DIETHYL ZINC MEDIATED METALLOAMINATION: DEVELOPMENT AND ITS APPLICATION TO THE SYNTHESIS OF FUNCTIONALIZED PYRROLIDINES AND PIPERIDINES

by

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Dedicated to Norman and Gregory Sunsdahl

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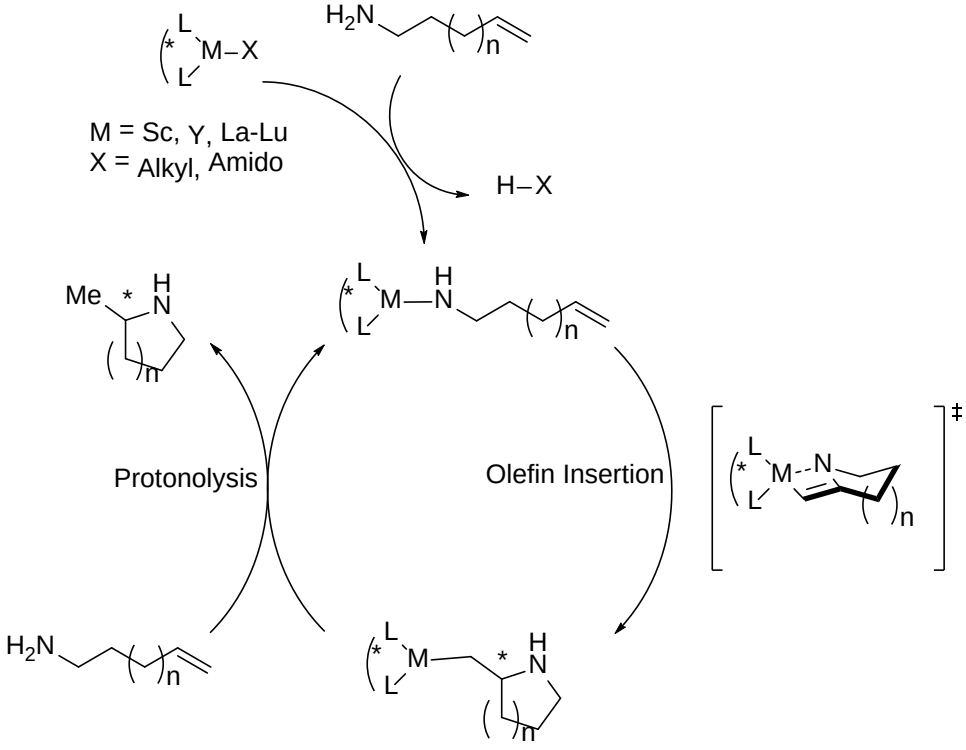
ABSTRACT

The ability to synthesize nitrogen heterocycles of industrial and academic significance remains a central goal of organic synthesis. Substantial effort has been made to develop new methodologies that allow the construction of these targets in an atom economical and efficient manner. Herein, we describe the development of a metalloamination transformation mediated by diethyl zinc. The resulting organozinc intermediates undergo facile electrophilic addition, resulting in a one-pot reaction sequence to access functionalized pyrrolidines and piperidines. Optimization of the reaction conditions for the initial metalloamination/cyclization, as well as the addition of electrophiles was examined. The scope of the metalloamination, including functional group tolerance was evaluated by synthesizing a number of mono- and disubstituted hydrazinoalkenes. This new methodology provides the synthetic community with a variety of new tools for accessing academic and industrial molecules of interest.

INTRODUCTION

The prevalence of nitrogen containing natural products and bioactive molecules has garnered significant research endeavors in academic and industrial laboratories. The catalytic hydroamination of aminoalkenes constitutes a synthetic route to these molecules that proceeds with efficiency and exceptional atom economy.[1] In recent years the Livinghouse group has been focused on this process utilizing non-metallocene catalysts of group III metals and the lanthanides.[1b-k] These systems are highly robust and versatile, however a major disadvantage with hydroamination, in general, is the delivery of a simple hydrogen atom to the carbon-carbon unsaturation **(Figure 1)**.

Figure 1. Catalytic cycle of hydroamination by group III metals.



Interception of the metal-alkyl intermediate in a tandem C-N/C-C bond forming process would significantly improve the synthetic utility in hydroamination or similar reactions. There have been reports from several laboratories of metalloaminations that lead to these tandem transformations. These include the stoichiometric use of Ti(IV)[3s-t] and Zn(II)[3u-w] intermediates (**Figure 2**), as well as catalytic use of Pd(II)[3a-p], Cu(II)[3q] and Au(I)[3r] (**Figure 3**). These processes have generally been limited in the range of electrophiles that can be successfully utilized. This is primarily due to the instability of the generated intermediates towards β-hydride elimination. Additionally many of the transformations involving Ti and Zn rely on a highly exothermic addition to an alkyne[4].

Figure 2. Stoichiometric Ti and Zn C/N-C/C reactions.

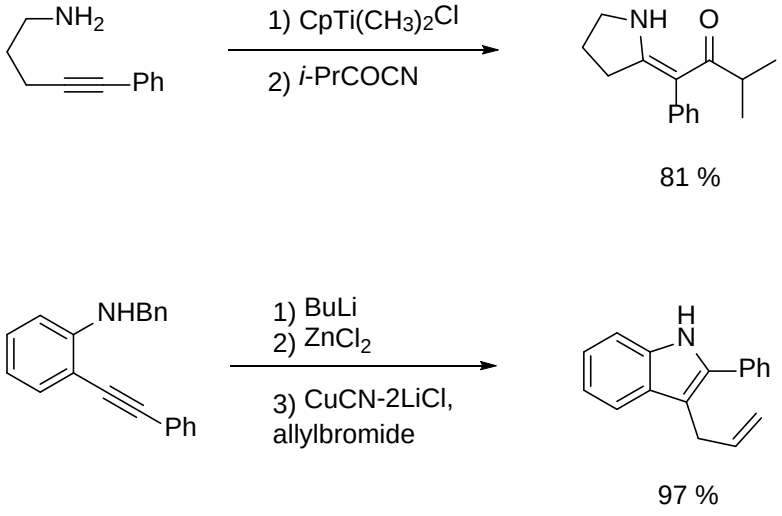
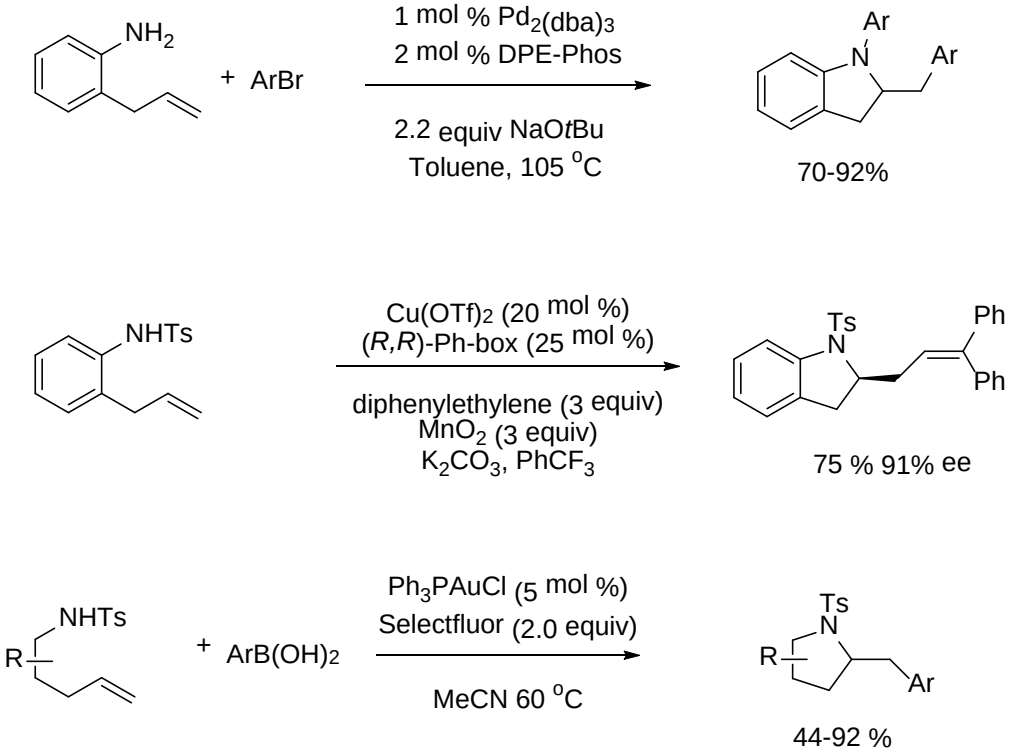
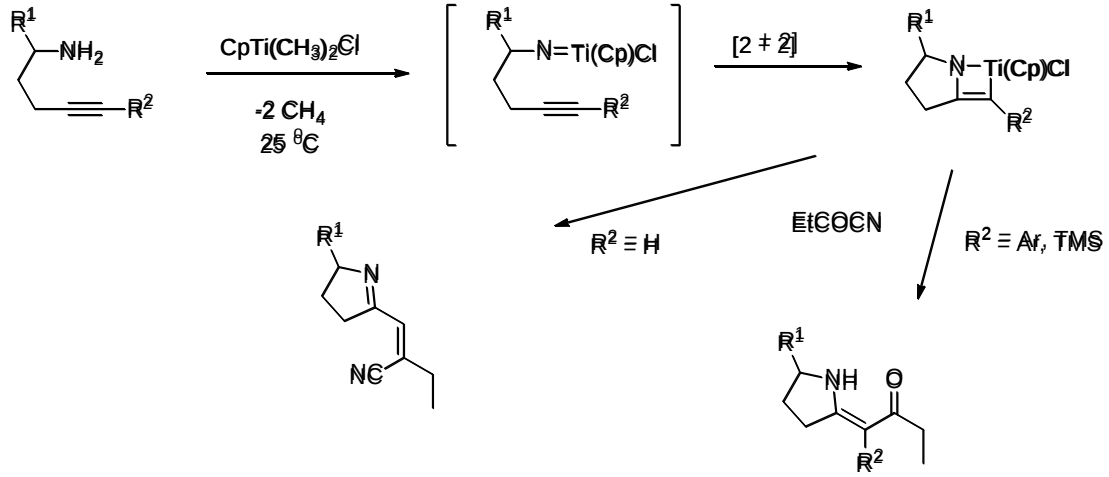


Figure 3. Representative catalytic hydroamination/oxidative functionalization of aminoalkenes.



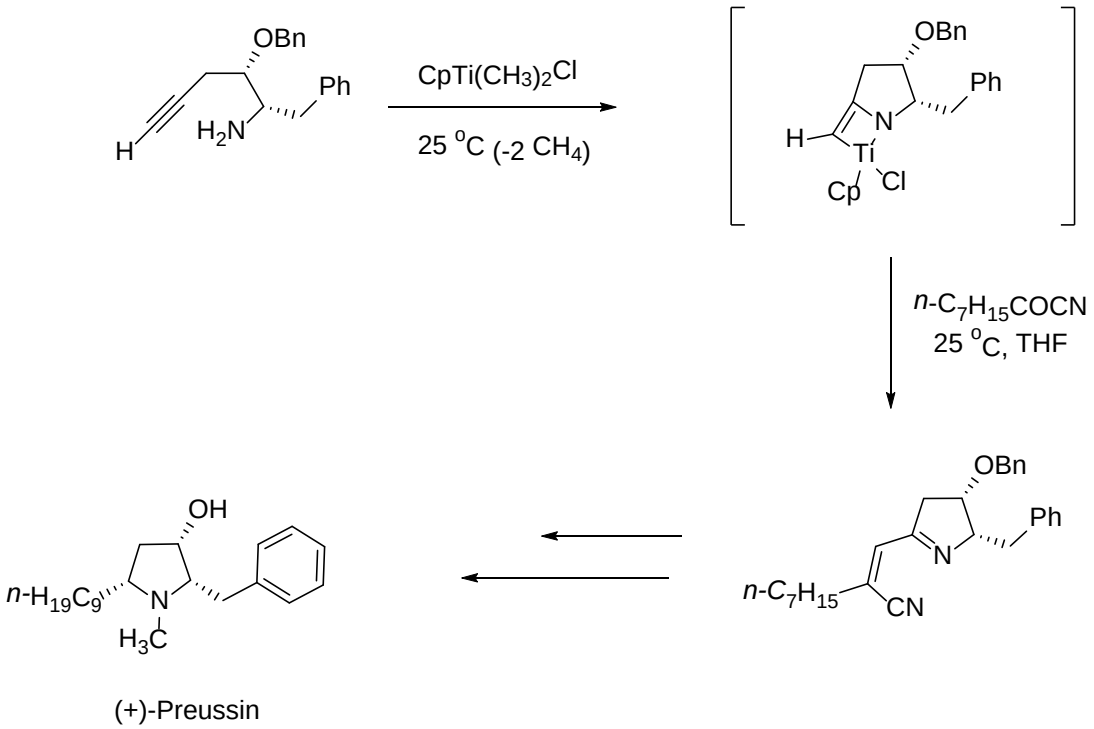
The development of metalloamination reactions by the Livinghouse group[3s] began with the titanocene complexes (**Figure 4**). Aminoalkynes, when treated with $CpTi(CH_3)_2Cl$ (prepared *in situ* from $CpTiCl_3$ and 2 equiv. of CH_3Li), undergo a formal [2 + 2] cycloaddition[3s] to give rise to azametalletines that can serve as conventional organometallics for electrophilic substitution. Thus, when the azametalletines are treated with acyl cyanides they give rise to vinylogous amides in excellent yields. Interestingly, when terminal alkynes are utilized, elimination of the oxotitanium intermediate results in α,β-unsaturated nitriles.

Figure 4. Intramolecular metalloaminations mediated by titanocene complexes.



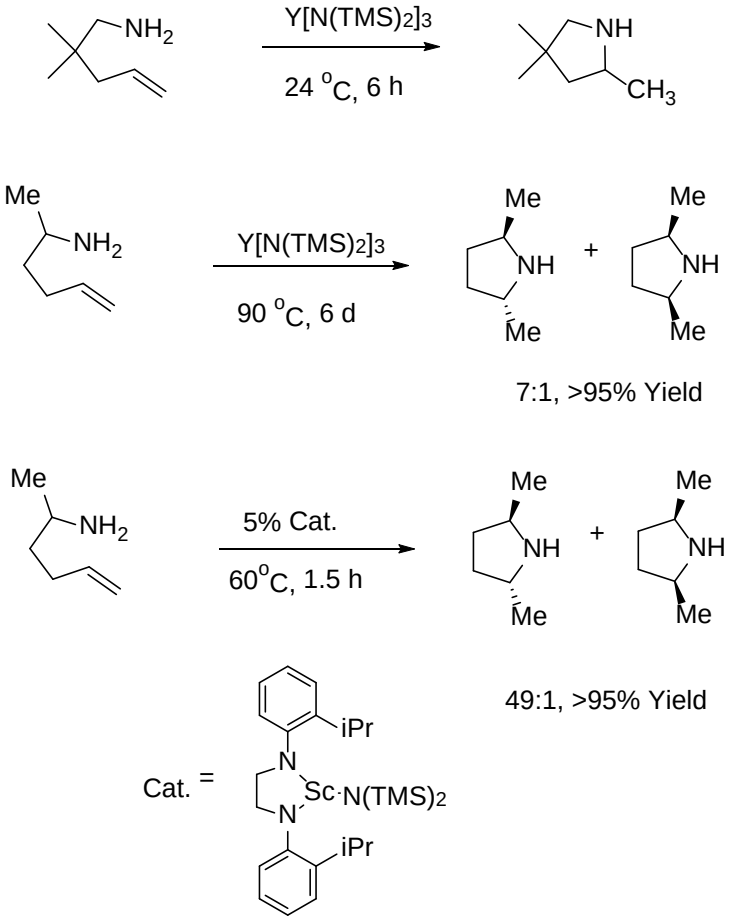
This synthetic methodology has been applied to the synthesis of natural products, and was highlighted in the synthesis of (+)-preussin[3t] (**Figure 5**). The chiral aminoalkyne, derived from phenylalanine, when treated with $CpTi(CH_3)_2Cl$ followed by trapping with octanoyl cyanide gave the substituted dihydropyrolle in excellent (81%) yield. Subsequent reduction and deprotection completed the synthesis of (+)-preussin. This concise and straightforward approach is an exceptional example of how metalloamination methodology can be applied to the synthesis of complex synthetic targets. While the use of titanocene complexes to mediate the metalloamination of aminoalkynes provided new synthetic methods for accessing pyrrolidines and piperidines, the reaction was unable to be extended to aminoalkenes.

Figure 5. Synthesis of (+)-preussin via titanium metalloamination.



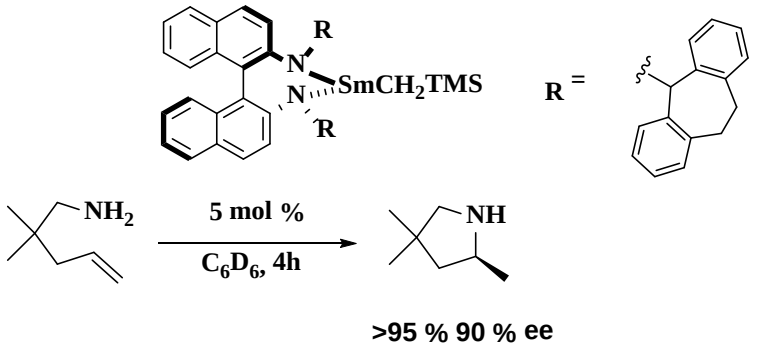
In recent years the Livinghouse group has focused on catalytic hydroaminations, primarily involving complexes of the group III metals and the lanthanides.[1b-k] The development of simple tris(amide) complexes as well as diamine ligands provided catalysts with exceptional activity and selectivity in the cyclization of aminoalkenes. (**Figure 6**).

Figure 6. Hydroamination of aminoalkenes catalyzed by group III complexes.



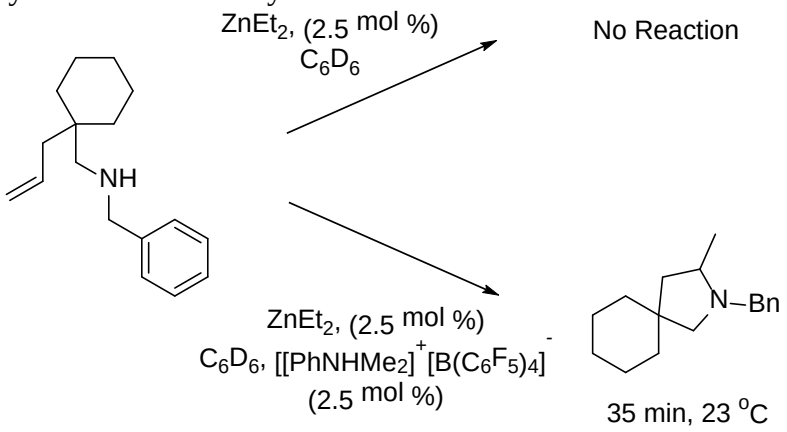
This work has also been expanded to enantioselective catalysis by replacement of the achiral scaffolding with a chiral diamine[1k]. Tuning of the steric environment around the metal center allows for excellent enantioselectivity while maintaining good catalyst turnover (**Figure 7**).

Figure 7. Enantioselective hydroamination of aminoalkenes catalyzed by a samarium *N*,*N*'-dibenzosuberyl-1,1'-binaphthyl-2,2'-diamine.



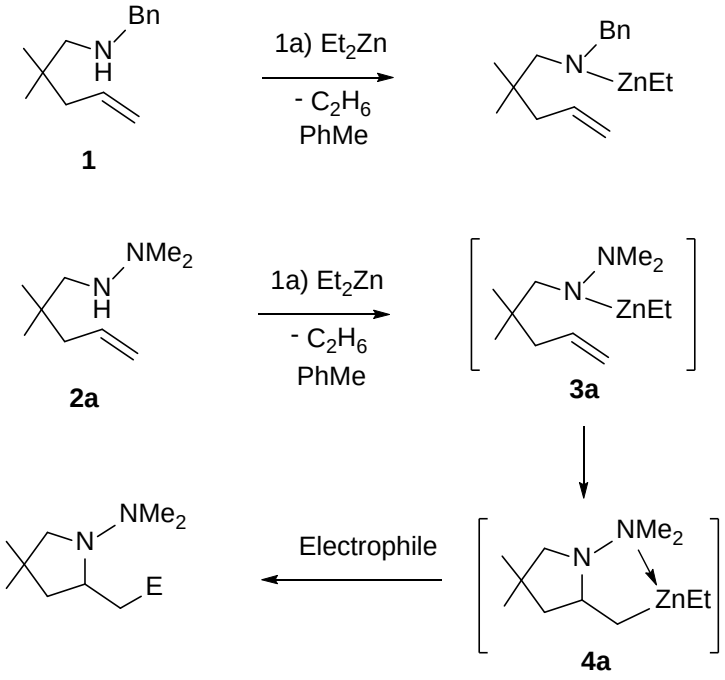
Recently several cationic Zn(II) catalysts have shown excellent activity in hydroamination processes[2]. It is of note that many neutral Zn(II) catalysts are extremely sluggish or simply fail to proceed, even at elevated temperatures, due to the inability of the protonation event to occur under these conditions[2] (**Figure 8**). The generation of a stabilized organozinc intermediate that could be functionalized by a range of electrophiles would result in a tandem C-N/C-C bond forming process leading to a greater degree of molecular complexity than found in conventional hydroamination reactions. The wide array of reliable reactions available to sp^3 hybridized Zn-C bonds makes this type of transformation an attractive target for metalloamination/cyclization[5].

Figure 8. Catalytic zinc mediated hydroamination.



Initial studies in our labs began by examining the prospective cyclization of aminoalkene **1** in the presence of $ZnEt_2$ (PhMe, 110 ^oC, **Figure 9**). Formation of the zinc amide proceeded as expecgted, however no cyclization occurred and prolonged heating resulted in the deposition of metallic zinc[6]. Due to the known instability of zinc amides[6], attention was focused towards hydrazine **2a**. Substrates of this type could benefit from a stabilized internally coordinated organozinc intermediate that would undergo more facile cyclization. Heating of hydrazine **2a** in the presence of $ZnEt_2$ (PhMe, 90 ^oC, 18 h) resulted in complete cyclization (>95%, ^1H NMR) of the starting material. The cyclization appears to be particularly facile as no evidence of the zinc amide **3a** was present during NMR studies. With the organozinc intermediate **4a** in hand, a variety of electrophiles could be examined, as well as additional substrates to explore the scope of the metalloamination/cyclization reaction.

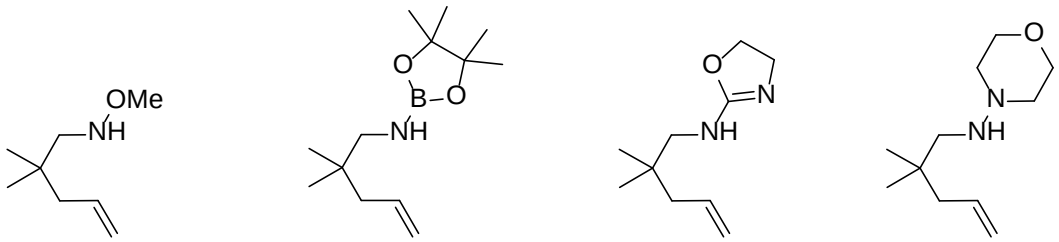
Figure 9. Initial metalloamination screening.



RESULTS AND DISCUSSION

The successful metalloamination of 2-(2,2-dimethylpent-4-en-1-yl)-1,1-dimethylhydrazine **2a** prompted a study to determine if other *N*-heteroaminoalkene substrates could serve as potential substrates for cyclization. Alkoxyamines, aminoboranes and aminooxazolines, as well as morpholinohydrazines could act as internally coordinating species that would stabalize the initially formed zinc amide (**Figure 10**).

Figure 10. Target substrates for metalloamination.



5a **6** **7** **8**

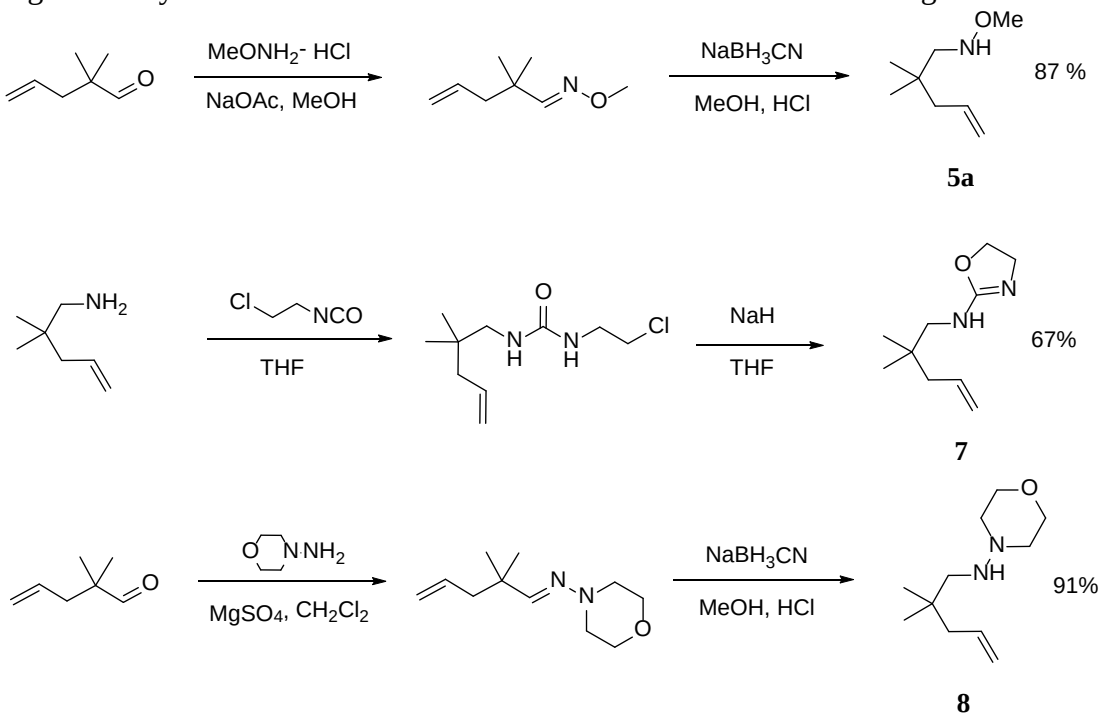
N-Heteroaminoalkene Metalloamination Rate and Selectivity

Synthesis of Substrates

Synthesis of the methoxyamine substrate consisted of a simple condensation of 2,2-dimethylpent-4-enal with methoxyamine hydrochloride in the presence of sodium acetate. The resulting oxime was reduced with $NaBH_3CN$ to give methoxyaminoalkene **5a** in 87% yield over 2 steps. In a analogous manner, condensation of 4-aminomorpholine with 2,2-dimethylpent-4-enal, followed by reduction with $NaBH_3CN$ gave aminomorpholine **8** in excellent yield (91%). Treatment of 2,2-dimethylpent-4-en-1-

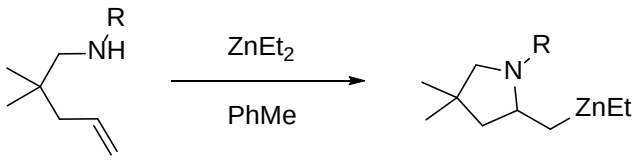
amine with 2-chloroethylisocyanate, followed by addition of the resulting urea to a slurry of NaH in THF gave rise to the aminooxazoline in moderate yield (64 %) after purification. The aminopinnacolborane was generated *in situ* by addition of 1 equiv. of pinnacolborane to a solution of 2,2-dimethylpent-4-en-1-amine in C_6D_6. Outlines of these syntheses are given in **Figure 11**.

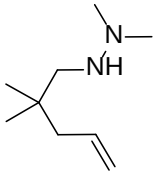
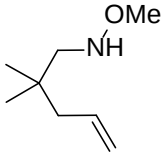
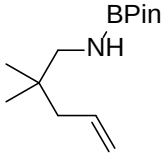
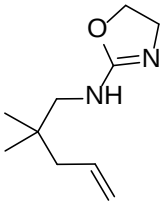
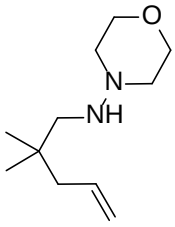
Figure 11. Synthesis outline of substrates for metalloamination screening.



With the requisite substrates in hand, they were subjected to the reaction conditions which had been successful for hydrazinoalkene **2a**. The results of these experiments are outlined in **Table 1**.

Table 1. Metalloamination of *N*-substituted aminoalkenes.



Substrate	Temp	Time[a]	% Conv[b]
 **2a**	90 °C	18h	>95
 **5a**	90 °C	36 h	80
 **6**	23 - 90 °C	3 d	NR – decomp.
 **7**	90 - 120 °C	3d	NR
 **8**	90 °C	2d	90

[a] Reactions conducted on a 0.1 mmol scale in sealed J. Young NMR tube. [b] Determined by ^{1}H NMR, *p*-xylene internal standard.

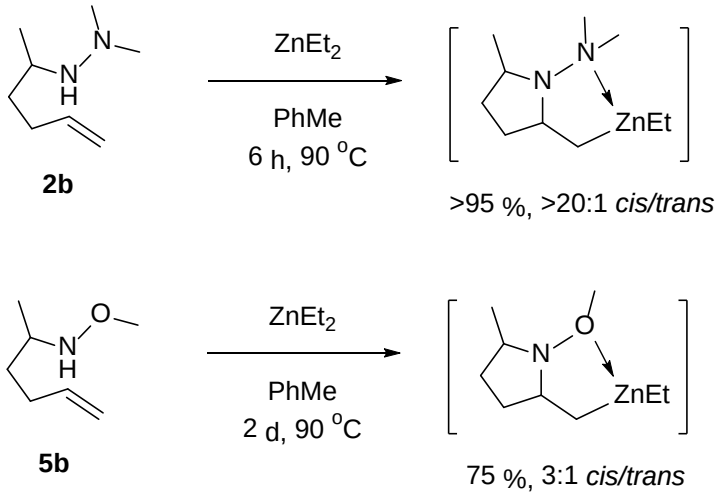
When *N*-(2,2-dimethylpent-4-en-1-yl)-*O*-methylhydroxylamine **5a** was treated with $ZnEt_2$ in toluene at 90 °C for 36 h, cyclization occurred to 80 % (^{1}H NMR, *p*-xylene internal standard). Further heating resulted in no additional ring closure, while prolonged heating producing black precipitate and decomposition of the starting material.

Aminoborane **6** failed to cyclize at room temperature despite quantitative formation of the corresponding zinc amide. Heating of the reaction mixture resulted in immediate discoloration and decomposition. Oxazoline substrate **7** also failed to cyclize, even at elevated temperatures, despite quantitative formation of the zinc amide. The morpholinohydrazine **8** cyclized cleanly at 90 ^{o}C, though the reaction was considerably more sluggish than the corresponding *N*,*N*-dimethylhydrazinoalkene, taking a full 2 d to reach 90% completion. This is presumably due to the increased steric congestion around the small zinc center as well as potential inhibitory effects of an internally coordinated oxygen atom.

Selectivity of Hydrazinoalkenes and Methoxyaminoalkenes

With hydrazinoalkene **2a** and methoxyaminoalkene **5a** displaying the most promising potential for further extrapolation of metalloamination methodology, we sought to examine the stereoslectivity of the aforementioned substrates. To this end, 2-(hex-5-en-2-yl)-1,1-dimethylhydrazine **2b** and *N*-(hex-5-en-2-yl)-*O*-methylhydroxylamine **5b** were synthesized by condensing 5-hexene-2-one with *N*,*N*-dimethylhydrazine and methoxyamine hydrochloride, respectively, followed by reduction. They were then evaluated for diastereoselectivity by treatment with $ZnEt_2$ in toluene at 90 ^{o}C (**Figure 12**).

