.98
0.99
0.94
2.92
10.0
9.5
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


162.44
160.50
139.95
138.90
138.87
135.47
131.64
129.78
129.71
127.90
121.10
119.42
119.34
115.78
115.06
114.90
112.64
110.42
45.26
12.40
200
190
180
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150
140
130
120
110
100
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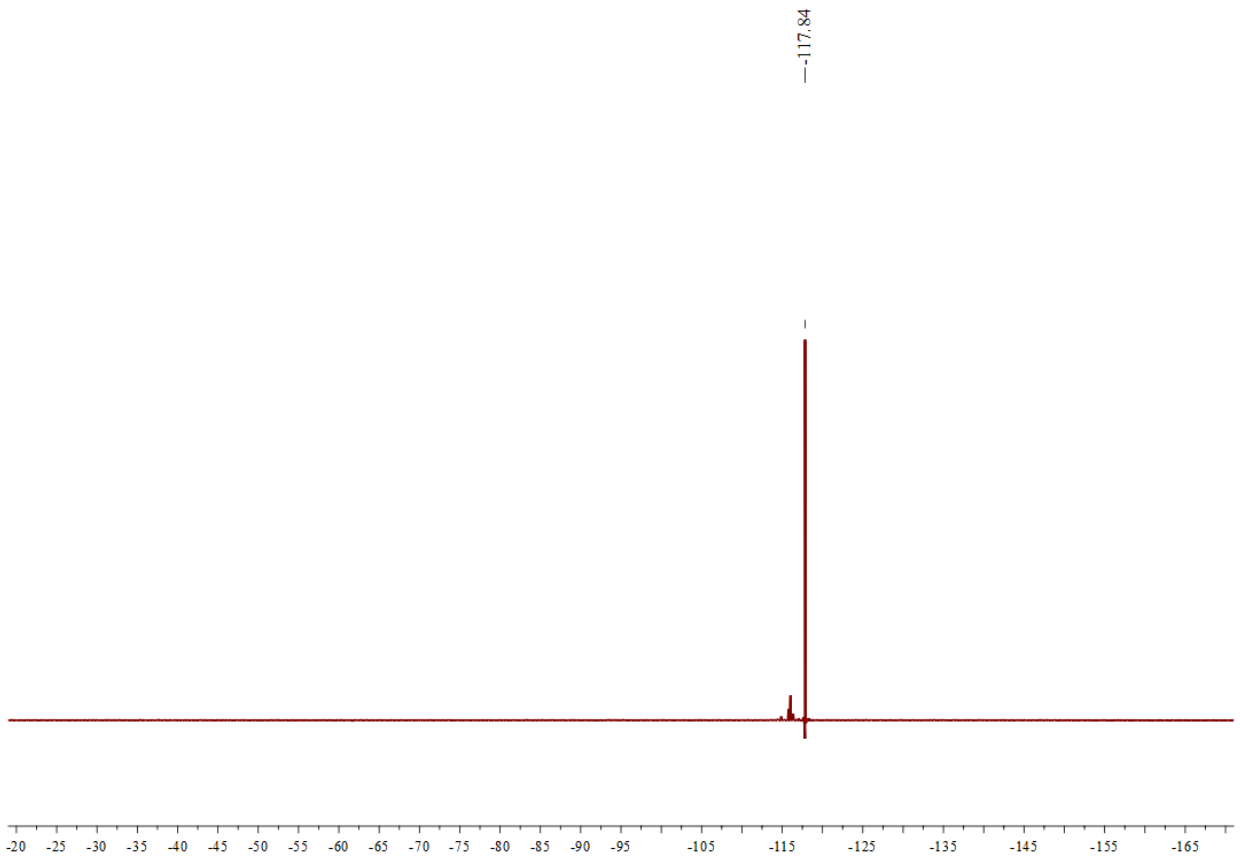
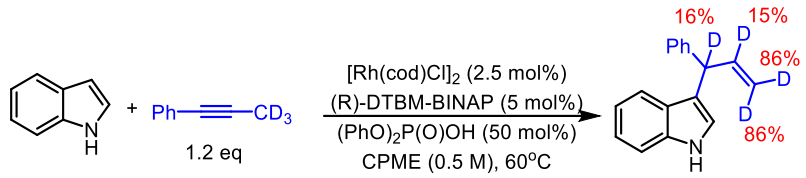
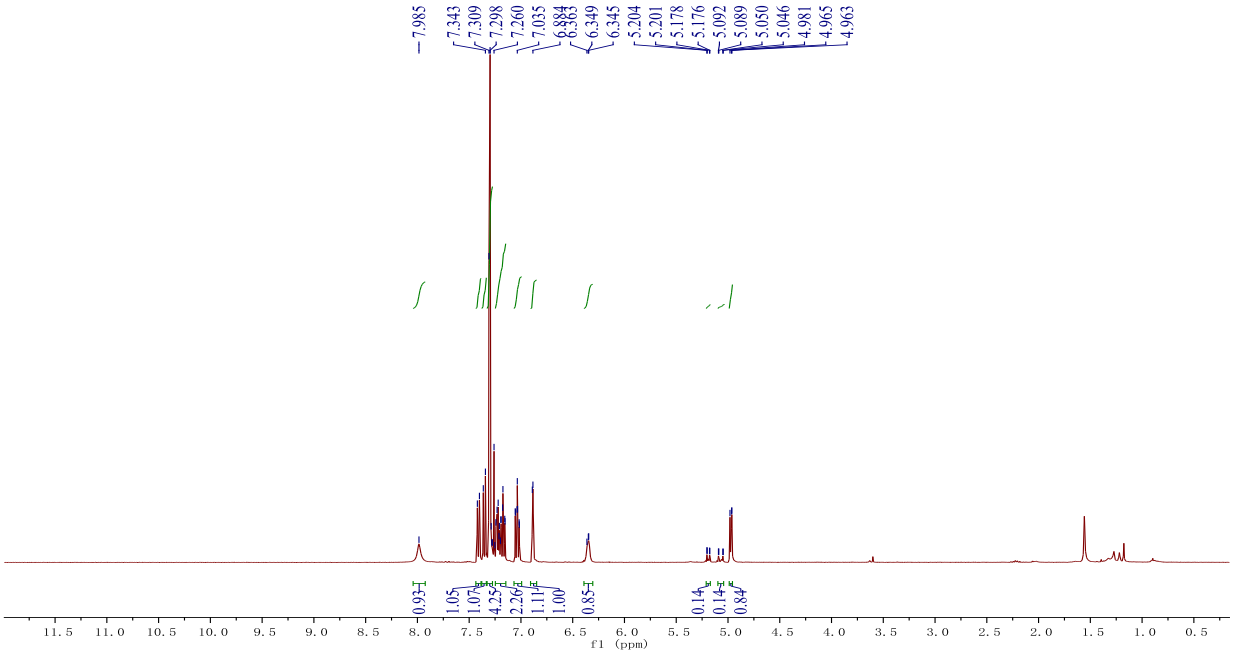
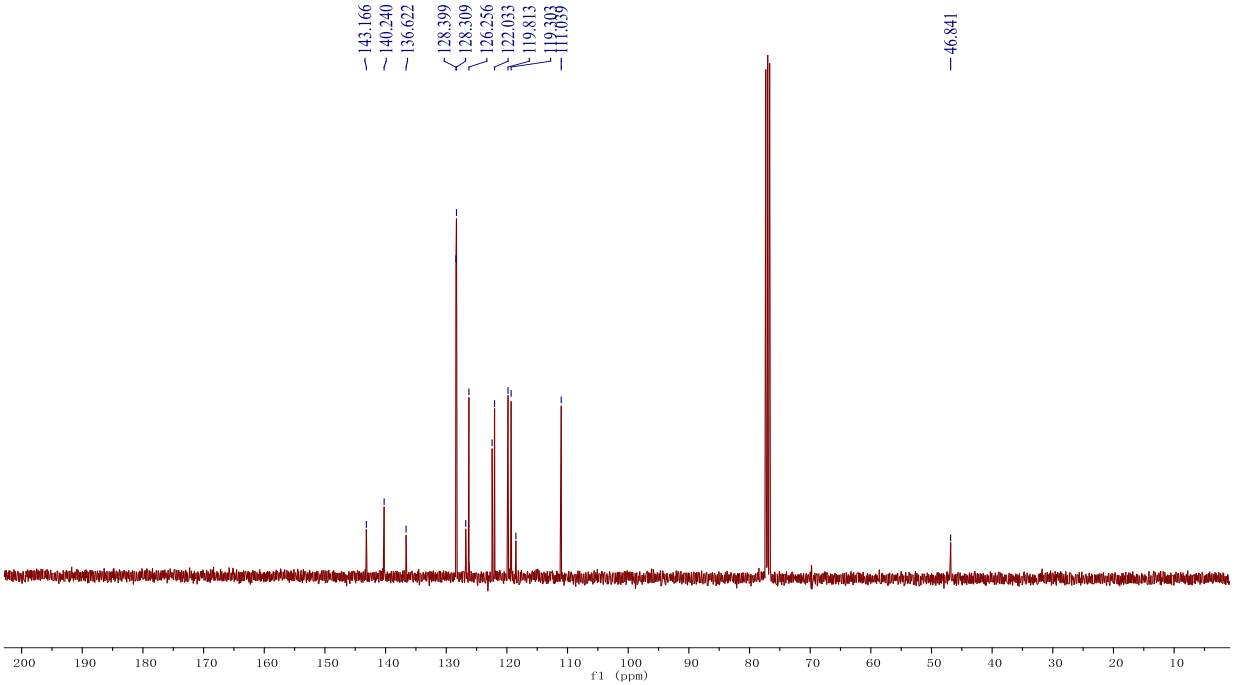
70
60
50
40
30
20
10
0

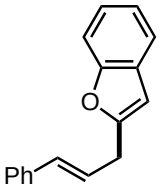

-117.84
-20 -25 -30 -35 -40 -45 -50 -55 -60 -65 -70 -75 -80 -85 -90 -95 -105 -115 -125 -135 -145 -155 -165