Figure 12. Diastereoselectivity screening of metalloamination substrates.



Hydrazinoalkene **2b** cyclized cleanly to >95% (^{1}H NMR) conversion at 90 ^{o}C in just 6 h, additionally it exhibited extraordinary diastereoselectivity, resulting in a 20:1 *cis*/*trans* ratio. Conversely, the methoxyaminoalkene **5b** took 2 full days at 90 ^{o}C to reach 75% (^{1}H NMR) completion, with a *cis*/*trans* ratio of 3:1. The exceptional diastereoselectivity was also remarkable due to the preference of the *trans* pyrrolidine to form when subjected to typical group 3 catalyzed hydroamination reaction *vide supra*[1k].

This reversal of selectivity is most likely due to the presence of the dimethyl amino "cap" coordinated to the zinc center prior to cyclization. This internal coordination coupled with the small ionic radius of zinc, results in exceedingly high diastereoselectivity with stereocenters adjacent to the developing metalloamination event. This was evidenced by subjecting the hydrazinoalkene **2b** to standard group III hydroamination conditions (5 mol % $Y[N(TMS)_2]_3$, C_6D_6, 60 ^{o}C). The hydroamination resulted in a >95% conversion and a 5:1 *cis*/*trans* ratio. Based on these results,

hydrazinoalkenes were chosen to as the initial substrate class for metalloamination optimization.

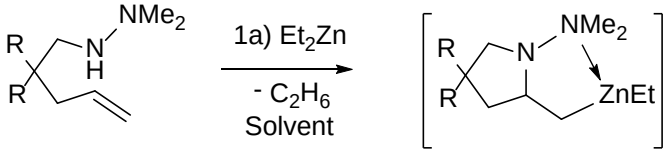
Solvent and Additive Effects on Metalloamination

With a substrate class selected, we sought to examine the effects of solvents and additional additives (i.e. alkoxides) on the rate and efficiency of the metalloamination reaction. If modification of the reaction conditions could facilitate a more rapid formation of the zinc amide, it may be possible to accelerate the rate of reaction and lower the temperature required for cyclization to occur.

Solvent Effects

A number of solvents were screened as alternatives to toluene for the metalloamination reaction. Diisopropyl ether and (trifluoromethyl)benzene proceeded efficiently, however the more strongly coordinating solvent THF, significantly supressed the reaction. The use of benzene, while sufficient for cyclizations that do not require elevated temperatures, significantly reduced the rates of reaction for those transformations which required temperatures of 90 ^{o}C (**Table 2**).

Table 2. Solvent effect on cyclization.



2a R = Me
2c R= H

4a R = Me
4c R= H

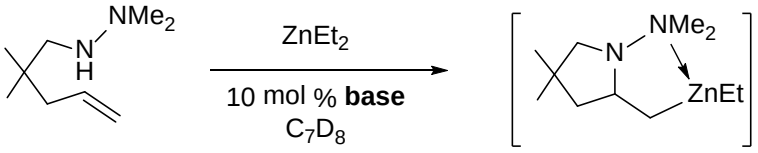
Substrate	Solvent	Oil Bath Temp ^{o}C	Time (yield)
2a	PhMe	90	18 h (>95 %)
2c	PhMe	60	9 h (90 %)
2c	PhMe	90	4 h (90 %)
2a	$PhCF_3$	90	18 h (>95 %)
2c	$PhCF_3$	90	4 h (90 %)
2a	*i*-Pr_2O	90	24 h (>95 %)
2c	*i*-Pr_2O	90	6 h (90 %)
2a	THF	60	14 d (25 %
2c	THF	60	2 d (75 %)
2a	PhH	90	6 d (80 %)
2c	PhH	90	8 h (90 %)

Base Catalysis of Metalloamination Reaction

In an effort to lower the reaction temperature and increase the rate of cyclization, several bases were screened as additives to the reaction medium. Initially TMSMeLi was chosen to generate of a catalytic amount of the zincate species $[TMSCH_2ZnEt_2]^{-}Li^{+}$ *in situ*. Most gratifyingly when hydrazinoalkene **2a** was treated with $ZnEt_2$ in toluene with 20 mol % TMSMeLi, the reaction temperature was able to be lowered to 60 ^{o}C. However, required extended reaction times (4 d, 50 % conv) and minor amounts of the

corresponding hydroamination product were present in the reaction mixture. Based on this initial positive result a number of other bases were evaluated, the results are summarized in **Table 3**.

Table 3. Screening of base catalysis for metalloamination.



	Base	Temp (°C)	Time (h)	% Conv[a]
1.	--	60	96	<10
2.	--	90	18	>95
3.	TMSMeLi	60	96	50
4.	LiHMDS	60	96	25
5.	KHMDS	60	96	40
6.	TMEDA	90	96	n.r.[b]
7.	*t*-BuOLi	90	16	>95
8.	*t*-BuONa	45	72	>95
9.	*t*-BuONa	60	12	>95
10.	*t*-BuOK	45	8	>95
11.	*t*-BuOK	90	2	>95
12.	*i*-PrOK	45	10	>95
13.	*t*-BuOCs	60	96	<10
14.	*t*-BuOCu(I)	23	0	decomp.[c]
15.	Cu(I)TFA	23	0	decomp.[c]
16.	Cu(I)OPiv	23	0	decomp.[c]
17.	Cu(I)ThC	23	0	decomp.[c]

.

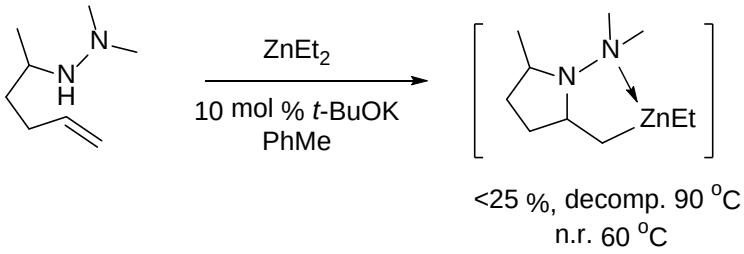
[a] Conversion determined by ^{1}H NMR, *p*-xylene internal standard. [b] TMEDA completely inhibits the metalloamination, preventing formation of the initial zinc amide. [c] Immediately upon addition of Cu(I) salts, the reaction mixture deposits a large amount of black precipitate.

The addition of lithium hexamethyldisilizane (LiHMDS, entry 4 **Table 3**) to the metalloamination reaction mixture resulted in slow conversion at lower reaction

temperatures, however it did display slight improvement when compared to control experiments (entry 1 **Table 3**). Interestingly, simply changing the counterion for the HMDS salt to potassium resulted in improved reaction rates at lower temperatures (entry 5 **Table 3**). This suggests that counter-ion can play an important role in the acceleration of the metalloamination/cyclization. Indeed, when *tert*-butoxide bases are utilized there is a marked trend of increased reaction rates moving from lithium to potassium (entries 7-11 **Table 3**). Lithium *tert*-butoxide (*t*-BuOLi) provided no increase in reaction rate at lower temperatures, however there was a slight increase, when compared to the uncatalyzed reaction at 90 ^{o}C. Utilizing *t*-BuONa produced a striking improvement in reaction rate and temperature, with cyclization occurring in 12 h at 60 ^{o}C and 72 h at 45 ^{o}C. The most significant improvement of both reaction rates and temperatures at which the metalloamination is conducted occurred with the use of *t*-BuOK, which facilitated cyclization at 45 ^{o}C in only 8 h. Significantly, the addition of *t*-BuOK to the reaction mixture did not affect stability and the reaction was tolerated at 90 ^{o}C, with cyclization occurring in 2 h (entry 11 **Table 3**). Altering of the alkyl portion of the alkoxide salt produced minimal changed in reactivity as evidenced by the use of *i*-PrOK, which cyclized at 45 ^{o}C in 10 h. Unfortunately, addition of *t*-BuOCs to the reaction resulted in no rate acceleration when compared to the control experiments (entry 13 **Table 3**). Several copper(I) salts were screened for activity, however immediately upon addition to the reaction mixture a large amount of precipitate formed, coinciding with decomposition of the starting material (^{1}H NMR, entries 14-17 **Table 3**).

While these studies provided proof of concept that additives to the metalloamination reaction could markedly improve reaction rates and temperature, attempts to extend the use of alkoxide catalysis to additional hydrazine substrates was unsuccessful with the more facile substrates. Addition of 10 mol % *t*-BuOK to hydrazinoalkene **2b** resulted in retardation of the cyclization as well as destabilizing the resulting organozinc intermediate (**Figure 13**).

Figure 13. Cyclization of 2-(hex-5-en-2-yl)-1,1-dimethylhydrazine with 10 mol % *t*-BuOK.



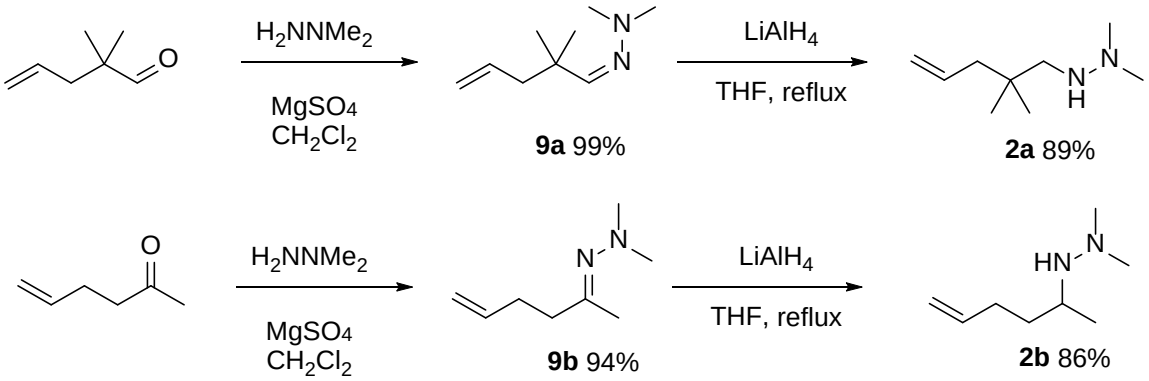
With the completion of initial studies on the effects of reaction conditions on the metalloamination of hydrazinoalkenes complete, we sought to explore the scope of the metalloamination reaction and subsequent functionalization. To this end, a number of mono-substituted hydrazinoakenes were synthesized.

Synthesis of Hydrazinoalkene Substrates

Synthesis of the requisite substrates needed for the scope of this study was simple and straightforward. Treatment of 2,2-dimethylpent-4-enal with *N*,*N*-dimethylhydrazine (CH_2Cl_2, $MgSO_4$, 23 ^oC) (**Figure 14**) resulted in quantitative formation of hydrazone **9a**. Reduction with $LiAlH_4$ (THF, reflux) for 24 h, followed by distillation gave rise to the

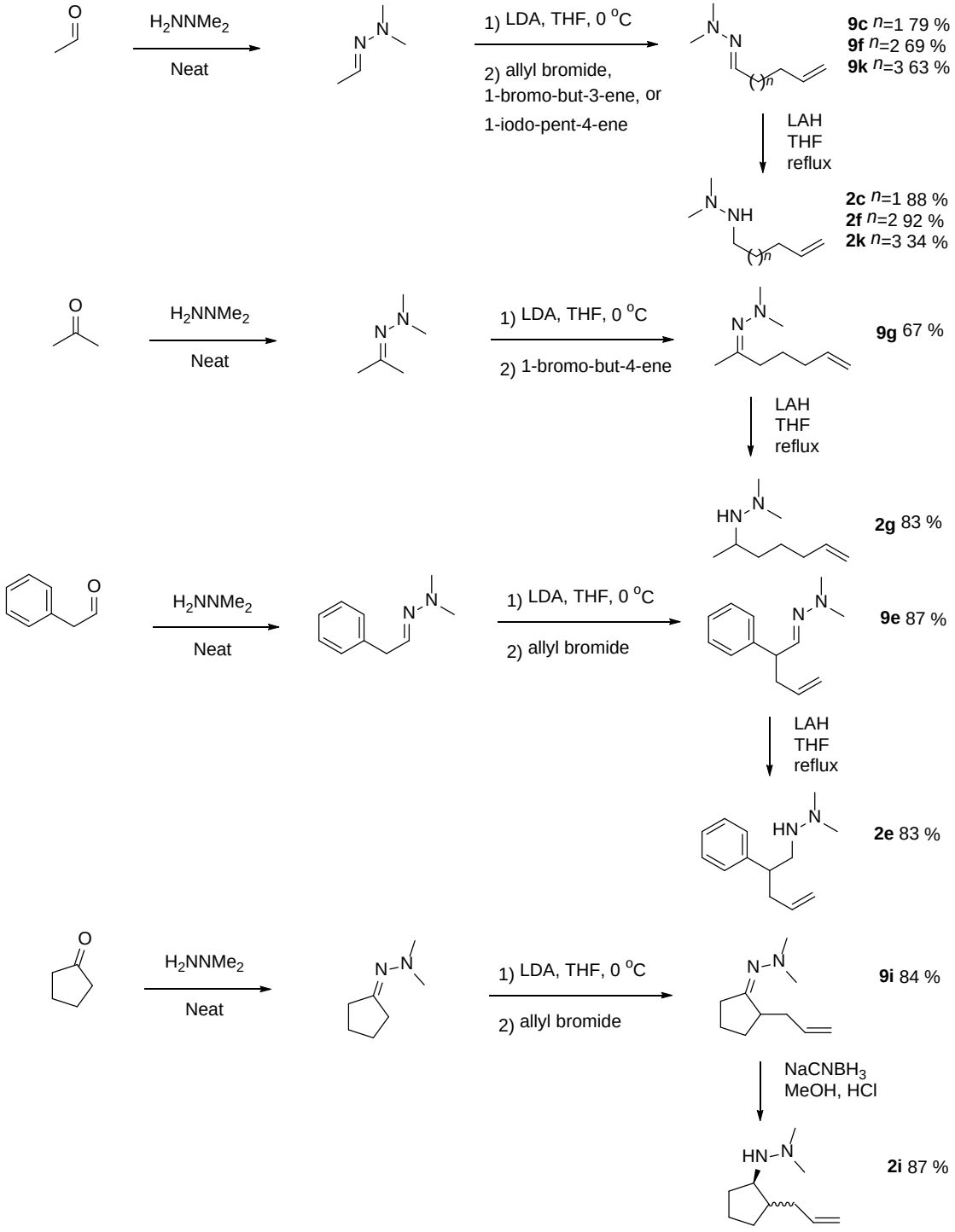
target hydrazine **2a** in 89% yield. Similarly, treatment of 5-hexen-2-one with *N*,*N*-dimethylhydrazine gave hydrazone **9b**, which after reduction with $LiAlH_4$ furnished hydrazine **2b (**86%).

Figure 14. Synthesis of hydrazinoalkenes.



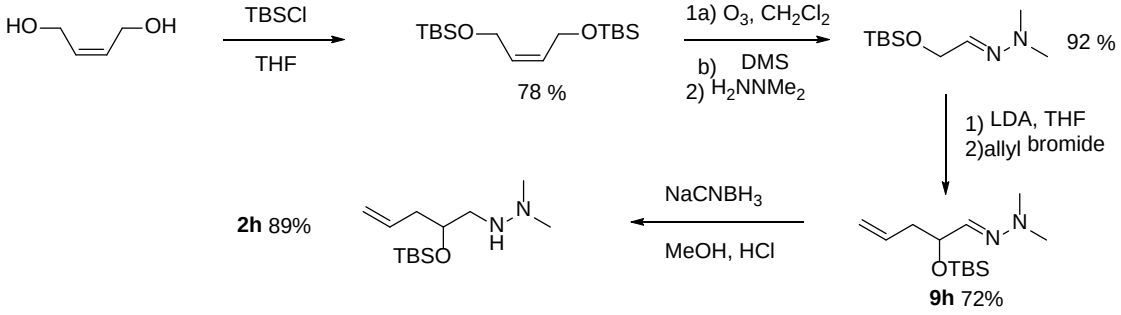
To explore the effect of substitution, as well as functional group tolerance, on the metalloamination process a number of additional substrates were synthesized by alkylation of the appropriate hydrazone using the procedure of Corey and Enders[7] (**Figure 15**). Stable hydrazones derived from acetaldehyde, acetone, phenylacetaldehyde and cyclopentanone were synthesized by direct treatement with *N*,*N*-dimethylhydrazine followed by distillation. Lithiation with LDA and subsequent alkylation with allyl bromide or 1-bromo-3-butene gave the hydrazones **9c,e-g,** and **i**, which upon reduction with $LiAlH_4$ furnished the hydrazines in good to excellent yields. Hydrazine **2k** was synthesized from acetaldehyde *N*,*N*-dimethylhydrazone and 1-iodo-4-pentene to give hydrazone **7k**, followed by reduction with $LiAlH_4$. Reduction of cyclopentyl hydrazone **9i** gave a mixture of *cis* and *trans* isomers using both $LiAlH_4$ (1:1.2 *t/c*) and $NaCNBH_3$ (1.8:1 *t/c*). These diastereomers were easily separated via flash column chromatography.

Figure 15. Synthesis of hydrazines.



Synthesis of hydrazine **2h** was achieved by treating *cis*-1,4-butenediol with TBSCl followed by ozonolysis to give 2-((tert-butyldimethylsilyl)oxy)acetaldehyde. Conversion to the hydrazone followed by alkylation gave hydrazone **9h**. Reduction with $LiAlH_4$ resulted in partial desilylation and a complex mixture of inseparable products. However, using $NaCNBH_3$ (MeOH, HCl, pH 3-4, 0 ^oC) gave hydrazine **2h** in 89% yield (**Figure 16**).

Figure 16. Synthesis of hydrazine **2h**.

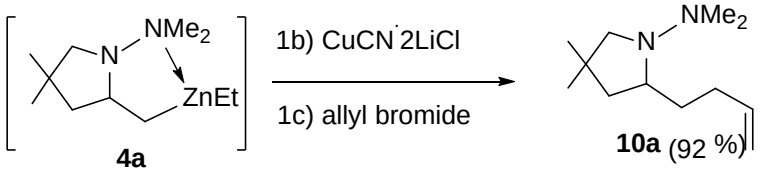


Functionalization of the Organozinc Intermediate

The functionalization of organozinc intermediate **4a** was screened using several well established conditions. Attempts to alkylate directly using allyl bromide proceeded slowly and resulted in decomposition after prolonged exposure at elevated temperatures. Removal of the solvent and treatment with $PdCl_2(PPh_3)_2$ in THF with allyl bromide gave rise to a complex mixture of inseparable products. Following the procedure of Knochel et. al., the addition of CuCN•2LiCl (1.5 equiv.) and allyl bromide (2.5 equiv.) to metallocycle **4a** gave pyrrolidine **10a** in 92% yield overall as its trifluoroacetate salt (**Figure 17**)[8]. Alternatively, removal of the initial reaction solvent *in vacuo*, followed by addition of THF, CuCN•2LiCl (1.5 equiv.) and an allyl halide (1.2 equiv.) gave

comparable results. Traditionally, the functionalization of organozinc species is performed utilizing the monoalkyl zinc halide[5] (RZnX, X= Cl, Br, I). Treatment of the organozinc cycles with $ZnX_2(THF)_2$ (X= Cl, Br, I) and THF, after removal of the initial reaction solvent, results in a Schlenk equilibrium giving rise to solely the monoalkyl zinc halide, with no ^1H NMR evidence of ethylzinc halide. This is presumably due to excess diethylzinc (via schlenk equilibrium) being driven off during solvent removal and formation of a zinc dimer as evidenced by ^1H NMR.

Figure 17. Functionalization of organozinc intermediate.

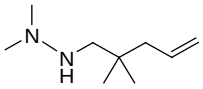
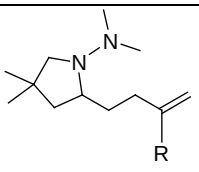
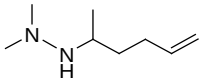
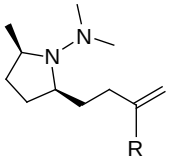
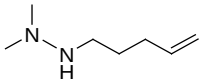
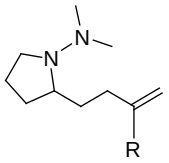
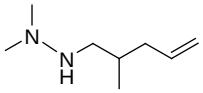
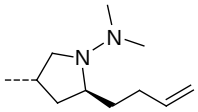
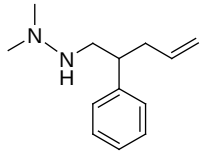
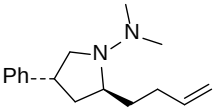
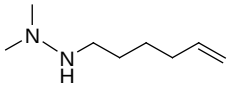
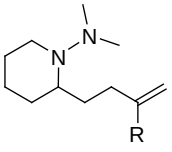


Metalloamination/Functionalization
of Terminal Hydrazinoalkenes

With an efficient alkylation procedure in hand, the scope of the metalloamination reaction was examined utilizing a range of substrates. The details are summarized in **Table 4**. In nearly all cases the yields were excellent. The Thorpe-Ingold effect, which is of vital importance to many hydroamination reactions[1a], is not necessary for the diethyl zinc mediated metalloamination. Two significant examples of this are hydrazinoalkene **2c** and **2f** in which unsubstituted 5- and 6-membered rings are formed at faster rates than the cyclization of **2a**. Unfortunately, attempts to form a 7-membered ring via hydrazinoalkene **2k** were unsuccessful. Excellent diastereoselectivity was also achieved.

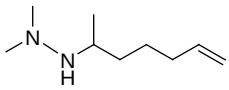
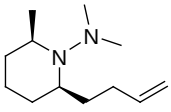
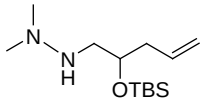
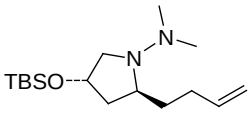
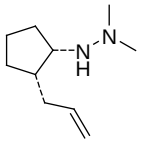
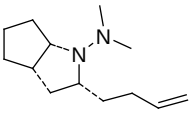
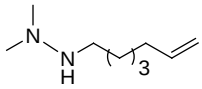
Specifically, the metalloamination/allylation of **2b** gave rise to pyrrolidines **10b** (>20:1 *cis/trans*)[9a, 11] and **2g** gave piperidines **10g** (9:1 *cis/trans*)[9b, 11]. If the cyclization of **2e** is

Table 4 (part 1) Metalloamination/allylation of hydrazinoalkenes.

	Hydrazinoalkene	%Conv.[a]	dr	Product	Yield%[f]
1.	 **2a**	>95 (18 h)[b]	--	 **10a**	92 (R=H) 83 (R=Me)
2.	 **2b**	>95 (6 h)[b]	>20:1 (*c/t*)	 **10b**	81 (R=H) 85 (R=Me)
3.	 **2c**	90 (4 h)[b]	--	 **10c**	80 (R=H) 76 (R=Me)
4.	 **2d**	90 (15 h)[c]	1:6 (*c/t*)	 **10d**	83
5.	 **2e**	90 (24 h)[d]	1:15 (*c/t*)	 **10e**	85
6.	 **2f**	>95 (3 h)[b]	--	 **10f**	93 (R=H) 88 (R=Me)

[a] As calculated from ^{1}H NMR utilizing *p*-xylene as an internal standard. [b] Reaction conducted on a 0.1 mmol scale in a 90 °C oil bath with toluene or (trifluoromethyl)benzene as solvent. [c] Experiment performed by co-author Adrian Smith, conducted at 10 °C. [d] Reaction conducted at 23 °C. [e] Required 2 equiv. of $ZnEt_2$. [f] All products were isolated as the TFA salts unless otherwise noted.

Table 4 (part 2). Metalloamination/allylation of hydrazinoalkenes.

Hydrazinoalkene	%Conv.[a]	dr	Product	Yield%[f]
7.  **2g**	70 (12 h)[b][e]	9:1 (*c/t*)	 **10g**	63
8.  **2h**	90 (8 h)[b]	1:2 (*c/t*)	 **10h**	83[i]
9.  **2i**	>95 (16 h)[b]	>20:1 (*c/t*)	 **10i**	87
11.  **2k**	N. R. (3 d)[h]	--	--	--

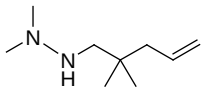
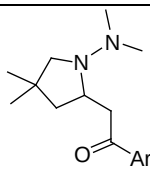
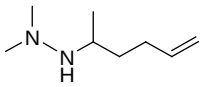
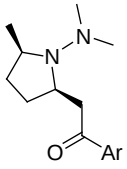
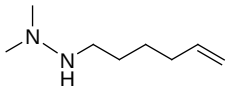
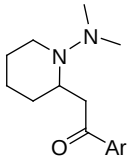
[a] As calculated from ^{1}H NMR utilizing *p*-xylene as an internal standard. [b] Reaction conducted on a 0.1 mmol scale in a 90 °C oil bath with toluene or (trifluoromethyl)benzene as solvent. [c] Experiment performed by co-author Adrian Smith, conducted at 10 °C. [d] Reaction conducted at 23 °C. [e] Required 2 equiv. of $ZnEt_2$. [f] All products were isolated as the TFA salts unless otherwise noted. [h] Cyclization was not observed. [i] Product isolated as the free base.

conducted at 90 ^{o}C temperature, no diastereoselectivity is achieved (1:1 *cis/trans*). However if the reaction is conducted at 23 ^{o}C, diastereoselectivity significantly increases (1:15 *cis/trans*). Interestingly if the completed cyclization of **2e** (1:15 *cis/trans*)[10a] is heated at 90 ^{o}C it leads to a rapid equilibration to a 1:1 mixture of diastereomers. This suggests that the reaction is reversible. Similar behavior is observed for hydrazine **2d**.

The *tert*-butyldimethylsilyl ether substituent was easily tolerated, though elevated temperatures were required, resulting in poor diastereoselectivity (1:2 *cis/trans*)[12]. Additionally, cyclic hydrazine **2i** underwent stereospecific cyclization giving **10i** in 87% yield. These reactions have also been shown to be scalable as evidenced by the synthesis of **10a** and **10f** on a 1 mmol scale in comparable yields, 91 and 93% respectively.

Additional methods of electrophilic functionalization of the cyclic organozinc intermediate were also explored by coworker Adrian Smith. Acylation of **2a,b** and **f** under the conditions of Fukuyama[13] ([$PdCl_2(PPh_3)_2$] (5 mol %), PhMe) with 4-*t*BuC_6H_4COSEt gave the ketones **11** in good yields (**Table 5**).

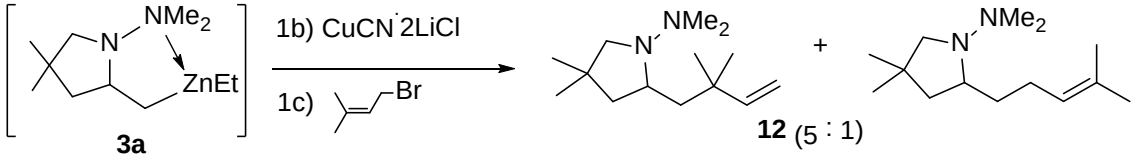
Table 5. Fukuyama coupling of organozinc intermediates.

Hydrazinoalkene	%Conv.[a]	dr	Product	Yield%[f]
1.  **2a**	>95 (18 h)[b, d]	--	 **11a**	64
2.  **2b**	>95 (6 h)[b,d]	>20:1 (*c/t*)	 **11b**	61
3.  **2f**	>95 (3 h)[b]	--	 **11f**	61

[a] As calculated from ^{1}H NMR utilizing *p*-xylene as an internal standard. [b] All reactions conducted at a 0.1 mmol scale with toluene or (trifluoromethyl)benzene as solvent. [c] Ar = 4-(t-Bu)C_6H_4. [d] Reactions performed by co-author Adrian Smith.

Organozinc alkylations mediated by Cu(I) are known to proceed via an S_N2' mechanism[16]. To confirm this, the organozinc intermediate **4a** was alkylated via the usual procedure CuCN•2LiCl (1.5 equiv) substituting 1-bromo-3-methylbut-2-ene for allylbromide. Indeed, the major product, despite forming a new quaternary carbon bond is pyrrolidine **12** (5 : 1 $S_n2' : S_n2$) (**Figure 18**).

Figure 18. Alkylation of organozinc intermediate with 1-bromo-3-methylbut-2-ene.

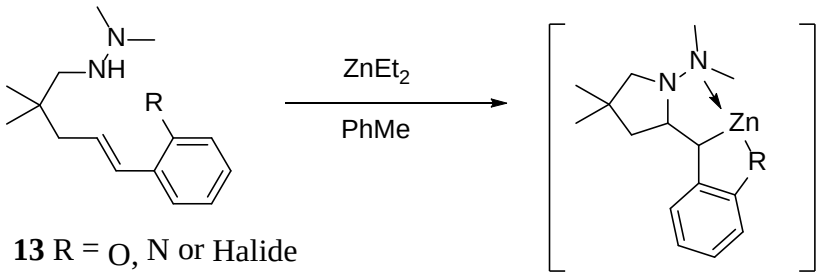


As an alternative alkylation procedure, treatment of intermediates **4a** and **4b** with $Pd(PPh_3)_4$ (5 mol %) and allylbromide, in the initial reaction mixture, furnishes pyrrolidines **10a** (69%) and **10b** (63%). These transformations are, however, less efficient resulting in lower yields and requiring flash column chromatography for purification.

Disubstituted Hydrazinoalkenes: Synthesis and Scope

Having obtained excellent results with a number of terminal hydrazinoalkenes, we next sought to explore the cyclization of disubstituted alkenes. Specifically it was envisioned that aryl-substituted hydrazine alkenes of type **13** would be particularly prone to cyclization owing to the activation of the styrenyl alkene as this has been demonstrated for catalytic hydroamination[1j]. Additionally, substitution at the *ortho* position could impart stereocontrol via an internal 5-membered chelate to the zinc center of the cyclized intermediate (**Figure 19**).

Figure 19. Proposed cyclization of aryl disubstituted hydrazinolkenes.

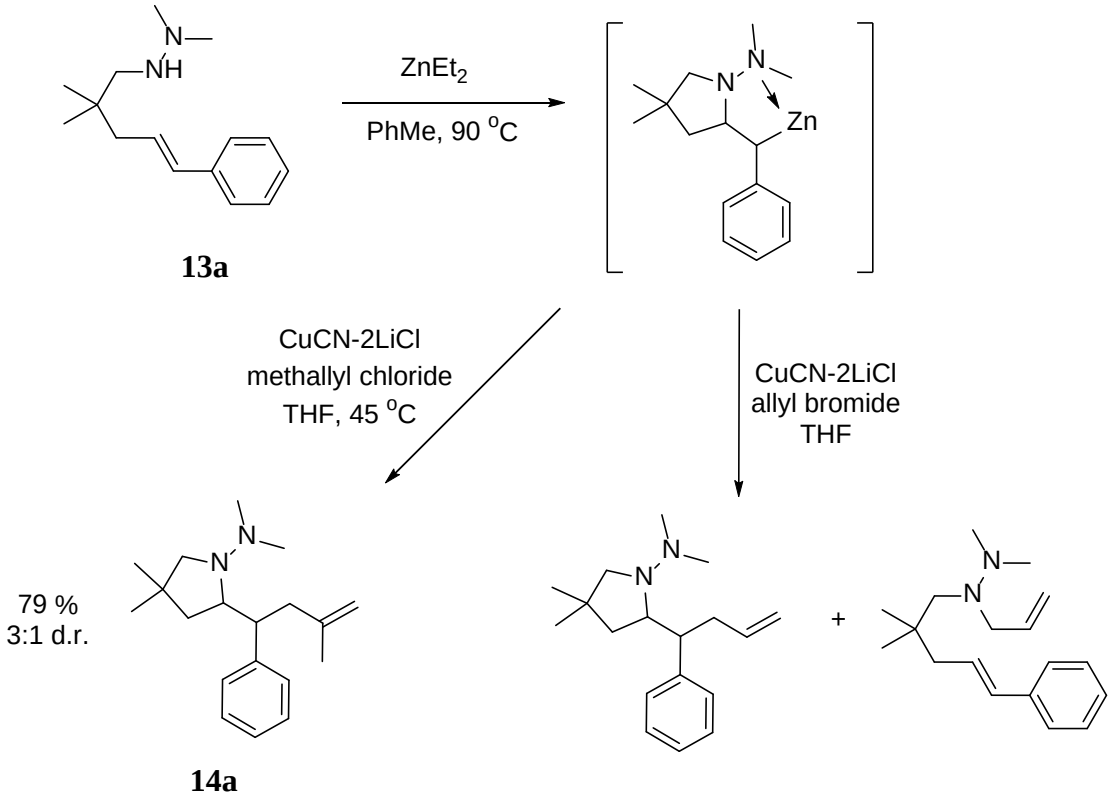


13 R = O, N or Halide

The initial investigation began with a simple styrenyl hydrazinoalkene (**13a**, R = H). Thus, when **13a** was treated with $ZnEt_2$ in toluene at 90 ^oC for 24 hours, cyclization proceeded efficiently, however attempts to functionalize with allyl bromide were unsuccessful and gave mixtures of the desired pyrrolidine and alkylation at the nucleophilic nitrogen with concurrent ring opening (**Figure 20)**. Fortunately, use of less electrophilic allylic chlorides proceeded smoothly, albeit with longer reaction times and gentle heating (8 h, 45 ^oC). Initial ^1H NMR experiments suggest that the diastereoselectivity is determined during the metalloamination and is conserved after transmetallation with CuCN•2LiCl.

With the initial cyclization/functionalization for aryl substituted hydrazinoalkenes optimized, we synthesized a number of additional substrates to attempt to improve upon the diastereoselectivity of the reaction, as well as examine the effects of substituents on the rate of cyclization. Additional substrates to probe the reactivity of non-aryl disubstituted hydrazinoalkens were also examined.

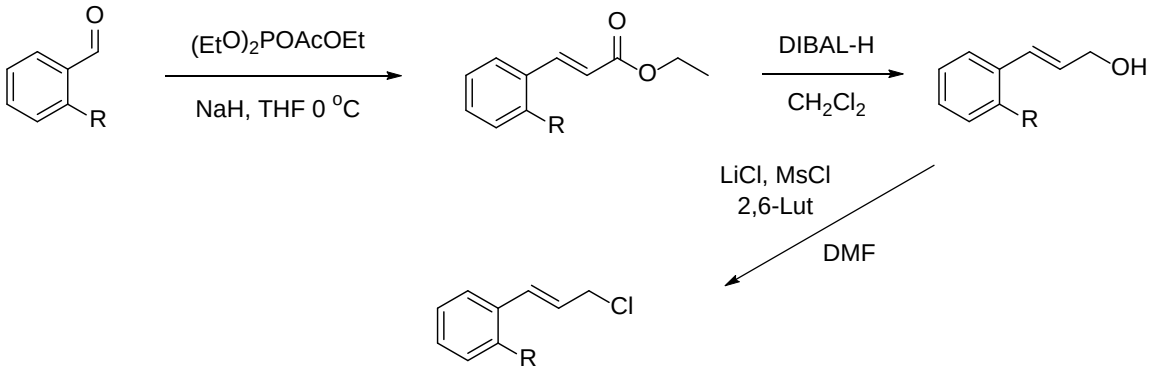
Figure 20. Metalloamination/functionalization of **13a**.



Synthesis of Disubstituted Hydrazinoalkenes

We began by synthesizing a number of *ortho*-substituted styrenyl hydrazines to examine the effects of chelation control on the diastereoselectivity of the metalloamination/cyclization. Substituted cinnamyl chlorides were synthesized via known procedures[1b-f] initiated by a Horner-Wadsworth-Emmons olefination on the appropriate aryl aldehyde, followed by reduction with DIBAL to give the allylic alcohols. These were converted directly to the allylic chlorides by treatment with LiCl, 2,6-lutedine and MsCl in anhydrous DMF (**Figure 21**).

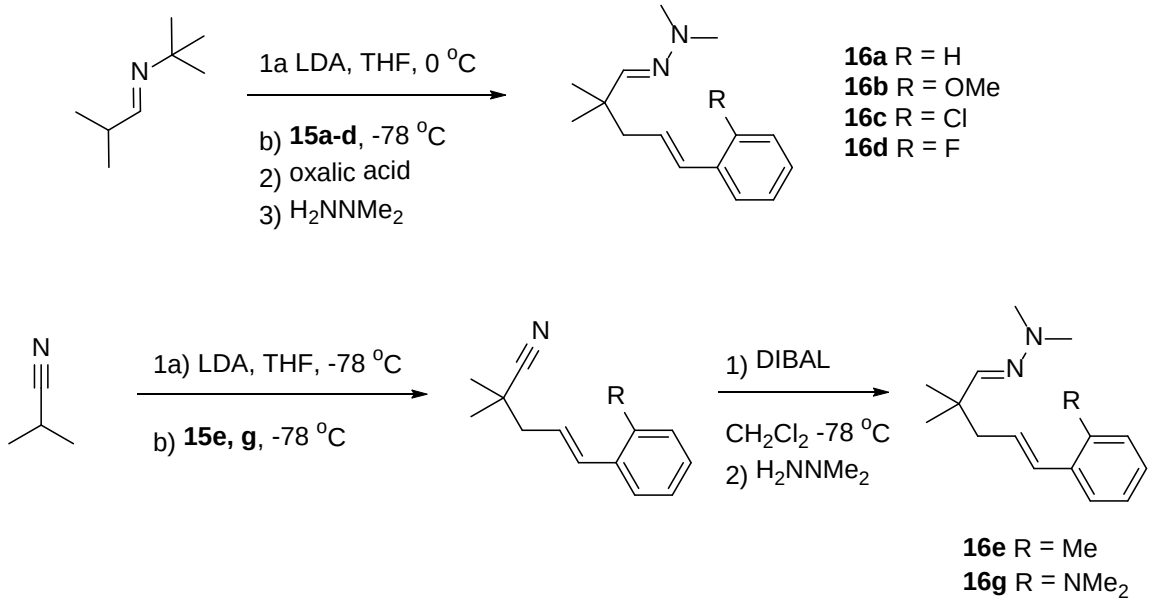
Figure 21. General synthesis of *o*-substituted cinnamyl chlorides.



15a R = H
15b R = OMe
15c R = Cl
15d R = F
15e R = CH_3
15g R = NMe_2

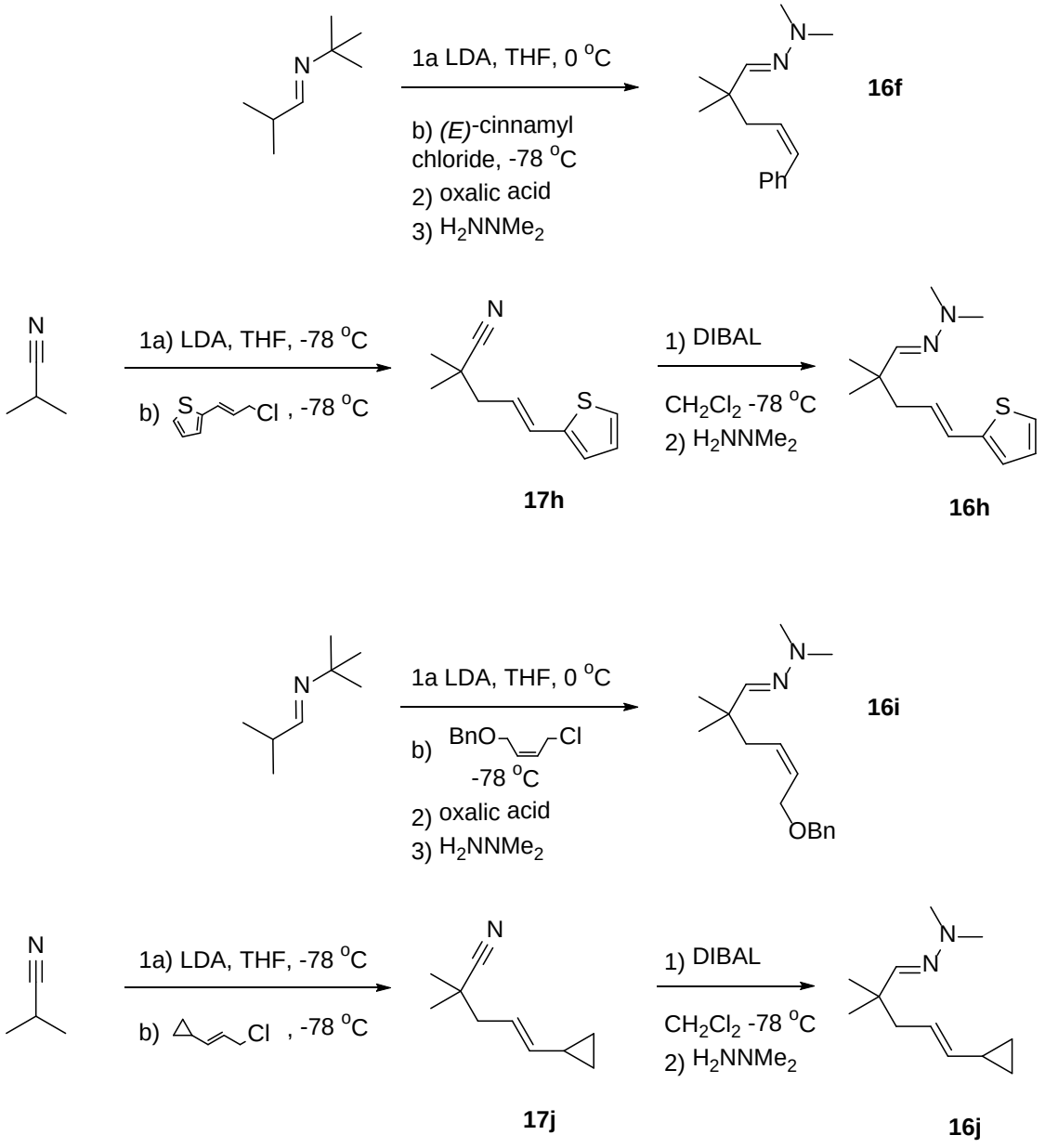
With the requisite allylic chlorides in hand, one of two methods was used to access the hydrazone of interest. Alkylation of *N*-(tert-butyl)-2,-methylpropan-1-imine (LDA, THF, -78 ^oC) with the appropriate allylic chloride gave crude aldehydes, which were immediately converted to hydrazones by treatment with *N*,*N*-dimethylhydrazine (Method 1. **Figure 22**). Alternatively, for sluggish electrophiles, isobutryonitrile could be alkylated. The purified nitriles were easily converted to the corresponding hydrazones via reduction with DIBAL (CH_2Cl_2, -78 ^oC), followed by condensation of the crude aldehyde with *N*,*N*-dimethylhydrazine (Method 2).

Figure 22. Synthesis of aryl hydrazones.



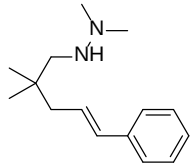
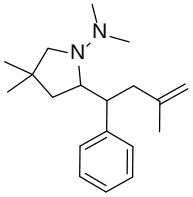
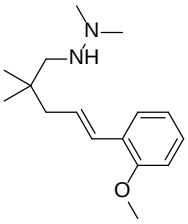
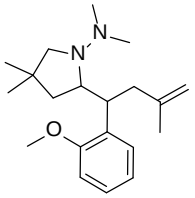
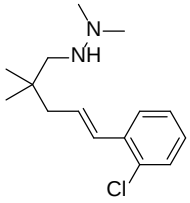
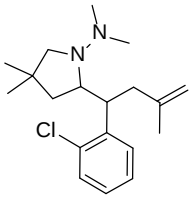
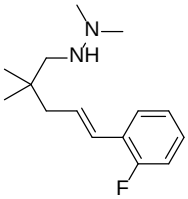
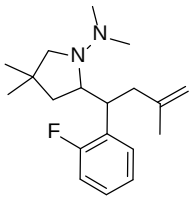
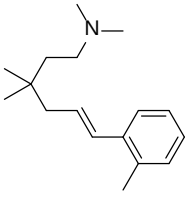
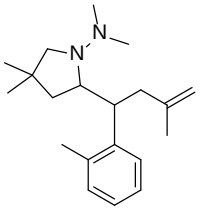
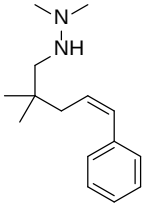
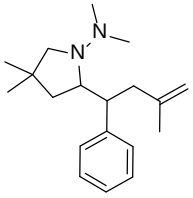
The *cis*-cinnamyl chloride needed for hydrazone **16f** was synthesized by alkylation of phenylacetylene with paraformaldehyde (*n*-BuLi, THF), followed by reduction with Ni_2B. The resulting alcohol was then converted to the allylic chloride, and utilized to alkylate *N*-(tert-butyl)-2,-methylpropan-1-imine via method 1. To explore the viability of heteroaromatic hydrazinoalkenes, hydrazone **16h** was synthesized from isobutryonitrile and (*E*)-2-(3-chloroprop-1-en-1-yl)thiophene according to method 2. Two additional hydrazones were synthesized to examine the effect of a terminal "leaving group" on the metalloamination/cyclization. The benzyl protected *cis*-allyl alcohol derived hydrazone (**16i)** was synthesized from mono-benzylated *cis*-butene diol. The mono-protected alcohol was converted to the corresponding allylic chloride and subsequently utilized in method 1 to arrive at the hydrazone of interest. The vinyl cyclopropyl hydrazone was synthesized from isobutryonitrile and (*E*)-(3-chloroprop-1-en-1-yl)cyclopropane via method 2 (**Figure 23**).

Figure 23. Synthesis of aryl and disubstituted hydrazones..



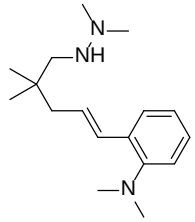
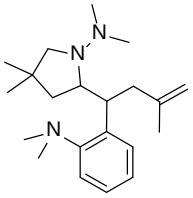
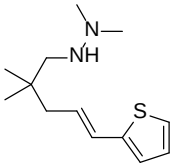
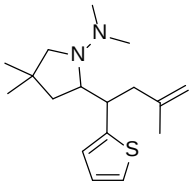
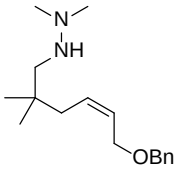
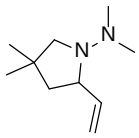
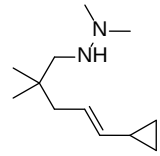
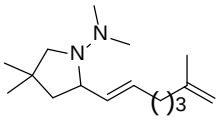
The hydrazones were then reduced with $NaBH_3CN$ in MeOH (pH 3) and dried with CaH_2 prior to use. The hydrazines obtained were subjected to the cyclization/alkylation procedure optimized for **16a**, the results of these studies are compiled in **Table 6**.

Table 6 (part 1). Metalloamination/allylation of disubstituted hydrazinoalkenes.

	Hydrazinoalkene	%Conv.[a]	dr[c]	Product[d]	Yield%[b]
1.	 **13a**	90	1:3	 **14a**	79
2.	 **13b**	90	5:1	 **14b**	83
3.	 **13c**	90	10:1	 **14c**	72
4.	 **13d**	90	>20:1	 **14d**	78[e]
5.	 **13e**	90	3:1	 **14e**	78
6.	 **13f**	90	1:3	 **14a**	63

[a] As calculated from ^{1}H NMR utilizing *p*-xylene as an internal standard. [b] Reaction conducted on a 0.1 mmol scale in a 90 °C oil bath with toluene as solvent. [c] Stereochemistry unassigned, ratio calculated from ^{1}H NMR and GC analysis. [d] All products were isolated as the free base unless otherwise noted. [e] Crystal structure pending.

Table 6 (part 2). Metalloamination/allylation of disubstituted hydrazinoalkenes.

	Hydrazinoalkene	%Conv.[a,b]	dr[c]	Product	Yield%[d]
7.	 **13g**	80	2:1	 **14g**	62
8.	 **13h**	75	1:1.5	 **14h**	58
9.	 **13i**	>95	--	 **14i**	90[e]
10.	 **13j**	>95	--	 **14j**	92[e]

[a] As calculated from ^{1}H NMR utilizing *p*-xylene as an internal standard. [b] Reaction conducted on a 0.1 mmol scale in a 90 °C oil bath with toluene as solvent. [c] Stereochemistry unassigned, ratio from ^{1}H NMR and GC analysis. [d] All products were isolated as the free base unless otherwise noted. [e] Isolated as TFA salt.

Results of the Metalloamination/Cyclization
of Disubstituted Hydrazinoalkenes

Several results in the preceding table are noteworthy. While all the cyclizations of aryl substituted hydrazinoalkenes required heating 24 h at 90 ^{o}C, introduction of a potential chelating group resulted in marked improvement in diastereoselectivity. In the case of the *ortho*- methoxy substituted hydrazine **13b**, cyclization/allylation resulted in a dr. improvement to 5:1. Interestingly the resulting pyrrolidine is tentatively assigned as the opposite diastereomers than that which is obtained from unsubstituted hydrazine **13a**.

When the *ortho*- methoxy substituent is replaced with chlorine (**13c**) an even greater improvement in selectivity is achieved (10:1). This trend continues with *ortho*-fluoro hydrazine **13d**, that when subjected to the metalloamination/allylation conditions, gives rise to a single diastereomer. It should be noted that these reactions are also scalable, without loss of selectivity. This is evidenced by the cyclization/functionalization of hydrazine **13d** on a 2 mmol scale, obtaining pyrrolidine **14d** in 84 % yield as a single diastereomer.

The increase in selectivity is not strictly due to an increase in steric bulk around the zinc center. The pyrrolidine obtained from the cyclization of hydrazine **13e**, while proceeding at an identical rate, suffers from a considerable loss in selectivity, resulting in a 3:1 dr. The *cis*-styrenyl hydrazine **13f** undergoes immediate isomerization to its *trans*-congener, even at decreased temperatures (45 ^{o}C), and then proceed to cyclize, giving the identical pyrrolidine as hydrazine **13a**. The *ortho*-aniline hydrazine **13g** exhibits lower selectivity, in addition to a decrease in reactivity (80% cyclization after 24 h at 90 ^{o}C), resulting in a decrease in overall yield (62%). Heteroaromatic hydrazine **13h** was also less reactive, cyclizing to only 75% completion after 24 h, and gave rise to the lowest selectivity of the substrates examined. Further heating resulted in no additional ring-closure, with prolonged heating (>2d) resulting in decomposition of starting material.

The *cis*-benzyl ether hydrazine **13i** also underwent immediate isomerization, and interestingly rapidly eliminated benzyl alkoxide (presumably as its zinc derivative), resulting in pyrrolidine **14i** in 90% isolated yield after only 4 hours at 90 ^{o}C. Reduction in the reaction temperature did not prevent elimination. Metalloamination/cyclization of

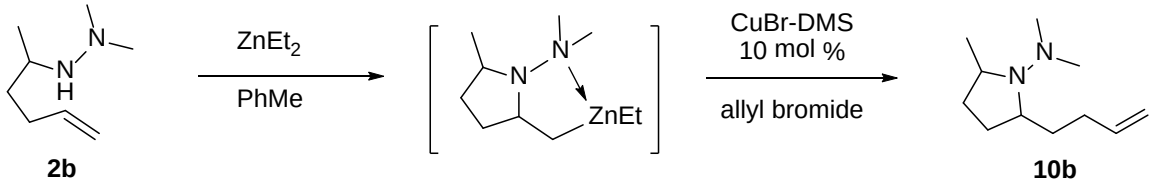
vinylcyclopropyl hydrazine **13j** was extremely facile, with an immediate ring-opening of the cyclopropane after cyclization in just 12 h at 60 ^{o}C. These reactions of a disubstiuted alkene, which proceeds so rapidly, may in future work provide opportunities to access pyrrolidines and piperidines with tri-substituted alkene appendeges. The vincylopropane moiety may also provide a means to cyclize more difficult substrate classes, as the resulting organozinc compound can no longer revert to its starting zinc amide.

Copper(I) Catalyzed Alkylations

The inability of the secondary organozinc intermediates to tolerate more reactive electrophiles such as allyl bromide, prompted an examination of alternative transmetallation conditions for facilitating the functionalization of the cyclized organozinc intermediates. Additionally, the use of stoichiometric copper(I) cyanide produces a large volume of metal salts upon work-up, from which extraction of products can prove problematic. The use of catalytic copper(I) sources (i.e., CuBr) have been shown to functionalize a variety of organozinc intermediates[14a]. The use of CuBr would also allow for the use of asymmetric ligands, which could improve the diastereoselectivity of the $ZnEt_2$ mediated metalloamination[14b].

Initial screening began with the use of CuBr-DMS complex. Hydrazine **2b** was cyclized, followed by addition of 10 mol % CuBr-DMS and 2.2 equiv. of allyl bromide (**Figure 24**). Immediately upon addition of the CuBr the solution discolored and precipitate appeared, after 24 h at 23 ^{o}C, no alkylation had occurred. Removal of the initial solvent, toluene, followed by introduction of THF, also resulted in a discolored solution with precipitate and no alkylation. Cooling of a heterogeneous solution of CuBr-

Figure 24. CuBr-DMS mediated alkylation of **2b**.



2b **10b**

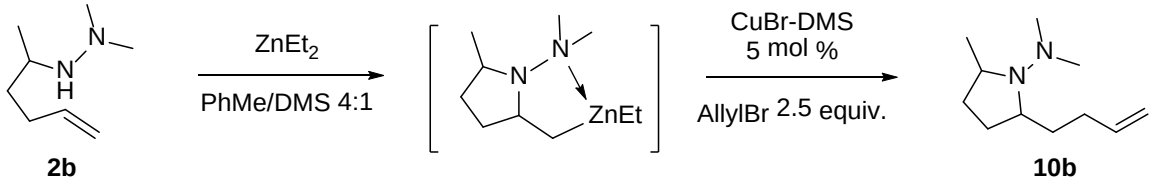
DMS in a solution of THF to -78 ^{o}C, followed by addition of the cyclic organozinc intermediate via gas-tight syringe afforded the desired pyrrolidine **10b**, but in a low (10%) yield.

Since the addition of CuBr-DMS to the reactant mixture produced unstable Zn/Cu complexes, our attention focused on the addition of ancillary ligands for Cu(I) which could potentially stabilize the resulting intermediates, and increase their solubility in aromatic hydrocarbon solvents (i.e., toluene). CuBr complexes of pyridine and imidizole[15] were examined but were insoluble in aromatic solvents and only sparingly soluble in THF. (5,5-dimethyl-2-oxido-1,3,2-dioxaphosphinan-2-yl)copper was also synthesized by deprotonation of the phosphonate with BuLi, followed by addition to a slurry of CuI in THF. This complex also proved to have a limited solubility profile.

Our focus next turned to the addition of a co-solvent that could potentially stabilize the zinc/copper intermediate. Dimethyl sulfide was chosen as the initial co-solvent, when a 4:1, PhMe:DMS solvent ratio was utilized no effect on the rate of metalloamination for hydrazine **2b** was observed. Additionally, the resulting organozinc intermediate, when treated with CuBr-DMS (5 mol %) produced a homogeneous solution that did not discolor for 2 h. Upon addition of allyl bromide (3 equiv., 8 h, 23 ^{o}C), pyrrolidine **10b** was obtained in 60 % yield (20:1, *cis*/trans) with an additional 30%

recovered as starting material (**Figure 25**). With these positive results in hand, tetrahydrothiophene (THT) was employed as a co-solvent.

Figure 25. CuBr-DMS catalyzed alkylation with DMS co-solvent.



2b **10b**

60 %

It was envisaged that the more strongly donating THT would increase the stability of the organozinc intermediate, as well as give a broader temperature profile for additional substrates. Indeed, when **2b** was treated with $ZnEt_2$ in a 4:1, PhMe:THT solvent mixture, followed by addition of 5 mol % CuBr-DMS, the resulting solution remained homogeneous, even when warmed to 60 ^{o}C. Upon addition of allyl bromide (2.5 equiv.) the resulting pyrrolidine **10b** was obtained in 89 % isolated yield (20:1, *cis/trans*). The initial reaction involves the transfer of an ethyl group from the organozinc intermediate, followed by alkylation of the pyrrolidine. Experiments are currently underway to extend the use of catalytic copper(I) to additional electrophiles Additionally, the stability imparted by the addition of THT may prove beneficial for substrates that exhibit lower thermal stability.

CONCLUSIONS

The metalloamination/cyclization of hydrazinoalkenes mediated by $ZnEt_2$ and subsequent functionalization provides a new method for accessing a variety of nitrogen containing heterocycles with excellent yields and diastereoselectivity. Considering the multitude of reactions which utilize carbon-zinc intermediates, this reaction sequence has the potential to be a powerful method for accessing a diverse array of synthetically relevant molecules.

We have shown that terminal hydrazinolkenes of broad structural arrays and substitution patterns undergo metalloamination/cyclization and subsequent functionalization in excellent yields. The cyclization tolerates a variety of solvents and in some cases may be accelerated by base catalysis. Palladium(0) and copper(I) are both viable catalysts for the alkylation of the cyclic organozinc intermediates.

2-Aryl ethenyl hydrazinoalkenes undergo metalloamination in good yields with fair to excellent diastereoselectivity. *Ortho*-substitution of the aryl ring with chelating functional groups increases the diastereoselectivity of the subsequent metalloamination/cyclization, with fluorine exhibiting the highest selectivity (>20:1). Additionaly, vinylcyclopropane bearing hydrazinoalkenes undergo rapid metalloamination with concurrent ring opening, resulting in an irreversible metalloaminatioin/cyclization.

We have also shown that catalytic Cu(I) sources are able to efficiently mediate the alkylation of the cyclic organozinc intermediates. The use of tetrahydrothiophene as a cosolvent stabilizes the Zn/Cu intermediate and increases the solubility of the CuBr-DMS

catalyst. These effects are being explored to access additional functionalization processes, as well as stabilization of the more thermally labile metalloamination substrates.

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10. a) The relative configuration for **4e** *trans* is supported by NOE experiments. Irradiation of the 2b hydrogen atom [3.20 ppm (free pyrrolidine)] resulted in a 12%

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APPENDICES

APPENDIX A

EXPERIMENTAL SUPPORTING INFORMATION

Materials and Methods: Reactions employed oven- or flame-dried glassware under nitrogen unless otherwise noted. J. Young NMR experiments were performed under an argon atmosphere, using standard Schlenk line techniques or in an argon-filled dry-box. THF and diethyl ether were distilled from sodium/benzophenone ketyl under nitrogen. Dichloromethane, diisopropylamine, trifluoromethylbenzene and toluene were distilled from CaH_2 under nitrogen. Benzene and *p*-xylene were distilled from potassium metal. 2,2-dimethyl-4-pentenal[1], 2,2-dimethyl-4-pentenal-*N*,*N*-dimethylhydrazone[2], 5-hexen-2-one-*N*,*N*-dimethylhydrazone[3], 5-hexenal-*N*,*N*-dimethylhydrazone[4], 6-hepten-2-one-*N*,*N*-dimethylhydrazone[5], (*E*)-2,2-dimethyl-5-phenylpent-4-enal[6], acetaldehyde-*N*,*N*-dimethylhydrazone[7], acetone-*N*,*N*-dimethylhydrazone[7] and propionaldehyde-*N*,*N*-dimethylhydrazone[7] were prepared as previously reported. All other materials were used as received from commercial sources. Thin-layer chromatography (TLC) employed 0.25 mm glass silica gel plates with UV indicator and visualized with UV light (254 nm) or potassium permanganate staining. Flash chromatographic columns were packed with Merck silica gel 60 as a slurry in the initial elution solvent. Nuclear magnetic resonance (NMR) data were obtained from Bruker DRX-300 (300 MHz) and Bruker DRX-500 (500 MHz). Infrared spectra (IR) were obtained from JASCO FTIR-4100. High-resolution mass spectra (HRMS) were obtained from Bruker MicroTOF with a Dart 100 – SVP 100 ion source (Ionsense Inc, Saugus, MA).

Synthesis of Hydrazines and Electrophiles.

2-(2,2-Dimethylpent-4-en-1-yl)-1,1-dimethylhydrazine (2a). A 100-mL, round-bottomed flask equipped with a magnetic stirring bar, an N_2 inlet and fitted with a reflux condenser was charged with $LiAlH_4$ (1.03 g, 27.1 mmol) and THF (40 mL) was subsequently added. The reactant mixture was cooled to 0 ^oC and a solution of 2,2-dimethyl-4-pentenal-*N*,*N*-dimethylhydrazone (2.79 g, 18.1 mmol) in THF (10 mL) was added dropwise. The reactant mixture was allowed to warm to room temperature and stirred for 30 min, followed by warming to a gentle reflux for 12 h. The resulting mixture was diluted with diethyl ether (25 mL) and cooled to 0 ^oC. Aqueous sodium hydroxide (15% w/v, 3.09 mL) was carefully added dropwise over 10 min with stirring, followed by warming to room temperature for 3 h. The white slurry was dried with $MgSO_4$ and filtered through a pad of Celite. After concentration the crude product was dried with CaH_2 and distilled in vacuo (23 ^oC, 0.5 torr) to afford 2.53g (89%) of the title compound as a clear liquid. **^{1}H-NMR** (500 MHz; C_6H_6): δ 6.01-5.95 (m, 1H), 5.18-5.15 (m, 2H), 2.62 (s, 2H), 2.35 (s, 6H), 2.16 (d, *J* = 7.5 Hz, 2H), 1.74 (d, *J* = 0.4 Hz, 1H), 1.02 (s, 6H). **^{13}C-NMR** (126 MHz; $CDCl_3$): δ 136.3, 117.0, 59.1, 47.9, 45.2, 34.5, 26.05, 26.01, 25.3 **IR** (Film): 3075, 2952, 2906, 2869, 2836, 2807, 2765, 1638, 1474, 1448, 912, cm^{-1} **HRMS** (ESI): Calcd for $C_9H_{20}N_2$ $[M+H]^+$: 157.1705, found: 157.1631.

2-(Hex-5-en-2-yl)-1,1-dimethylhydrazine (2b). A 250-mL, round-bottom flask equipped with a magnetic stirring bar and an N_2 inlet was charged with $LiAlH_4$ (2.27 g, 58.9 mmol) and THF (100 mL) was subsequently added. The suspension was cooled to 0

^{o}C and a solution of hydrazone **4** (5.5 g, 39.2 mmol) in THF (15 mL) was added dropwise. The reactant mixture was allowed to warm to room temperature, followed by heating at reflux for 8 h. The resulting mixture was diluted with diethyl ether (50 mL) and cooled to 0 ^{o}C. Water (2.27 mL) was carefully added dropwise, followed by $NaOH_{(aq)}$ (15% w/v, 2.27 mL) and H_2O (4.54 mL). Magnesium sulfate was added to the resultant slurry and the solution was filtered through Celite. After concentration in vacuo, subsequent distillation of the crude product (79-82 ^{o}C, 15 torr) from CaH_2 afforded 5.03g (90%) of the title compound. **^{1}H-NMR** (500 MHz; C_6H_6): δ 5.90 (ddt, *J* = 17.0, 10.3, 6.7 Hz, 1H), 5.16-5.05 (m, 2H), 2.86 (q, *J* = 6.0 Hz, 1H), 2.34 (s, 6H), 2.22-2.16 (m, 1H), 2.13-2.09 (m, 1H), 1.75-1.66 (m, 2H), 1.49 (ddt, *J* = 13.2, 9.8, 6.5 Hz, 1H), 1.10 (d, *J* = 6.2 Hz, 3H). **^{13}C-NMR** (126 MHz, C_6D_6): δ 139.49, 114.45, 51.95, 48.31, 35.31, 30.56, 19.80. **IR** (Film): 3184, 3078, 2977, 2946, 2842, 2809, 2766, 1641, 1478, 1450, 907, cm^{-1} **HRMS** (ESI): Calcd for $C_8H_{18}N_2$ $[M+H]^+$: 143.1548, found: 143.1495.