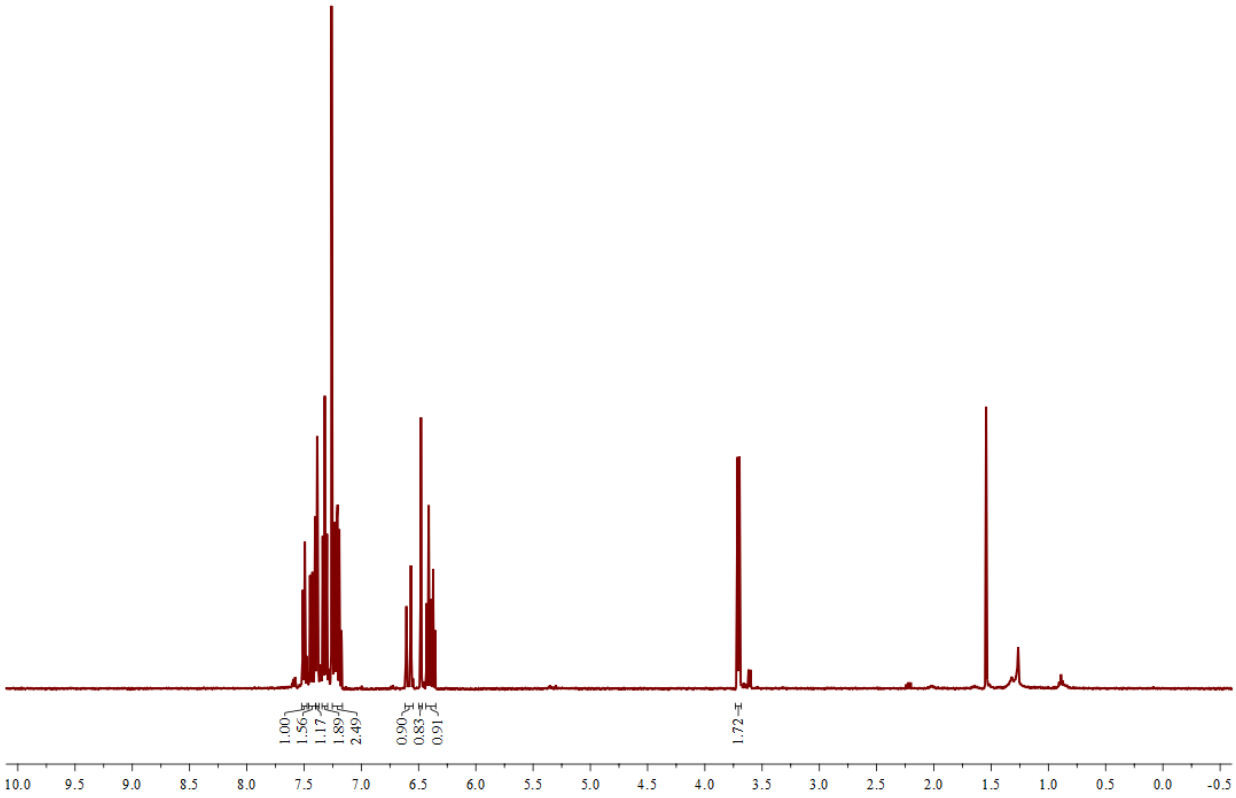
1a **2a-d_3** **3aa-d_n**, 86%, >20:1rr

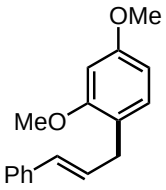




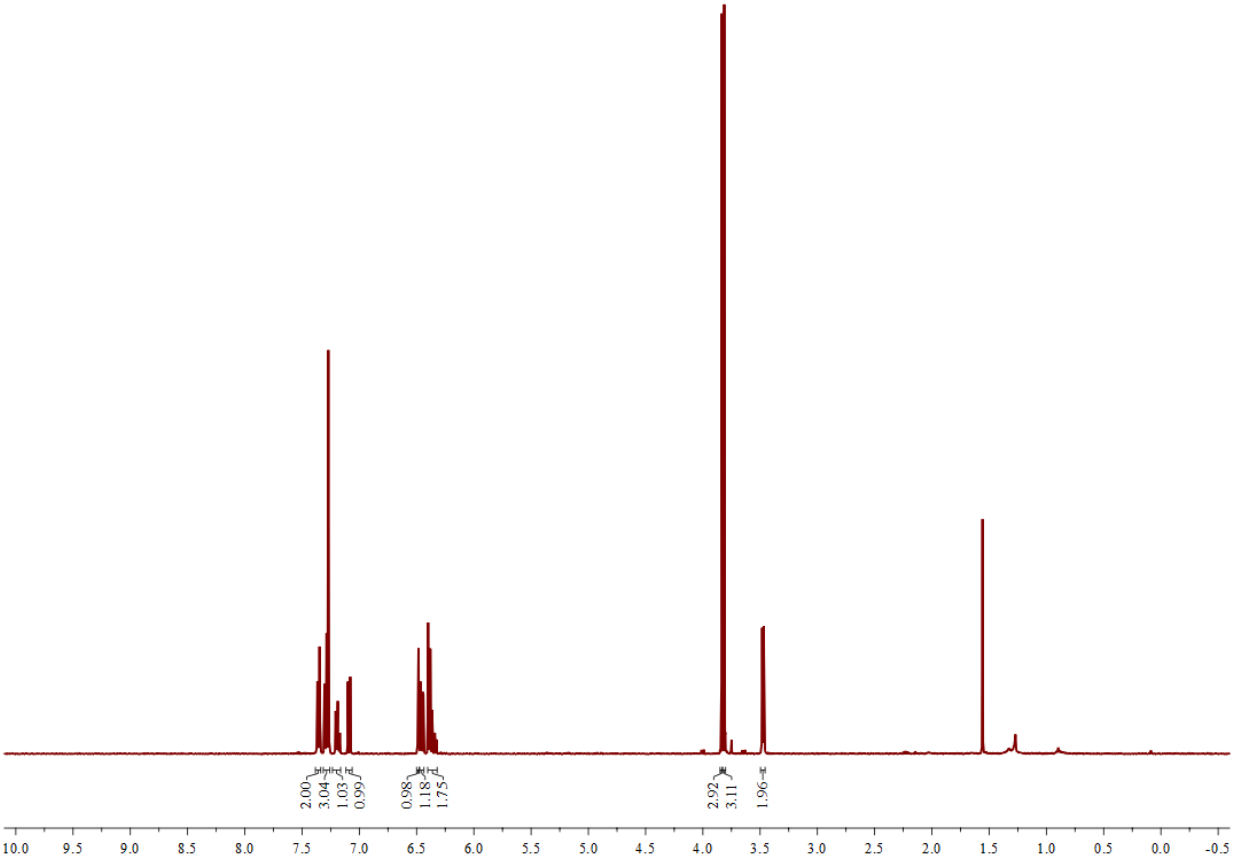


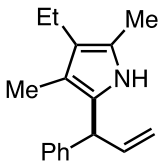
1-phenyl-3-(benzofuran-2-yl)-1-propene



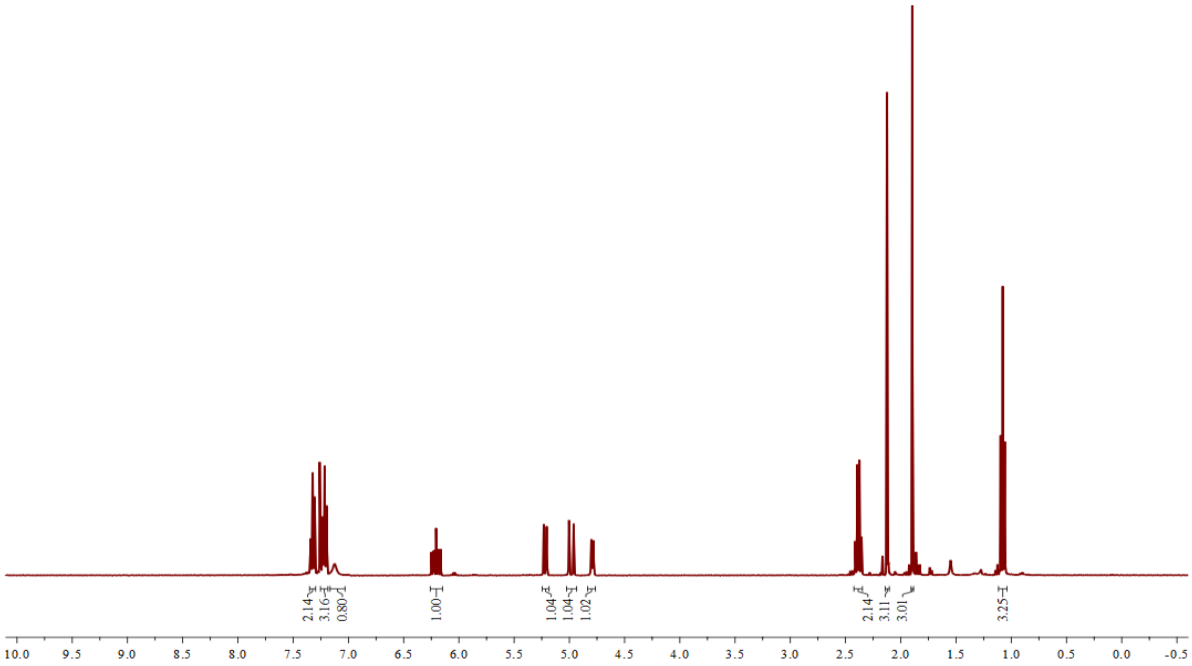


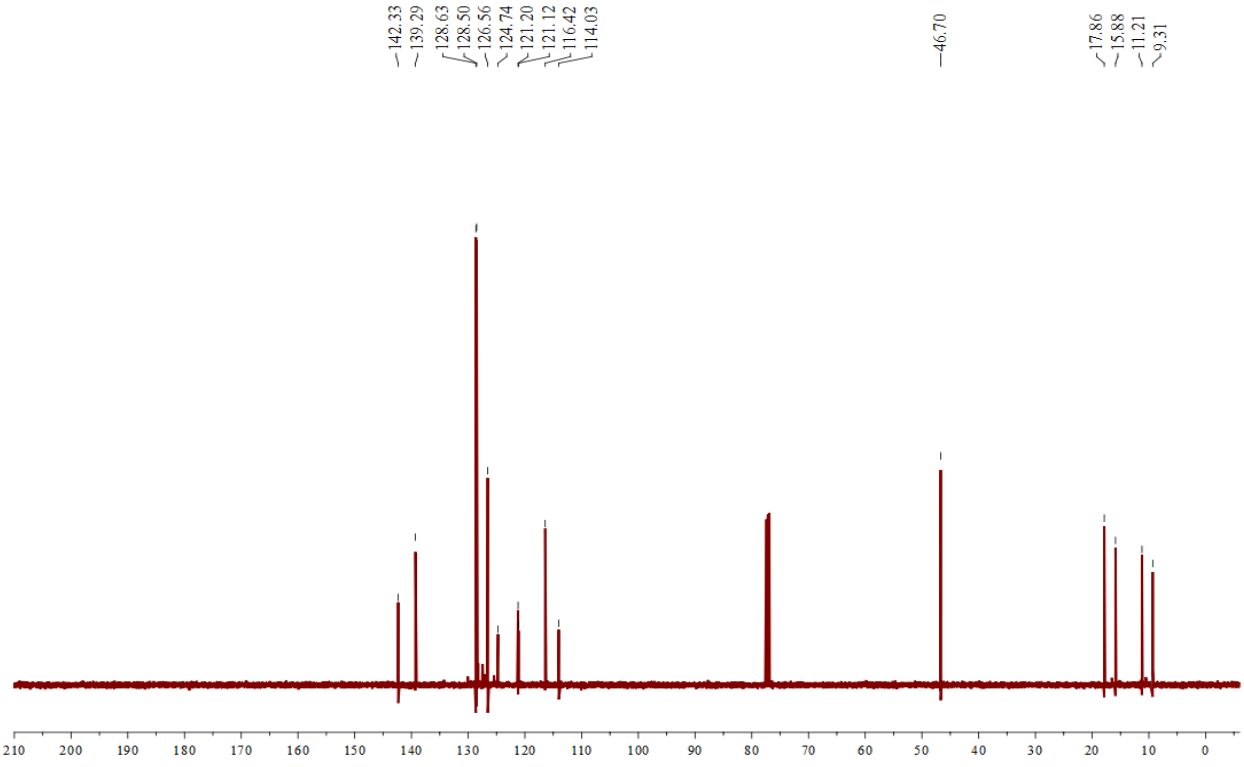
1-phenyl-3-(2,4-dimethoxyphenyl)-1-propene



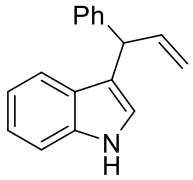


3-ethyl-2,4-dimethyl-5-(1-phenylallyl)-1*H*-pyrrole

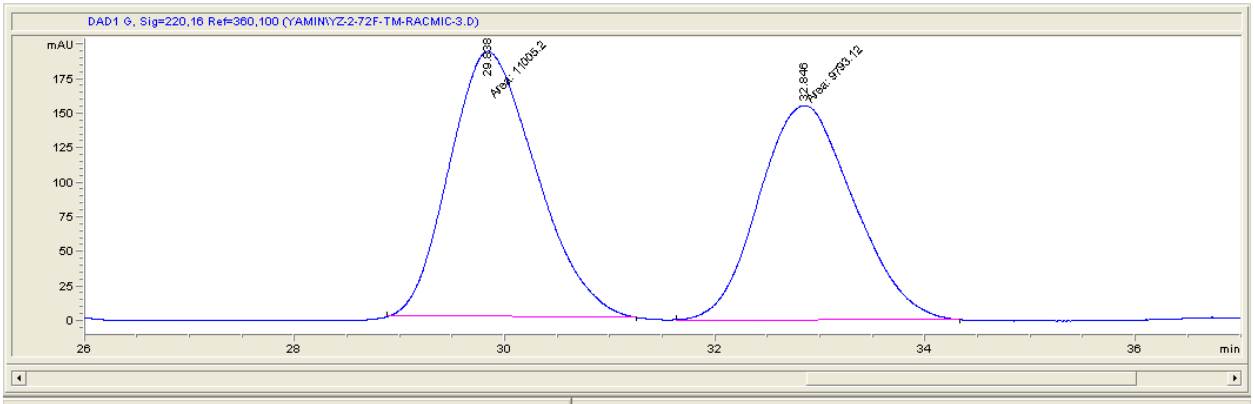




6. SFC Spectra

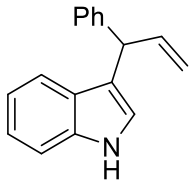


***rac*-3aa**

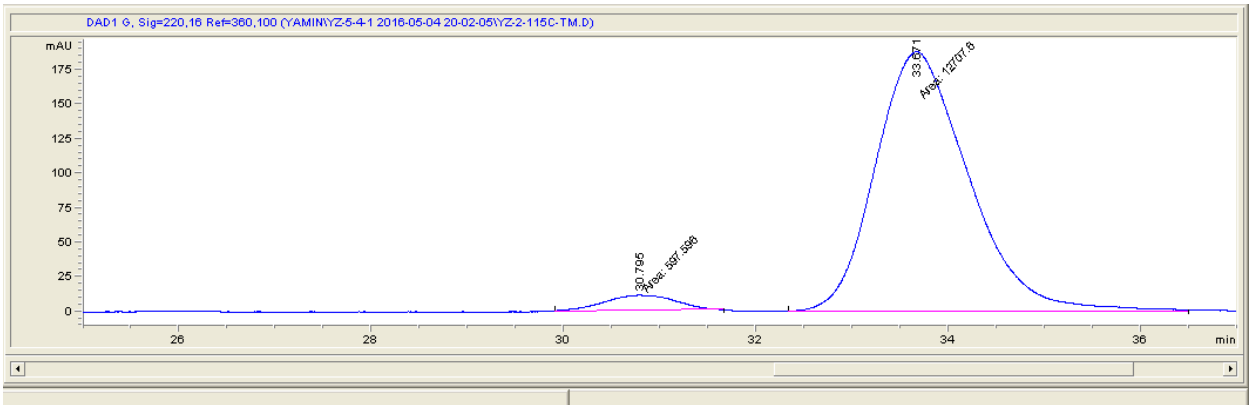


File Information	
LC-File	YZ-2-72F-TM-RACMIC-3.D
File Path	C:\CHEM32\1\DATA\YAMIN\

#	Time	Area	Height	Width	Area%	Symmetry
1	29.838	11005.2	192.2	0.9541	52.914	0.779
2	32.846	9793.1	155.6	1.0488	47.086	0.889

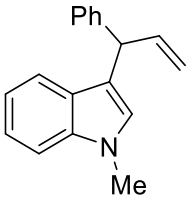


3aa

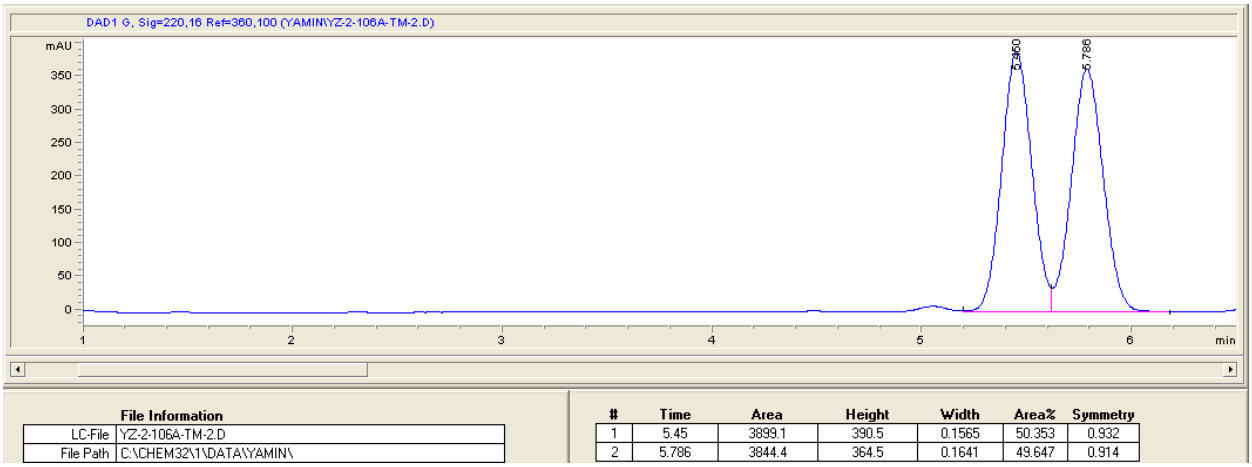


File Information	
LC-File	YZ-2-115C-TM.D
File Path	C:\CHEM32\1\DATA\YAMIN\YZ-5-4-1 2016-05-04 20-02-05\

#	Time	Area	Height	Width	Area%	Symmetry
1	30.795	597.6	11.3	0.8825	4.491	1.082
2	33.671	12707.6	188.4	1.1241	95.509	0.771

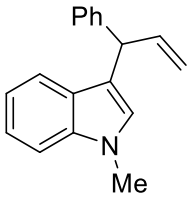


***rac*-3ba**

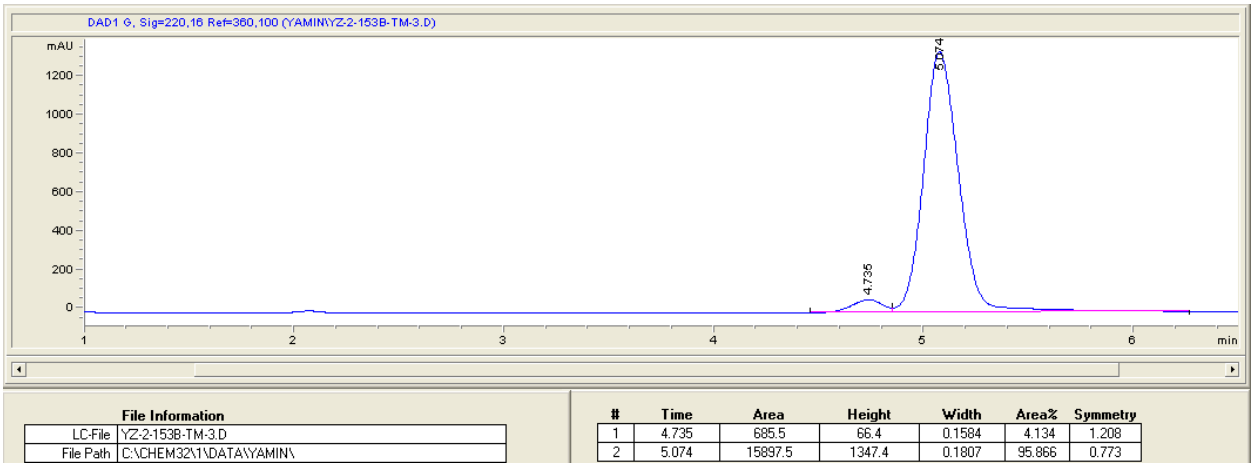


File Information	
LC-File	YZ-2-106A-TM-2.D
File Path	C:\CHEM32\1\DATA\YAMIN\

#	Time	Area	Height	Width	Area%	Symmetry
1	5.45	3899.1	390.5	0.1565	50.353	0.932
2	5.786	3844.4	364.5	0.1641	49.647	0.914

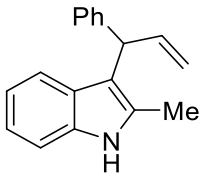


3ba

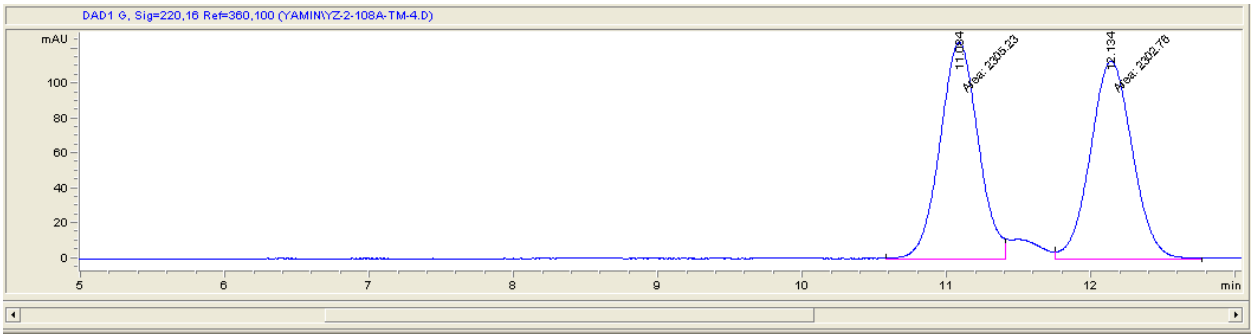


File Information	
LC-File	YZ-2-153B-TM-3.D
File Path	C:\CHEM32\1\DATA\YAMIN\

#	Time	Area	Height	Width	Area%	Symmetry
1	4.735	685.5	66.4	0.1584	4.134	1.208
2	5.074	15897.5	1347.4	0.1807	95.866	0.773

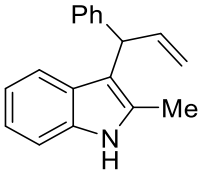


***rac*-3ca**

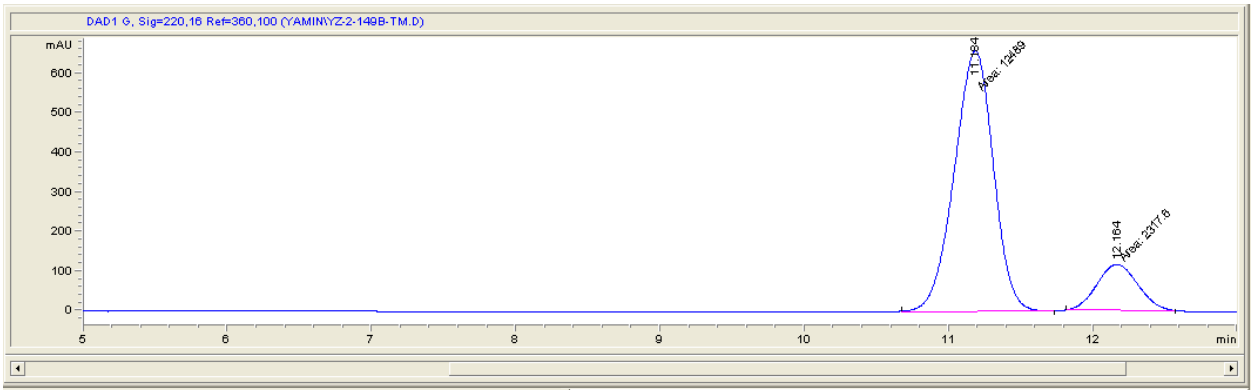


File Information	
LC-File	YZ-2-108A-TM-4.D
File Path	C:\CHEM32\1\DATA\YAMIN\

#	Time	Area	Height	Width	Area%	Symmetry
1	11.084	2305.2	124.3	0.3092	50.027	0.999
2	12.134	2302.8	113.6	0.3378	49.973	0.931

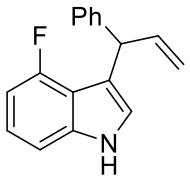


3ca

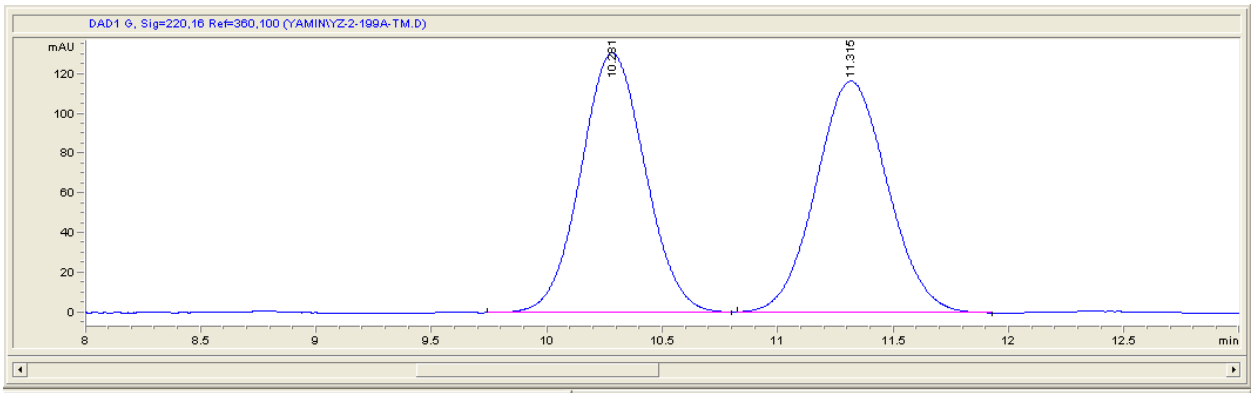


File Information	
LC-File	YZ-2-149B-TM.D
File Path	C:\CHEM32\1\DATA\YAMIN\

#	Time	Area	Height	Width	Area%	Symmetry
1	11.184	12489	659.6	0.3155	84.347	1.142
2	12.164	2317.6	116.6	0.3313	15.653	0.891