4-Pentenal-*N*,*N*-dimethylhydrazone (7c). The title compound was prepared following the procedure of Corey and Enders[7]. A 100-mL round-bottomed flask equipped with a magnetic stirring bar and an N_2 inlet was charged with diisopropylamine (2.84 g, 28.0 mmol) and THF (30 mL) was subsequently added. The resulting mixture was cooled to 0 ^{o}C and *n*-BuLi in hexanes (3.70 M, 7.57 mL) was added dropwise with subsequent stirring at this temperature for 1 h. A solution of acetaldehyde-*N*,*N*-dimethylhydrazone (2.39 g, 27.8 mmol) in THF (10 mL) was added dropwise with stirring and after 1 h the resulting suspension was cooled to -78 ^{o}C and allyl bromide (3.69 g, 30.5 mmol) was added dropwise via syringe. The reactant mixture was stirred at this temperature for 2 h

and then allowed to warm slowly to -10 ^{o}C for 1 h, at which point no precipitate remained. The resulting mixture was poured into water/ethyl acetate (3:1, 50 mL) and transferred to a separatory funnel. The aqueous layer was extracted with ethyl acetate (2 x 15 mL) and the combined organic layers were dried with $MgSO_4$, filtered through a plug of Celite and concentrated in vacuo. The crude compound was purified by bulb to bulb distillation (23 ^{o}C, 0.5 torr) to yield 2.77g (79%) of the title compound. **^{1}H-NMR** (500 MHz; $CDCl_3$): δ 6.64 (t, *J* = 5.3 Hz, 1H), 5.87-5.82 (m, 1H), 5.07-4.97 (m, 2H), 2.72 (s, 6H), 2.36-2.32 (m, 2H), 2.25 (t, *J* = 6.8 Hz, 2H). **^{13}C-NMR** (126 MHz, $CDCl_3$): δ 138.96, 137.94, 115.37, 43.63, 32.53, 32.18. **IR** (Film): 30745, 3027, 2978, 2952, 2914, 2853, 2823, 2783, 1681, 1640, 1468, 1452, 1030, 914, 760, 700, cm^{-1}. **HRMS** (ESI): Calcd for $C_7H_{14}N_2$ $[M+H]^+$: 127.1235, found:127.1184.

1,1-Dimethyl-2-(pent-4-en-1-yl)hydrazine (1c). The title compound was prepared by the general procedure described for compound **1ad** employing hydrazone **SI-1** (2.00 g, 15.8 mmol) and $LiAlH_4$ (0.90g, 23.8 mmol) to furnish 2-(pent-4-enyl)-1,1-dimethylhydrazine (1.79 g, 88%) as a clear liquid. **^{1}H-NMR** (500 MHz; $CDCl_3$): δ 6.64 (t, *J* = 5.3 Hz, 1H), 5.87-5.82 (m, 1H), 5.07-4.97 (m, 2H), 2.72 (s, 6H), 2.36-2.32 (m, 2H), 2.25 (t, *J* = 6.8 Hz, 2H). **^{13}C- NMR** (126 MHz; $CDCl_3$): δ 138.9, 115.0, 48.5, 48.1, 31.9, 28.2 **IR (Film):** 3181, 3076, 2977, 2944, 2838, 2807, 2765, 1640, 1474, 1448, 1095, 1014, 994, 908 cm^{-1} **HRMS** (ESI): Calcd for $C_7H_{16}N_2$ $[M+H]^+$: 129.1392, found: 129.1331.

2-Phenylpent-4-enal-*N,N*-dimethylhydrazone (9e). The title compound was prepared following the procedure of Corey and Enders[6]. A 50-mL round-bottomed flask equipped

with a magnetic stirring bar and an N_2 inlet was charged with diisopropylamine (0.86 g, 8.48 mmol) and THF (20 mL) was subsequently added. The resulting mixture was cooled to 0 ^oC and *n*-BuLi in hexanes (3.70 M, 2.29 mL) was added dropwise and the mixture was subsequently stirred at this temperature for 1 h. A solution of phenylacetaldehyde-*N*,*N*-dimethylhydrazone (1.25 g, 7.70 mmol) in THF (10 mL) was added dropwise with stirring. After 1 h the resulting suspension was cooled to -78 ^oC and allyl bromide (1.12 g, 9.24 mmol) was added dropwise via syringe. The reactant mixture was stirred at this temperature for 2 h and then allowed to warm slowly to 23 ^oC. After 12 h the resulting mixture was poured into water/ethyl acetate (3:1, 25 mL) and transferred to a separatory funnel. The aqueous layer was extracted with ethyl acetate (2 x 10 mL), the combined organic layers were dried with $MgSO_4$, filtered through a plug of Celite and concentrated in vacuo. The crude compound was purified by bulb to bulb distillation (65 ^oC, 0.5 torr) to yield 1.35g (87%) of the title compound**.** **^{1}H-NMR** (500 MHz, $CDCl_3$): δ 7.34-7.31 (m, 2H), 7.27-7.21 (m, 3H), 6.68 (d, *J* = 6.3 Hz, 1H), 5.75 (ddt, *J* = 17.1, 10.2, 6.9 Hz, 1H), 5.05-4.96 (m, 2H), 3.59 (q, *J* = 7.0 Hz, 1H), 2.75 (d, *J* = 5.2 Hz, 6H), 2.73-2.66 (m, 2H), 2.56 (ddd, *J* = 14.3, 6.7, 1.0 Hz, 1H). **^{13}C-NMR** (126 MHz, $CDCl_3$): δ 142.85, 141.06, 136.69, 128.95, 128.29, 126.90, 116.75, 49.20, 43.69, 39.09. **IR** (Film): 3075, 3027, 2979, 2952, 2914, 2853, 1681, 1468, 1452, 1030, 914, 700, cm^{-1} **HRMS** (ESI): Calcd for $C_{13}H_{18}N_2$ $[M+H]^+$: 203.1548, found: 203.1519.

1,1-Dimethyl-2-(2-phenylpent-4-en-1-yl)hydrazine (2e). The title compound was prepared by the general procedure described for compound **1a** employing **SI-3** (1.25 g, 6.31 mmol) and $LiAlH_4$ (0.36 g, 9.50 mmol) to furnish 1,1-dimethyl-2-(2-phenylpent-4-

en-1-yl)hydrazine (0.86 g, 83%) as a clear liquid. **^{1}H-NMR** (500 MHz, $CDCl_3$): δ 7.34-7.31 (m, 2H), 7.24-7.21 (m, 3H), 5.74-5.68 (m, 1H), 5.02-4.94 (m, 2H), 3.03 (qd, *J* = 11.8, 7.2 Hz, 2H), 2.93-2.88 (m, 1H), 2.50 (ddd, *J* = 14.0, 7.3, 6.5 Hz, 1H), 2.41-2.35 (m, 7H), 1.92 (s, 1H). **^{13}C-NMR** (126 MHz, $CDCl_3$): δ 143.83, 136.94, 128.85, 128.12, 126.84, 116.54, 54.17, 47.90, 44.83, 39.54. **IR** (Film): 3076, 3063, 3027, 2978, 2946, 2923, 2838, 2809, 2766, 1640, 1493, 1475, 1452, 911, 700, cm^{-1}. **HRMS** (ESI): Calcd for $C_{13}H_{20}N_2$ $[M+H]^+$: 205.1705, found: 205.1720.

2-(Hex-5-en-1-yl)-1,1-dimethylhydrazine (2f). The title compound was prepared by the general procedure described for compound **1a** employing 5-Hexenal-*N*,*N*-dimethylhydrazone (1.00 g, 7.13 mmol) and $LiAlH_4$ (0.41 g, 10.7 mmol) to furnish 2-(hex-5-enyl)-1,1-dimethylhydrazine (0.93 g, 92%) as a clear liquid. **^{1}H-NMR** (500 MHz, $CDCl_3$): δ 5.81-5.76 (m, 1H), 5.00-4.90 (m, 2H), 2.74 (t, *J* = 6.8 Hz, 2H), 2.45-2.40 (m, 6H), 2.05 (q, *J* = 6.9 Hz, 2H), 1.97 (s, 1H), 1.48-1.40 (m, 4H). **^{13}C-NMR** (126 MHz, $CDCl_3$): δ 139.13, 114.77, 48.98, 48.11, 34.04, 28.47, 27.07. **IR** (Film) 3076, 2977, 2935, 2839, 2807, 2765, 1640, 1473, 1458, 910, cm^{-1}. **HRMS** (ESI): Calcd for $C_8H_{18}N_2$ $[M+H]^+$: 143.1548, found: 143.1559.

2-(Hept-6-en-2-yl)-1,1-dimethylhydrazine (2g). The title compound was prepared by the general procedure described for compound **1a** employing 6-hepten-2-one-*N*,*N*-dimethylhydrazone (1.00 g, 6.64 mmol) and $LiAlH_4$ (0.37 g, 9.70 mmol) to furnish 2-(1-methyl-5-hexenyl)-1,1-dimethylhydrazine (0.86 g, 83%) as a clear liquid. **^{1}H-NMR** (500 MHz, $CDCl_3$): δ 5.82 (ddt, *J* = 17.0, 10.3, 6.7 Hz, 1H), 5.03-4.94 (m, 2H), 2.81 (td, *J* = 6.6, 4.9 Hz, 1H), 2.42 (s, 6H), 2.09-2.05 (m, 2H), 1.97 (s, 1H), 1.50-1.37 (m, 3H), 1.31-

1.25 (m, 1H), 1.03 (d, *J* = 6.2 Hz, 3H). **^{13}C-NMR** (126 MHz, $CDCl_3$): δ 139.25, 114.77, 52.70, 48.70, 35.66, 34.41, 25.80, 20.00. **IR** (Film): 3189, 3076, 2975, 2942, 2839, 2808, 2764, 1641, 1478, 1448, 1368, 1015, 996, 908, cm^{-1}. **HRMS** (ESI): Calcd for $C_9H_{20}N_2$ $[M+H]^+$: 157.1705, found: 157.1713.

2-((2-*tert*-butyldimethylsilyl)oxy)ethylidene)-1,1-dimethylhydrazine. A 25-mL round-bottomed flask equipped with a magnetic stirring bar and an N_2 inlet was charged with 2-((*tert*-butyldimethylsilyl)oxy)acetaldehyde (3.00 g, 17.2 mmol) and cooled to 0 ^oC. *N,N*-dimethylhydrazine (2.06g, 34.4 mmol) was added dropwise and the reaction mixture was stirred for 2 h at 23 ^oC. Pentane (10 mL) was added followed by potassium hydroxide pellets and the solution was allowed to stand for 2 h until biphasic. The organic layer was decanted, dried with Na_2SO_4 and concentrated. Bulb to bulb distillation (60 ^oC, 0.5 torr) afforded the title compound as a clear oil (3.32 g, 88%). **^{1}H NMR** (500 MHz, Chloroform-*d*) δ = 6.55 (t, *J*=5.1, 1H), 4.23 (d, *J*=5.1, 2H), 2.74 (s, 6H), 0.87 (s, 9H), 0.05 (s, 6H). **^{13}C NMR** (126 MHz, Chloroform-*d*) δ = 135.57 , 64.26 , 42.76 , 25.93 , -5.04 . **IR** (Film): 2955, 2929, 2857, 1471, 1255, 835, cm^-1. **HRMS** (ESI): Calcd for $C_{10}H_{24}N_2OSi$ $[M+H]^+$: 217.1818, found: 217.1736.

2-((2-*tert*-butyldimethylsilyl)oxy)pent-4-en-1-ylidene)-1,1-dimethylhydrazone (9h). The title compound was prepared by the general procedure of **7d**, utilizing 2-((2-*tert*-butyldimethylsilyl)oxy)ethylidene)-1,1-dimethylhydrazine (0.71 g, 3.3 mmol) and allylbromide (0.48 g, 3.9 mmol) to yield 2-((2-*tert*-butyldimethylsilyl)oxy)pent-4-en-1-ylidene)-1,1-dimethylhydrazine as a clear oil. (0.61 g, 72%). **^{1}H NMR** (300 MHz, Chloroform-*d*) δ = 6.49 (d, *J*=6.5, 1H), 5.86 (ddt, *J*=17.3, 10.2, 7.1, 1H), 5.15 – 5.02 (m,

2H), 4.29 (q, *J*=6.5, 1H), 2.78 (d, *J*=0.5, 6H), 2.43 (s, 1H), 2.41 – 2.33 (m, 2H), 0.91 (s, 9H), 0.08 (d, *J*=10.5, 6H). **^{13}C NMR** (75 MHz, Chloroform-*d*) δ = 139.48 , 134.64 , 117.07 , 73.31 , 42.96 , 41.74 , 25.90 , -4.11 , -4.67. **IR** (Film): 2955, 2856, 1471, 1255, 1073, 835, cm^{-1}. **HRMS** (ESI): Calcd for $C_{13}H_{28}N_2OSi$ $[M+H]^+$: 257.2049, found: 257.2059.

2-((2-*tert*-butyldimethylsilyl)oxy)pent-4-en-1-yl)-1,1-dimethylhydrazine (2h). The title compound was prepared by the general procedure described for **1j** utilizing hydrazone **SI-7** (0.360 g, 1.40 mmol) and $NaBH_3CN$ (0.100 g, 1.54 mmol) to yield 2-((2-*tert*-butyldimethylsilyl)oxy)pent-4-en-1-yl)-1,1-dimethylhydrazine as a clear oil. (0.322 g, 89%). **^{1}H NMR** (500 MHz, Chloroform-*d*) δ = 5.78 (ddt, *J*=17.3, 10.2, 7.2, 1H), 5.08 – 4.96 (m, 2H), 3.87 – 3.78 (m, 1H), 2.77 (dd, *J*=5.5, 1.7, 2H), 2.41 (s, 6H), 2.33 – 2.18 (m, 3H), 1.23 (s, 1H), 0.87 (s, 9H), 0.06 (d, *J*=5.7, 6H). **^{13}C NMR** (126 MHz, Chloroform-*d*) δ = 134.70 , 117.08 , 70.59 , 53.87 , 47.49 , 40.49 , 25.84 , -4.32 , -4.57 . **IR** (Film): 3076, 2955, 2856, 1471, 1255, 1073, 835, cm^{-1}. **HRMS** (ESI): Calcd for $C_{13}H_{30}N_2OSi$ $[M+H]^+$: 259.2206, found: 259.2298.

2-(2-Allylcyclopentyl)-1,1-dimethylhydrazine (2i). The title compound was prepared by the general procedure described for **1j**, employing 2-(2-allylcyclopentylidene)-1,1-dimethylhydrazine (1.00 g, 6.00 mmol) and $NaBH_3CN$ (0.416g, 6.60 mmol) to yield 2-(2-allylcyclopenty)-1,1-dimethylhydrazine in 87 % yield (0.878 g) as a 1.8:1 (t/c) mixture of diastereomers. These were separated via column chromatography (silica gel, 15% EtOAc/Hex) to give the pure *cis*-hydrazine (0.301 g). $R_{f(cis)}$ = 0.2, $R_{f(trans)}$ = 0.13**.** (*cis*) **^{1}H NMR** (500 MHz, Chloroform-*d*) δ = 5.87 – 5.74 (m, 1H), 5.07 – 4.92 (m, 2H), 3.24 (q,

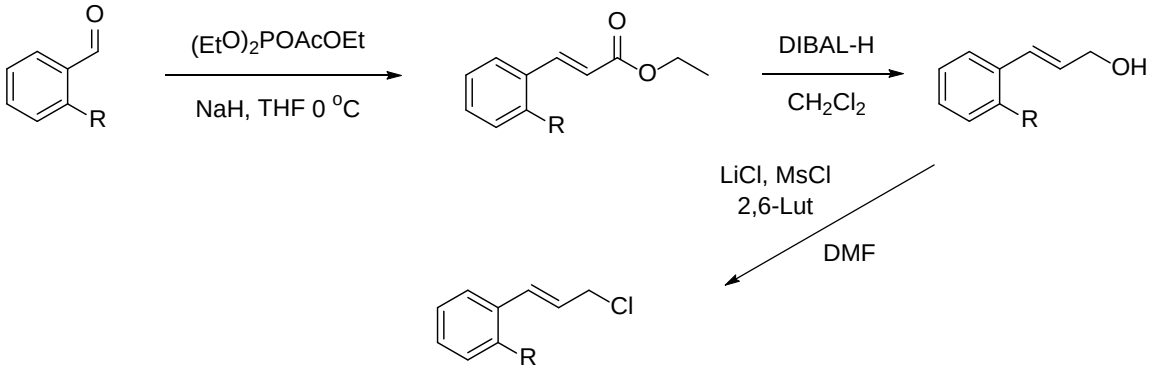
J=5.4, 1H), 2.39 (s, 6H), 2.27 – 2.20 (m, 1H), 1.99 (t, *J*=1.2, 1H), 1.98 – 1.89 (m, 2H), 1.76 – 1.69 (m, 1H), 1.68 – 1.62 (m, 2H), 1.60 – 1.55 (m, 1H), 1.54 – 1.47 (m, 1H), 1.47 – 1.40 (m, 1H). **^{13}C NMR** (126 MHz, Chloroform-*d*) δ = 138.53 , 114.76 , 59.37 , 47.96 , 42.74 , 33.43 , 31.05 , 29.43 , 21.80 . **IR** (film): 3073, 2947, 2867, 2765, 1476, 1447, 907, cm^{-1}. **HRMS** (ESI): Calcd for $C_{10}H_{20}N_2$ $[M+H]^+$: 169.1705, found: 169.1755. (*trans*) **^{1}H NMR** (500 MHz, Chloroform-*d*) δ = 5.77 (ddt, *J*=17.1, 10.2, 7.0, 1H), 5.05 – 4.91 (m, 2H), 2.91 (dt, *J*=7.0, 5.3, 1H), 2.38 (s, 6H), 2.13 (dt, *J*=13.8, 7.0, 2H), 2.00 (dt, *J*=14.2, 7.4, 1H), 1.87 – 1.73 (m, 2H), 1.62 (dt, *J*=12.6, 7.4, 2H), 1.58 – 1.51 (m, 1H), 1.46 (ddd, *J*=15.7, 8.3, 5.1, 1H), 1.21 (dt, *J*=12.6, 7.8, 1H). **^{13}C NMR** (126 MHz, Chloroform-*d*) δ = 137.74 , 115.48 , 63.33 , 48.10 , 44.02 , 38.93 , 32.43 , 31.22 , 23.27.

2-(Hept-6-en-1-yl)-1,1-dimethylhydrazine (2k). The title compound was prepared by the general procedure employed for **1a** employing 2-(hept-6-en-1ylidene)-1,1-dimethylhydrazine (1.05 g, 6.80 mmol) and $LiAlH_4$ (0.387 g, 10.2 mmol) to yield 2-(hept-6-en-1-yl)-1,1-dimethylhydrazine as a colorless oil. (0.364 g, 34 %). **^{1}H NMR** (500 MHz, Chloroform-*d*) δ = 5.69 (ddt, *J*=16.9, 10.2, 6.7, 1H), 4.92 – 4.78 (m, 2H), 2.66 – 2.61 (m, 2H), 2.32 (s, 6H), 1.96 – 1.91 (m, 2H), 1.87 (s, 1H), 1.37 – 1.21 (m, 6H). **^{13}C NMR** (126 MHz, Chloroform-*d*) δ = 138.90 , 114.22 , 48.69 , 47.70 , 43.33 , 33.65 , 28.79 , 28.41 , 26.84. **IR** (film): 3075, 2930, 2854, 1641, 1461, 1443, 909, cm^{-1}. **HRMS** (ESI): Calcd for $C_9H_{20}N_2$ $[M+H]^+$: 157.1704, found: 157.1736.

The cinnamyl chlorides where synthesized from known literature procedures[1a-f] via a Horner-Wadsworth-Emmons reactions followed by reduction with DIBAL to the allylic

alcohols. The alcohols were then treated with LiCl, MsCl, and 2,6-lutadine in DMF to provide the allylic chlorides (**Figure A1)**.

Figure A1. Synthesis of aryl-substituted cinnamyl chlorides.



2,2-Dimethyl-5-phenylpent-4-enal-*N*,*N*-dimethylhydrazone (16a). A 50-mL round-bottomed flask equipped with a magnetic stirring bar, a reflux condenser and an N_2 inlet was charged with (*E*)-2,2-dimethyl-5-phenylpent-4-enal (3.66 g, 19.4 mmol) and benzene (15 mL) was subsequently added. The reactant mixture was cooled to 0 ^oC and *N*,*N*-dimethylhydrazine (2.96 mL, 38.9 mmol) was added dropwise via syringe. The reactant mixture was heated to reflux for 12 h. After cooling, the resulting mixture was dried with $MgSO_4$ and filtered through a pad of Celite. The crude product was purified by bulb to bulb distillation (75 ^oC, 0.5 torr) to afford 3.99g (89%) of the title compound as a clear oil. **^{1}H-NMR** (500 MHz, DMSO-d_6): δ 7.37 (d, *J* = 7.2 Hz, 2H), 7.32 (t, *J* = 7.6 Hz, 2H), 7.23 (t, *J* = 7.2 Hz, 1H), 6.63 (s, 1H), 6.41 (d, *J* = 15.8 Hz, 1H), 6.26 (dt, *J* = 15.5, 7.7 Hz, 1H), 2.74 (s, 6H), 2.34 (d, *J* = 6.7 Hz, 2H), 1.14 (s, 6H). **^{13}C-NMR** (126 MHz, $CDCl_3$): δ 146.29, 138.25, 132.63, 128.84, 127.84, 127.25, 126.42, 45.44, 43.84, 38.19, 26.50. **IR**

(Film): 3025, 2957, 2906, 2864, 2820, 2782, 1598, 1495, 1468, 1444, 1019, 966, 740, 693, cm^{-1}. **HRMS** (ESI): Calcd for $C_{15}H_{22}N_2$ $[M+H]^+$: 231.1861, found 231.1883.

2-(2,2-dimethyl-5-phenylpent-4-en-1-yl)-1,1-dimethylhydrazine (13a). A 100-mL round-bottomed flask equipped with a magnetic stirring bar and an N_2 inlet was charged with hydrazone **9j** (0.60g, 2.60 mmol) and methanol 30 mL was subsequently added. Sodium cyanoborohydride (0.18g, 2.87 mmol) was added in one portion and the solution was titrated with HCl:MeOH (methyl orange indicator, 20% v/v) until a light red color persisted. The reactant mixture was stirred for 30 minutes and then neutralized with aqueous NaOH (25% w/v) to a pH of 11. The volatiles were removed in vacuo and the crude product extracted with diethyl ether (3 x 10 mL). The organic layer was dried with $MgSO_4$, filtered through a pad of Celite and concentrated in vacuo. The crude product was purfied by bulb to bulb distillation (75-80 ^oC, 0.5 torr) to afford 0.52 g (85%) of the title compound. **^{1}H-NMR** (500 MHz, $CDCl_3$): δ 7.42 (d, *J* = 7.2 Hz, 2H), 7.26 (t, *J* = 7.5 Hz, 2H), 7.17 (t, *J* = 7.2 Hz, 1H), 6.52 (d, *J* = 15.7 Hz, 1H), 6.43 (dt, *J* = 15.7, 7.5 Hz, 1H), 2.66 (s, 2H), 2.36 (s, 6H), 2.29 (d, *J* = 7.5 Hz, 2H), 1.78 (s, 1H), 1.07 (s, 6H). **^{13}C-NMR** (126 MHz, $CDCl_3$): δ 138.59, 132.78, 128.94, 127.98, 127.26, 126.60, 59.22, 47.95, 44.32, 35.29, 26.21. **IR** (Film): 3197, 3025, 2949, 2835, 2764, 1494, 1474, 1448, 966, 692 **HRMS** (ESI): Calcd for $C_{15}H_{24}N_2$ $[M+H]^+$: 233.2018, found 233.2045.

(E)-2-((E)-5-(2-methoxyphenyl)-2,2-dimethylpent-4-en-1-ylidene)-1,1-dimethylhydrazine (16b). A 25-mL round-bottom flask equipped with a magnetic stirring bar and an N_2 inlet was charged with diisopropyl amine (0.415 g, 4.10 mmol) followed by THF (10 mL). The resulting mixture was cooled to 0 ^oC and *n*-butyllithium

(1.30 mL, 3.10 M in hexane) was added and the solution was allowed to stir for 30 min at this temperature. A solution of *N*-(tert-butyl)-2-methylpropan-1-imine (0.521 g, 4.10 mmol) in THF (1 mL) was added dropwise via syringe and the reaction mixture was warmed to room temperature. After 2 hours the resulting yellow solution was cooled to -78 ^{o}C and (E)-1-(3-chloroprop-1-en-1-yl)-2-methoxybenzene (0.601 g, 3.90 mmol) was added dropwise via syringe. The reaction mixture was allowed to warm to 23 ^{o}C and stirred at this temperature for 12 h. The resulting homogenous solution was diluted with ether (25 mL) and quenched with $NH_4Cl_{(aq)}$ (10 mL). The organic layer was washed with brine (10 mL), dried with $MgSO_4$ and concentrated *in vacuo*. The crude imine was immediately dissolved in THF 15 mL and a solution of oxalic acid (1.01 g, 8.00 mmol) in H_2O (5 mL) was added at room temperature. The reaction mixture was allowed to stir for 2 h and subsequently diluted with diethyl ether (25 mL). The organic layer was washed with brine (10 mL), dried with $MgSO_4$ and concentrated *in vacuo*. The crude aldehyde was then dissolved in CH_2Cl_2 (10 mL) followed by *N*,*N*-dimethylhydrazine (0.458 g, 8.00 mmol) and $MgSO_4$. The solution was allowed to stir for 4 h, filtered through a plug of Celite and concentrated *in vacuo*. The crude hydrazone was purified by column chromatography on silica gel (5 % EtOAc/Hex to 15 % EtOAc/Hex) to yield the title compound as a clear oil (0.673 g, 63%). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.41 (dd, *J* = 7.6, 1.7 Hz, 1H), 7.20 – 7.15 (m, 1H), 6.90 (t, *J* = 7.5 Hz, 1H), 6.84 (d, *J* = 8.2 Hz, 1H), 6.70 (d, *J* = 15.9 Hz, 1H), 6.61 (s, 1H), 6.20 (dt, *J* = 15.5, 7.5 Hz, 1H), 3.85 – 3.80 (m, 29H), 2.71 (s, 6H), 2.32 (d, *J* = 7.4 Hz, 2H), 1.11 (s, 6H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 156.30, 146.26, 127.93, 127.88, 126.99, 126.88, 126.48, 120.59, 110.83, 55.45, 45.49,

43.46, 37.81, 26.06. **IR** (Film): 2956, 2834, 1596, 1487, 1464, 1241, 1028, 750 cm^{-1}. **HRMS** (ESI): Calcd for $C_{16}H_{24}N_2O$ $[M+H]^+$: 261.1968, found: 261.1950

(E)-2-(5-(2-methoxyphenyl)-2,2-dimethylpent-4-en-1-yl)-1,1-dimethylhydrazine (13b). The title compound was synthesized by the general reduction method for **13a**, utilizing (E)-2-((E)-5-(2-methoxyphenyl)-2,2-dimethylpent-4-en-1-ylidene)-1,1-dimethylhydrazine (0.512 g, 1.93 mmol) and $NaBH_3CN$ (0.243 g, 3.90 mmol). The crude hydrazine was purified by bulb-to-bulb distillation (120 ^oC, 0.5 torr) to give (E)-2-(5-(2-methoxyphenyl)-2,2-dimethylpent-4-en-1-yl)-1,1-dimethylhydrazine (0.486 g, 93 %) as a clear oil. **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.42 (d, *J* = 7.6 Hz, 1H), 7.17 (t, *J* = 8.5 Hz, 1H), 6.89 (t, *J* = 7.5 Hz, 1H), 6.83 (d, *J* = 8.2 Hz, 1H), 6.70 (d, *J* = 15.9 Hz, 1H), 6.23 (dt, *J* = 15.6, 7.6 Hz, 1H), 3.81 (s, 3H), 2.59 (s, 2H), 2.41 (s, 6H), 2.16 (d, *J* = 7.6 Hz, 2H), 0.94 (s, 6H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 156.28, 128.23, 127.82, 126.99, 126.62, 126.42, 120.58, 110.81, 58.76, 55.42, 47.75, 44.28, 34.57, 25.84. **IR** (Film) 2951, 2905, 2834, 2764, 1597, 1488, 1463, 1029, 974, 750 cm^{-1}. **HRMS** (ESI): Calcd for $C_{16}H_{26}N_2O$ $[M+H]^+$: 263.2124, found: 263.2117

(E)-2-((E)-5-(2-chlorophenyl)-2,2-dimethylpent-4-en-1-ylidene)-1,1-dimethylhydrazine (16c). The title compound was synthesized by the general procedure for hydrazone **16b**, utilizing *N*-(tert-butyl)-2-methylpropan-1-imine (0.890 g, 7.00 mmol) and (E)-1-chloro-2-(3-chloroprop-1-en-1-yl)benzene (1.40 g, 7.50 mmol). The crude hydrazone was purified by column chromatography (5% EtOAc/Hex) to give (E)-2-((E)-5-(2-chlorophenyl)-2,2-dimethylpent-4-en-1-ylidene)-1,1-dimethylhydrazine (1.13 g, 61 %) as a clear oil. **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.47 (dd, *J* = 7.8, 1.8 Hz, 1H),

7.31 (dd, *J* = 7.9, 1.4 Hz, 1H), 7.17 (td, *J* = 7.5, 1.4 Hz, 1H), 7.12 (td, *J* = 7.6, 1.8 Hz, 1H), 6.73 (d, *J* = 15.6 Hz, 1H), 6.57 (s, 1H), 6.19 (dt, *J* = 15.4, 7.6 Hz, 1H), 2.70 (s, 6H), 2.34 (dd, *J* = 7.5, 1.4 Hz, 2H), 1.10 (s, 6H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 145.58, 135.94, 132.51, 130.54, 129.52, 128.53, 127.89, 126.81, 126.69, 45.09, 43.40, 37.77, 26.15. **IR** (Film) 2948, 2734, 1566, 1457, 1434, 1251, 1025, 751 **HRMS** (ESI): Calcd for $C_{15}H_{21}ClN_2O$ $[M+H]^+$: 265.1472, found: 265.1457

(E)-2-((E)-5-(2-fluorophenyl)-2,2-dimethylpent-4-en-1-ylidene)-1,1-dimethylhydrazine (16d). The title compound was synthesized by the general procedure for hydrazone **16b**, utilizing *N*-(tert-butyl)-2-methylpropan-1-imine (1.00 g, 7.86 mmol) and (E)-1-(3-chloroprop-1-en-1-yl)-2-fluorobenzene (1.48 g, 8.65 mmol). The crude hydrazone was purified by column chromatography (5 % EtOAc/Hex) to give (E)-2-((E)-5-(2-fluorophenyl)-2,2-dimethylpent-4-en-1-ylidene)-1,1-dimethylhydrazine (1.13 g, 59%) as a clear oil. **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.41 (td, *J* = 7.7, 1.8 Hz, 1H), 7.14 (ddd, *J* = 7.3, 5.4, 1.9 Hz, 1H), 7.05 (td, *J* = 7.5, 1.2 Hz, 1H), 6.99 (ddd, *J* = 10.9, 8.1, 1.2 Hz, 1H), 6.58 (s, 1H), 6.52 (d, *J* = 16.0 Hz, 1H), 6.29 (dt, *J* = 16.0, 7.5 Hz, 1H), 2.70 (s, 6H), 2.33 (dd, *J* = 7.5, 1.3 Hz, 2H), 1.10 (s, 6H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 145.67, 130.23, 128.07, 128.01, 127.09, 124.48, 123.95, 115.65, 115.48, 45.35, 43.41, 37.78, 26.12. **IR** (Film) 3040, 2957, 2922, 2864, 2782, 1486, 1468, 1229, 1020, 970, 753 cm^{-1} **HRMS** (ESI): Calcd for $C_{15}H_{21}FN_2$ $[M+H]^+$: 249.1768, found: 249.1746