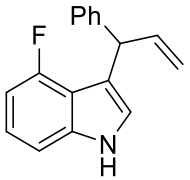


***rac*-3da**

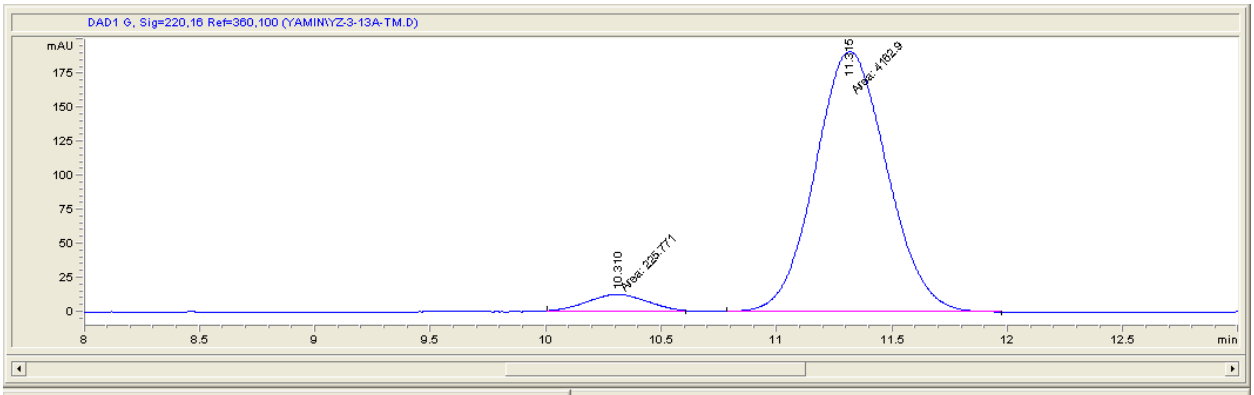


File Information	
LC-File	YZ-2-199A-TM.D
File Path	C:\CHEM32\1\DATA\YAMIN\

#	Time	Area	Height	Width	Area%	Symmetry
1	10.281	2541.4	131	0.2993	50.108	0.929
2	11.315	2530.5	116.7	0.331	49.892	0.931

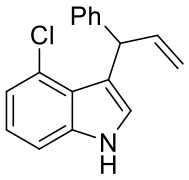


3da

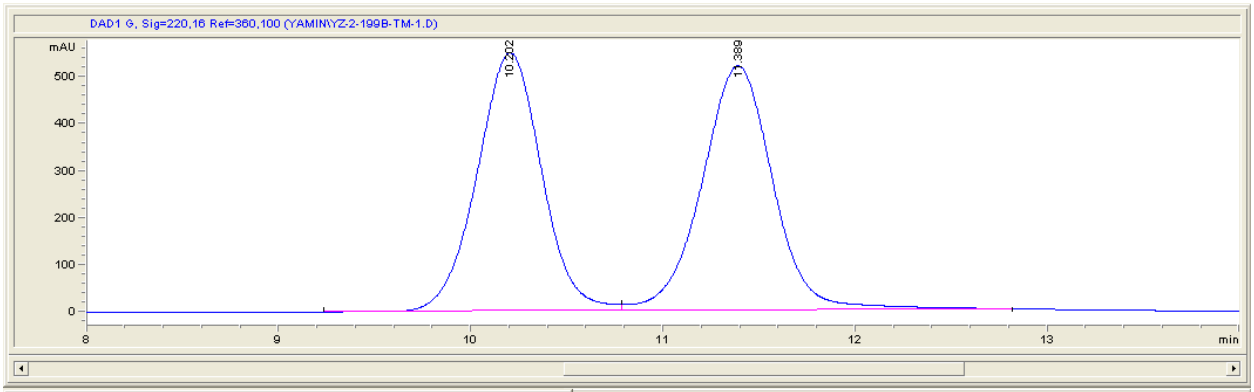


File Information	
LC-File	YZ-3-13A-TM.D
File Path	C:\CHEM32\1\DATA\YAMIN\

#	Time	Area	Height	Width	Area%	Symmetry
1	10.31	225.8	12.4	0.3036	5.144	1.013
2	11.315	4162.9	191.6	0.3622	94.856	0.911



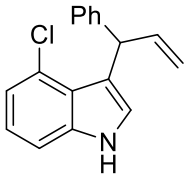
***rac*-3ea**



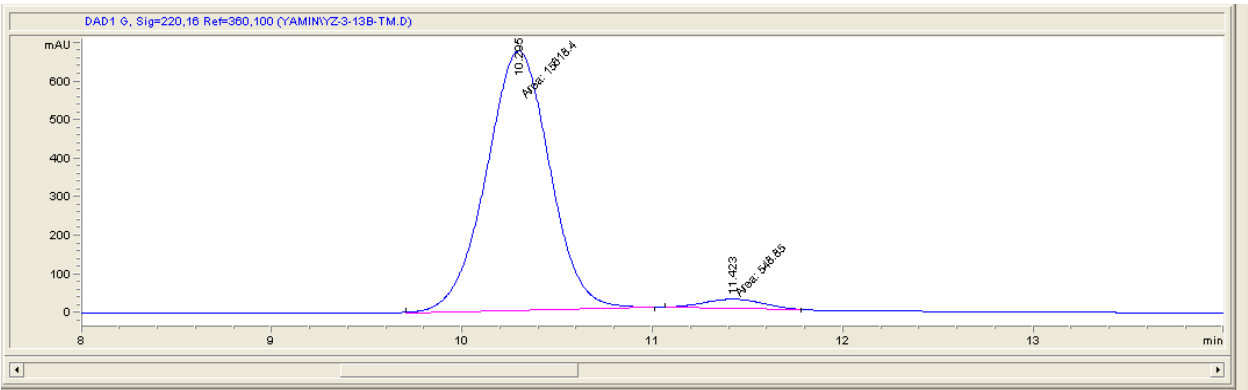
File Information

LC-File	YZ-2-199B-TM-1.D
File Path	C:\CHEM32\1\DATA\YAMIN\

#	Time	Area	Height	Width	Area%	Symmetry
1	10.202	12877.3	550.8	0.3597	48.857	1.003
2	11.389	13479.8	521.3	0.3957	51.143	0.987



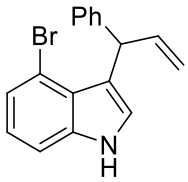
3ea



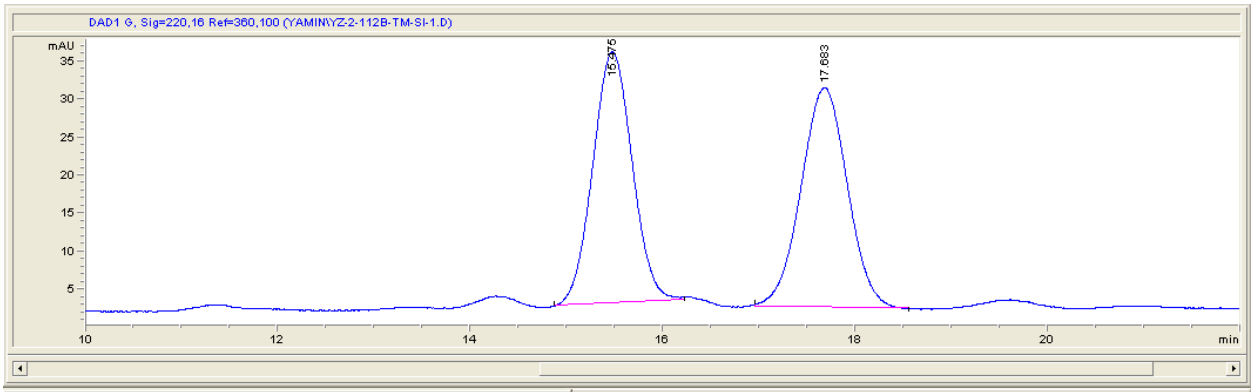
File Information

LC-File	YZ-3-13B-TM.D
File Path	C:\CHEM32\1\DATA\YAMIN\

#	Time	Area	Height	Width	Area%	Symmetry
1	10.295	15618.4	674	0.3862	96.605	1.018
2	11.423	548.9	24.7	0.3698	3.395	0.882

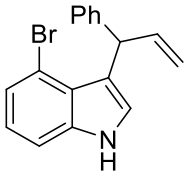


***rac*-3fa**

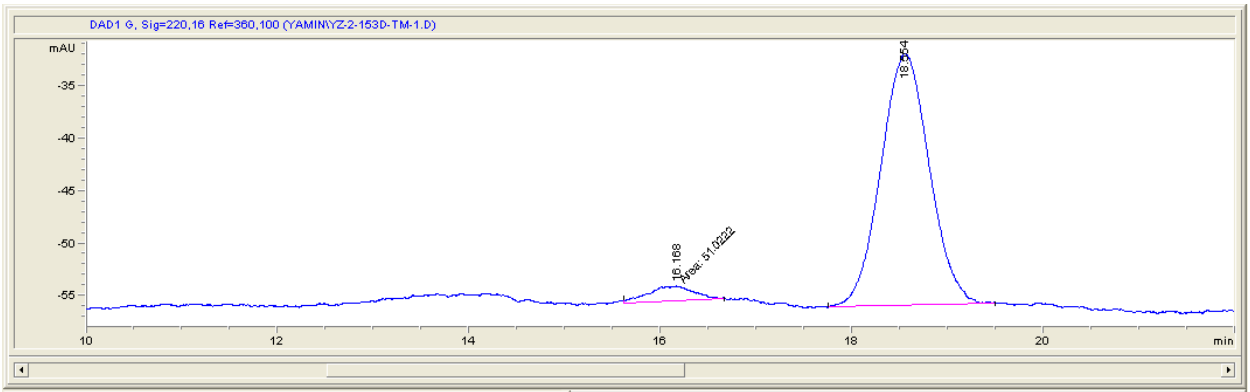


File Information	
LC-File	YZ-2-112B-TM-SI-1.D
File Path	C:\CHEM32\1\DATA\YAMIN\

#	Time	Area	Height	Width	Area%	Symmetry
1	15.475	947.2	33.1	0.431	49.417	0.951
2	17.683	969.5	28.9	0.4598	50.583	1.008

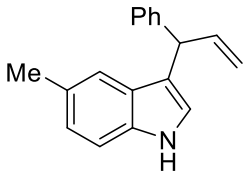


3fa

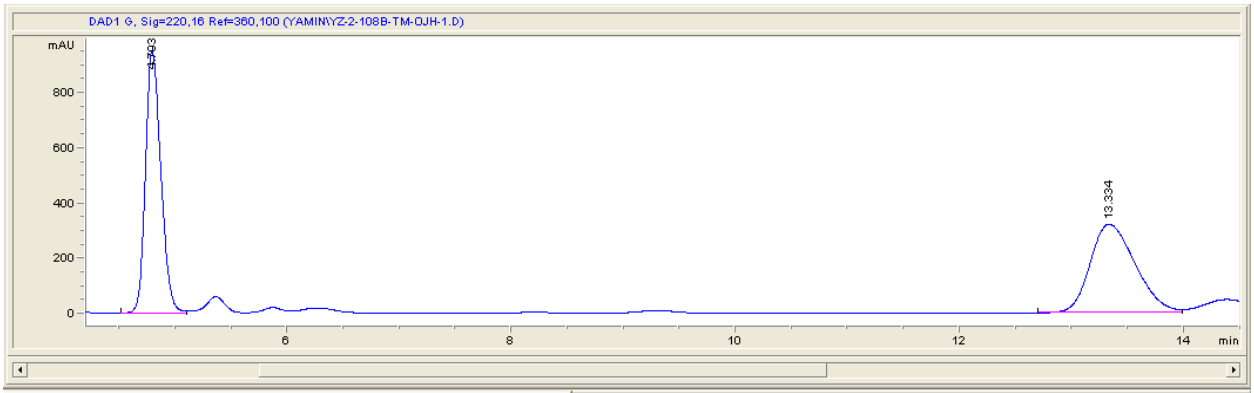


File Information	
LC-File	YZ-2-153D-TM-1.D
File Path	C:\CHEM32\1\DATA\YAMIN\

#	Time	Area	Height	Width	Area%	Symmetry
1	16.168	51	1.5	0.5738	5.684	1.642
2	18.554	846.7	24	0.4357	94.316	0.952



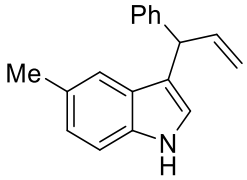
***rac*-3ga**



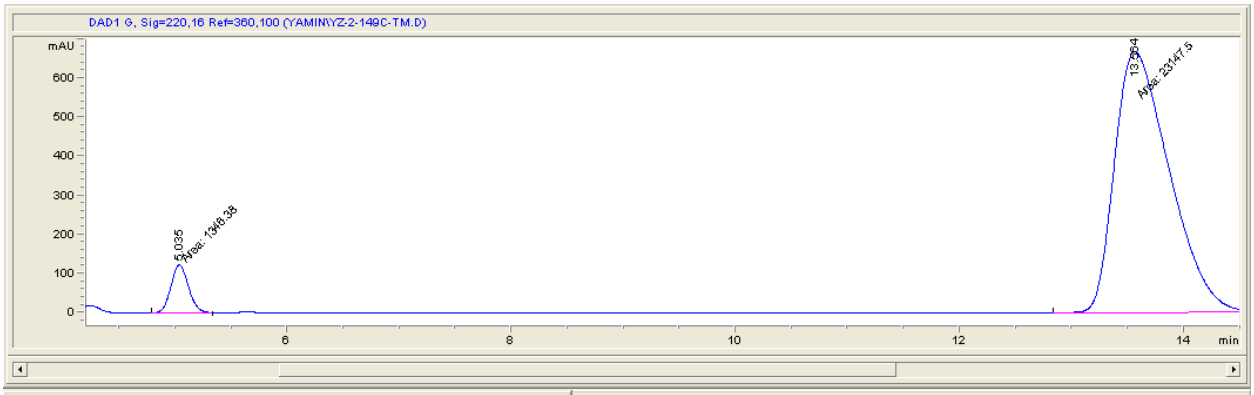
File Information

LC-File	YZ-2-108B-TM-OJH-1.D
File Path	C:\CHEM32\1\DATA\YAMIN\

#	Time	Area	Height	Width	Area%	Symmetry
1	4.793	9105.5	949.8	0.1488	50.241	0.729
2	13.334	9018.2	320.8	0.43	49.759	0.698



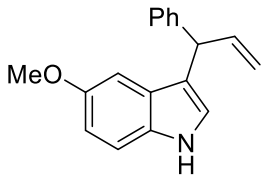
3ga



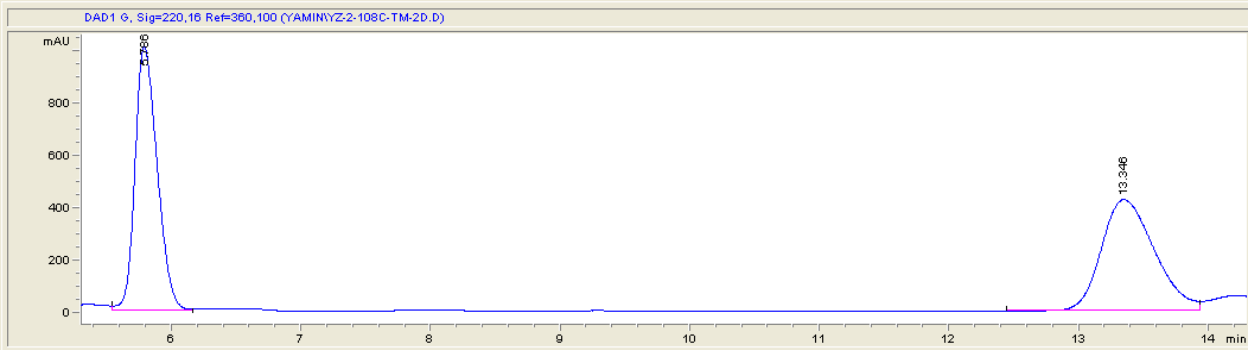
File Information

LC-File	YZ-2-149C-TM.D
File Path	C:\CHEM32\1\DATA\YAMIN\

#	Time	Area	Height	Width	Area%	Symmetry
1	5.035	1346.4	122.7	0.1829	5.497	0.878
2	13.564	23147.5	669.4	0.5764	94.503	0.563

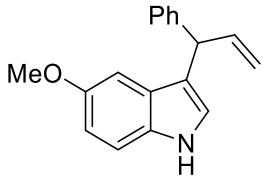


***rac*-3ha**

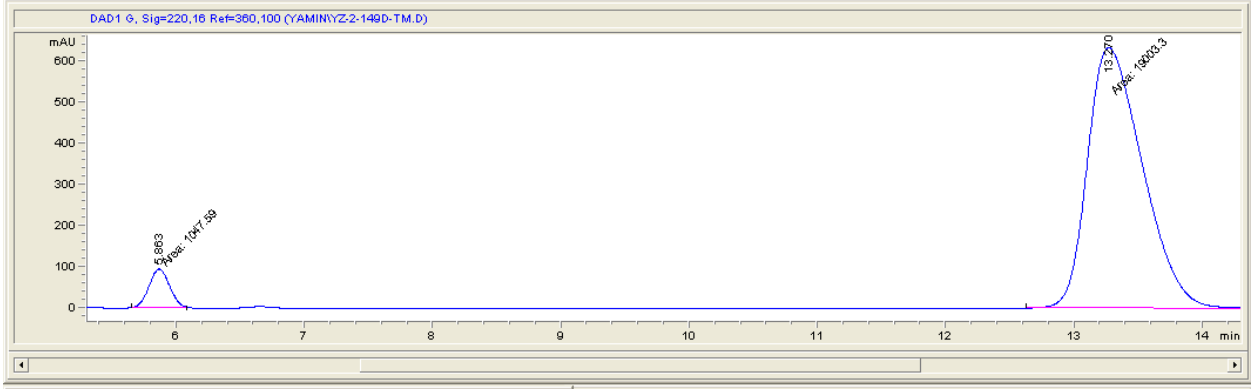


File Information	
LC-File	YZ-2-108C-TM-2D.D
File Path	C:\CHEM32\1\DATA\YAMIN\

#	Time	Area	Height	Width	Area%	Symmetry
1	5.786	12123.2	1009.5	0.1861	49.829	0.69
2	13.346	12206.2	426.2	0.4362	50.171	0.711