(E)-2-(5-(2-fluorophenyl)-2,2-dimethylpent-4-en-1-yl)-1,1-dimethylhydrazine (13d). The title compound was synthesized by the general reduction procedure of **13b** utilizing hydrazone **16d** (0.751 g, 3.00 mmol) and $NaBH_3CN$ (0.375 g, 6.00 mmol) to yield (E)-2-

(5-(2-fluorophenyl)-2,2-dimethylpent-4-en-1-yl)-1,1-dimethylhydrazine (0.668 g, 89%) as a clear oil. **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.41 (td, *J* = 7.7, 1.8 Hz, 1H), 7.13 (tdd, *J* = 7.2, 5.1, 1.8 Hz, 1H), 7.04 (td, *J* = 7.5, 1.3 Hz, 1H), 6.98 (ddd, *J* = 10.9, 8.1, 1.3 Hz, 1H), 6.52 (d, *J* = 15.9 Hz, 1H), 6.31 (dt, *J* = 15.6, 7.6 Hz, 1H), 2.58 (s, 2H), 2.45 – 2.38 (m, 6H), 2.16 (dd, *J* = 7.6, 1.3 Hz, 2H), 1.92 (s, 1H), 0.92 (s, 6H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 130.48, 127.99, 127.92, 127.07, 124.29, 123.91, 115.65, 115.47, 58.74, 47.75, 44.23, 34.60, 25.76. **IR** (Film) 2952, 2837, 1486, 1455, 1229, 970, 753 cm^{-1}. **HRMS** (ESI): Calcd for $C_{15}H_{23}FN_2$ $[M+H]^+$: 251.1924, found: 251.1912

(E)-2,2-dimethyl-5-(o-tolyl)pent-4-enenitrile (17e). A 25-mL round-bottomed flask equipped with a magnetic stirring bar and an N_2 inlet was charged with diisopropylamine (0.561 g, 5.50 mmol) and THF (10 mL). The reaction mixture was cooled to 0 ^{o}C and *n*-butyllithium (1.85 mL, 3.0M, 5.50 mmol) was added dropwise via syringe. The resulting solution was allowed to stir at this temperature for 30 min and then cooled to -78 ^{o}C and isobutyrnitrile (0.377 g, 0.55 mmol) was added dropwise via syringe and the reaction mixture was stirred for an additional 2 hours at this temperature. A solution of (E)-1-(3-chloroprop-1-en-1-yl)-2-methylbenzene (0.911 g, 0.55 mmol) in THF (1 mL) was added all at once and the reaction mixture was allowed to slowly warm to 23 ^{o}C over 3 hours. The reaction was quenched with aqueous NH_4Cl (5 mL) and diluted with ether (25 mL). The organic layer was washed with brine (10 mL), dried with $MgSO_4$ and concentrated *in vacuo*. The crude nitrile was purified by column chromatography (5 % - 15 % EtOAc/Hex) to yield the title compound (1.01 g, 92 %) as a clear oil. **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.48 – 7.41 (m, 1H), 7.20 – 7.11 (m, 3H), 6.73 (d, *J* = 15.6 Hz, 1H), 6.12

(dt, *J* = 15.3, 7.5 Hz, 1H), 2.45 (dd, *J* = 7.5, 1.3 Hz, 2H), 2.35 (s, 3H), 1.39 (s, 6H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 136.05, 135.26, 132.96, 130.24, 127.61, 126.14, 125.85, 125.03, 124.77, 44.52, 32.73, 26.33, 19.84. **IR** (Film) 3061, 2976, 2935, 2234, 1484, 1460, 1369, 970, 950 cm^{-1}. **HRMS** (ESI): Calcd for $C_{14}H_{17}N$ $[M+H]^+$: 200.1440, found: 200.1427

(E)-2-((E)-2,2-dimethyl-5-(o-tolyl)pent-4-en-1-ylidene)-1,1-dimethylhydrazine (16e). A 50-mL round-bottomed flask equipped with a magnetic stirring bar and an N_2-inlet was charged with nitrile **9e** (0.771 g, 3.90 mmol) and CH_2Cl_2 (15 mL). The reaction mixture was cooled to -78 ^oC, DIBAL (6.20 mL, 8.11 mmol, 1.3 M) was added dropwise via syringe and the resulting solution was allowed to stir at this temperature for 1 h, then slowly warmed to 23 ^oC and stirred for an additional 12 hours. The reaction mixture was cooled to 0 ^oC, diluted with ether (10 mL) and methanol (1 mL) followed by 1 M HCl (5 mL) were slowly added. The resulting heterogeneous solution was allowed to stir at room temperature until all solids were dissolved. The organic layer was washed with 1 M HCl (2 x 5 mL), brine (5 mL), dried with $MgSO_4$ and concentrated *in vacuo*. The crude aldehyde was dissolved in CH_2Cl_2 and *N*,*N*-dimethyl hydrazine (0.469 g, 7.80 mmol) and $MgSO_4$ were subsequently added. The reaction mixture was stirred for 2 h until judged complete by TLC, filtered through Celite and concentrated *in vacuo*. The crude hydrazone was purified by column chromotagraphy (5% EtOAc/Hex) to yield the title compound (0.848 g, 89%) as a clear oil. **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.42 – 7.36 (m, 1H), 7.17 – 7.09 (m, 3H), 6.61 – 6.52 (m, 2H), 6.09 (dd, *J* = 15.4, 7.7 Hz, 1H), 2.71 (s, 6H), 2.33 (d, *J* = 6.5 Hz, 5H), 1.11 (s, 6H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 145.86,

137.12, 134.91, 130.26, 130.09, 128.86, 126.84, 125.97, 125.71, 45.35, 43.42, 37.73, 26.08, 19.87. **IR** (Film) 2956, 2922, 2781, 1467, 1443, 1249, 1138, 1009, 967, 744 cm^{-1}. **HRMS** (ESI): Calcd for $C_{16}H_{24}N_2$ $[M+H]^+$: 245.2018, found: 245.2085

(E)-2-(2,2-dimethyl-5-(o-tolyl)pent-4-en-1-yl)-1,1-dimethylhydrazine (13e). The title compound was synthesized by the general reduction procedure of **13a** utilizing hydrazone **16e** (0.400 g, 1.60 mmol) and $NaBH_3CN$ (0.205 g, 3.20 mmol) to give the hydrazine (0.367 g, 93 %) as a clear oil. **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.41 (d, *J* = 7.0 Hz, 1H), 7.16 – 7.09 (m, 3H), 6.57 (d, *J* = 15.6 Hz, 1H), 6.11 (dt, *J* = 15.4, 7.6 Hz, 1H), 2.60 (s, 2H), 2.42 (s, 6H), 2.33 (s, 3H), 2.17 (dd, *J* = 7.6, 1.4 Hz, 2H), 2.00 (s, 1H), 0.94 (s, 6H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 137.12, 134.86, 130.10, 130.03, 129.09, 126.79, 125.98, 125.61, 58.79, 47.78, 44.11, 34.55, 25.74, 19.87. **IR** (Film) 3019, 2956, 2864, 1697, 1467, 1443, 1020, 967, 743 cm^{-1}. **HRMS** (ESI): Calcd for $C_{16}H_{26}N_2$ $[M+H]^+$: 247.2175, found: 247.2155

(E)-2-((Z)-2,2-dimethyl-5-phenylpent-4-en-1-ylidene)-1,1-dimethylhydrazine (16f). The title compound was synthesized by the general alkylation procedure used for **16b** utilizing *N*-(tert-butyl)-2-methylpropan-1-imine (1.65 g, 13.0 mmol) and *cis*-cinnamyl chloride (1.92 g, 12.6 mmol) to give the hydrazone **16f** (1.89 g, 65%) as a clear oil. **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.30 – 7.23 (m, 4H), 7.20 – 7.17 (m, 1H), 6.50 – 6.42 (m, 2H), 5.67 (dt, *J* = 11.8, 7.2 Hz, 1H), 2.66 (s, 6H), 2.41 (dd, *J* = 7.2, 2.0 Hz, 2H), 1.04 (s, 6H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 145.53, 137.80, 130.13, 129.22, 128.82, 128.16, 128.07, 127.46, 126.41, 43.35, 43.30, 39.78, 26.00. **IR** (Film) 2957, 2865, 2783, 1468,

1444, 1011, 910, 732 cm^{-1}. **HRMS** (ESI): Calcd for $C_{15}H_{22}N_2$ $[M+H]^+$: 231.1862, found: 231.1836

(Z)-2-(2,2-dimethyl-5-phenylpent-4-en-1-yl)-1,1-dimethylhydrazine (13f). The title compound was synthesized by the general reduction procedure for hydrazine **13a** utilizing hydrazone **16f** (1.13 g, 4.90 mmol) and $NaBH_3CN$ (0.462 g 9.80 mmol) to yield (Z)-2-(2,2-dimethyl-5-phenylpent-4-en-1-yl)-1,1-dimethylhydrazine (0.948 g, 84 %) as a clear oil. **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.34 – 7.27 (m, 4H), 7.23 – 7.17 (m, 1H), 6.49 (dt, *J* = 11.8, 1.9 Hz, 1H), 5.74 (dt, *J* = 11.8, 7.4 Hz, 1H), 2.54 (s, 2H), 2.34 (s, 6H), 2.29 (dd, *J* = 7.4, 1.9 Hz, 2H), 1.79 (s, 1H), 0.91 (s, 6H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 137.78, 131.51, 130.19, 129.30, 128.86, 128.15, 128.06, 126.39, 63.97, 58.51, 47.65, 38.15, 34.33, 25.71. **IR** (Film) **HRMS** (ESI): Calcd for $C_{15}H_{24}N_2$ $[M+H]^+$: 233.2018, found 233.2046

(E)-5-(2-(dimethylamino)phenyl)-2,2-dimethylpent-4-enenitrile (17g). The title compound was synthesized by the general procedure for nitrile **17e** utilizing isobutyrnitrile (0.345 g, 5.00 mmol) and (E)-2-(3-chloroprop-1-en-1-yl)-*N*,*N*-dimethylaniline (1.00 g, 5.10 mmol) to yield (E)-5-(2-(dimethylamino)phenyl)-2,2-dimethylpent-4-enenitrile (1.04 g, 91 %) as a clear oil. **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.44 (dd, *J* = 7.7, 1.7 Hz, 1H), 7.25 – 7.18 (m, 1H), 7.00 (ddd, *J* = 15.6, 7.9, 1.2 Hz, 2H), 6.85 (d, *J* = 15.8 Hz, 1H), 6.24 – 6.15 (m, 1H), 2.71 (s, 6H), 2.47 (dd, *J* = 7.5, 1.3 Hz, 2H), 1.39 (s, 6H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 151.69, 132.79, 130.88, 128.26,

127.20, 124.91, 122.86, 122.42, 118.09, 44.74, 44.68, 32.76, 26.41. **HRMS** (ESI): Calcd for $C_{15}H_{20}N_2$ $[M+H]^+$: 229.1705, found 229.1698

2-((1E,5E)-5-(2,2-dimethylhydrazono)-4,4-dimethylpent-1-en-1-yl)-N,N-dimethylaniline (16g). The title compound was synthesized by the general reduction procedure for hydrazone **16e** utilizing nitrile **17g** (0.891 g, 3.90 mmol) and DIBAL (8.3 mL, 8.30 mmol, 1 M) to give 2-((1E,5E)-5-(2,2-dimethylhydrazono)-4,4-dimethylpent-1-en-1-yl)-N,N-dimethylaniline (0.938 g, 88 %) **^{1}H NMR** (500 MHz, DMSO) δ 7.39 (dd, *J* = 7.7, 1.6 Hz, 1H), 7.21 – 7.13 (m, 1H), 7.02 – 6.93 (m, 2H), 6.69 (d, *J* = 15.8 Hz, 1H), 6.60 (s, 1H), 6.20 – 6.09 (m, 1H), 2.72 – 2.70 (m, 6H), 2.70 (s, 6H), 2.34 (d, *J* = 7.5 Hz, 2H), 1.11 (s, 6H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 151.28, 146.03, 131.92, 130.18, 127.49, 127.07, 126.74, 122.23, 117.82, 45.51, 44.52, 43.41, 38.06, 26.14. **IR** (Film) 2953, 2826, 1594, 1487, 1455, 1008, 947, 759 cm^{-1}. **HRMS** (ESI): Calcd for $C_{17}H_{27}N_3$ $[M+H]^+$: 274.2284, found 274.2298

(E)-2-(5-(2,2-dimethylhydrazinyl)-4,4-dimethylpent-1-en-1-yl)-N,N-dimethylaniline (13g). The title compound was prepared by the general reduction procedure of **13a** utilizing hydrazone **16g** (0.750 g, 2.74 mmol) and $NaBH_3CN$ (0.344 g, 5.48 mmol) to yield (E)-2-(5-(2,2-dimethylhydrazinyl)-4,4-dimethylpent-1-en-1-yl)-N,N-dimethylaniline (0.619 g, 81 %) as a clear oil. **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.42 (dd, *J* = 7.7, 1.6 Hz, 1H), 7.18 (ddd, *J* = 8.7, 7.2, 1.6 Hz, 1H), 7.02 – 6.94 (m, 2H), 6.70 (d, *J* = 15.8 Hz, 1H), 6.24 – 6.13 (m, 1H), 2.72 (d, *J* = 0.9 Hz, 6H), 2.62 (s, 2H), 2.42 (d, *J* = 0.9 Hz, 6H), 2.20 (dd, *J* = 7.6, 1.3 Hz, 2H), 1.94 (s, 1H), 0.95 (s, 6H). **^{13}C NMR** (126 MHz,

$CDCl_3$) δ 151.26, 132.00, 130.00, 127.45, 126.99, 122.29, 117.87, 59.04, 47.78, 44.55, 44.33, 34.87, 25.80. **IR** (Film) 3330, 2974, 2863, 2781, 1594, 1487, 1453, 1118, 760 cm^{-1}. **HRMS** (ESI): Calcd for $C_{17}H_{29}N_3$ $[M+H]^+$: 276.2440, found 276.2476

(E)-2,2-dimethyl-5-(thiophen-2-yl)pent-4-enenitrile (17h). The title compound was prepared by the general alkylation procedure for nitrile **17e** utilizing isobutyrnitrile (0.483 g, 7.00 mmol) and (E)-2-(3-chloroprop-1-en-1-yl)thiophene (1.13 g, 7.10 mmol) to give (E)-2,2-dimethyl-5-(thiophen-2-yl)pent-4-enenitrile (0.750 g, 56 %) as clear oil. **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.14 (d, *J* = 5.1 Hz, 1H), 6.94 (d, *J* = 4.6 Hz, 2H), 6.65 – 6.57 (m, 1H), 6.05 (dt, *J* = 15.3, 7.6 Hz, 1H), 2.39 (d, *J* = 7.6 Hz, 2H), 1.36 (s, 6H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 141.68, 127.85, 127.31, 125.61, 124.68, 124.24, 123.07, 44.17, 32.62, 26.27, 26.24. **IR** (Film) 3437, 2977, 2233, 1646, 1467, 1205, 959, 700 cm^{-1}. **HRMS** (ESI): Calcd for $C_{11}H_{13}NS$ $[M+H]^+$: 192.0848, found 192.0855

(E)-2-((E)-2,2-dimethyl-5-(thiophen-2-yl)pent-4-en-1-ylidene)-1,1-dimethylhydrazine (16h). The title compound was prepared by the general reduction procedure for hydrazone **16e** utilizing nitrile **17h** (0.700 g, 3.66 mmol) and DIBAL (8.05 mL, 8.05 mmol, 1 M) to give (E)-2-((E)-2,2-dimethyl-5-(thiophen-2-yl)pent-4-en-1-ylidene)-1,1-dimethylhydrazine (0.753 g, 87 %) as a clear oil. **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.07 (d, *J* = 5.0 Hz, 1H), 6.92 (dd, *J* = 5.0, 3.6 Hz, 1H), 6.86 (d, *J* = 3.3 Hz, 1H), 6.57 (s, 1H), 6.49 (d, *J* = 15.6 Hz, 1H), 6.06 (dt, *J* = 15.4, 7.6 Hz, 1H), 2.70 (s, 6H), 2.26 (dd, *J* = 7.6, 1.4 Hz, 2H), 1.09 (s, 6H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 145.79, 143.01, 127.43, 127.19, 125.36, 124.29, 123.15, 44.83, 43.43, 37.83, 26.08. **IR** (Film) 2956, 2923, 2863,

1468, 1441, 1019, 956, 694. **HRMS** (ESI): Calcd for $C_{13}H_{20}N_2S$ $[M+H]^+$: 237.1426, found 237.1475

(E)-2-(2,2-dimethyl-5-(thiophen-2-yl)pent-4-en-1-yl)-1,1-dimethylhydrazine (13h). The title compound was prepared by the general reduction procedure for hydrazine **13a** utilizing hydrazone **16h** (0.600 g, 2.50 mmol) and $NaBH_3CN$ (0.319 g, 5.00 mmol) to give (E)-2-(2,2-dimethyl-5-(thiophen-2-yl)pent-4-en-1-yl)-1,1-dimethylhydrazine (0.483 g, 81 %) as clear oil. **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.09 – 7.02 (m, 1H), 6.91 (dd, *J* = 5.1, 3.5 Hz, 1H), 6.84 (d, *J* = 3.3 Hz, 1H), 6.52 – 6.44 (m, 1H), 6.08 (dt, *J* = 15.4, 7.7 Hz, 1H), 2.56 (s, 2H), 2.40 (s, 6H), 2.10 (dd, *J* = 7.7, 1.4 Hz, 2H), 1.90 (s, 1H), 0.91 (s, 6H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 143.09, 127.74, 127.17, 125.18, 124.19, 123.06, 58.76, 47.77, 43.78, 34.68, 25.71. **IR** (Film) 2952, 2865, 1675, 1468, 1442, 1016, 957, 693. **HRMS** (ESI): Calcd for $C_{13}H_{22}N_2S$ $[M+H]^+$: 239.1583, found 239.1599

(E)-2-((Z)-6-(benzyloxy)-2,2-dimethylhex-4-en-1-ylidene)-1,1-dimethylhydrazine (16i). The title compound was synthesized by the general method of hydrazone **16b** utilizing *N*-(tert-butyl)-2-methylpropan-1-imine (1.09 g, 8.60 mmol) and (Z)-(((4-bromobut-2-en-1-yl)oxy)methyl)benzene (2.29 g, 9.50 mmol) to yield (E)-2-((Z)-6-(benzyloxy)-2,2-dimethylhex-4-en-1-ylidene)-1,1-dimethylhydrazine (1.58 g, 67 %) as a clear oil. **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.33 (d, *J* = 4.3 Hz, 4H), 7.29 – 7.25 (m, 1H), 6.49 (s, 1H), 5.71 – 5.57 (m, 2H), 4.49 (s, 2H), 4.06 (d, *J* = 6.1 Hz, 2H), 2.67 (s, 6H), 2.13 (d, *J* = 7.3 Hz, 2H), 1.03 (s, 6H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 145.27, 138.42, 131.17, 129.77, 128.96, 128.34, 127.97, 127.76, 127.54, 72.18, 65.95, 43.31, 39.09,

37.55, 25.95. **IR** (Film) 2956, 2926, 2853, 1468, 1444, 1098, 1072, 1026, 1010, 735, 698 cm^{-1}. **HRMS** (ESI): Calcd for $C_{17}H_{26}N_2O$ $[M+H]^+$: 275.2124, found 275.2115

(Z)-2-(6-(benzyloxy)-2,2-dimethylhex-4-en-1-yl)-1,1-dimethylhydrazine (13i). The title compound was synthesized by the general reduction method of hydrazine **13a** utilizing hydrazone **16i** (1.00 g, 3.64 mmol) and $NaBH_3CN$ (0.458 g, 7.29 mmol) to yield **(**Z)-2-(6-(benzyloxy)-2,2-dimethylhex-4-en-1-yl)-1,1-dimethylhydrazine (0.916 g, 91%) as a clear oil. **^{1}H NMR** (500 MHz, DMSO) δ 7.33 (q, *J* = 3.9, 2.9 Hz, 4H), 7.26 (ddd, *J* = 7.3, 4.9, 2.3 Hz, 1H), 5.72 – 5.60 (m, 2H), 4.50 (s, 2H), 4.07 (d, *J* = 5.8 Hz, 2H), 2.51 (s, 2H), 2.38 (s, 6H), 1.99 (d, *J* = 7.0 Hz, 2H), 1.86 (s, 1H), 0.86 (s, 6H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 138.43, 130.08, 128.33, 127.87, 127.76, 127.52, 127.49, 72.19, 65.91, 58.60, 47.74, 37.73, 34.42, 25.56. **IR** (Film) 2956, 2926, 2853, 1468, 1444, 1098, 1072, 1026, 1010, 735, 698 cm^{-1} **HRMS** (ESI): Calcd for $C_{17}H_{28}N_2O$ $[M+H]^+$: 277.2281, found 277.2276

(E)-5-cyclopropyl-2,2-dimethylpent-4-enenitrile (17j). The title compound was synthesized by the general alkylation procedure of nitrile **17e** utilizing isobutyrnitrile (0.621 g, 9.00 mmol) and (E)-(3-chloroprop-1-en-1-yl)cyclopropane (1.19 g, 10.2 mmol) to yield (E)-5-cyclopropyl-2,2-dimethylpent-4-enenitrile (1.52 g, 87 %) as a clear oil. **^{1}H NMR** (500 MHz, $CDCl_3$) δ 5.60 – 5.51 (m, 1H), 5.12 (ddt, *J* = 15.1, 8.6, 1.3 Hz, 1H), 2.20 (dd, *J* = 7.4, 1.2 Hz, 2H), 1.44 – 1.38 (m, 1H), 1.32 (s, 6H), 0.76 – 0.67 (m, 2H), 0.38 (dt, *J* = 6.4, 4.4 Hz, 2H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 139.66, 124.95, 120.94,

43.78, 32.58, 26.12, 13.54, 6.65. **IR** (Film) 3005, 2987, 2933, 2234, 1662, 1468, 1459, 1021, 966. **HRMS** (ESI): Calcd for $C_{10}H_{15}N$ $[M+H]^+$: 150.1283, found 150.1289

(E)-2-((E)-5-cyclopropyl-2,2-dimethylpent-4-en-1-ylidene)-1,1-dimethylhydrazine (16j). The title compound was synthesized by the general reduction procedure of hydrazone **16e** utilizing nitrile **17j** (1 g, 6.70 mmol) and DIBAL (13.4 mL, 13.4 mmol, 1 M) to yield (E)-2-((E)-5-cyclopropyl-2,2-dimethylpent-4-en-1-ylidene)-1,1-dimethylhydrazine (1.20 g, 92 %) as a clear liquid. **^{1}H NMR** (500 MHz, $CDCl_3$) δ 6.52 (s, 1H), 5.45 (dt, *J* = 14.9, 7.4 Hz, 1H), 4.98 – 4.87 (m, 1H), 2.73 – 2.60 (m, 6H), 2.11 – 1.94 (m, 2H), 1.32 (dt, *J* = 9.0, 4.5 Hz, 1H), 0.99 (d, *J* = 8.1 Hz, 6H), 0.65 – 0.57 (m, 2H), 0.30 – 0.23 (m, 2H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 146.73, 136.55, 124.02, 44.60, 43.45, 37.41, 25.74, 24.60, 13.53, 6.40. **IR** (Film) 3001, 2956, 2864, 1468, 1443, 1249, 1019, 963, 810, 587, 526 cm^{-1}. **HRMS** (ESI): Calcd for $C_{12}H_{22}N_2$ $[M+H]^+$: 195.1862, found 195.1883

(E)-2-(5-cyclopropyl-2,2-dimethylpent-4-en-1-yl)-1,1-dimethylhydrazine (13j). The title compound was synthesized by the general reduction procedure of hydrazine **13a** utilizing hydrazone **16j** (0.988 g, 5.00 mmol) and $NaBH_3CN$ (0.628 g, 10.0 mmol) to yield (E)-2-(5-cyclopropyl-2,2-dimethylpent-4-en-1-yl)-1,1-dimethylhydrazine (0.746 g, 76%) as a clear liquid. **^{1}H NMR** (500 MHz, $CDCl_3$) δ 5.45 (dt, *J* = 15.1, 7.5 Hz, 1H), 4.92 (dd, *J* = 15.1, 8.4 Hz, 1H), 2.48 (s, 2H), 2.36 (s, 6H), 1.84 (s, 2H), 1.30 (qt, *J* = 8.4, 4.8 Hz, 1H), 0.82 (s, 6H), 0.65 – 0.54 (m, 2H), 0.26 (dt, *J* = 6.3, 4.2 Hz, 2H). **^{13}C NMR**

(126 MHz, $CDCl_3$) δ 136.17, 124.29, 58.51, 47.68, 43.32, 33.99, 25.61, 24.58, 13.52, 6.34. **IR** (Film) **HRMS** (ESI): Calcd for $C_{12}H_{24}N_2$ $[M+H]^+$: 197.2018, found 197.2033.

***N*-(2,2-dimethylpent-4-en-1-yl)-*O*-methylhydroxylamine (5a)**. A 25-mL round-bottomed flask equipped with a magnetic stirring bar and an N_2-inlet was charged with (E)-2,2-dimethylpent-4-enal O-methyl oxime (0.5 g, 3.50 mmol), methyl orange (5 mg) and MeOH (10 mL). The resulting reaction mixture was cooled to 0 ^oC and $NaBH_3CN$ (0.245 g, 7.00 mmol) was added all at once. The reaction mixture was acidified with HCl/MeOH (1:5 v/v) to pH 3 and allowed to warm to 23 ^oC. After stirring for 30 min, the volatiles were removed *in vacuo* and the resulting pink solid was treated with 1 M NaOH (10 mL). The aqueous layer was extracted with ether (3 x 15 mL) and the organic layer was washed with brine (10 mL), dried with $MgSO_4$, and concentrated. The crude methoxyamine was purified by bulb-to-bulb distillation (23 ^oC, 0.5 torr) to yield the title compound as a clear oil. (0.461 g, 92 %). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 5.80 (ddt, *J* = 16.5, 10.6, 7.5 Hz, 1H), 5.14 – 4.89 (m, 2H), 3.48 (s, 3H), 2.72 (s, 2H), 1.99 (dt, *J* = 7.4, 1.2 Hz, 2H), 0.89 (s, 6H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 135.12, 117.15, 61.18, 61.13, 45.06, 33.63, 25.74. **IR** (Film) 3075, 2958, 2870, 1638, 1466, 1021, 910, 736. **HRMS** (ESI): Calcd for $C_8H_{17}NO$ $[M+H]^+$: 144.1389, found 144.1343.

***N*-(hex-5-en-2-yl)-*O*-methylhydroxylamine (5b)**. The title compound was synthesized in an analogous fashion to **5a** utilizing (E)-hex-5-en-2-one O-methyl oxime (1.00g, 7.86 mmol) and $NaBH_3CN$ (0.543g, 8.65 mmol) to yield *N*-(hex-5-en-2-yl)-*O*-methylhydroxylamine as clear oil. (0.792 g, 78 %). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 5.85

(ddt, *J* = 16.9, 10.2, 6.6 Hz, 1H), 5.14 – 4.95 (m, 2H), 3.58 (s, 3H), 3.05 (d, *J* = 6.4 Hz, 1H), 2.21 – 2.06 (m, 2H), 1.71 – 1.61 (m, 1H), 1.47 – 1.35 (m, 1H), 1.11 (d, *J* = 6.4 Hz, 3H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 138.39, 114.64, 62.42, 55.51, 32.94, 30.18, 17.84. **IR** (Film) 2976, 2857, 1641, 1464, 1372, 1054, 995, 911, 734. **HRMS** (ESI): Calcd for $C_7H_{15}NO$ $[M+H]^+$: 130.1233, found 130.1227.

Synthesis of Cyclic Hydrazines.

General Procedure for CuCN Mediated Allylation of Metalloamination Intermediates: In an argon-filled glove box, $ZnEt_2$ in *p*-xylene (50 μL, 2.0 M, 0.10 mmol) and toluene or (trifluoromethyl)benzene (0.5 mL) were introduced into a J. Young NMR tube equipped with a Teflon screw cap, and hydrazinoalkene (**2a-2k**) (0.10 mmol) was subsequently added. The reactant mixture was heated in a 90 ^oC oil bath until metalloamination was complete (≥ 90% by ^1H NMR, *p*-xylene as internal standard). The volatiles were removed in vacuo and THF (0.5 mL) was introduced to the J. Young tube in an argon-filled dry box followed by the addition of a solution of CuCN•2LiCl in THF[7] (150 μL, 1.0 M, 0.15 mmol). After 5 min, allyl bromide (14.5 mg, 0.12 mmol) [or methallyl chloride (10.9 mg, 0.12 mmol)] was added and the reactant mixture was kept at 23 ^oC for 2 h (or until the reaction was complete ≥95% ^1H NMR). The Teflon screw cap was removed and the reactant mixture transferred to a 10 mL test tube, diluted with diethyl ether (2.0 mL) and an aqueous solution of $NH_4Cl_{(sat)}$ and NH_3/H_2O (1:1 v/v, 2 mL) was subsequently added. The resulting suspension was vigorously stirred for 10 min until the aqueous layer developed a deep blue color. The organic layer was removed and

washed with a second portion of NH_4Cl and NH_3/H_2O (1:1 v/v, 2 mL), followed by brine (2 mL) and dried with $MgSO_4$. The ether solution was then transferred to a 10-mL round-bottomed flask equipped with a magnetic stirring bar and a N_2 inlet and cooled to 0 ^oC. Trifluoroacetic acid (13.7 mg, 0.12 mmol) was added dropwise via gas-tight syringe and the reactant mixture was allowed to stir for 1 h. The volatiles were removed in vacuo and the resultant viscous oil was triturated with pentane (3 x 1 mL) to afford the trifluoroacetate salts **4a-4j**.

2-(But-3-en-1-yl)-*N*,*N*,4,4-tetramethylpyrrolidin-1-amine (10a R=H). The title compound was isolated as a light yellow oil, which slowly solidified upon storage. 28.6 mg (92%) **^{1}H-NMR** (500 MHz, C_6H_6): δ 5.77 (ddt, *J* = 17.0, 10.3, 6.7 Hz, 1H), 5.10-5.05 (m, 2H), 3.45 (tdd, *J* = 10.3, 6.8, 3.4 Hz, 1H), 3.37 (d, *J* = 10.8 Hz, 1H), 2.98 (d, *J* = 10.8 Hz, 1H), 2.75 (s, 6H), 2.23 (td, *J* = 13.5, 6.0 Hz, 1H), 2.18-2.11 (m, 1H), 2.04 (td, *J* = 14.4, 7.3 Hz, 1H), 1.96 (dd, *J* = 13.2, 6.7 Hz, 1H), 1.84-1.78 (m, 1H), 1.74 (dd, *J* = 13.0, 10.7 Hz, 1H), 1.24 (s, 3H), 1.20 (s, 3H). **^{13}C-NMR** (126 MHz, $CDCl_3$): δ 161.47, 161.16, 160.85, 160.54, 136.79, 116.59, 64.13, 56.11, 43.13, 41.04, 35.59, 30.59, 29.70, 29.43, 28.73. **IR** (Film): 3448 (b), 2968, 2875, 1674, 1463, 1409, 1197, 1132, cm^{-1}. **HRMS** (ESI): Calcd for $C_{12}H_{24}N_2$ $[M+H]^+$: 197.2018, found: 197.2058.