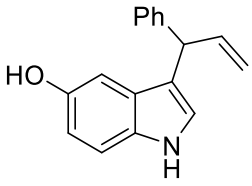


3ha

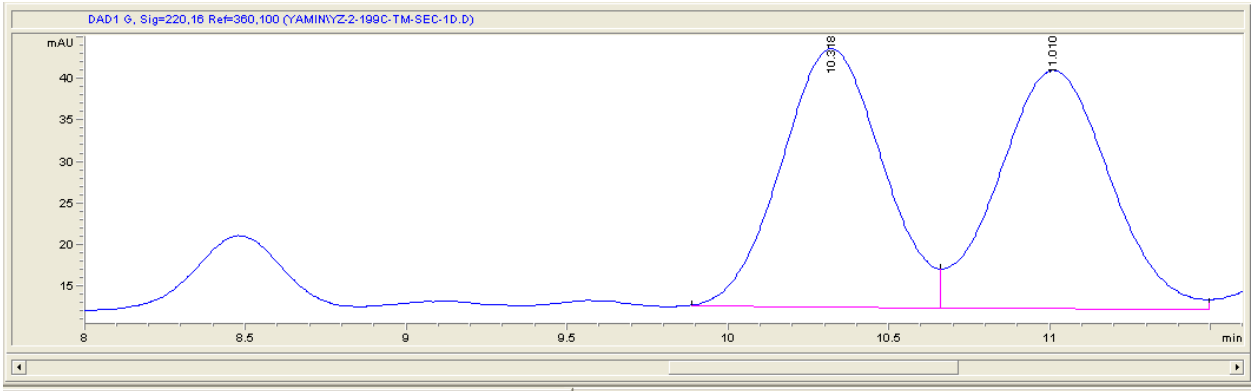


File Information	
LC-File	YZ-2-149D-TM.D
File Path	C:\CHEM32\1\DATA\YAMIN\

#	Time	Area	Height	Width	Area%	Symmetry
1	5.863	1047.6	93.8	0.1862	5.225	0.945
2	13.27	19003.3	632.8	0.5005	94.775	0.617

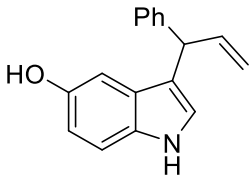


***rac*-3ia**

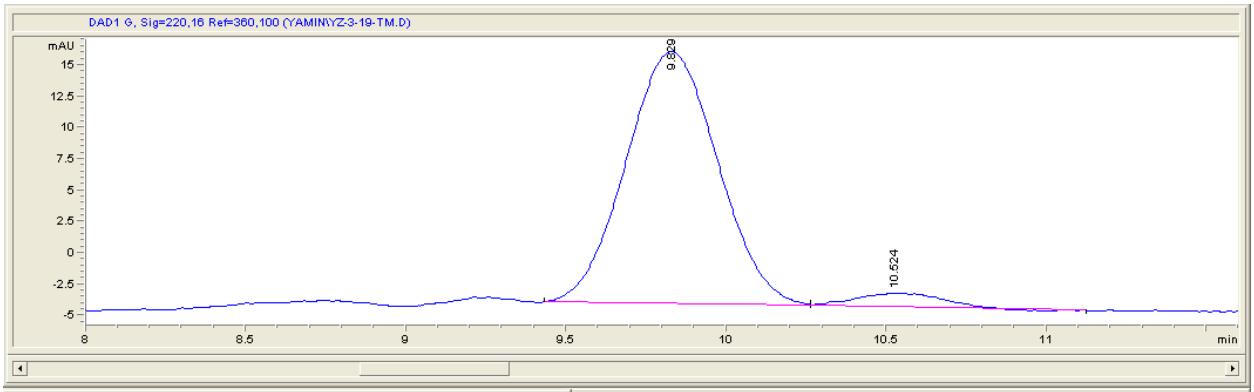


File Information	
LC-File	YZ-2-199C-TM-SEC-1D.D
File Path	C:\CHEM32\1\DATA\YAMIN\

#	Time	Area	Height	Width	Area%	Symmetry
1	10.318	683.9	31.2	0.3338	49.660	0.942
2	11.01	693.3	28.8	0.3411	50.340	0.938

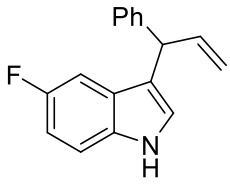


3ia

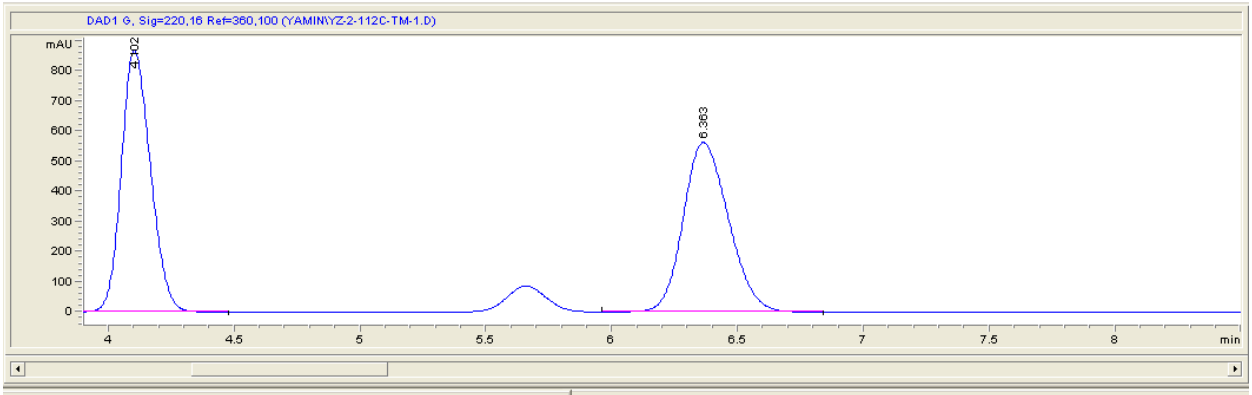


File Information	
LC-File	YZ-3-19-TM.D
File Path	C:\CHEM32\1\DATA\YAMIN\

#	Time	Area	Height	Width	Area%	Symmetry
1	9.829	401.7	20.1	0.2629	94.986	0.937
2	10.524	21.2	1.1	0.2203	5.014	0.804

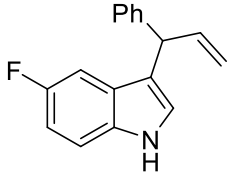


***rac*-3ja**



File Information	
LC-File	YZ-2-112C-TM-1.D
File Path	C:\CHEM32\1\DATA\YAMIN\

#	Time	Area	Height	Width	Area%	Symmetry
1	4.102	7016.8	869.7	0.1251	49.870	0.775
2	6.363	7053.4	563.2	0.1961	50.130	0.776



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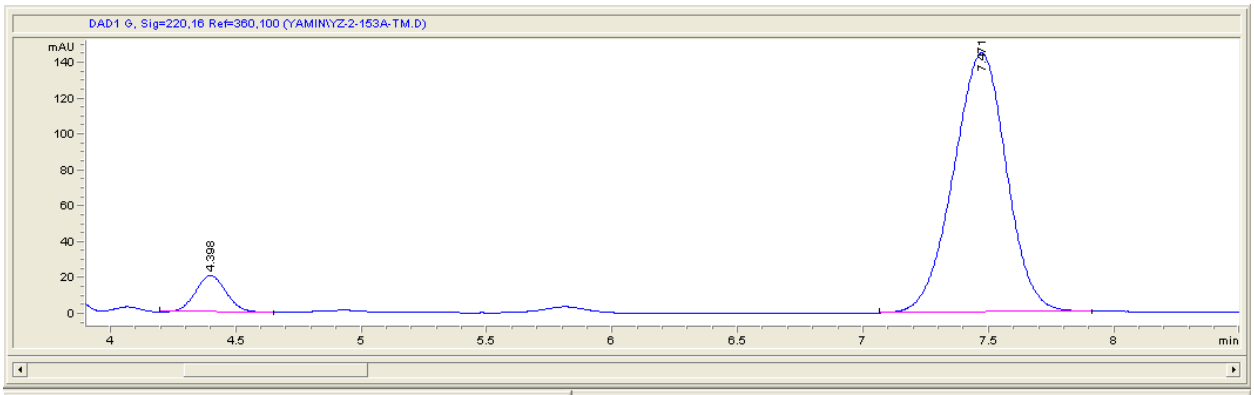
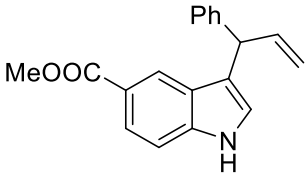
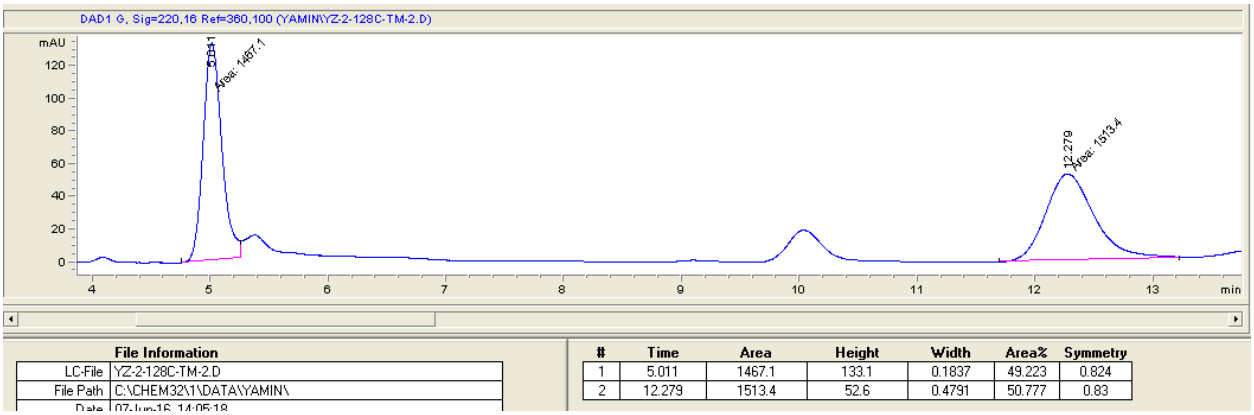


File Information	
LC-File	YZ-2-153A-TM.D
File Path	C:\CHEM32\1\DATA\YAMIN\

#	Time	Area	Height	Width	Area%	Symmetry
1	4.398	172.7	20.2	0.1317	7.505	0.947
2	7.471	2128.9	144.6	0.2277	92.495	1.085

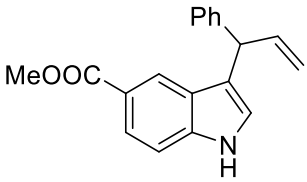


***rac*-3ka**

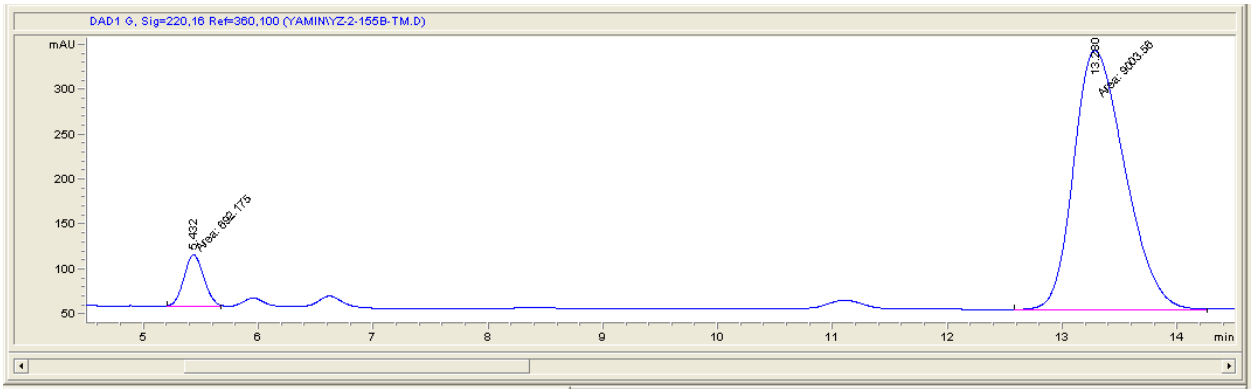


File Information	
LC-File	YZ-2-128C-TM-2.D
File Path	C:\CHEM32\1\DATA\YAMIN\
Date	07-Jun-16, 14:05:18

#	Time	Area	Height	Width	Area%	Symmetry
1	5.011	1467.1	133.1	0.1837	49.223	0.824
2	12.279	1513.4	52.6	0.4791	50.777	0.83

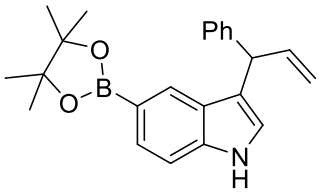


3ka

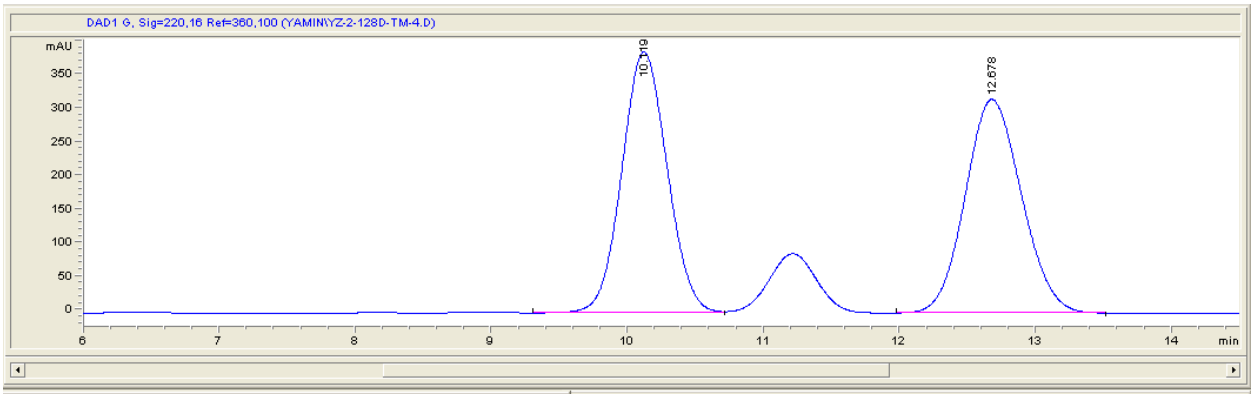


File Information	
LC-File	YZ-2-155B-TM.D
File Path	C:\CHEM32\1\DATA\YAMIN\

#	Time	Area	Height	Width	Area%	Symmetry
1	5.432	692.2	57.5	0.2005	7.139	0.902
2	13.28	9003.6	289.8	0.5178	92.861	0.698

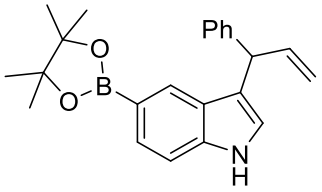


***rac*-3la**

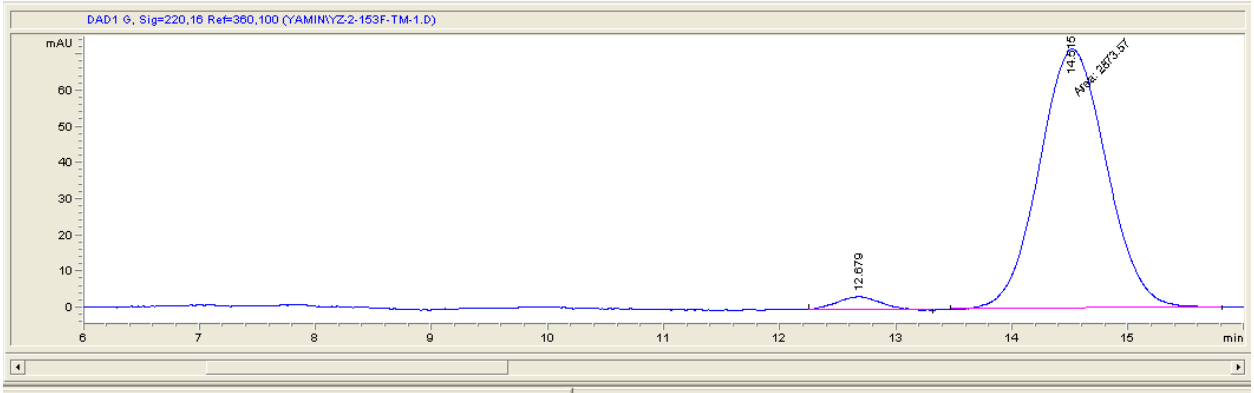


File Information	
LC-File	YZ-2-128D-TM-4.D
File Path	C:\CHEM32\1\DATA\YAMIN\

#	Time	Area	Height	Width	Area%	Symmetry
1	10.119	9021.4	388	0.3623	49.701	0.921
2	12.678	9130	317.6	0.4274	50.299	0.873

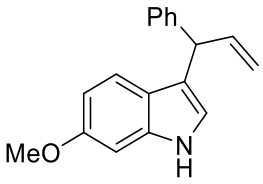


3la

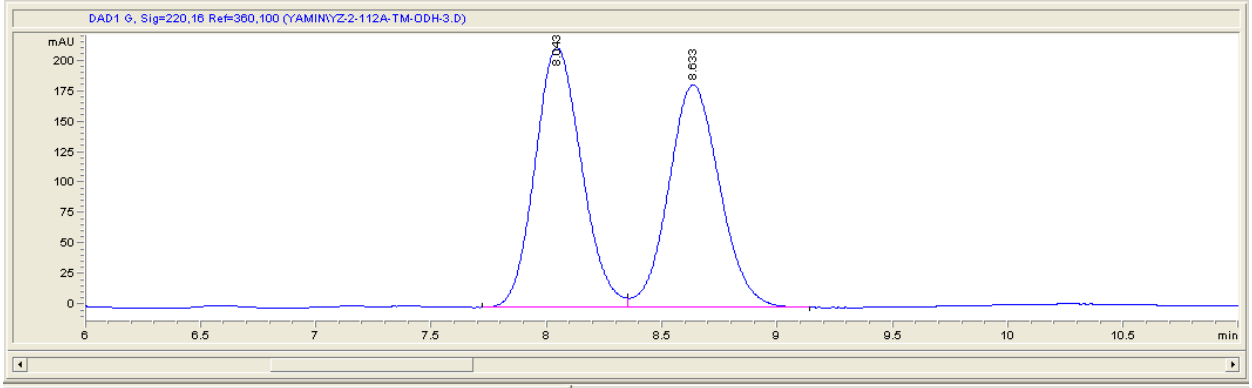


File Information	
LC-File	YZ-2-153F-TM-1.D
File Path	C:\CHEM32\1\DATA\YAMIN\

#	Time	Area	Height	Width	Area%	Symmetry
1	12.679	93.3	3.7	0.3096	3.144	0.986
2	14.515	2873.6	71.6	0.6686	96.856	0.929

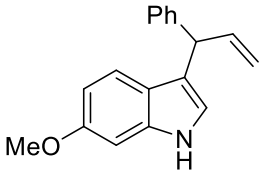


***rac*-3ma**

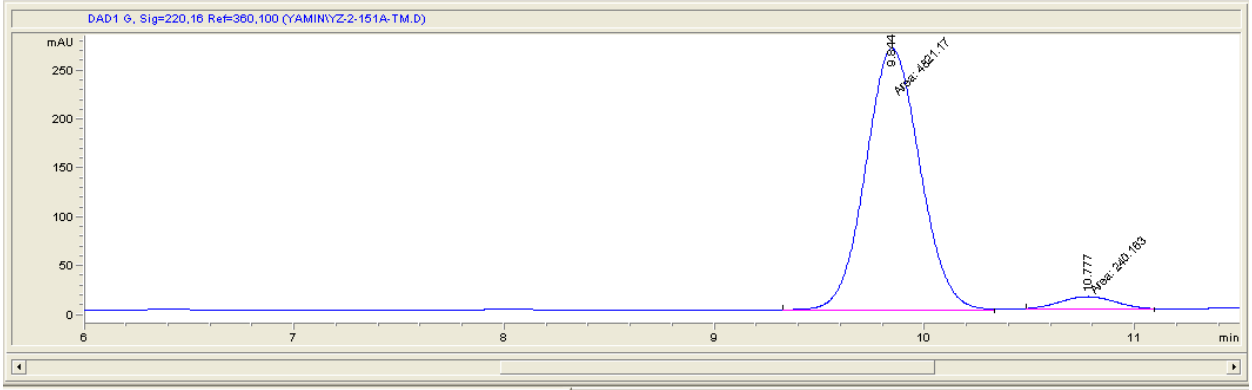


File Information	
LC-File	YZ-2-112A-TM-ODH-3.D
File Path	C:\CHEM32\1\DATA\YAMIN\

#	Time	Area	Height	Width	Area%	Symmetry
1	8.043	2999.6	213.2	0.2172	51.575	0.852
2	8.633	2816.4	182.7	0.2369	48.425	0.878

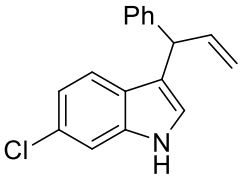


3ma

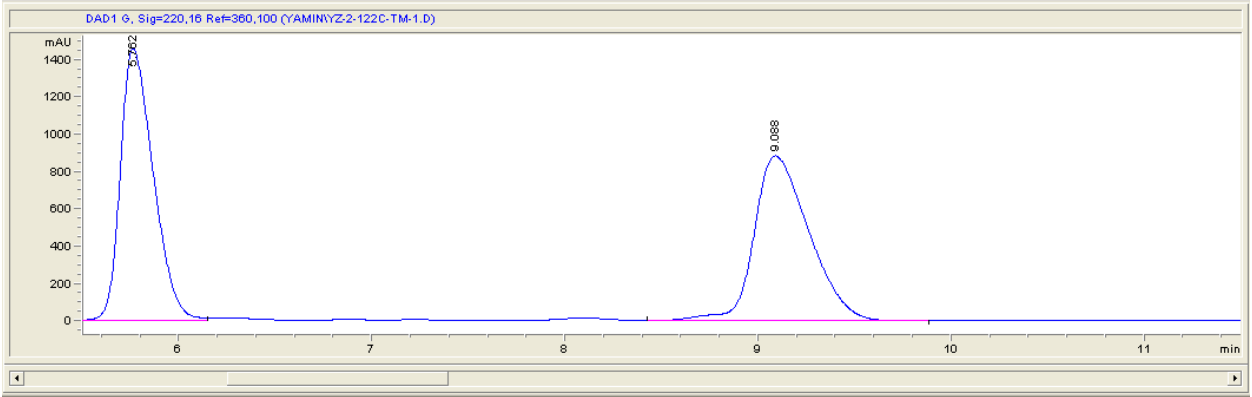


File Information	
LC-File	YZ-2-151A-TM.D
File Path	C:\CHEM32\1\DATA\YAMIN\

#	Time	Area	Height	Width	Area%	Symmetry
1	9.844	4821.2	268.4	0.2994	95.255	0.924
2	10.777	240.2	12.9	0.3099	4.745	1.014

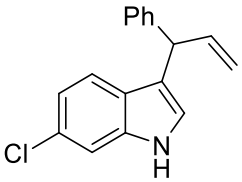


***rac*-3na**

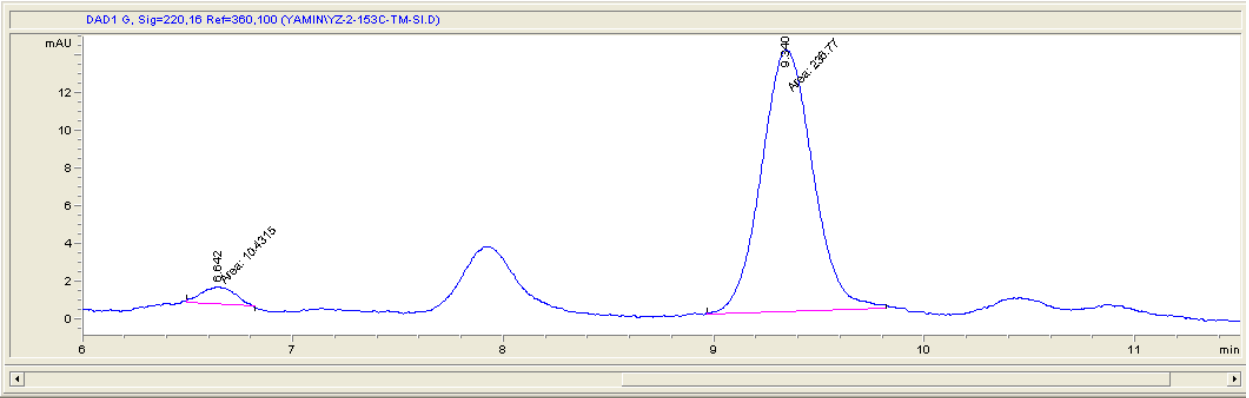


File Information	
LC-File	YZ-2-122C-TM-1.D
File Path	C:\CHEM32\1\DATA\YAMIN\

#	Time	Area	Height	Width	Area%	Symmetry
1	5.762	17419.6	1459	0.1853	49.824	0.614
2	9.088	17542.9	884	0.3055	50.176	0.636

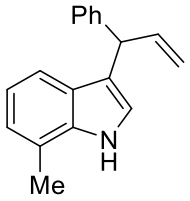


3na

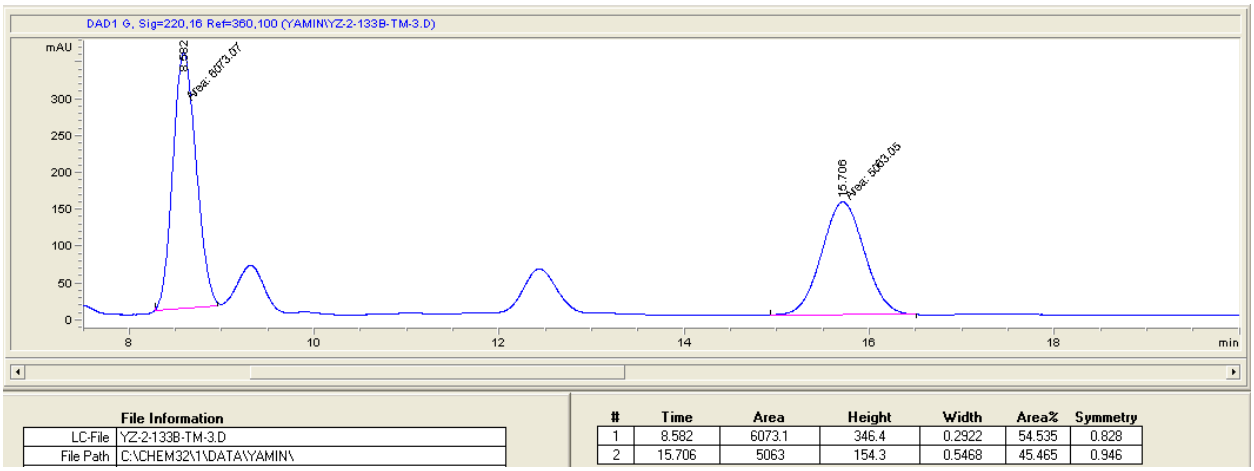


File Information	
LC-File	YZ-2-153C-TM-SI.D
File Path	C:\CHEM32\1\DATA\YAMIN\

#	Time	Area	Height	Width	Area%	Symmetry
1	6.642	10.4	9.5E-1	0.1826	4.220	0.929
2	9.34	236.8	13.9	0.2831	95.780	0.897

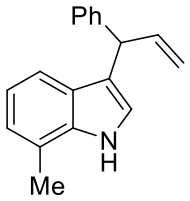


***rac*-3oa**

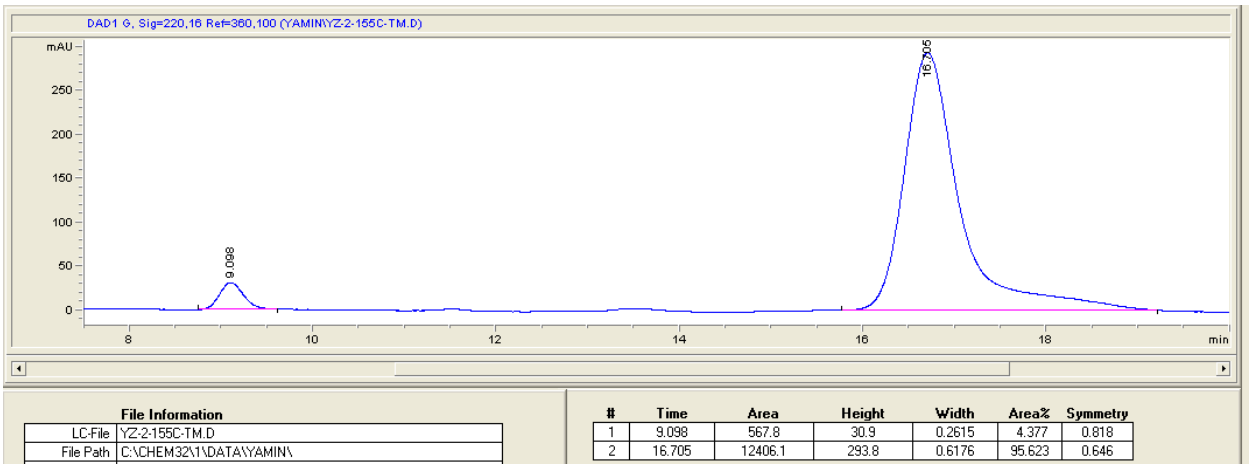


File Information	
LC-File	YZ-2-133B-TM-3.D
File Path	C:\CHEM32\1\DATA\YAMIN\

#	Time	Area	Height	Width	Area%	Symmetry
1	8.582	6073.1	346.4	0.2922	54.535	0.828
2	15.706	5063	154.3	0.5468	45.465	0.946

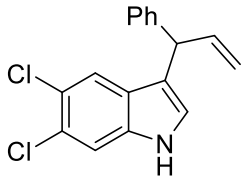


3oa

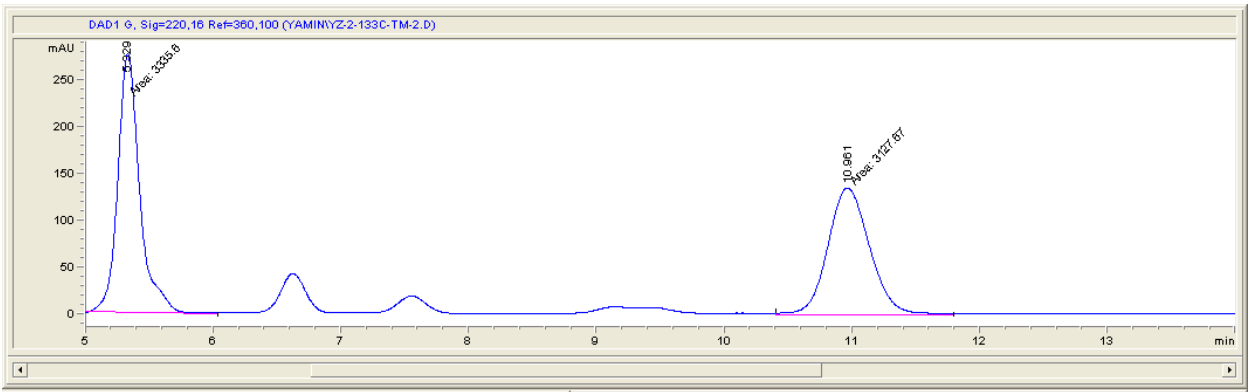


File Information	
LC-File	YZ-2-155C-TM.D
File Path	C:\CHEM32\1\DATA\YAMIN\

#	Time	Area	Height	Width	Area%	Symmetry
1	9.098	567.8	30.9	0.2615	4.377	0.818
2	16.705	12406.1	293.8	0.6176	95.623	0.646

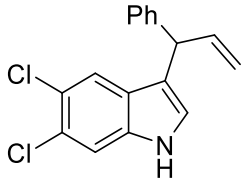


***rac*-3pa**

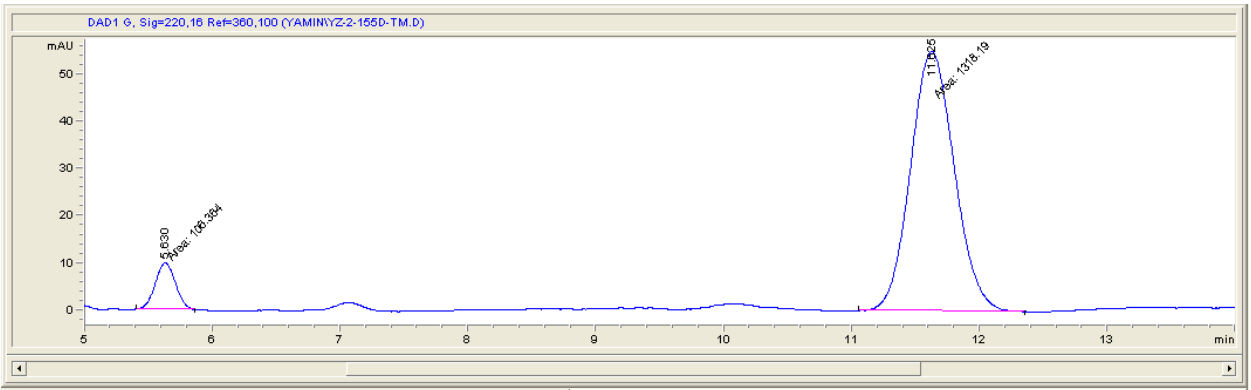


File Information	
LC-File	YZ-2-133C-TM-2.D
File Path	C:\CHEM32\1\DATA\YAMIN\

#	Time	Area	Height	Width	Area%	Symmetry
1	5.329	3335.6	277.1	0.2006	51.609	0.801
2	10.961	3127.7	135.8	0.3838	48.391	0.853

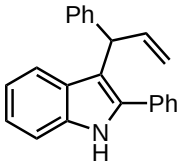


3pa

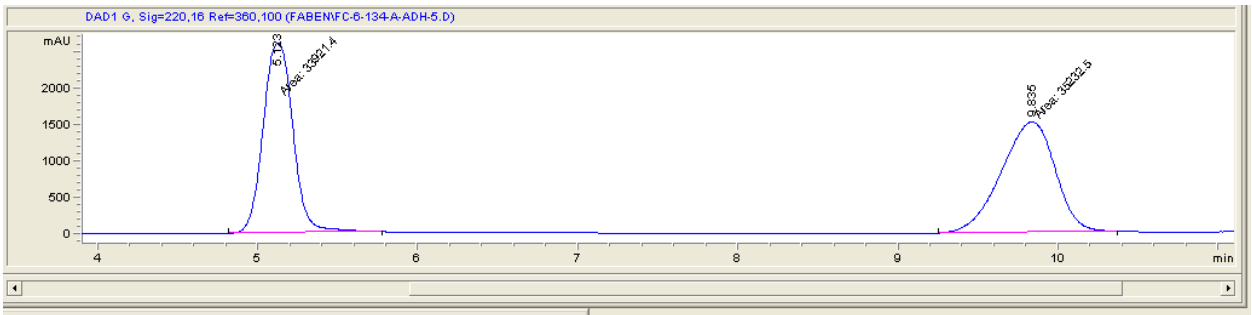


File Information	
LC-File	YZ-2-155D-TM.D
File Path	C:\CHEM32\1\DATA\YAMIN\

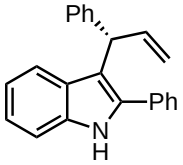
#	Time	Area	Height	Width	Area%	Symmetry
1	5.63	106.4	9.8	0.1813	7.466	0.94
2	11.625	1318.2	55.1	0.3984	92.534	0.908



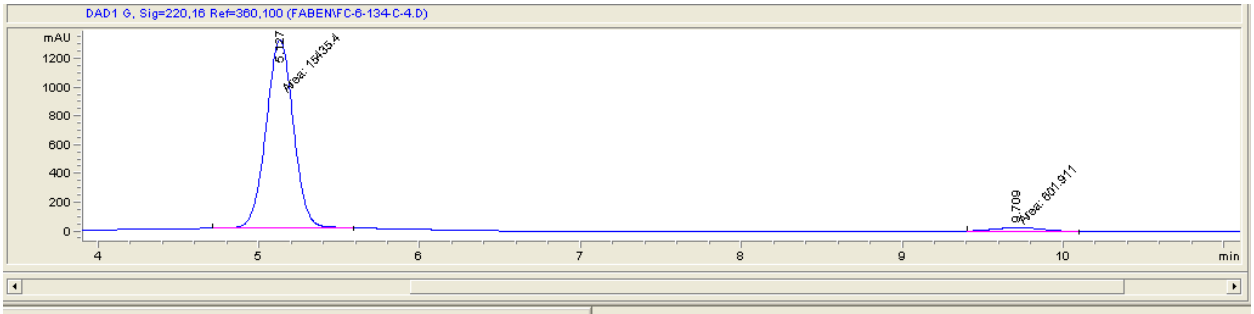
***rac*-3qa**



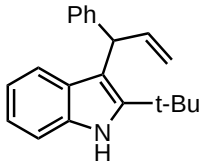
#	Time	Area	Height	Width	Area%	Symmetry
1	5.123	33921.4	2598.7	0.2176	49.052	0.921
2	9.835	35232.5	1506.2	0.3899	50.948	1.298