***N*,*N*,4,4-Tetramethyl-2-(3-methylbut-3-en-1-yl)pyrrolidin-1-amine (10a R=Me)**. The title compound was isolated as a light yellow oil. 26.8 mg (83%). **^{1}H-NMR** (500 MHz, $CDCl_3$): δ 4.75 (d, *J* = 34.9 Hz, 2H), 3.42 (d, *J* = 10.9 Hz, 2H), 2.95 (d, *J* = 10.8 Hz, 1H), 2.73 (s, 6H), 2.25 (dtd, *J* = 12.8, 8.6, 3.8 Hz, 1H), 2.14 (dt, *J* = 14.2, 7.0 Hz, 1H), 2.01 (dt, *J* = 14.8, 7.6 Hz, 1H), 1.94 (dd, *J* = 13.1, 6.6 Hz, 1H), 1.85 (ddd, *J* = 18.4, 9.2, 4.1

Hz, 1H), 1.78 (t, *J* = 12.0 Hz, 1H), 1.74 (d, *J* = 5.8 Hz, 3H), 1.25 (s, 3H), 1.19 (s, 3H). **^{13}C-NMR** (126 MHz, $CDCl_3$): δ 161.59, 161.29, 144.19, 111.65, 63.94, 55.55, 43.11, 40.87, 35.59, 34.70, 29.50, 28.70, 28.22, 22.33. **IR** (Film): 2969, 2936, 2877, 2667 (b), 1778, 1736, 1671, 1464, 1184, 1142, 910, 734, cm^{-1}. **HRMS** (ESI): Calcd for $C_{13}H_{26}N_2$ $[M+H]^+$: 211.2174, found: 211.2063.

2-(But-3-en-1-yl)-*N*,*N*,5-trimethylpyrrolidine-1-amine (10b R=H). The title compound was isolated as a light yellow oil. 23.9 mg (81%). **^{1}H-NMR** (500 MHz, $CDCl_3$): δ 5.83-5.75 (m, 1H), 5.09-5.03 (m, 2H), 3.59 (dt, *J* = 12.9, 6.4 Hz, 1H), 3.43-3.38 (m, 1H), 2.90 (s, 6H), 2.20 (dq, *J* = 13.5, 7.1 Hz, 1H), 2.07-1.97 (m, 4H), 1.85 (qd, *J* = 10.2, 5.8 Hz, 3H), 1.45 (d, *J* = 6.4 Hz, 3H). **^{13}C-NMR** (126 MHz, $CDCl_3$): δ 161.74, 161.46, 160.60, 159.76, 137.31, 116.22, 63.48, 58.88, 41.69, 32.89, 30.85, 30.31, 27.74, 19.93. **IR** (Film): 3360 (b), 2927, 2611 (b), 1738, 1672, 1465, 1409, 1199, 1134, 798, 719, cm^{-1}. **HRMS** (ESI): Calcd for $C_{11}H_{22}N_2$ $[M+H]^+$: 183.1861, found: 183.1734.

***N*,*N*,2-Trimethyl-5-(3-methylbut-3-en-1-yl)pyrrolidin-1-amine (10b R=Me)**. The title compound was isolated as a light yellow oil. 26.3 mg (86%). **^{1}H-NMR** (500 MHz, $CDCl_3$): δ 4.74 (d, *J* = 32.0 Hz, 2H), 3.61 (q, *J* = 6.6 Hz, 1H), 3.39 (td, *J* = 8.1, 5.2 Hz, 1H), 2.90 (s, 6H), 2.13-2.01 (m, 5H), 1.85 (dt, *J* = 7.0, 3.7 Hz, 3H), 1.74 (s, 3H), 1.46 (d, *J* = 6.4 Hz, 3H). **^{13}C-NMR** (126 MHz, $CDCl_3$): δ 144.39, 111.46, 64.01, 58.99, 41.65, 34.72, 31.24, 30.17, 27.53, 22.47, 19.69. **IR** (Film): 3385 (b), 2971, 2618 (b), 1671, 1463, 1200, 1138. **HRMS** (ESI): Calcd for $C_{12}H_{24}N_2$ $[M+H]^+$: 197.2018, found: 197.1886.

2-(But-3-en-1-yl)-*N*,*N*-dimethylpyrrolidin-1-amine (10c R=H). The title compound was isolated as a light yellow oil. 22.7 mg (80%). **^{1}H-NMR** (500 MHz, $CDCl_3$): δ 5.79-5.75 (m, 1H), 5.11-5.04 (m, 2H), 3.69-3.65 (m, 1H), 3.40-3.34 (m, 1H), 3.29-3.23 (m, 1H), 2.73 (s, 6H), 2.26-2.23 (m, 1H), 2.20-2.06 (m, 4H), 1.96 (td, *J* = 10.6, 6.5 Hz, 1H), 1.88-1.80 (m, 2H). **^{13}C-NMR** (126 MHz, $CDCl_3$): δ 136.92, 116.57, 64.93, 44.86, 41.31, 30.76, 29.88, 28.43, 21.71. **IR** (Film): 2978, 2803, 2527 (b), 1778, 1739, 1671, 1461, 1414, 1198, 1138, 798, 720 cm^{-1}. **HRMS** (ESI): Calcd for $C_{10}H_{20}N_2$ $[M+H]^+$: 169.1705, found: 169.1552.

***N*,*N*-Dimethyl-2-(3-methylbut-3-en-1-yl)pyrrolidin-1-amine (10c R=Me)**. The title compound was isolated as a yellow oil. 22.5 mg (76%). **^{1}H-NMR** (500 MHz, $CDCl_3$): δ 4.76 (d, *J* = 32.5 Hz, 2H), 3.69-3.64 (m, 1H), 3.35-3.31 (m, 1H), 3.28-3.23 (m, 1H), 2.72 (s, 6H), 2.24-2.12 (m, 4H), 2.06 (dd, *J* = 14.1, 6.8 Hz, 1H), 1.98-1.93 (m, 1H), 1.87-1.80 (m, 2H), 1.74 (s, 3H). **^{13}C-NMR** (126 MHz, $CDCl_3$): δ 144.09, 111.72, 65.06, 46.44, 44.53, 41.22, 34.69, 28.38, 22.38, 21.71. **IR** (Film): 3422 (b), 2969, 2927, 2853, 2581 (b), 1778, 1738, 1671, 1458, 1198, 1136, 798, 720, cm^{-1}. **HRMS** (ESI): Calcd for $C_{11}H_{22}N_2$ $[M+H]^+$: 183.1861, found 183.1844.

2-(But-3-en-1-yl)-*N*,*N*-dimethyl-4-phenylpyrrolidin-1-amine (10e). The title compound was isolated as mixture of diastereomers (1.2:1 *cis/trans*, FID GC with Alltech capillary column) as a yellow oil (30.5 mg, 85%). The *cis* diastereomer was isolated by preparative TLC of the free base (Silica gel, 15% EtOAc/Hex, R_f 0.6) and subsequently converted to the trifluoroacetic acid salt (12.9 mg). When the reaction was conducted at 23 ^{o}C the *cis/trans* selectivity increased to 15:1. The title compound was isolated as light

yellow oil (29.8 mg, 83%). Spectral information of *cis* diastereomer. **^{1}H-NMR** (500 MHz, $CDCl_3$): δ 7.39-7.30 (m, 5H), 5.80 (dddd, *J* = 17.1, 10.2, 7.1, 5.7 Hz, 1H), 5.12-5.06 (m, 2H), 3.71 (t, *J* = 8.9 Hz, 2H), 3.58-3.52 (m, 1H), 3.40-3.35 (m, 1H), 2.80 (s, 6H), 2.53 (dt, *J* = 12.9, 6.4 Hz, 1H), 2.29-2.25 (m, 2H), 2.14-1.98 (m, 3H). **^{13}C-NMR** (126 MHz, $CDCl_3$): δ 138.88, 136.95, 129.45, 128.17, 127.60, 116.62, 66.38, 50.55, 42.93, 41.25, 38.28, 30.85, 30.06. **IR** (Film): 2978, 2584 (b), 1734, 1671, 1457, 1196, 1140, 720, 701, cm^{-1}. **HRMS** (ESI): Calcd for $C_{16}H_{24}N_2$ $[M+H]^+$: 245.2018, found: 245.1904.

2-(But-3-en-1-yl)-*N*,*N*-dimethylpiperidin-1-amine (10f R=H). The title compound was isolated as a light yellow oil. 27.5 mg (93%). **^{1}H-NMR** (500 MHz, $CDCl_3$): δ 5.80-5.72 (m, 1H), 5.10-5.05 (m, 2H), 3.67 (d, *J* = 11.3 Hz, 1H), 3.06-3.02 (m, 1H), 2.83 (td, *J* = 12.0, 2.3 Hz, 1H), 2.68 (s, 6H), 2.39-2.33 (m, 1H), 2.28-2.22 (m, 1H), 2.13-2.03 (m, 3H), 2.02-1.96 (m, 1H), 1.91-1.86 (m, 2H), 1.78-1.71 (m, 1H), 1.40-1.36 (m, 1H). **^{13}C-NMR** (126 MHz, $CDCl_3$): δ 136.94, 116.65, 64.56, 44.94, 39.63, 29.88, 29.03, 28.97, 23.07, 22.71. **IR** (Film): 2956, 2566 (b), 1779, 1669, 1461, 1170, 797, cm^{-1}. **HRMS** (ESI): Calcd for $C_{11}H_{22}N_2$ $[M+H]^+$: 183.1861, found: 183.1733.

***N*,*N*-Dimethyl-2-(3-methylbut-3-en-1-yl)piperidin-1-amine (10f R=Me)**. The title compound was isolated as a light yellow oil. 27.3 mg (88%). **^{1}H-NMR** (500 MHz, $CDCl_3$): δ 4.80 (s, 1H), 4.72 (s, 1H), 3.68 (d, *J* = 11.3 Hz, 1H), 3.02 (t, *J* = 10.4 Hz, 1H), 2.84-2.79 (m, 1H), 2.74-2.66 (m, 6H), 2.45 (dtd, *J* = 13.8, 8.4, 3.0 Hz, 1H), 2.17 (dt, *J* = 14.5, 7.2 Hz, 2H), 2.11-2.07 (m, 2H), 2.05-1.97 (m, 2H), 2.20-1.75 (m, 13H), 1.89 (ddd, *J* = 14.0, 8.0, 3.8 Hz, 2H), 1.75 (s, 3H), 1.37 (dtdd, *J* = 13.7, 8.7, 4.7, 4.0 Hz, 1H). **^{13}C-**

NMR (126 MHz, $CDCl_3$): δ 144.23, 111.84, 64.65, 44.93, 39.65, 33.88, 29.08, 27.55, 23.06, 22.77, 22.44. **IR** (Film): 2949, 2757, 2678, 2570, 1780, 1740, 1670, 1461, 1200, 798, 720, 705, cm^{-1}. **HRMS** (ESI): Calcd for $C_{11}H_{22}N_2$ $[M+H]^+$: 197.2018, found: 197.2003.

2-(But-3-en-1-yl)-*N*,*N*,6-trimethylpiperidin-1-amine (10g). Metalloamination with 2 equiv. of $ZnEt_2$ only proceeded to 70 % ring closure as a cis/trans (9:1) mixture (^1H NMR). The title compound was isolated as a light yellow oil. 19.6 mg (63%). **^{1}H-NMR** (500 MHz, $CDCl_3$): δ 5.80-5.72 (m, 1H), 5.10-5.05 (m, 2H), 3.35-3.31 (m, 1H), 3.04 (t, *J* = 10.0 Hz, 1H), 2.92 (s, 6H), 2.29-2.19 (m, 2H), 2.17-2.09 (m, 1H), 2.08-2.01 (m, 2H), 1.99-1.93 (m, 1H), 1.91-1.81 (m, 3H), 1.53 (d, *J* = 6.4 Hz, 3H) *cis isomer*, 1.45 (d, *J* = 6.4 Hz,) *trans isomer*, 1.41-1.31 (m, 1H). **^{13}C-NMR** (75 MHz, $CDCl_3$): δ 136.49, 116.32, 66.19, 66.17, 62.61, 31.91, 30.07, 29.99, 28.47, 22.24, 19.03. **IR** (Film): 2450, 2876, 2760, 2688, 1780, 1740, 1670, 1201, cm^{-1} **HRMS** (ESI): Calcd for $C_{12}H_{24}N_2$ $[M+H]^+$: 197.2018, found: 197.2014.

2-(But-3-en-1-yl)-4-((*tert*-butyldimethylsilyl)oxy)-*N*,*N*-dimethylpyrrolidin-1-amine (10h). The title compound was isolated as a clear oil (free base). 24.8 mg (83 %). **^{1}H NMR** (500 MHz, $CDCl_3$) δ = 5.82 (ddt, *J*=16.9, 10.3, 6.6, 1H), 5.03 – 4.86 (m, 2H), 4.27 – 4.16 (m, 1H), 3.05 (dd, *J*=9.2, 5.8, 0.7H), 2.88 (td, *J*=7.0, 3.5, 1H), 2.68 (dd, *J*=10.1, 3.8, 0.36H), 2.65 – 2.60 (m, 0.33H), 2.53 (dd, *J*=9.2, 5.5, 0.7H), 2.32 (d, *J*=11.2, 6H), 2.15 – 1.95 (m, 3H), 1.91 – 1.81 (m, 1H), 1.68 (ddd, *J*=12.1, 7.8, 3.9, 1H), 1.58 (dt, *J*=12.8, 7.9, 1H), 1.45 – 1.32 (m, 1H), 1.27 (dp, *J*=13.2, 4.7, 4.0, 1H), 0.86 (s, 9H), 0.03

(s, 6H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ = 139.13 , 113.99 , 69.24 , 69.14 , 59.49 , 58.64 , 49.71 , 49.26 , 40.51 , 40.12 , 39.93 , 39.21 , 33.77 , 33.51 , 30.67 , 25.88 , 25.83 , -4.67 , -4.81. **IR** (film): 2930, 2856, 1471, 1452, 1255, 909, 734, cm^{-1}. **HRMS** (ESI): Calcd for $C_{13}H_{28}N_2OSi$ $[M+H]^+$: 257.2049, found: 257.2059.

2-(But-3-en-1-yl)-*N*,*N*-dimethylhexahydrocyclopenta[b]pyrrol-1(2*H*)-amine (10i). The title compound was isolated as a clear oil. 28.0 mg (87 %) **^{1}H NMR** (500 MHz, $CDCl_3$) δ = 5.72 (ddt, *J*=16.7, 10.1, 6.4, 1H), 5.06 – 4.93 (m, 2H), 3.95 – 3.85 (m, 1H), 3.27 (qd, *J*=9.9, 9.3, 4.4, 1H), 2.81 (s, 6H), 2.75 – 2.63 (m, 1H), 2.28 (s, 1H), 2.22 (td, *J*=8.3, 4.3, 1H), 2.19 – 2.13 (m, 1H), 2.11 (ddd, *J*=13.4, 7.3, 3.8, 1H), 2.03 – 1.92 (m, 3H), 1.84 – 1.75 (m, 1H), 1.67 – 1.58 (m, 3H), 1.57 – 1.48 (m, 1H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ = 136.87 , 115.91 , 65.84 , 63.72 , 40.87 , 40.77 , 33.97 , 32.33 , 31.39 , 30.33 , 29.19 , 25.21. **IR** (film): 3371, 2959, 2872, 1687, 1461, 1198, 916, 706, cm^{-1}. . **HRMS** (ESI): Calcd for $C_{13}H_{24}N_2$ $[M+H]^+$: 209.2018, found: 209.2018.

***N*,*N*,4,4-tetramethyl-2-(3-methyl-1-phenylbut-3-en-1-yl)pyrrolidin-1-amine (14a)**. The title compound was isolated as a clear oil (free base) 22.6 mg (79 %). **^{1}H NMR** (500 MHz, $CDCl_3$) δ = 7.27 – 7.22 (m, 2H), 7.21 – 7.17 (m, 2H), 7.17 – 7.13 (m, 1H), 4.70 – 4.61 (m, 1.5H), 3.39 (tt, *J*=8.0, 3.6, 1H), 2.97 (td, *J*=8.2, 4.3, 0.8H), 2.67 (d, *J*=14.5, 0.3H), 2.61 (d, *J*=8.0, 0.3H), 2.52 (dd, *J*=14.3, 7.8, .8H), 2.44 – 2.40 (m, 1.5H), 2.37 (s, 6H), 2.34 – 2.30 (m, 1H), 1.69 (s, 2.2H), 1.65 (s, .8H), 1.28 (dd, *J*=12.5, 8.9, 1H), 1.19 – 1.13 (m, 1H), 1.08 (s, 1H), 0.93 (s, 1H), 0.92 (s, 2H), 0.52 (s, 2H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ = 144.61 , 129.85 , 128.63 , 127.85 , 126.98 , 125.69 , 125.55 , 111.54 , 65.55 ,

63.36 , 53.62 , 52.81 , 43.25 , 43.16 , 40.47 , 39.79 , 39.61 , 38.72 , 38.28 , 34.85 , 33.55 , 30.61 , 29.28 , 29.15 , 29.02 , 22.69 , 22.27. **IR** (film): 2938, 2863, 2812, 1452, 1181, 700, cm^{-1}. **HRMS** (ESI): Calcd for $C_{19}H_{27}N_2$ $[M+H]^+$: 287.2566, found: 287.2487.

2-(1-(2-methoxyphenyl)-3-methylbut-3-en-1-yl)-*N*,*N*,4,4-tetramethylpyrrolidin-1-amine (14b). The title compound was isolated as mixture of diastereomers (1:5) (free base) 26.2 mg (83%). ^{1}H NMR (major diastereomer) (500 MHz, $CDCl_3$) δ 7.11 (t, *J* = 7.8 Hz, 2H), 6.90 – 6.80 (m, 2H), 4.49 – 4.38 (m, 2H), 3.77 (s, 3H), 3.53 – 3.42 (m, 1H), 3.11 – 3.00 (m, 1H), 2.97 (dd, *J* = 14.0, 4.5 Hz, 1H), 2.58 – 2.50 (m, 2H), 2.38 (s, 1H), 2.34 (s, 6H), 1.61 (s, 3H), 1.25 – 1.18 (m, 2H), 0.96 (s, 3H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 145.69, 129.54, 126.33, 119.93, 110.40, 110.29, 64.74, 55.15, 53.37, 42.73, 40.93, 39.93, 39.53, 29.22, 28.85, 22.37. **IR** (Film) **HRMS** (ESI): Calcd for $C_{20}H_{32}N_2O$ $[M+H]^+$: 317.2594 found: 317.2567

2-(1-(2-chlorophenyl)-3-methylbut-3-en-1-yl)-*N*,*N*,4,4-tetramethylpyrrolidin-1-amine (14c). The title compound was isolated as a mixture of diastereomers (1:10) (free base) 23.1 mg (72 %). ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.27 (ddd, *J* = 13.7, 8.2, 1.7 Hz, 2H), 7.15 (td, *J* = 7.5, 1.4 Hz, 1H), 7.09 – 7.00 (m, 1H), 4.49 (s, 1H), 4.39 (s, 1H), 3.59 (ddd, *J* = 11.7, 7.5, 4.0 Hz, 1H), 3.02 (dt, *J* = 14.1, 5.4 Hz, 2H), 2.58 (d, *J* = 8.5 Hz, 1H), 2.52 (d, *J* = 8.4 Hz, 1H), 2.40 (s, 1H), 2.31 (s, 6H), 1.66 (s, 3H), 1.30 – 1.26 (m, 1H), 1.25 – 1.22 (m, 1H), 1.07 (s, 3H), 0.93 (s, 3H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 144.78, 142.06, 134.67, 129.59, 129.16, 126.59, 126.11, 111.22, 64.92, 53.22, 42.92, 40.77,

39.78, 34.46, 29.34, 28.74, 22.49. **IR** (Film) 2952, 2865, 2844, 1472, 1441, 1025, 884, 750 cm^{-1}. **HRMS** (ESI): Calcd for $C_{19}H_{29}ClN_2$ $[M+H]^+$: 321.2098 found: 321.2101

2-(1-(2-fluorophenyl)-3-methylbut-3-en-1-yl)-,4,4- *N,N* tetramethylpyrrolidin-1-amine (14d). The title compound was isolated as a clear oil (free base) 23.7 mg (78 %). ^1H NMR (500 MHz, $CDCl_3$) δ 7.17 (td, *J* = 7.5, 1.8 Hz, 1H), 7.11 (tdd, *J* = 7.3, 5.1, 1.8 Hz, 1H), 7.01 (td, *J* = 7.5, 1.3 Hz, 1H), 6.94 (ddd, *J* = 10.9, 8.1, 1.3 Hz, 1H), 4.55 (d, *J* = 10.8 Hz, 2H), 3.50 (dd, *J* = 10.6, 5.7 Hz, 1H), 3.10 – 2.98 (m, 1H), 2.76 (dd, *J* = 14.4, 5.8 Hz, 1H), 2.52 – 2.38 (m, 3H), 2.39 – 2.29 (m, 6H), 1.65 (s, 3H), 1.34 (dd, *J* = 12.8, 8.7 Hz, 1H), 1.27 – 1.19 (m, 1H), 0.93 (s, 3H), 0.77 (s, 3H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 162.51, 160.56, 144.63, 131.21, 129.89, 127.09, 123.05, 115.14, 114.95, 111.26, 63.95, 53.00, 41.07, 40.37, 39.80, 34.11, 29.16, 28.88, 22.20. **IR** (Film) 3072, 2950, 2865, 2770, 1648, 1582, 1489, 1453, 1222, 886, 754 cm^{-1}. **HRMS** (ESI): Calcd for $C_{19}H_{29}ClN_2$ $[M+H]^+$: 305.2394 found: 305.2357

,*N*,4,4-tetramethyl-2-(3-methyl-1-(o-tolyl)but-3-en-1-yl)pyrrolidin-1-amine (14e). The title compound was isolated as a clear oil (free base) 23.4 mg (78 %). Major Diastereomer: **^1H NMR** (500 MHz, $CDCl_3$) δ 7.18 – 7.15 (m, 1H), 7.11 – 7.06 (m, 2H), 7.05 – 7.01 (m, 1H), 4.54 (dq, *J* = 3.0, 1.5 Hz, 1H), 4.44 (dt, *J* = 2.2, 1.1 Hz, 1H), 3.33 (ddd, *J* = 10.4, 6.9, 4.9 Hz, 1H), 3.05 (dt, *J* = 8.5, 7.0 Hz, 1H), 2.96 (dd, *J* = 13.6, 4.8 Hz, 1H), 2.56 – 2.48 (m, 2H), 2.34 (s, 6H), 2.30 – 2.25 (m, 1H), 1.60 (t, *J* = 1.0 Hz, 3H), 1.30 – 1.25 (m, 1H), 1.15 – 1.11 (m, 1H), 0.97 (s, 3H), 0.92 (s, 3H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 145.17, 142.95, 136.74, 129.78, 127.79, 127.07, 125.13, 111.24, 64.90, 53.11,

42.43, 39.76, 37.88, 34.52, 30.76, 28.82, 22.70, 20.37. **IR** (Film) 3019, 2950, 2865, 1646, 1451, 1364, 883, 751, 726 cm^{-1}. **HRMS** (ESI): Calcd for $C_{20}H_{32}N_2$ $[M+H]^+$: 301.2644 found: 301.2703

2-(1-(2-(dimethylamino)phenyl)-3-methylbut-3-en-1-yl)-*N*,*N*,4,4-tetramethylpyrrolidin-1-amine (14g). The title compound was isolated as a clear oil (free base) 20.4 mg (62 %). Major Diastereomer: **^{1}H NMR** (500 MHz, $CDCl_3$) δ 7.29 – 7.24 (m, 1H), 7.11 – 7.09 (m, 2H), 7.03 – 6.99 (m, 1H), 4.44 (dq, *J* = 2.8, 1.4 Hz, 1H), 4.31 (d, *J* = 2.6 Hz, 1H), 3.69 (ddd, *J* = 11.2, 7.6, 3.5 Hz, 1H), 3.14 – 3.05 (m, 1H), 2.98 (q, *J* = 7.9 Hz, 1H), 2.72 – 2.67 (m, 2H), 2.58 (s, 7H), 2.52 (d, *J* = 8.5 Hz, 1H), 2.34 (s, 6H), 2.30 (d, *J* = 2.8 Hz, 1H), 1.66 (s, 3H), 1.24 (d, *J* = 2.5 Hz, 1H), 1.18 (d, *J* = 6.9 Hz, 1H), 1.05 (s, 3H), 0.91 (s, 3H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 145.85, 141.89, 128.56, 125.85, 123.77, 122.21, 120.50, 110.93, 65.10, 53.56, 45.94, 43.86, 41.98, 39.82, 35.90, 34.96, 30.83, 29.40, 22.83. **IR** (Film) 3069, 2951, 2862, 2821, 1646, 1595, 1488, 1451, 909, 733 cm-1. **HRMS** (ESI): Calcd for $C_{21}H_{35}N_3$ $[M+H]^+$: 330.2910 found: 330.2977

***N*,*N*,4,4-tetramethyl-2-vinylpyrrolidin-1-amine (14i)**. The title compound was isolated as a clear oil (TFA salt) 25.4 mg (90 %). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 5.84 (ddd, *J* = 17.2, 10.2, 8.4 Hz, 1H), 5.36 – 5.22 (m, 2H), 3.81 (q, *J* = 8.3 Hz, 1H), 3.16 (d, *J* = 8.8 Hz, 1H), 2.95 (s, 6H), 2.81 (d, *J* = 8.8 Hz, 1H), 1.92 (dd, *J* = 13.1, 8.0 Hz, 1H), 1.62 (dd, *J* = 13.1, 8.5 Hz, 1H), 1.16 (s, 3H), 1.13 (s, 3H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 136.24, 119.76, 64.91, 60.85, 44.97, 41.95, 34.98, 29.12, 28.54. **IR** (Film) 2966, 2876, 1781,

1670, 1200, 1164, 796, 704 cm^{-1}. **HRMS** (ESI): Calcd for $C_{10}H_{20}N_2$ $[M+H]^+$: 169.1705 found: 169.1731

(*E*)-*N*,*N*,4,4-tetramethyl-2-(6-methylhepta-1,6-dien-1-yl)pyrrolidin-1-amine (14j). The title compound was isolated as a clear oil (TFA salt) 33.5 mg (92%). **^{1}H NMR** (500 MHz, $CDCl_3$) δ 5.79 – 5.70 (m, 1H), 5.48 (dd, *J* = 15.4, 8.6 Hz, 1H), 4.70 – 4.65 (m, 1H), 4.65 – 4.60 (m, 1H), 3.83 – 3.73 (m, 1H), 3.18 (d, *J* = 9.1 Hz, 1H), 2.90 (d, *J* = 5.1 Hz, 6H), 2.79 (d, *J* = 9.1 Hz, 1H), 2.06 – 1.95 (m, 4H), 1.87 (dd, *J* = 13.1, 7.5 Hz, 1H), 1.71 – 1.66 (m, 3H), 1.66 – 1.60 (m, 2H), 1.52 – 1.45 (m, 2H), 1.16 (s, 3H), 1.13 (s, 3H). **^{13}C NMR** (126 MHz, $CDCl_3$) δ 145.29, 137.01, 127.18, 110.13, 64.85, 60.15, 45.10, 41.60, 37.15, 34.74, 31.61, 29.19, 28.81, 26.50, 22.20. **IR** (Film) 2966, 2936, 2873, 1780, 1670, 1652, 1463, 1202, 1168, 704 cm^{-1}. **HRMS** (ESI): Calcd for $C_{16}H_{30}N_2$ $[M+H]^+$: 251.2120 found: 251.2163

Synthesis of Cycles: General Procedure for Fukuyama Coupling of Metalloamination Cycles: In an argon-filled glove box, $ZnEt_2$ in *p*-xylene (50 μL, 2.0 M, 0.10 mmol) and toluene or (trifluoromethyl)benzene (0.5 mL) were introduced into a J. Young NMR tube equipped with a Teflon screw cap, and the indicated hydrazinoalkene (0.10 mmol) was subsequently added. The reactant mixture was heated in a 90 ^oC oil bath until cyclization was complete (≥ 90% by ^{1}H NMR, *p*-xylene as internal standard). The volatiles were removed in vacuo and a THF/Toluene/dimethylacetamide mixture (0.5 mL 32:62:4 v/v/v) was introduced to the J. Young tube in an argon-filled dry box followed by bis(triphenylphosphine)palladium(II)

dichloride (7.02 mg, 0.01 mmol) and S-ethyl 4-tert-butylbenzothioate (22.2 mg, 0.1 mmol). The reactant mixture was kept at 23 °C until the reaction was judged complete by ^{1}H NMR. The Teflon screw cap was removed and the reactant mixture transferred with ethyl acetate to a scintillation vial, washed with saturated aqueous potassium carbonate (2 mL) and extracted with ethyl acetate (3 x 1 mL). The organic layer was dried with magnesium sulfate, filtered, and concentrated in vacuo. The crude residue was purified by silica gel chromatography (10% EtOAc/hexanes) to afford ketones **11**.

1-(4-(*tert*-Butyl)phenyl)(1-(dimethylamino)piperidin-2-yl)ethanone (**11f)**. The title compound was prepared via the standard protocol of Fukuyama coupling to give a yellow oil. 18.4 mg (61%). **^{1}H-NMR** (300 MHz, $CDCl_3$): δ 7.88 (d, *J* = 8.4 Hz, 2H), 7.46 (d, *J* = 8.4 Hz, 2H), 3.40-3.33 (m, 1H), 3.20 (t, *J* = 10.0 Hz, 1H), 2.89 (d, *J* = 10.0 Hz, 1H), 2.17 (dd, *J* = 21.8, 11.7 Hz, 2H), 1.91 (s, 6H), 1.80-1.74 (m, 3H), 1.52-1.43 (m, 2H), 1.36 (s, 9H), 0.90 (dd, *J* = 14.3, 7.1 Hz, 1H). **^{13}C-NMR** (75 MHz, $CDCl_3$): δ 195.05, 154.70, 136.31, 127.36, 124.98, 60.58, 43.71, 43.56, 34.90, 33.28, 31.19, 29.72, 26.04, 24.56. **IR** (Film): 2931, 2853, 2815, 1669, 1605, 1463, 1272, 1107, 837 cm^{-1}. . **HRMS** (ESI): Calcd for $C_{19}H_{30}N_2O$ $[M+H]^+$: 303.2436, found: 303.2452.

Representative Preparative Scale Reactions.