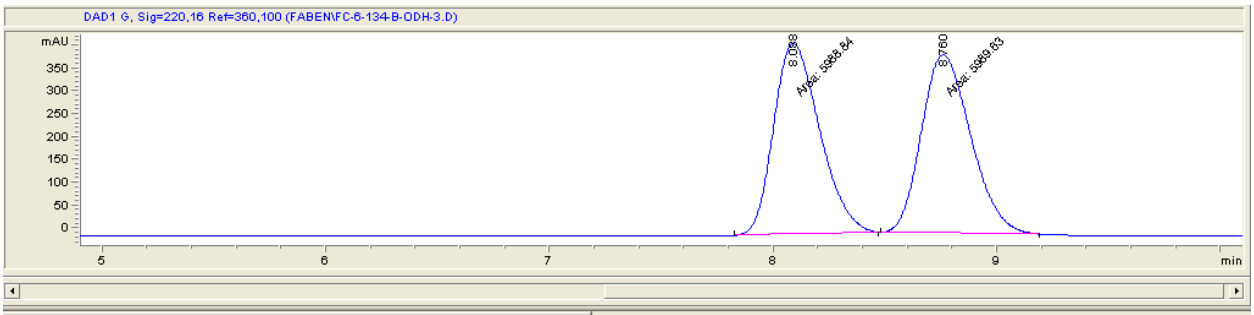
3qa



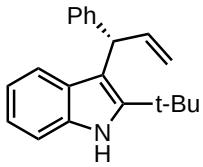
#	Time	Area	Height	Width	Area%	Symmetry
1	5.127	15435.4	1310.4	0.1963	96.247	0.99
2	9.709	601.9	27.4	0.3664	3.753	0.926



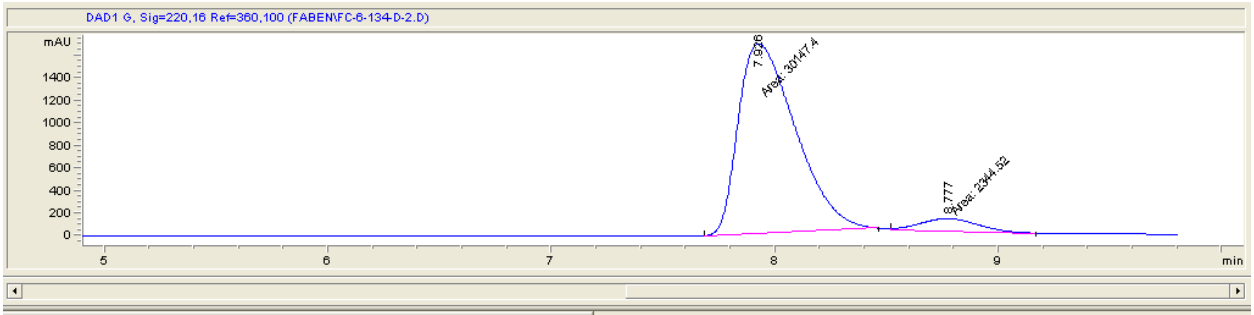
***rac*-3ra**



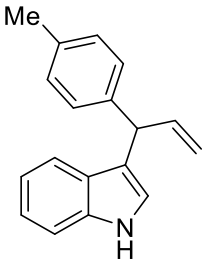
#	Time	Area	Height	Width	Area%	Symmetry
1	8.088	5988.8	417.9	0.2388	49.997	0.718
2	8.76	5989.6	389.9	0.256	50.003	0.773



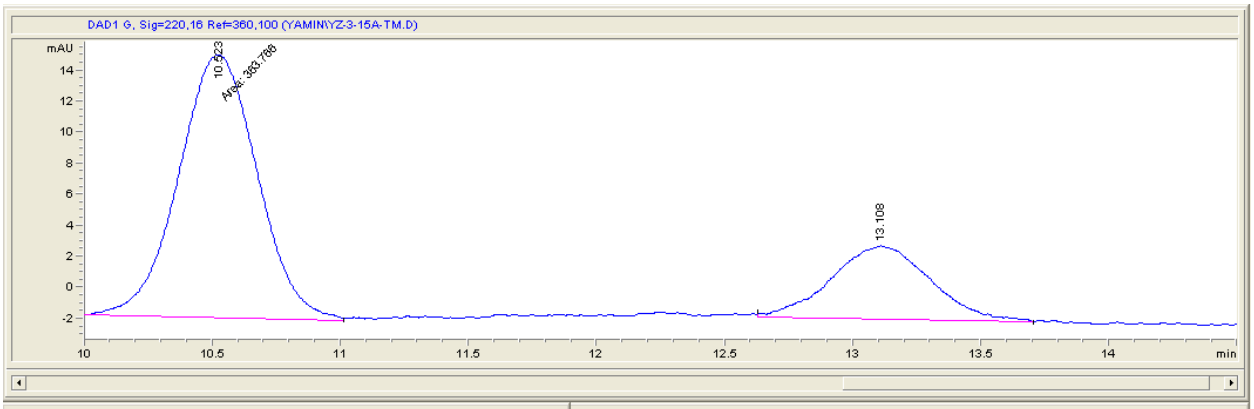
3ra



#	Time	Area	Height	Width	Area%	Symmetry
1	7.926	30147.4	1685.5	0.2981	92.784	0.536
2	8.777	2344.5	119.2	0.3278	7.216	0.779



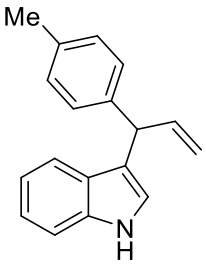
***rac*-3ab**



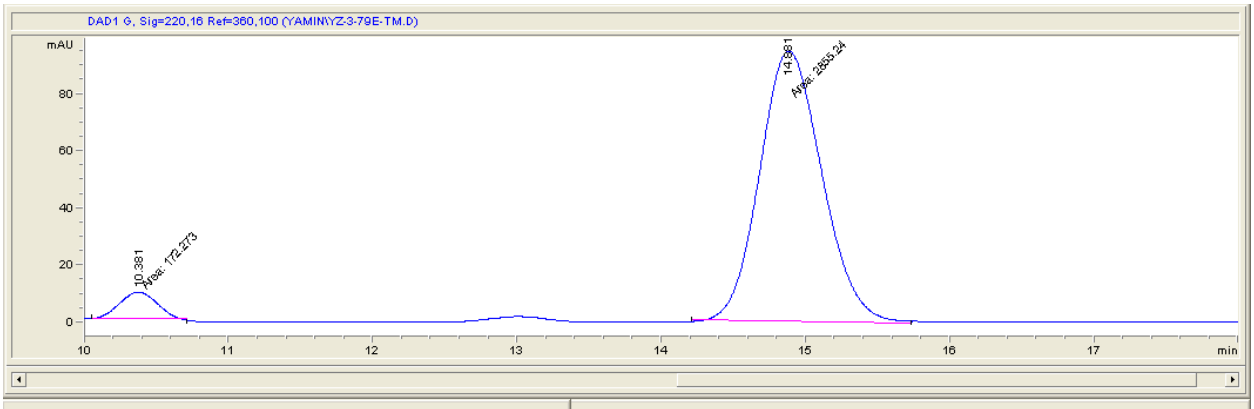
File Information

LC-File	YZ-3-15A-TM.D
File Path	C:\CHEM32\1\DATA\YAMIN\
Date	11-Aug-16, 19:09:57

#	Time	Area	Height	Width	Area%	Symmetry
1	7.81	124.3	8	0.2149	20.093	0.932
2	10.523	363.8	17	0.3567	58.825	0.998
3	13.108	130.4	4.8	0.3227	21.083	0.969