2-(But-3-en-1-yl)-*N*,*N*,4,4-Tetramethylpyrrolidin-1-amine (10a R=H) (1 mmol scale). In an argon-filled glove box, a 10-mL Schlenk flask equipped with a magnetic stirring bar was charged with $ZnEt_2$ in *p*-xylene (0.50 mL, 2.0 M, 1.0 mmol), potassium *tert*-butoxide (12.3 mg, 0.11 mmol), benzene (4 mL) and 2-(2,2-dimethylpent-4-en-1-yl)-1,1-

dimethylhydrazine (156.2 mg, 1.0 mmol) was subsequently added. The reactant mixture was removed from the dry box, fitted with an N_2 inlet and placed in a 45 ^oC oil bath for 12 h. The volatiles were removed in vacuo and dry THF (4 mL) was added via syringe. The resulting mixture was cooled to -40 ^oC and CuCN•2LiCl in THF (1.5 mL, 1.0 M, 1.5 mmol) was added dropwise. Allyl bromide (145 mg, 1.2 mmol) was subsequently added and the reactant mixture was allowed warm to 23 ^oC and held at this temperature for 4 hours. The reactant mixture was diluted with Et_2O (15 mL), and an aqueous solution of $NH_4Cl_{(sat)}$ and NH_3/H_2O (1:1 v/v, 15 mL) was subsequently added. The resulting suspension was vigorously stirred for 10 minutes until the aqueous layer developed a deep blue color. The organic layer was transferred to a separatory funnel and washed with a second portion of NH_4Cl and NH_3/H_2O (1:1 v/v, 15 mL), followed by brine (15 mL) and dried with $MgSO_4$. The resulting ether solution was transferred to a 50-mL round-bottomed flask equipped with a magnetic stirring bar and an N_2 inlet. The reactant mixture was cooled to 0 ^oC and trifluoroacetic acid (125 mg, 1.1 mmol) was added dropwise via syringe. The resulting mixture was stirred at this temperature for 1 h, the volatiles were removed in vacuo and the resulting oil was triturated with pentane (3 x 2 mL) to give 0.282 g (91 %) of the title compound as a slowly solidifying light yellow oil. Spectral data was identical with that previously reported (vide supra).

***N,N*-Dimethyl-2-(3-methylbut-3-en-1-yl)piperidin-1-amine (10f R=Me) (1 mmol scale)**. The title compound was prepared in a fashion analogous to hydrazine **4b** (1 mmol scale) utilizing 2-(hex-5-en-1-yl)-1,1-dimethylhydrazine (0.142 g, 1.00 mmol), methallyl chloride (0.117 g, 1.20 mmol) and omitting potassium *tert*-butoxide to yield cyclic

hydrazine **4g** (R=Me) (0.288 g, 93 %) as a light yellow oil. Spectral data was identical with that previously reported (vide supra).

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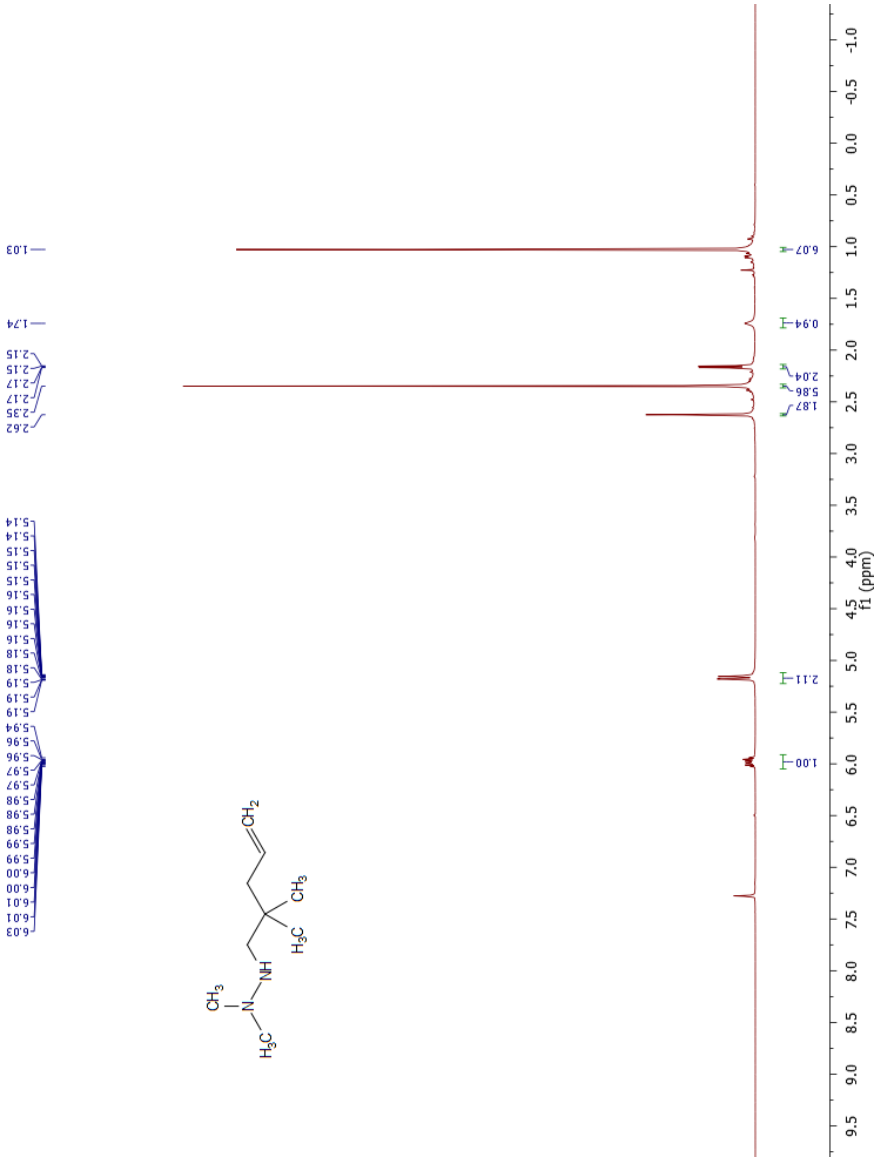
APPENDIX B