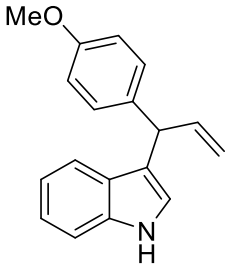
3ab



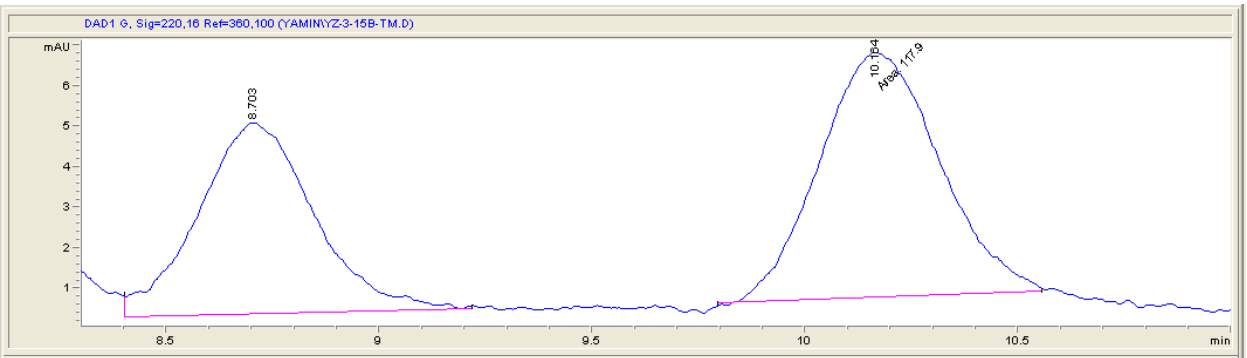
File Information

LC-File	YZ-3-79E-TM.D
File Path	C:\CHEM32\1\DATA\YAMIN\

#	Time	Area	Height	Width	Area%	Symmetry
1	10.381	172.3	9.4	0.3043	5.690	1.119
2	14.881	2855.2	94.9	0.5015	94.310	0.848

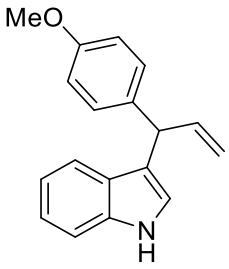


***rac*-3ac**

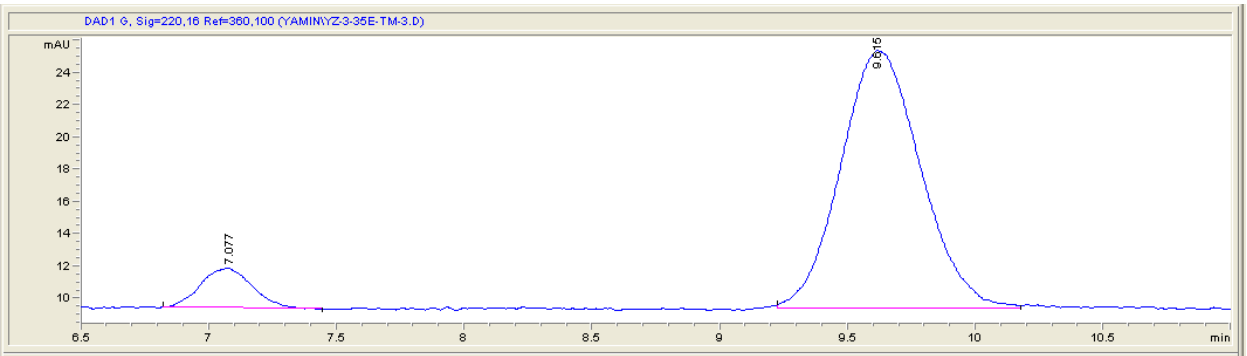


File Information	
LC-File	YZ-3-15B-TM.D
File Path	C:\CHEM32\1\DATA\YAMIN\

#	Time	Area	Height	Width	Area%	Symmetry
1	8.703	89.7	4.7	0.2354	43.216	0.87
2	10.164	117.9	6	0.3254	56.784	0.856

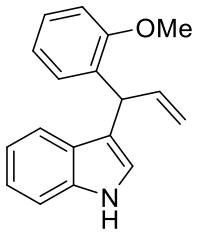


3ac

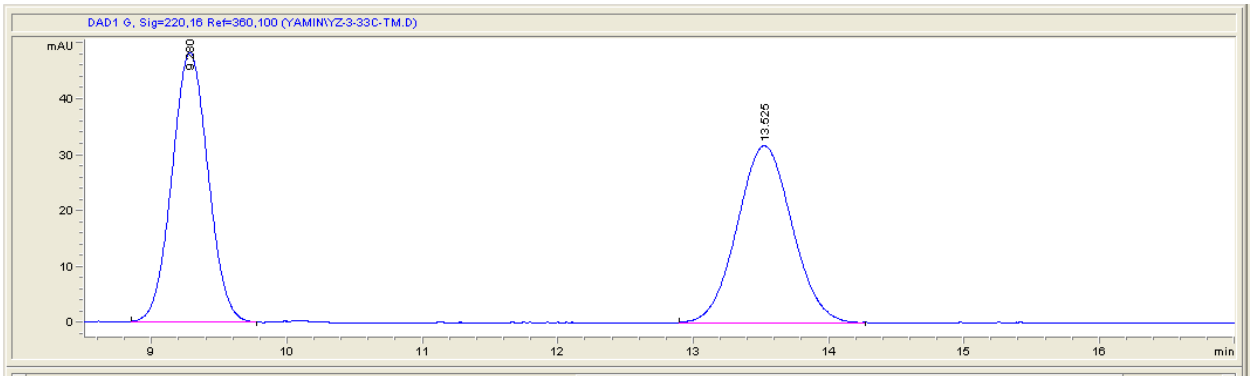


File Information	
LC-File	YZ-3-35E-TM-3.D
File Path	C:\CHEM32\1\DATA\YAMIN\

#	Time	Area	Height	Width	Area%	Symmetry
1	7.077	34.5	2.4	0.1787	9.029	1.116
2	9.615	347.7	16	0.2777	90.971	0.82

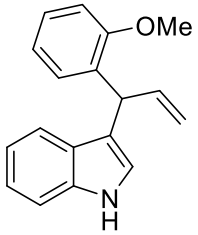


***rac*-3ad**

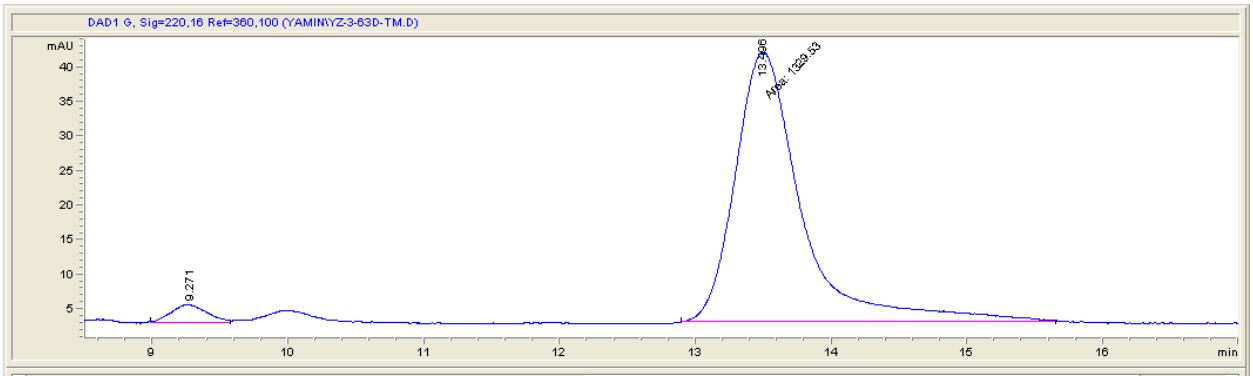


File Information	
LC-File	YZ-3-33C-TM.D
File Path	C:\CHEM32\1\DATA\YAMIN\

#	Time	Area	Height	Width	Area%	Symmetry
1	9.28	897.4	48.3	0.2818	50.034	0.977
2	13.525	896.1	31.7	0.4018	49.966	0.975

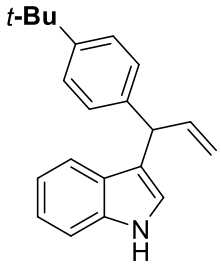


3ad

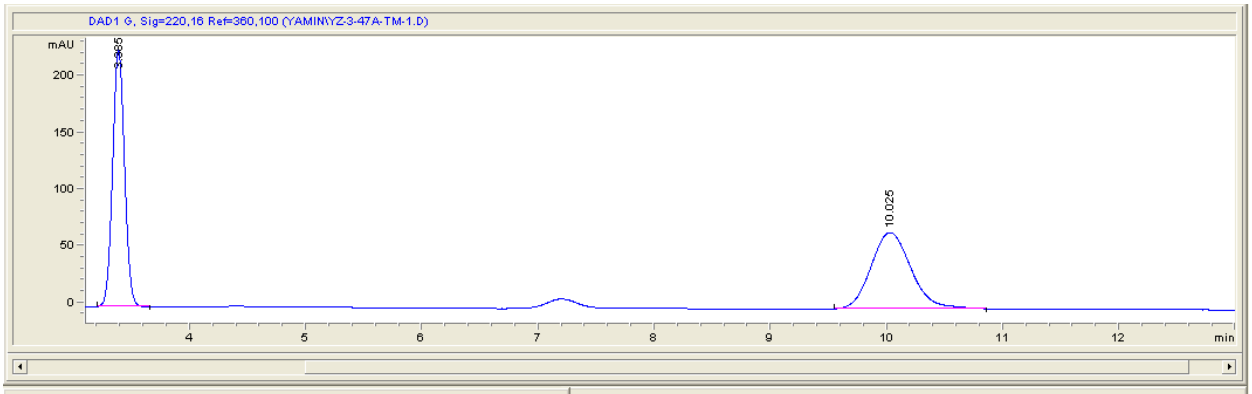


File Information	
LC-File	YZ-3-63D-TM.D
File Path	C:\CHEM32\1\DATA\YAMIN\

#	Time	Area	Height	Width	Area%	Symmetry
1	9.271	48.8	2.6	0.2268	3.541	0.997
2	13.496	1329.5	39	0.568	96.459	0.684

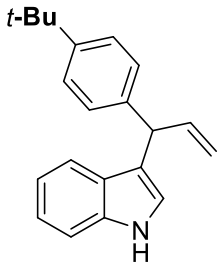


***rac*-3ae**

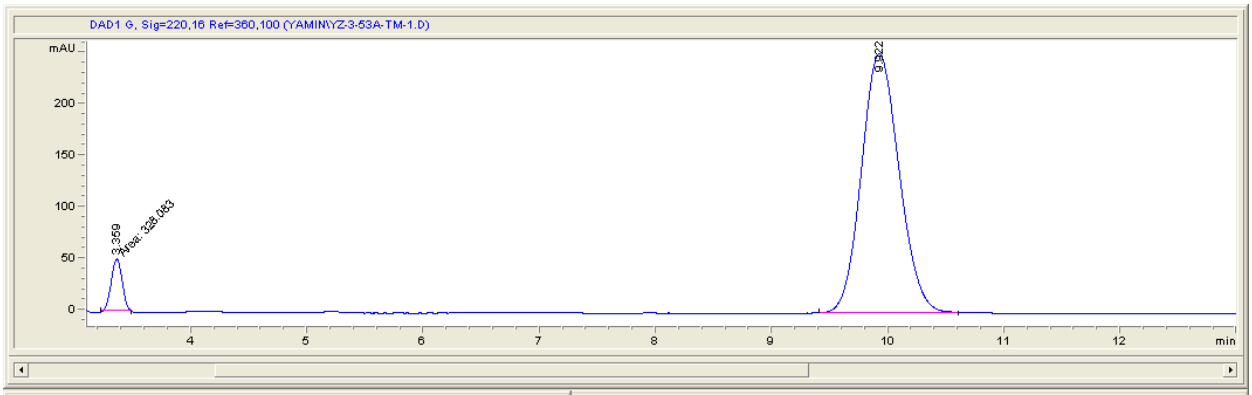


File Information	
LC-File	YZ-3-47A-TM-1.D
File Path	C:\CHEM32\1\DATA\YAMIN\

#	Time	Area	Height	Width	Area%	Symmetry
1	3.385	1602	225.9	0.1107	49.654	0.939
2	10.025	1624.3	67.5	0.3748	50.346	0.841

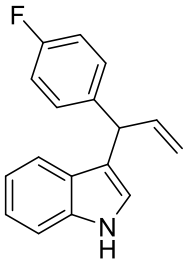


3ae

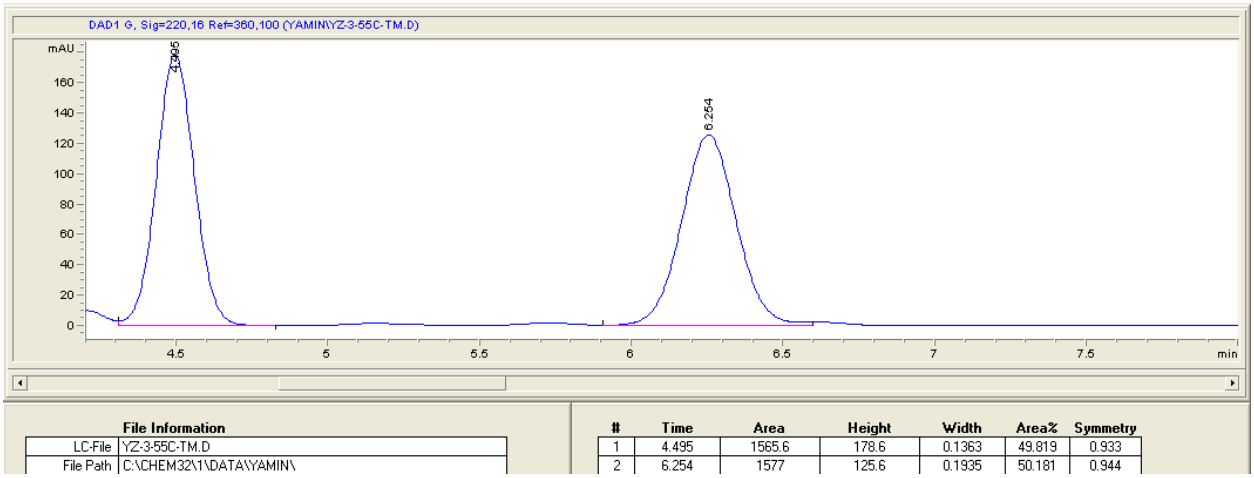


File Information	
LC-File	YZ-3-53A-TM-1.D
File Path	C:\CHEM32\1\DATA\YAMIN\

#	Time	Area	Height	Width	Area%	Symmetry
1	3.359	328.1	50.3	0.1087	5.455	0.976
2	9.922	5686.8	251.7	0.3516	94.545	0.848

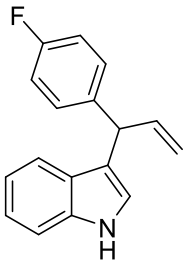


***rac*-3af**

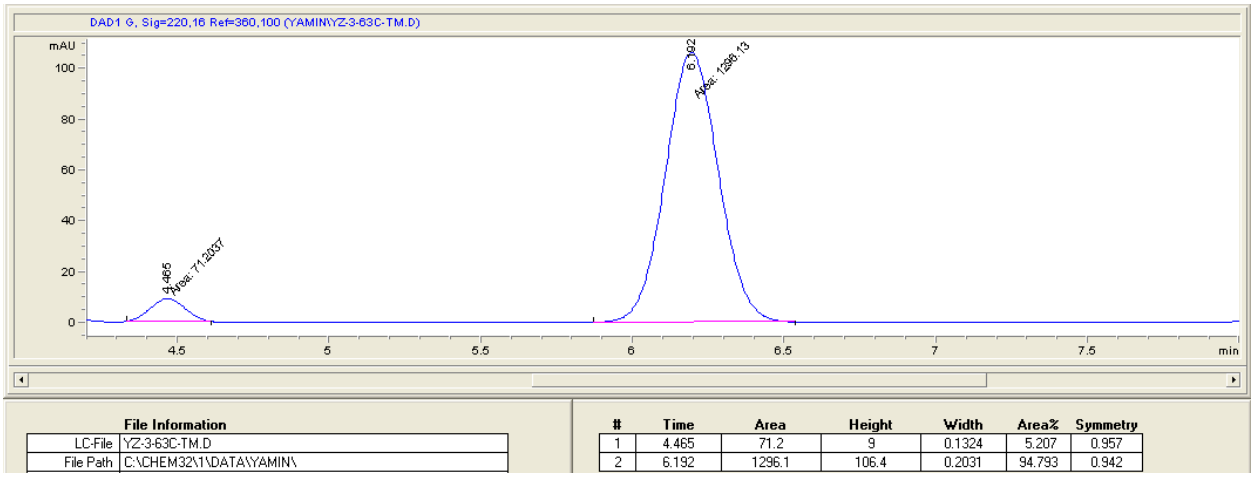


File Information	
LC-File	YZ-3-55C-TM.D
File Path	C:\CHEM32\1\DATA\YAMIN\

#	Time	Area	Height	Width	Area%	Symmetry
1	4.495	1565.6	178.6	0.1363	49.819	0.933
2	6.254	1577	125.6	0.1935	50.181	0.944

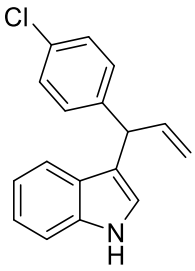


3af

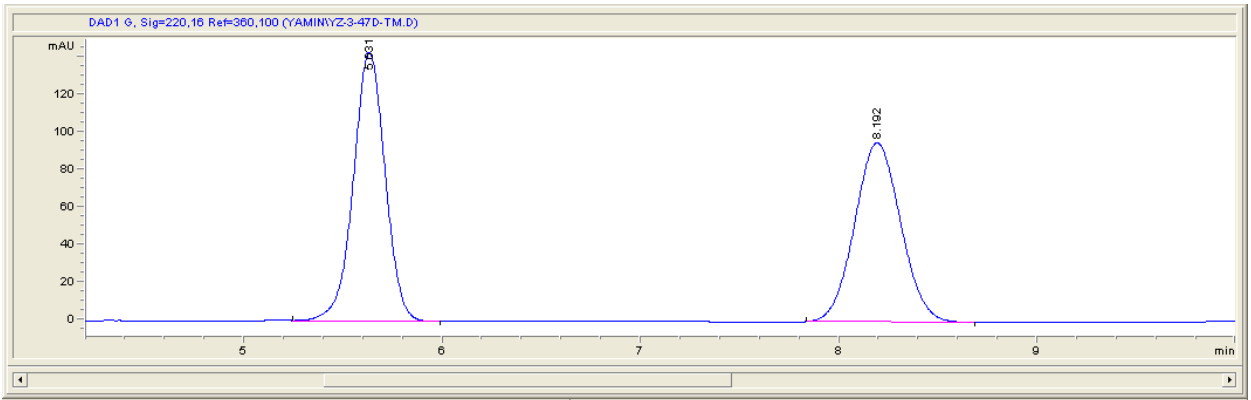


File Information	
LC-File	YZ-3-63C-TM.D
File Path	C:\CHEM32\1\DATA\YAMIN\

#	Time	Area	Height	Width	Area%	Symmetry
1	4.465	71.2	9	0.1324	5.207	0.957
2	6.192	1296.1	106.4	0.2031	94.793	0.942

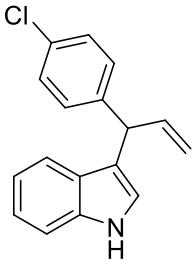


***rac*-3ag**

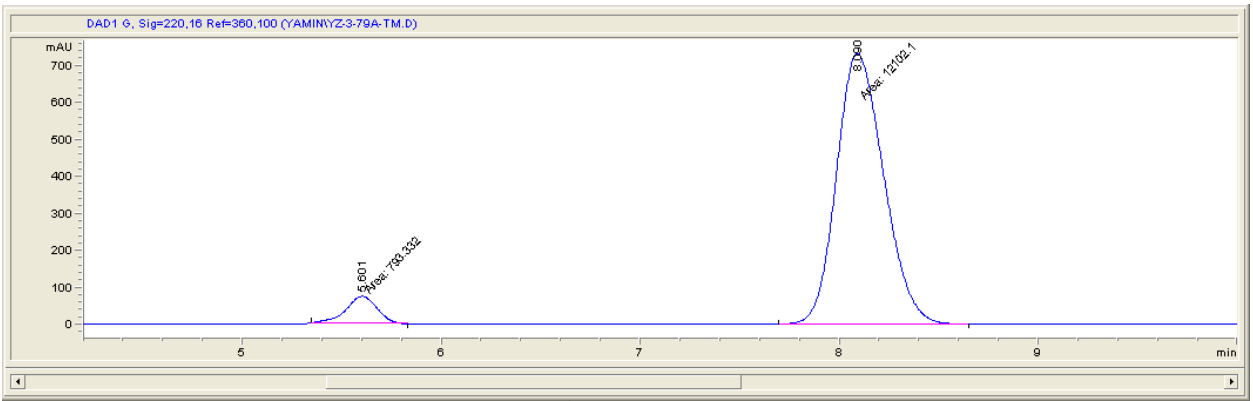


File Information	
LC-File	YZ-3-47D-TM.D
File Path	C:\CHEM32\1\DATA\YAMIN\

#	Time	Area	Height	Width	Area%	Symmetry
1	5.631	1604.8	143.3	0.1737	50.912	1.003
2	8.192	1547.4	95.4	0.2502	49.088	0.929

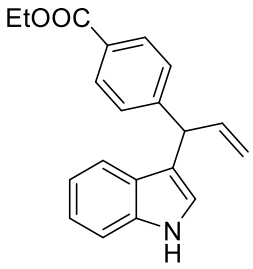


3ag

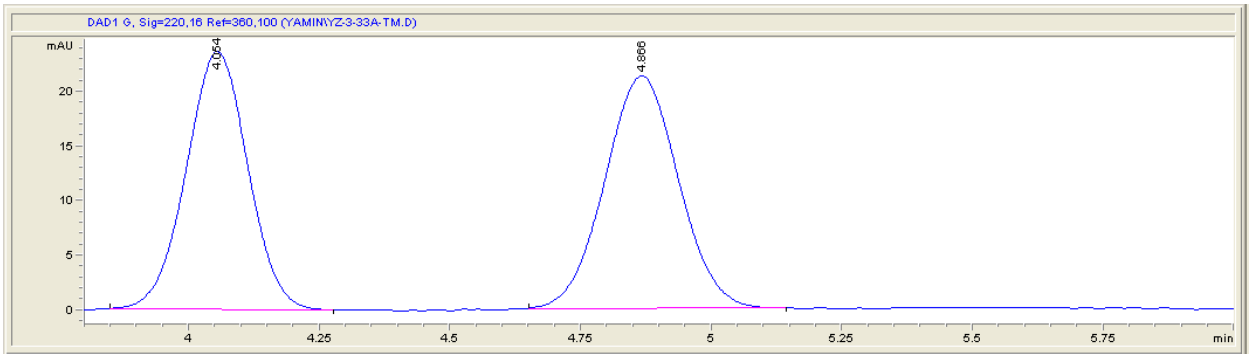


File Information	
LC-File	YZ-3-79A-TM.D
File Path	C:\CHEM32\1\DATA\YAMIN\

#	Time	Area	Height	Width	Area%	Symmetry
1	5.601	793.3	73.1	0.1809	6.152	1.092
2	8.09	12102.1	732.5	0.2754	93.848	0.778

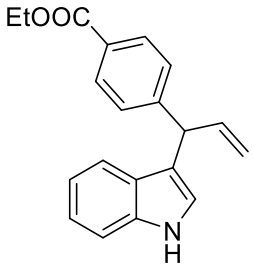


***rac*-3ah**

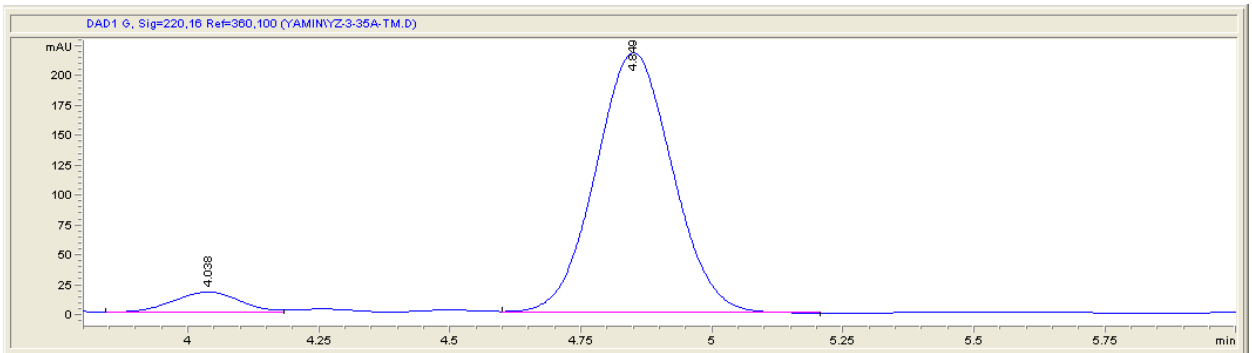


File Information	
LC-File	YZ-3-33A-TM.D
File Path	C:\CHEM32\1\DATA\YAMIN\
Date	22-Aug-16, 20:13:27

#	Time	Area	Height	Width	Area%	Symmetry
1	0.396	9.7	6.5	0.0236	2.344	0.869
2	4.054	194.1	23.6	0.1278	46.758	0.979
3	4.866	211.2	21.3	0.1535	50.898	0.971

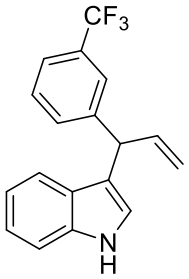


3ah

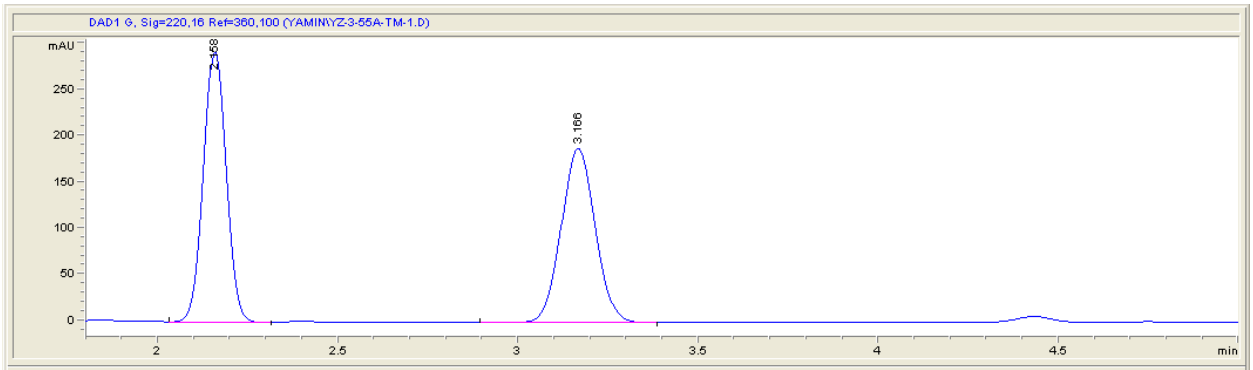


File Information	
LC-File	YZ-3-35A-TM.D
File Path	C:\CHEM32\1\DATA\YAMIN\

#	Time	Area	Height	Width	Area%	Symmetry
1	4.038	157.2	17.3	0.1412	6.606	1.049
2	4.849	2221.6	217.6	0.1591	93.394	0.94

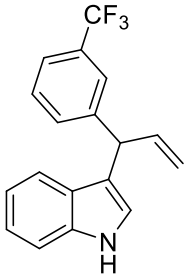


***rac*-3ai**

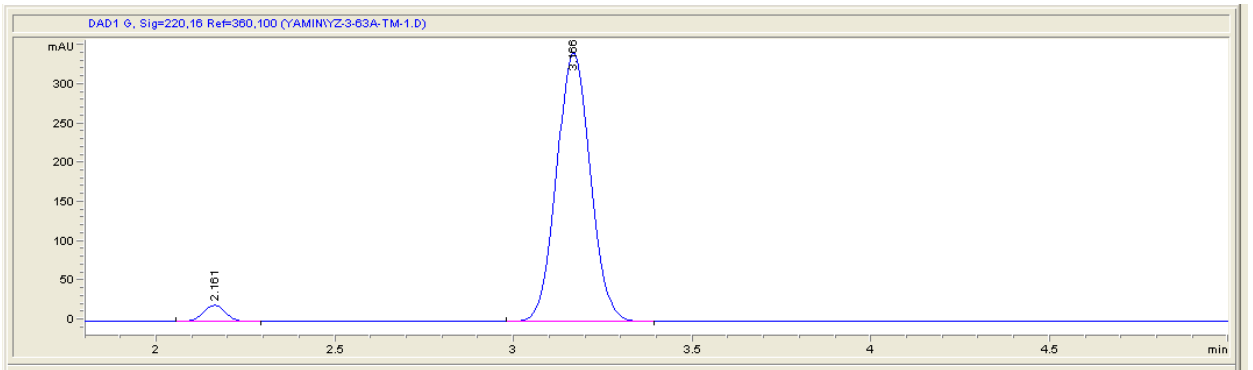


File Information	
LC-File	YZ-3-55A-TM-1.D
File Path	C:\CHEM32\1\DATA\YAMIN\

#	Time	Area	Height	Width	Area%	Symmetry
1	2.158	1289.2	293.3	0.0683	50.890	0.956
2	3.166	1244.1	188.6	0.1029	49.110	0.95

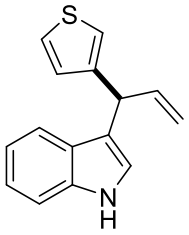


3ai

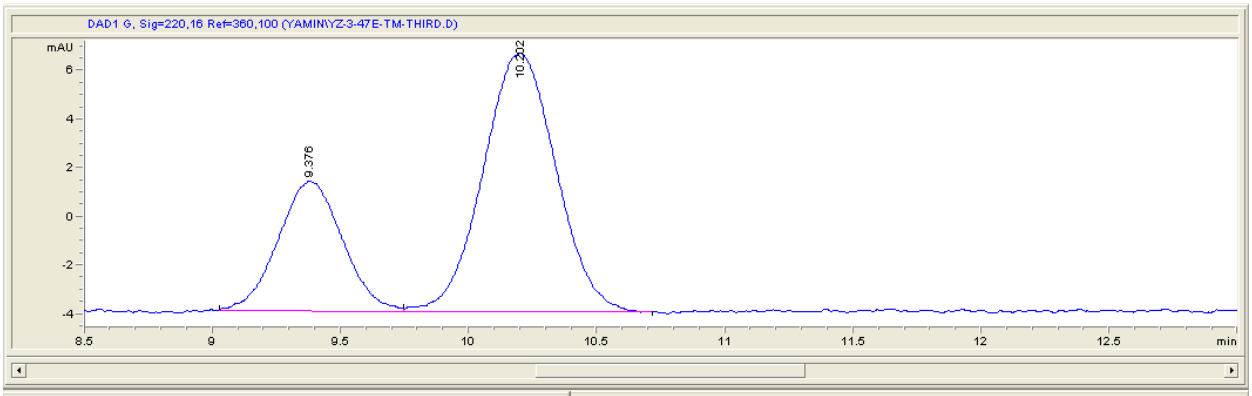


File Information	
LC-File	YZ-3-63A-TM-1.D
File Path	C:\CHEM32\1\DATA\YAMIN\

#	Time	Area	Height	Width	Area%	Symmetry
1	2.161	89.5	20.7	0.0665	3.810	0.989
2	3.166	2260.1	342.5	0.102	96.190	0.931

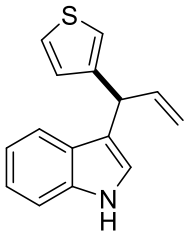


3aj

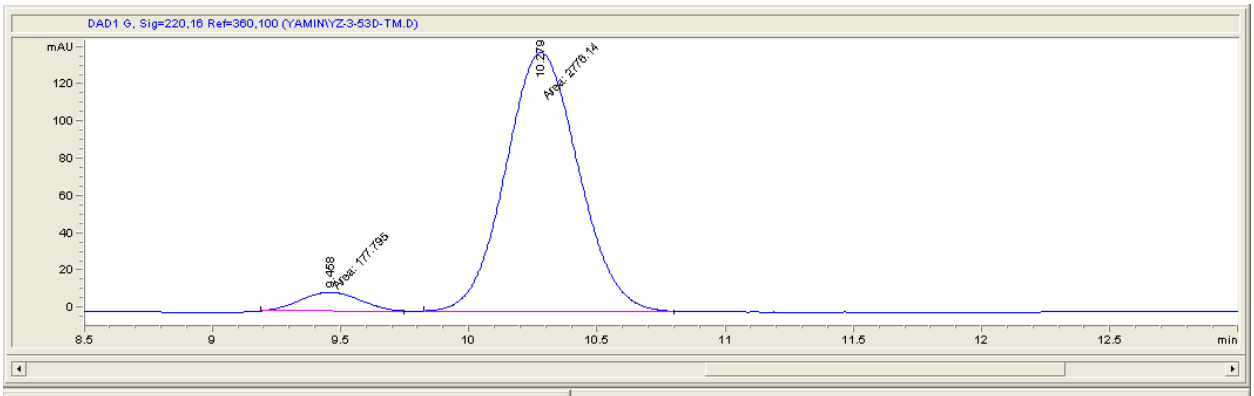


File Information	
LC-File	YZ-3-47E-TM-THIRD.D
File Path	C:\CHEM32\1\DATA\YAMIN\

#	Time	Area	Height	Width	Area%	Symmetry
1	9.376	94.1	5.4	0.2111	30.900	0.905
2	10.202	210.5	10.6	0.2599	69.100	1.016

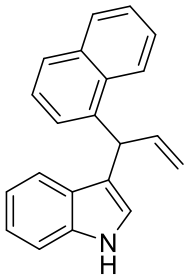


3aj

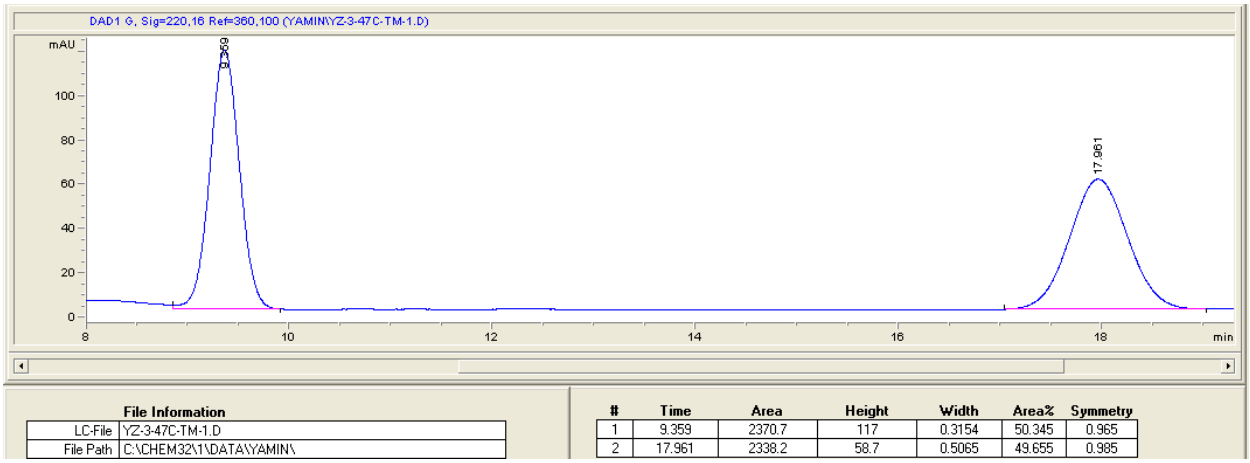


File Information	
LC-File	YZ-3-53D-TM.D
File Path	C:\CHEM32\1\DATA\YAMIN\

#	Time	Area	Height	Width	Area%	Symmetry
1	9.458	177.8	10.4	0.2836	6.019	0.906
2	10.279	2776.1	139.4	0.3318	93.981	0.915

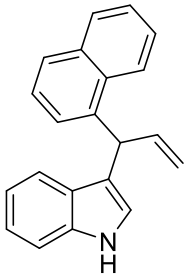


***rac*-3ak**

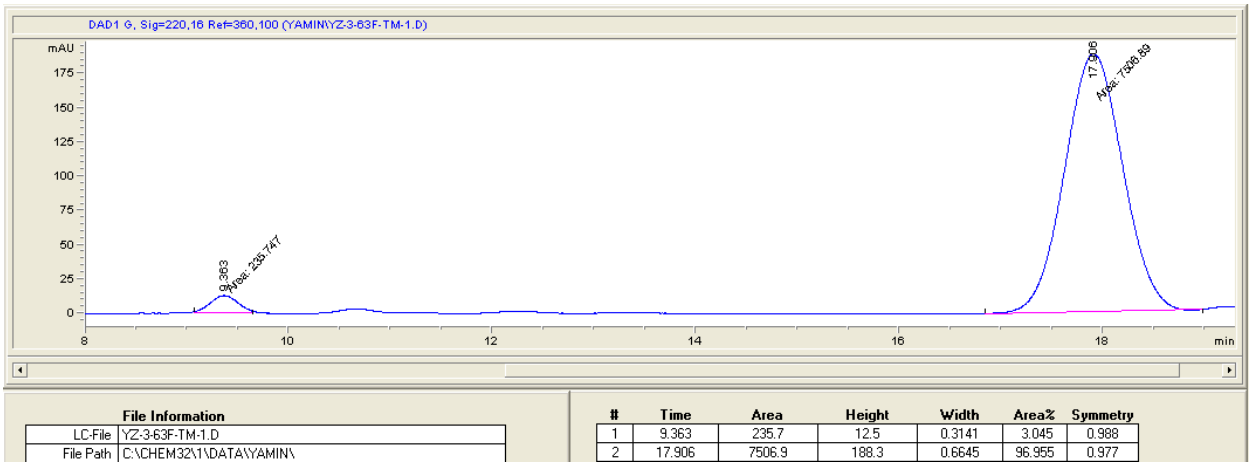


File Information	
LC-File	YZ-3-47C-TM-1.D
File Path	C:\CHEM32\1\DATA\YAMIN\

#	Time	Area	Height	Width	Area%	Symmetry
1	9.359	2370.7	117	0.3154	50.345	0.965
2	17.961	2338.2	58.7	0.5065	49.655	0.985



3ak



File Information	
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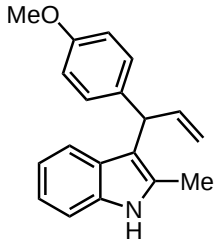
File Path	C:\CHEM32\1\DATA\YAMIN\

#	Time	Area	Height	Width	Area%	Symmetry
1	9.363	235.7	12.5	0.3141	3.045	0.988
2	17.906	7506.9	188.3	0.6645	96.955	0.977



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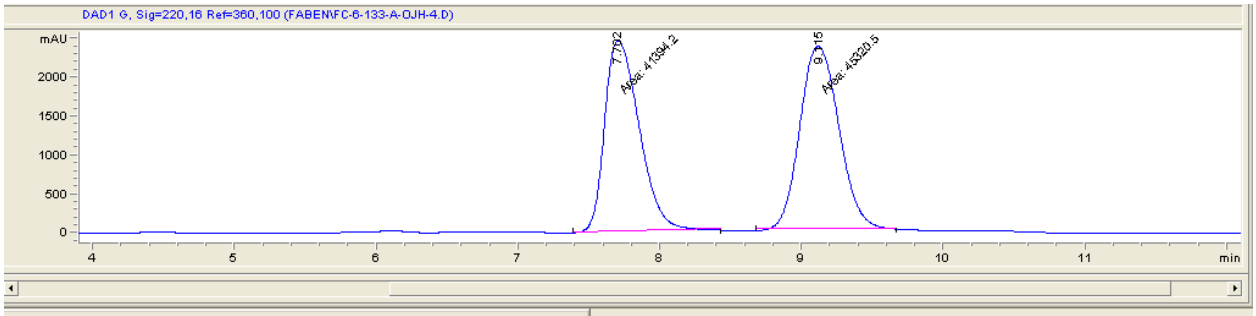
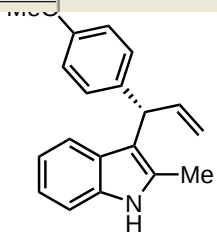
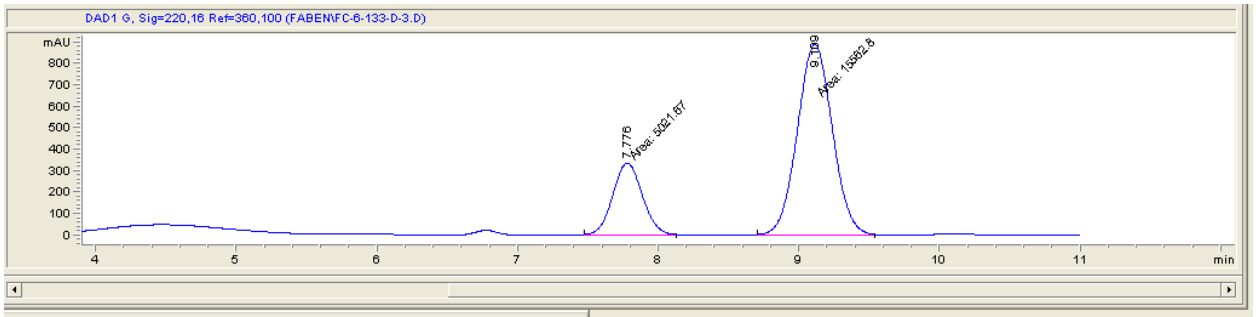


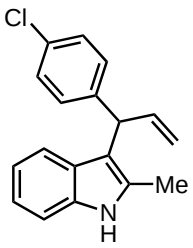
#	Time	Area	Height	Width	Area%	Symmetry
1	7.702	41394.2	2444.6	0.2822	47.736	0.606
2	9.115	45320.5	2356.7	0.3205	52.264	0.851



3cc



#	Time	Area	Height	Width	Area%	Symmetry
1	7.776	5021.7	338.4	0.2473	24.395	0.919
2	9.109	15562.8	891.6	0.2909	75.605	0.952



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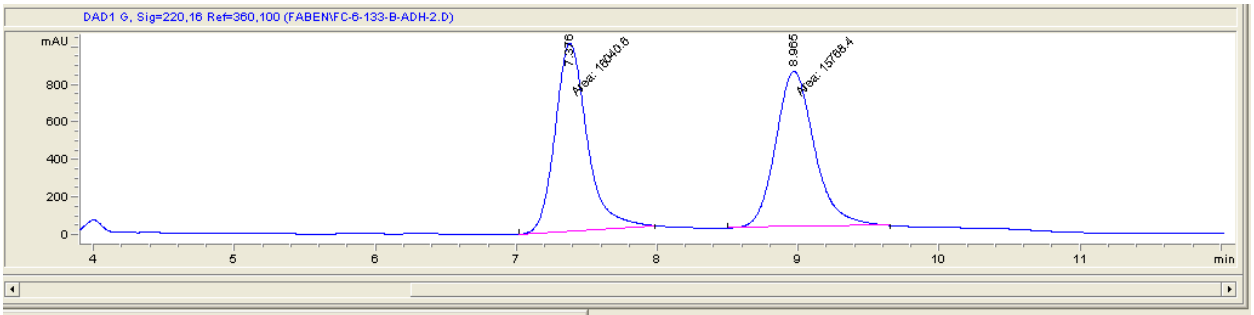
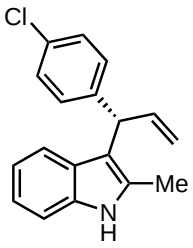
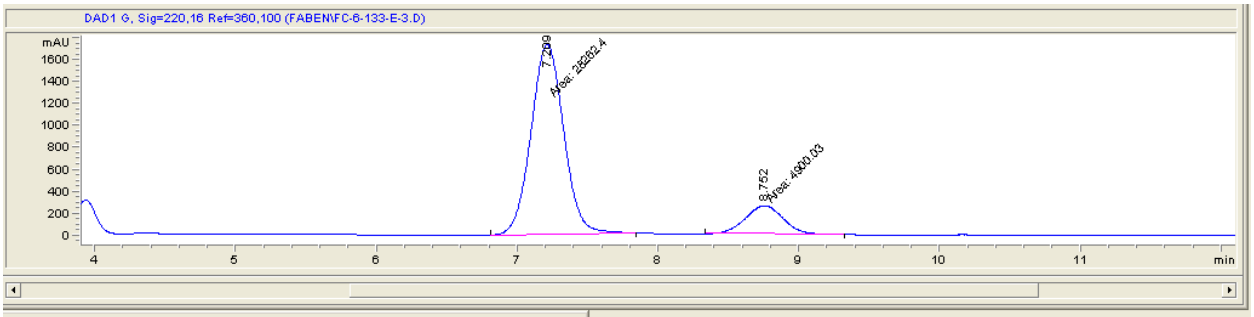


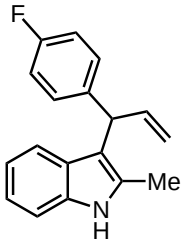
#	Time	Area	Height	Width	Area%	Symmetry
1	7.376	16040.6	1006	0.2658	50.428	0.829
2	8.965	15768.4	827.5	0.3176	49.572	0.849



3cg



#	Time	Area	Height	Width	Area%	Symmetry
1	7.209	28262.4	1737.9	0.271	85.224	0.94
2	8.752	4900	259.9	0.3142	14.776	1.014



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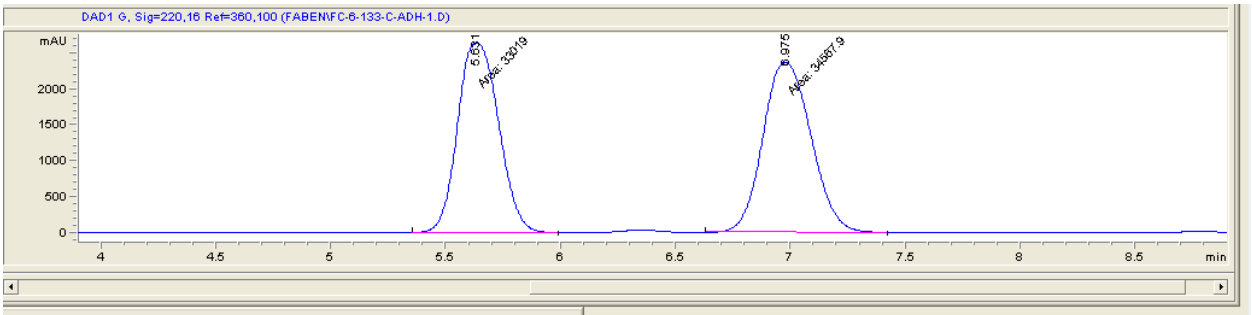
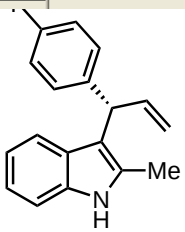
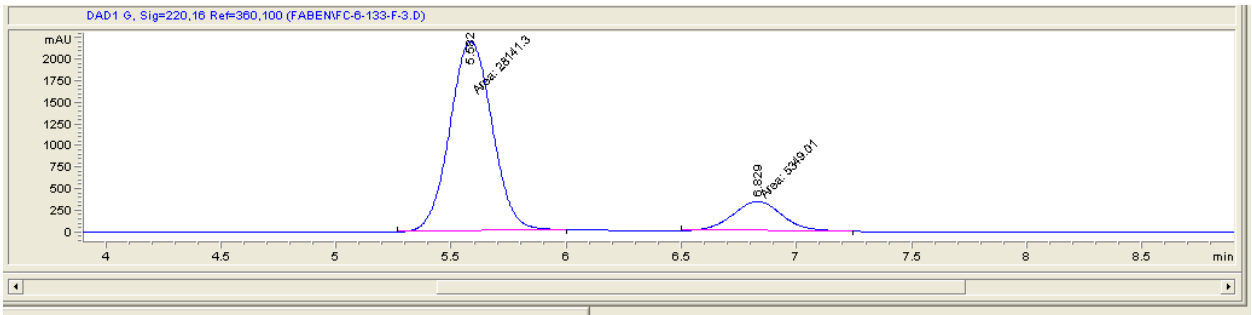


#	Time	Area	Height	Width	Area%	Symmetry
1	5.631	33019	2646.5	0.2079	48.854	0.811
2	6.975	34567.9	2369	0.2432	51.146	0.832



3cf



#	Time	Area	Height	Width	Area%	Symmetry
1	5.582	28141.3	2196.9	0.2135	84.028	0.924
2	6.829	5349	347.4	0.2566	15.972	0.962