SPECTRAL DATA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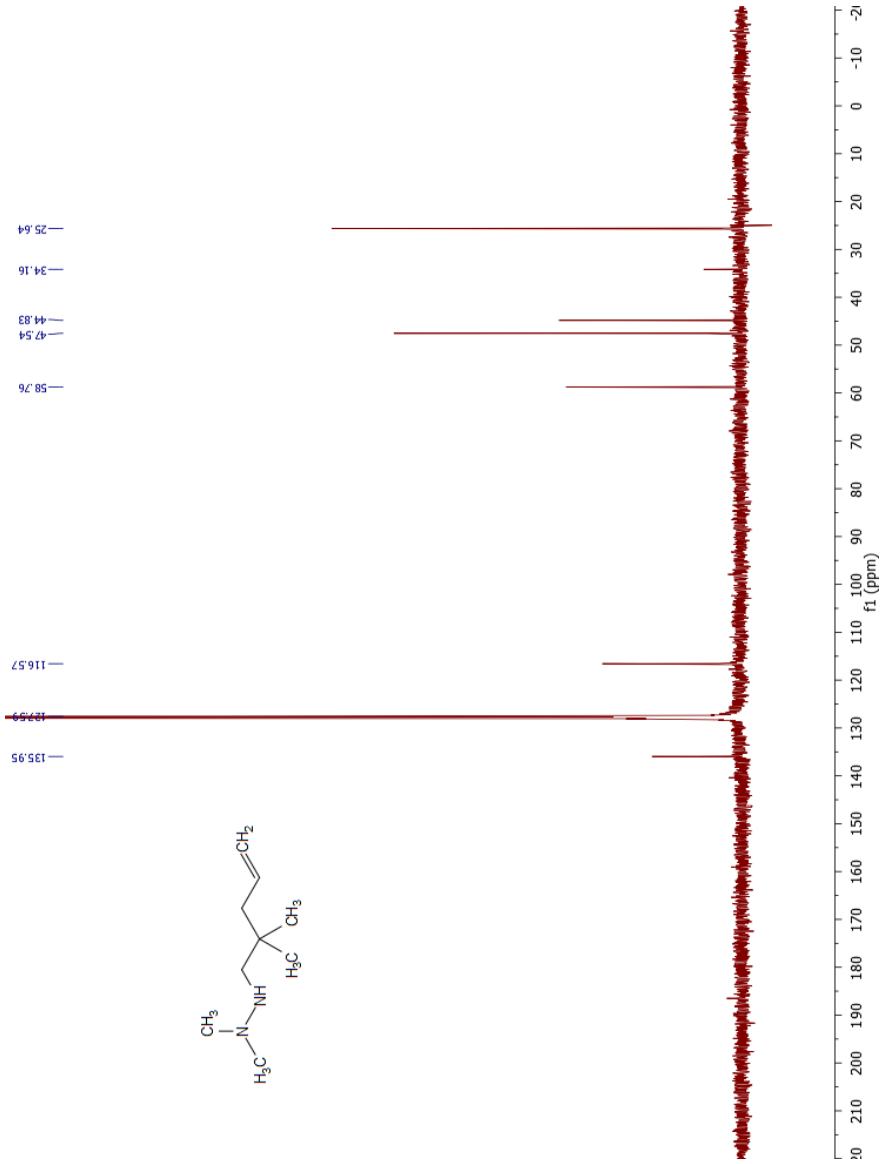
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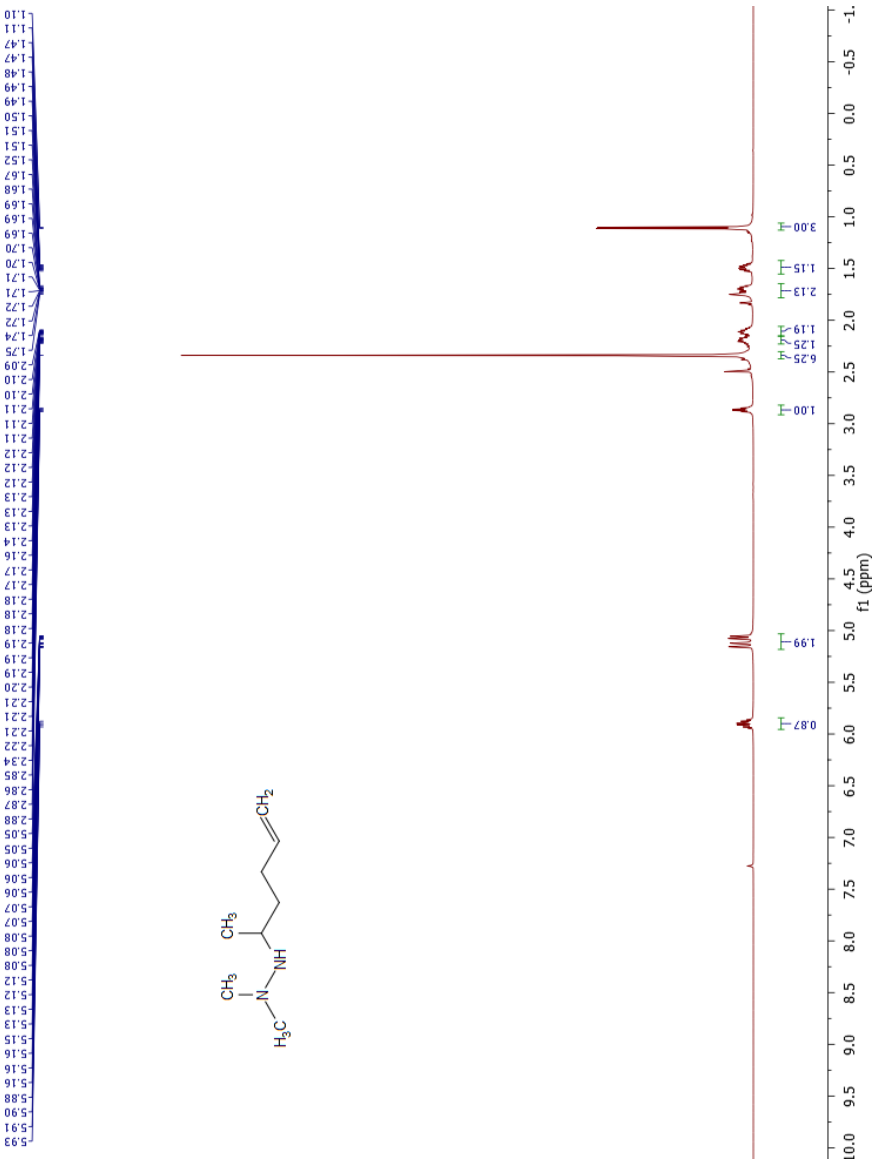
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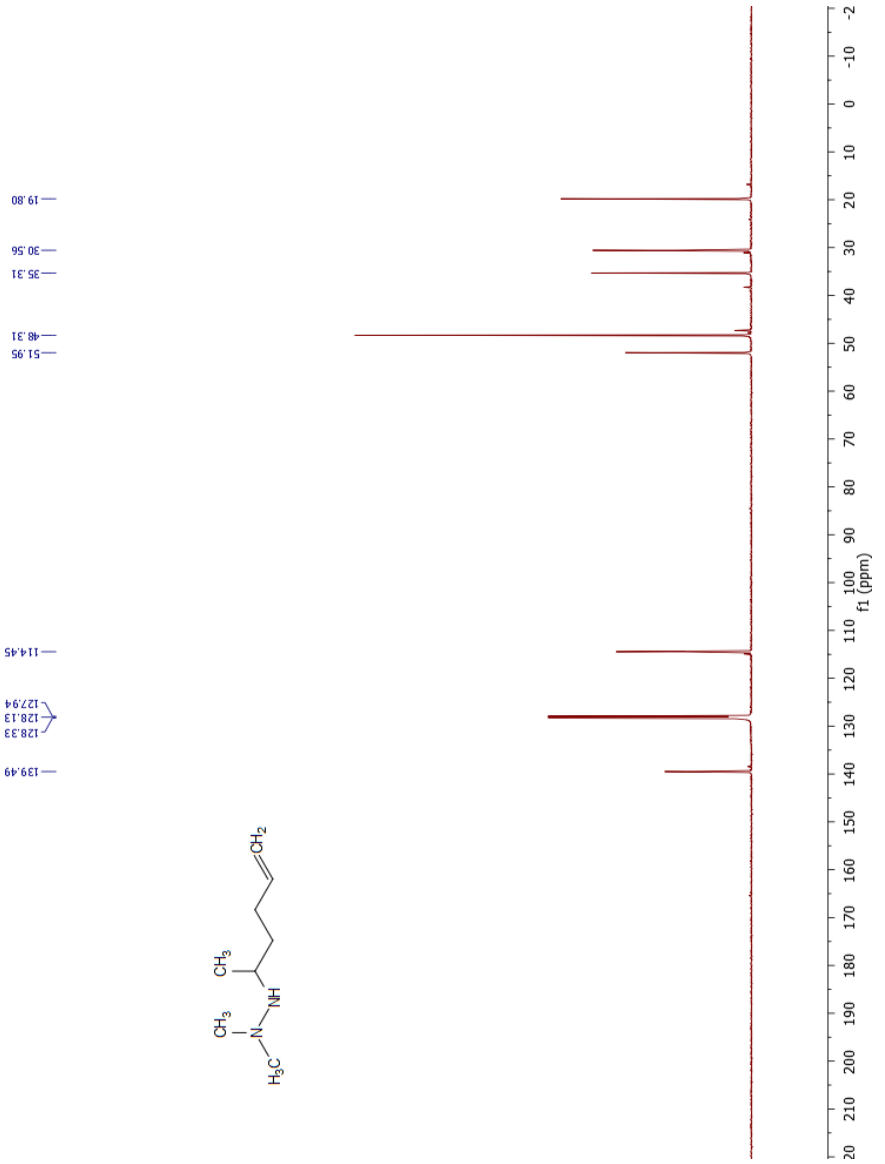
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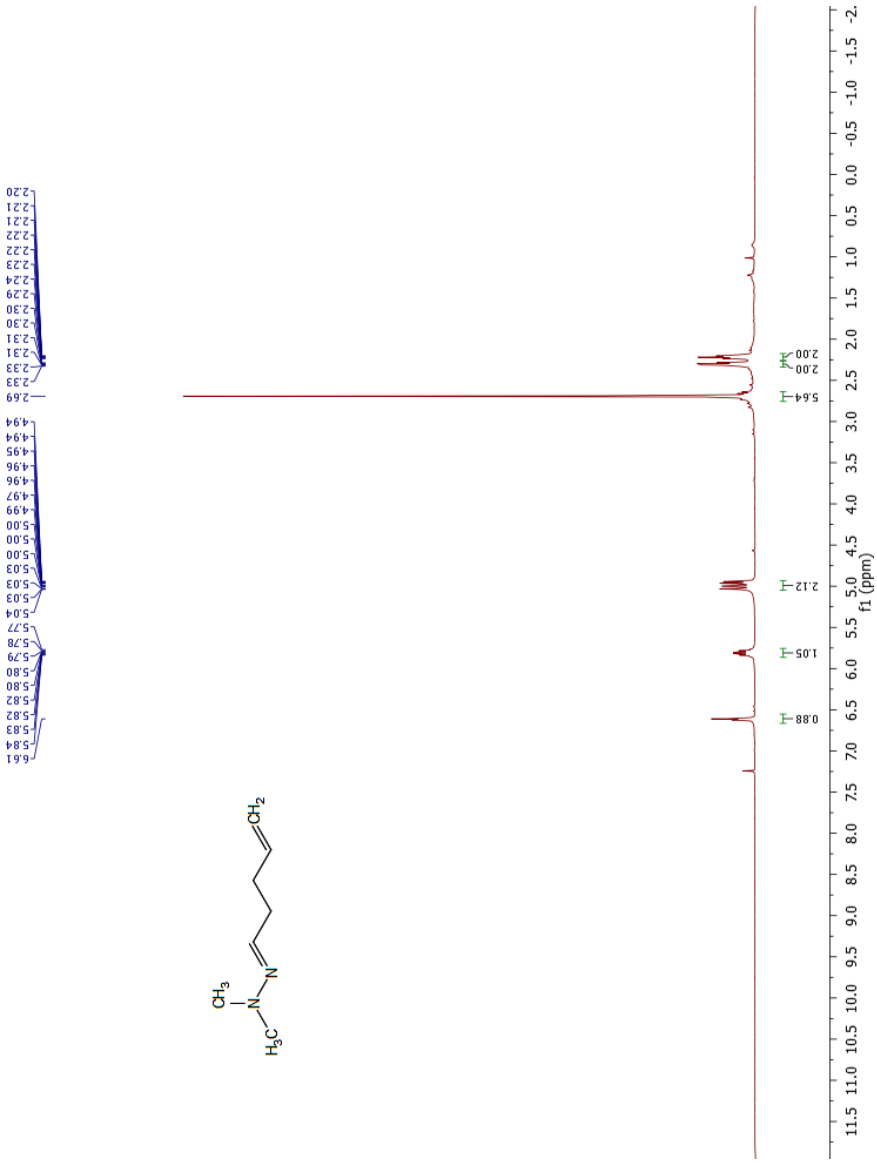
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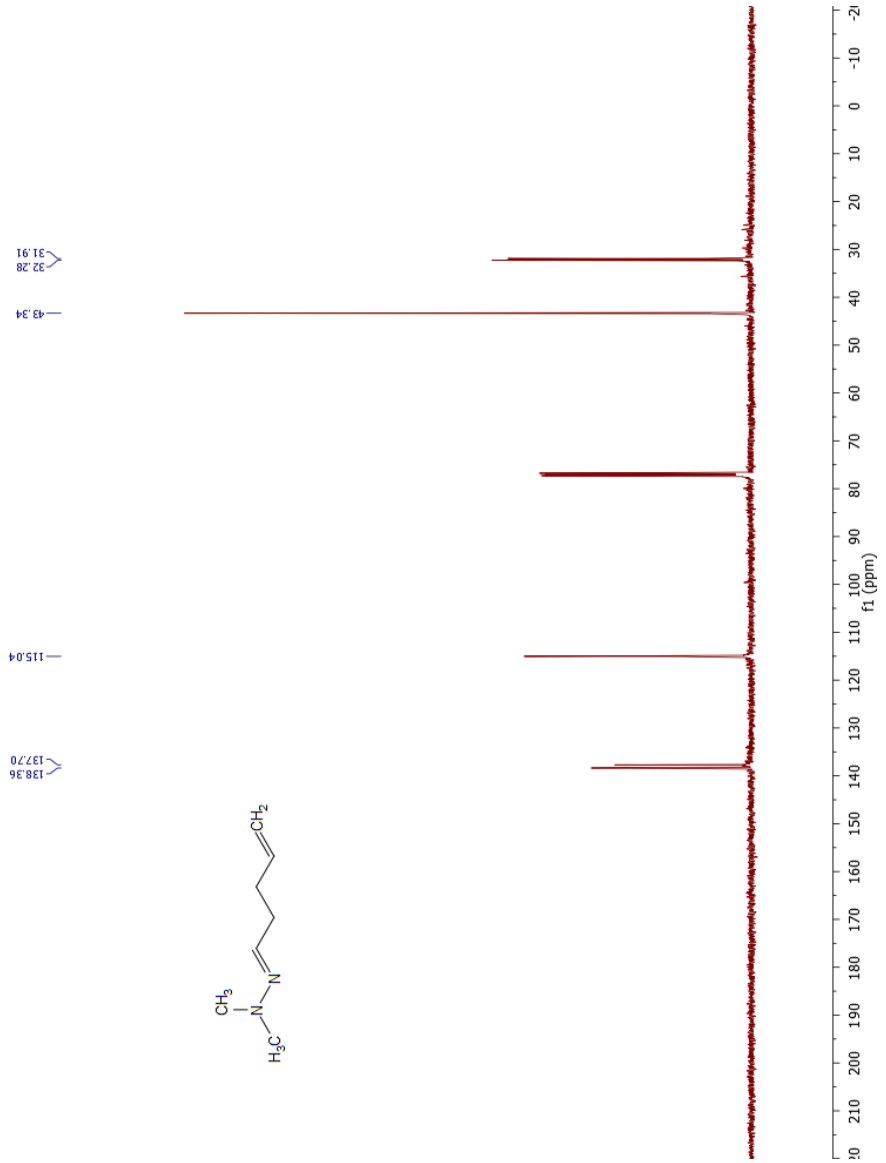
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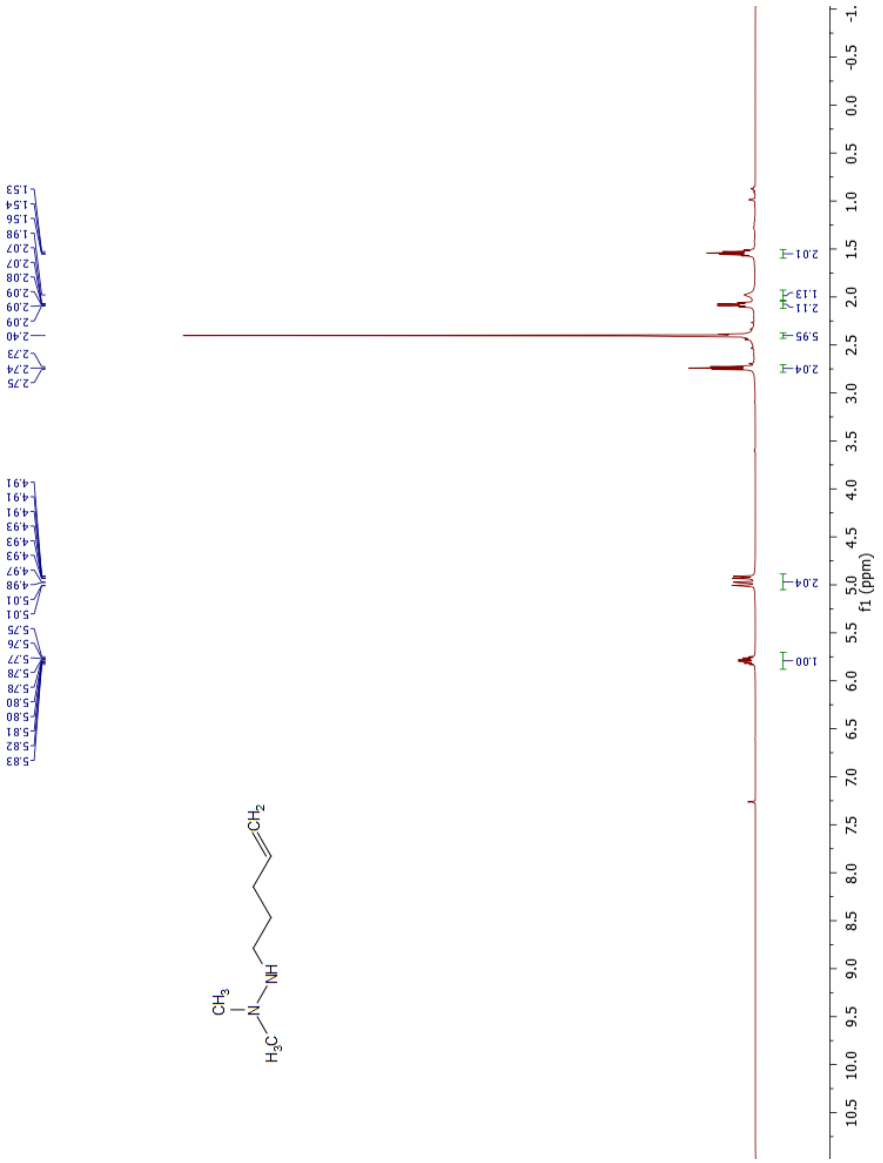
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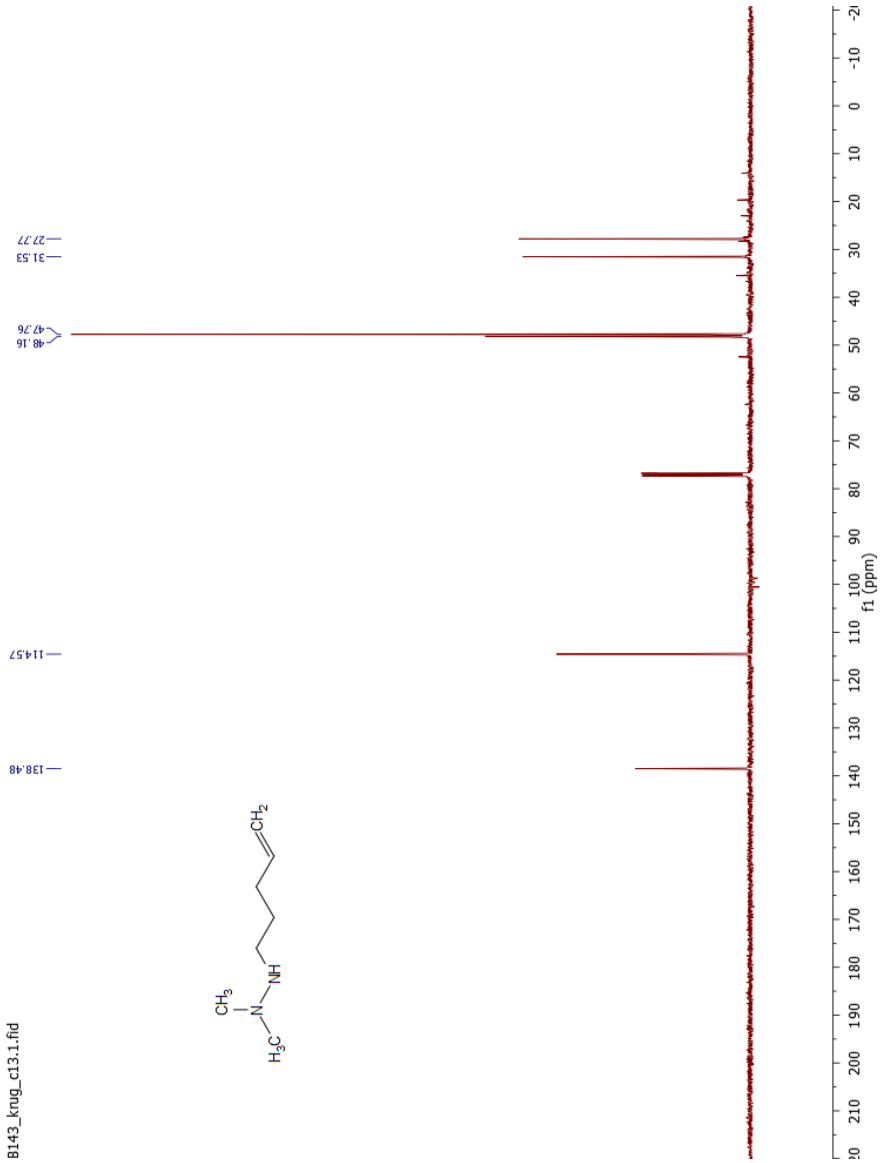
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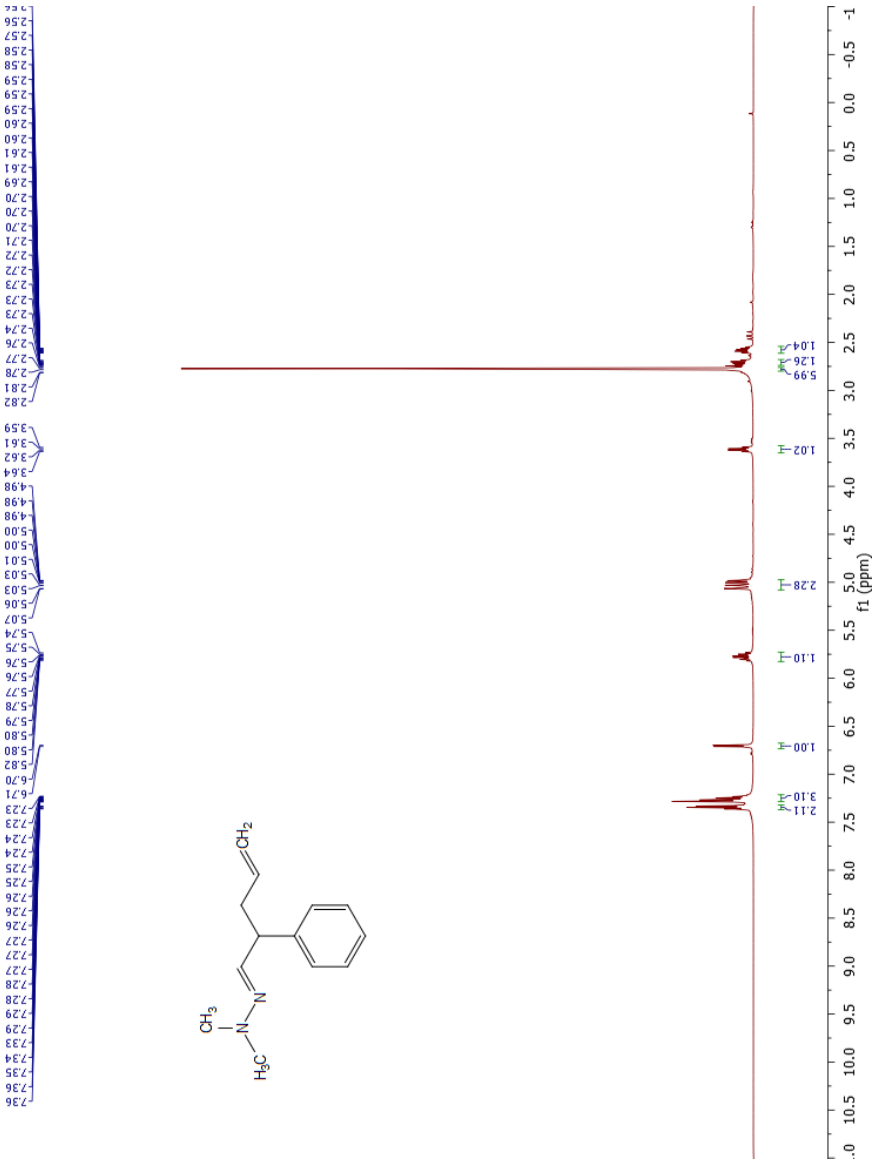
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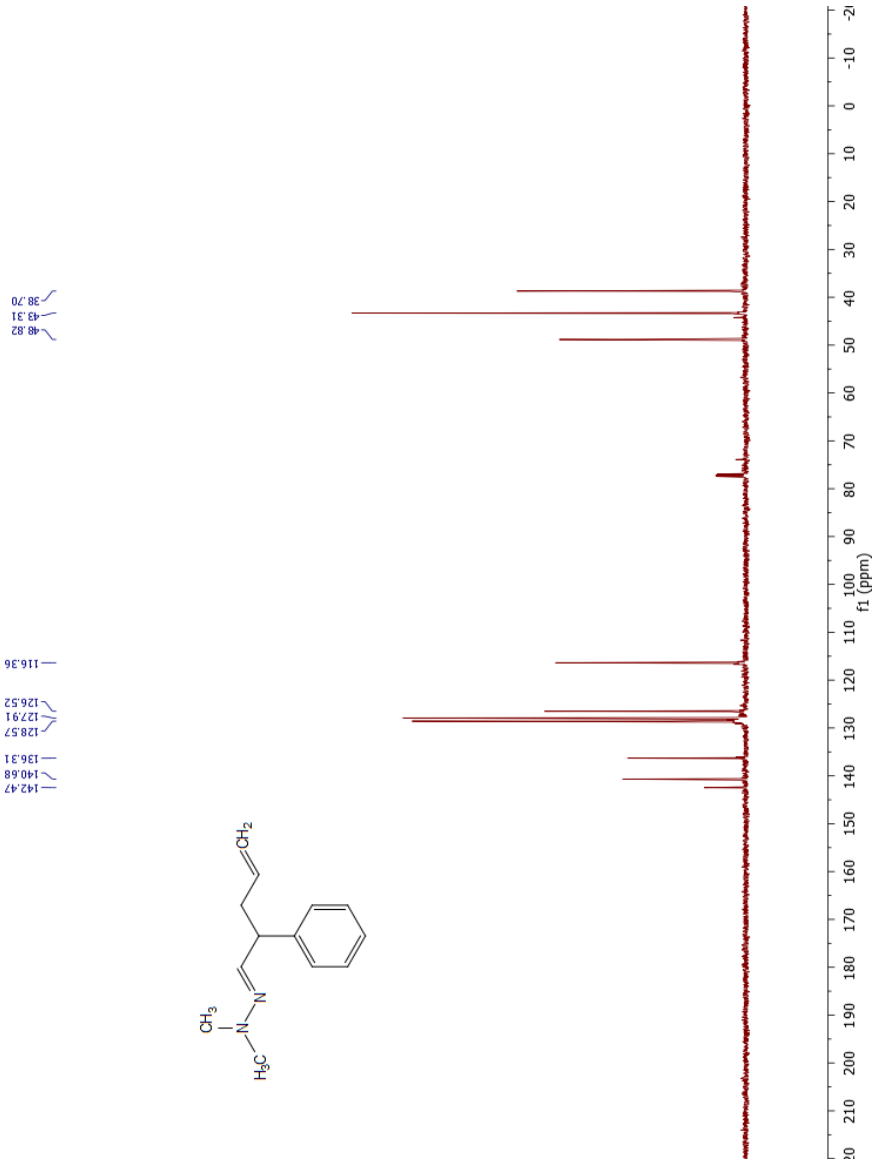
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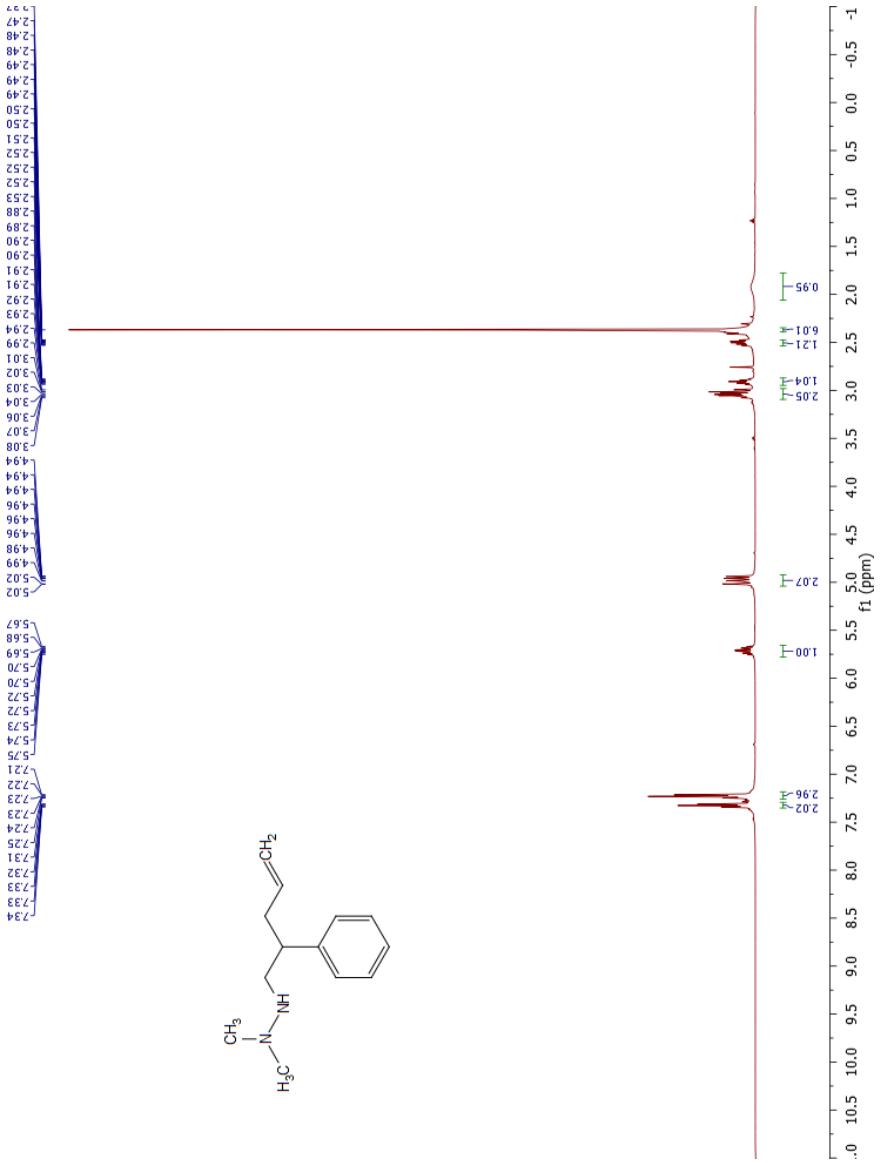
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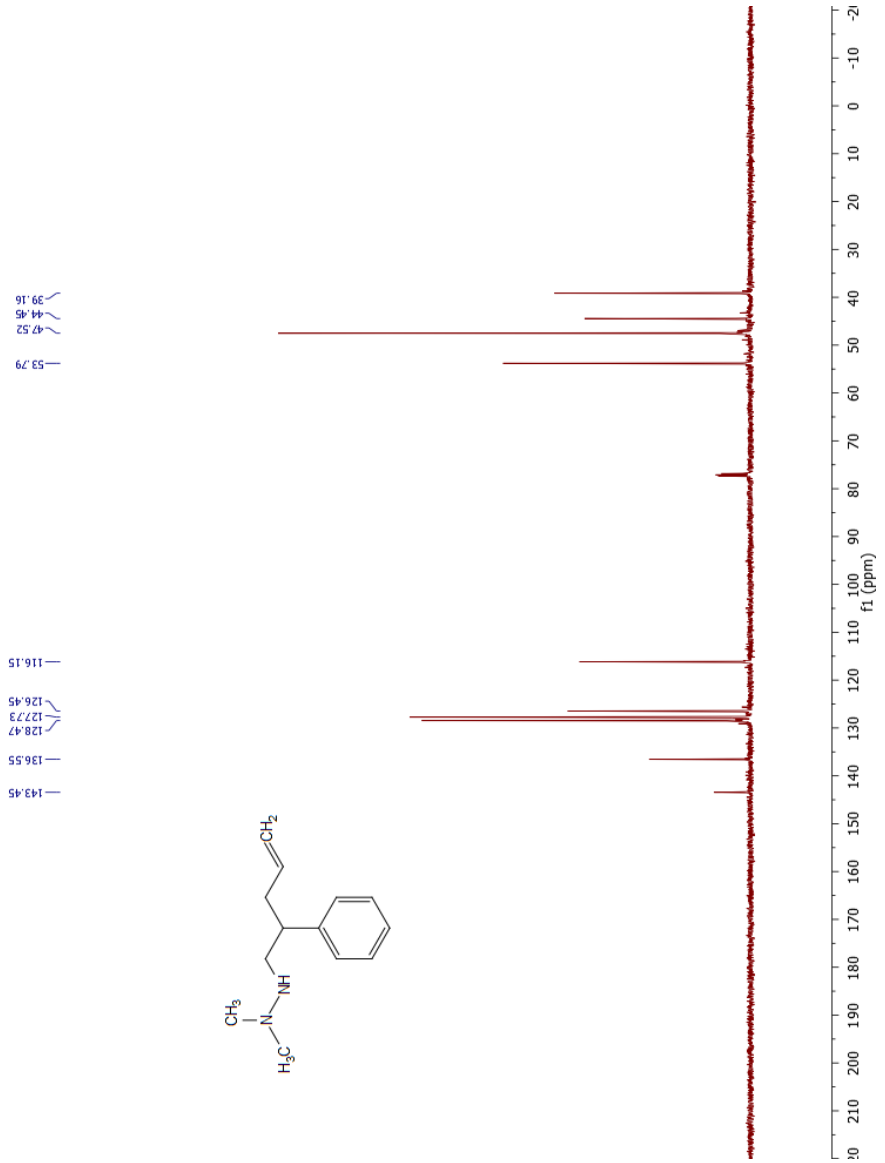
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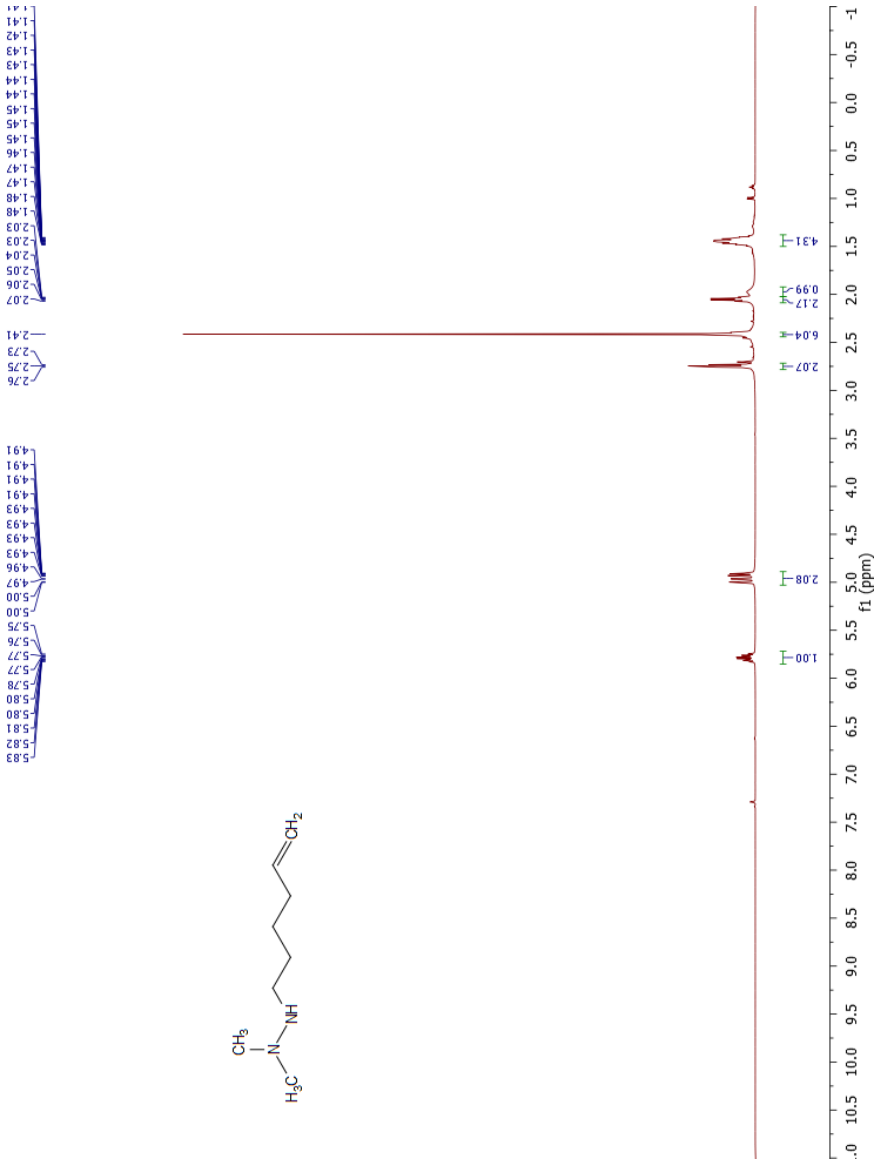
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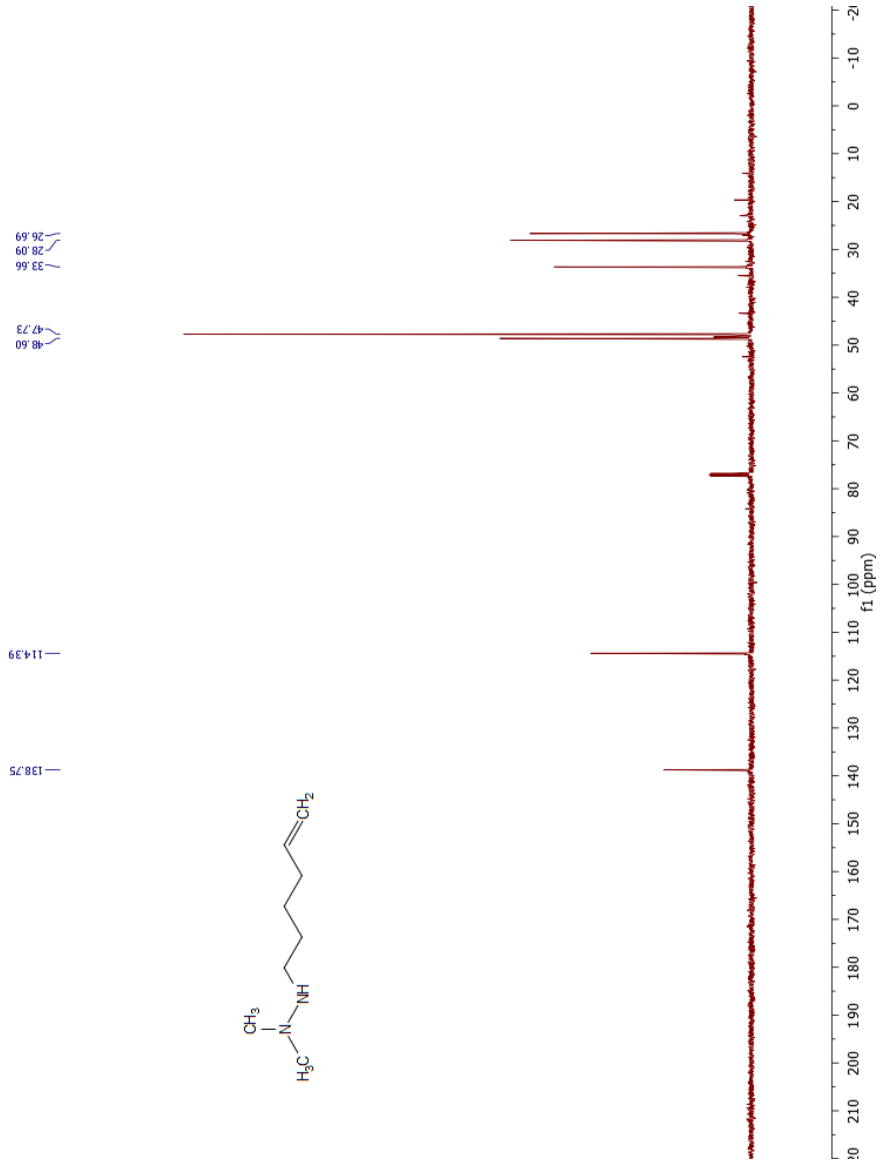
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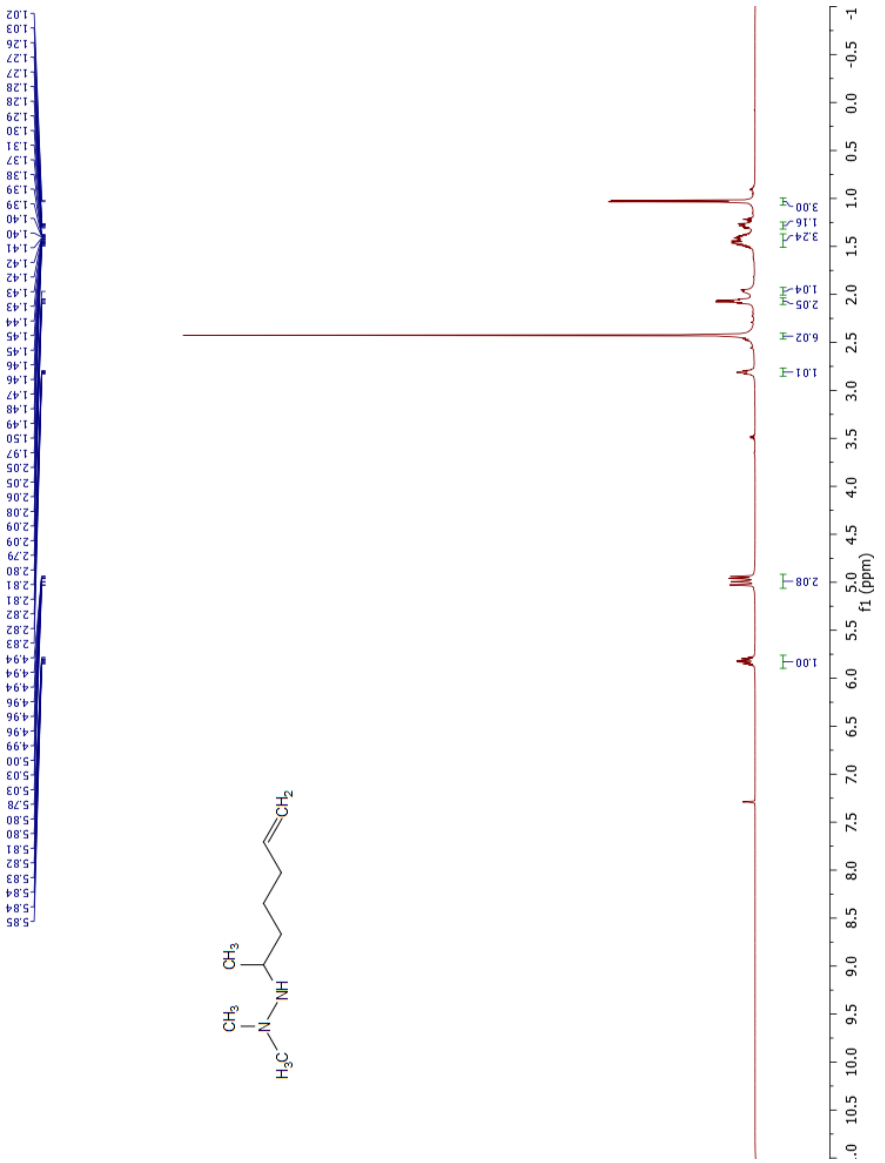
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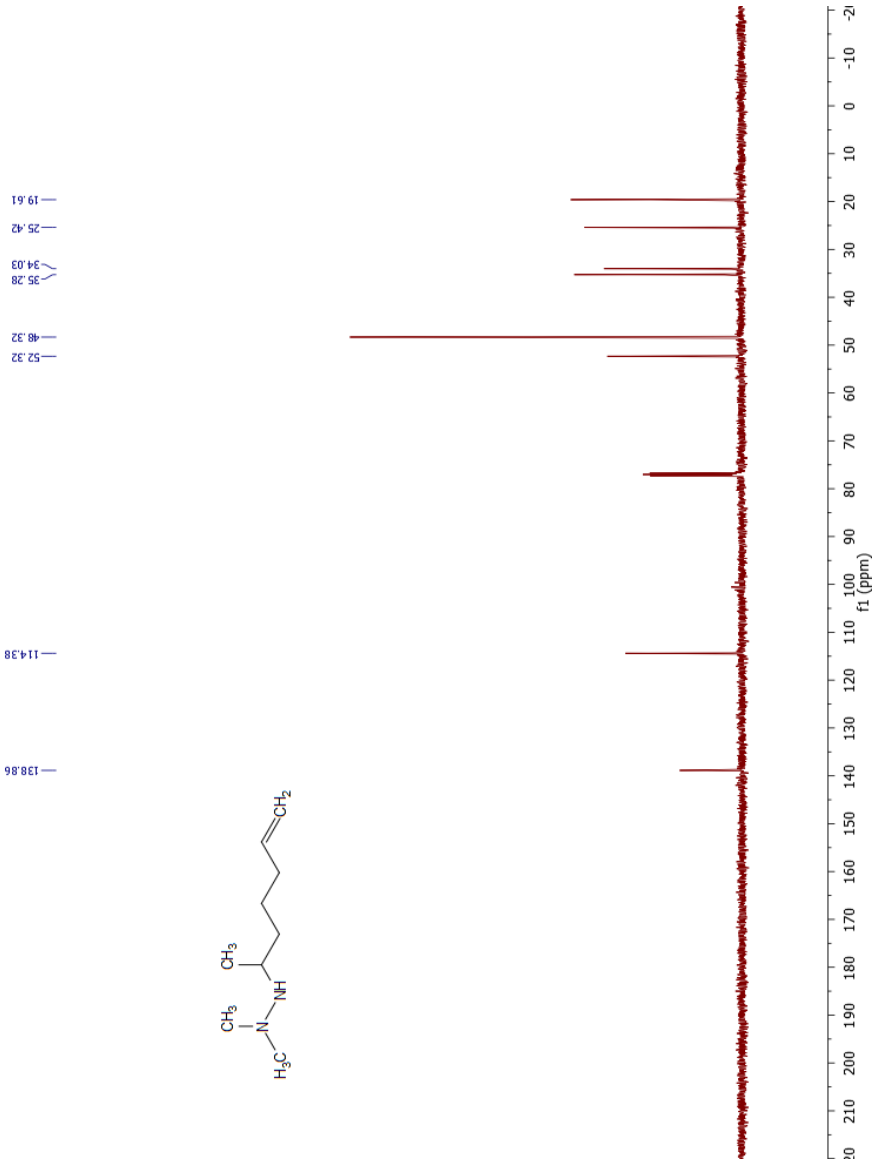
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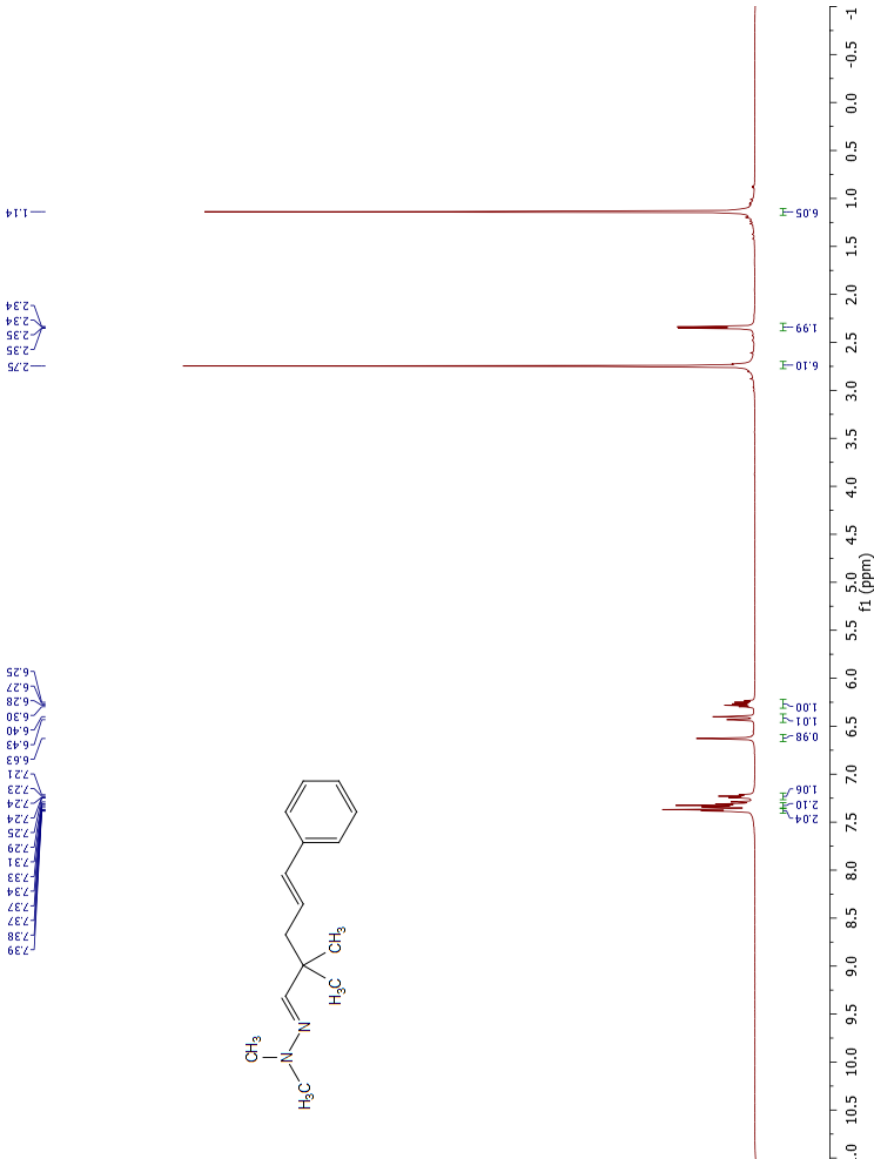
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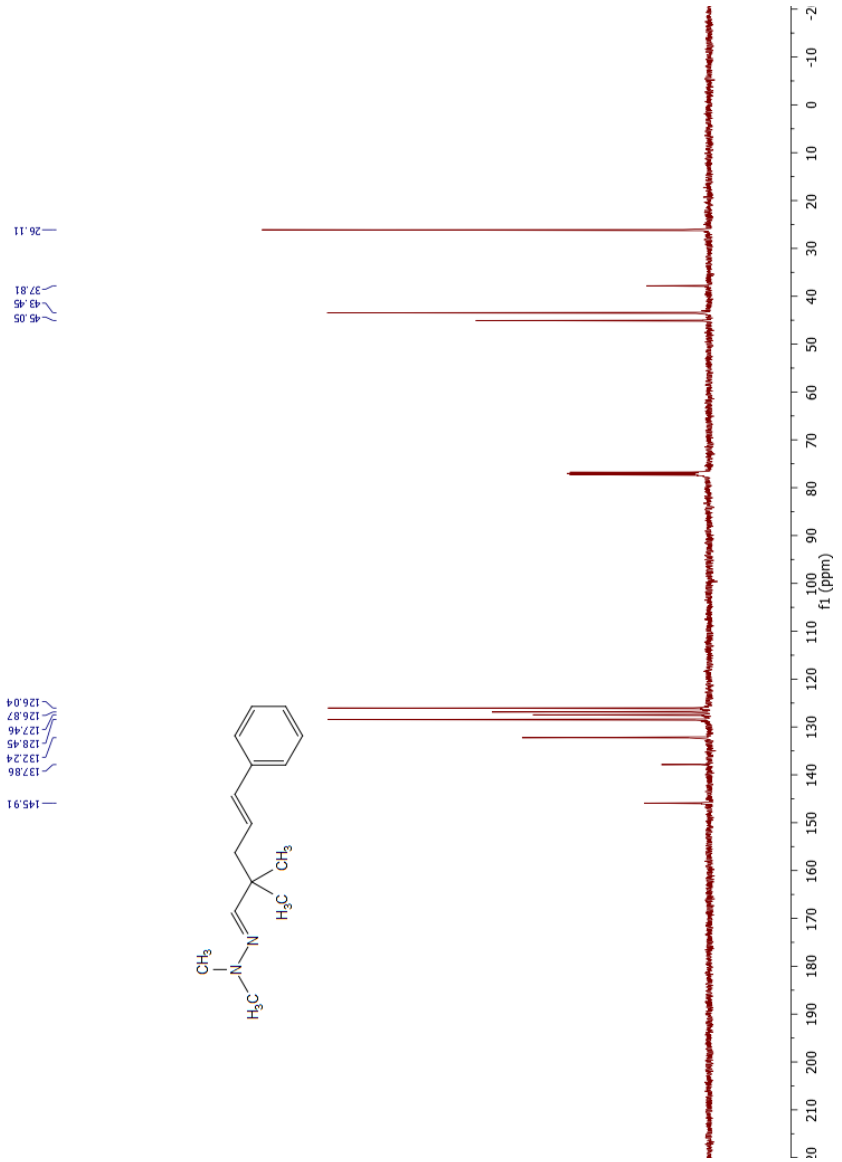
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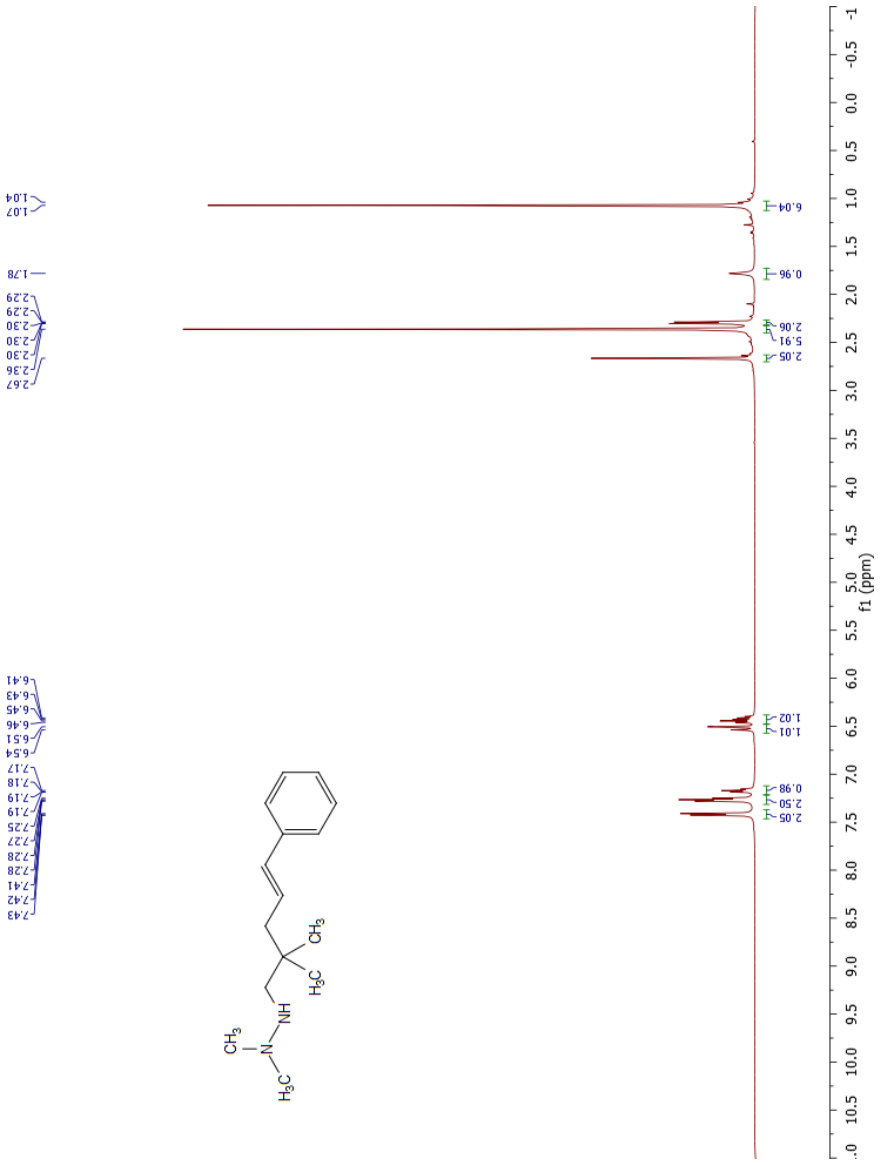
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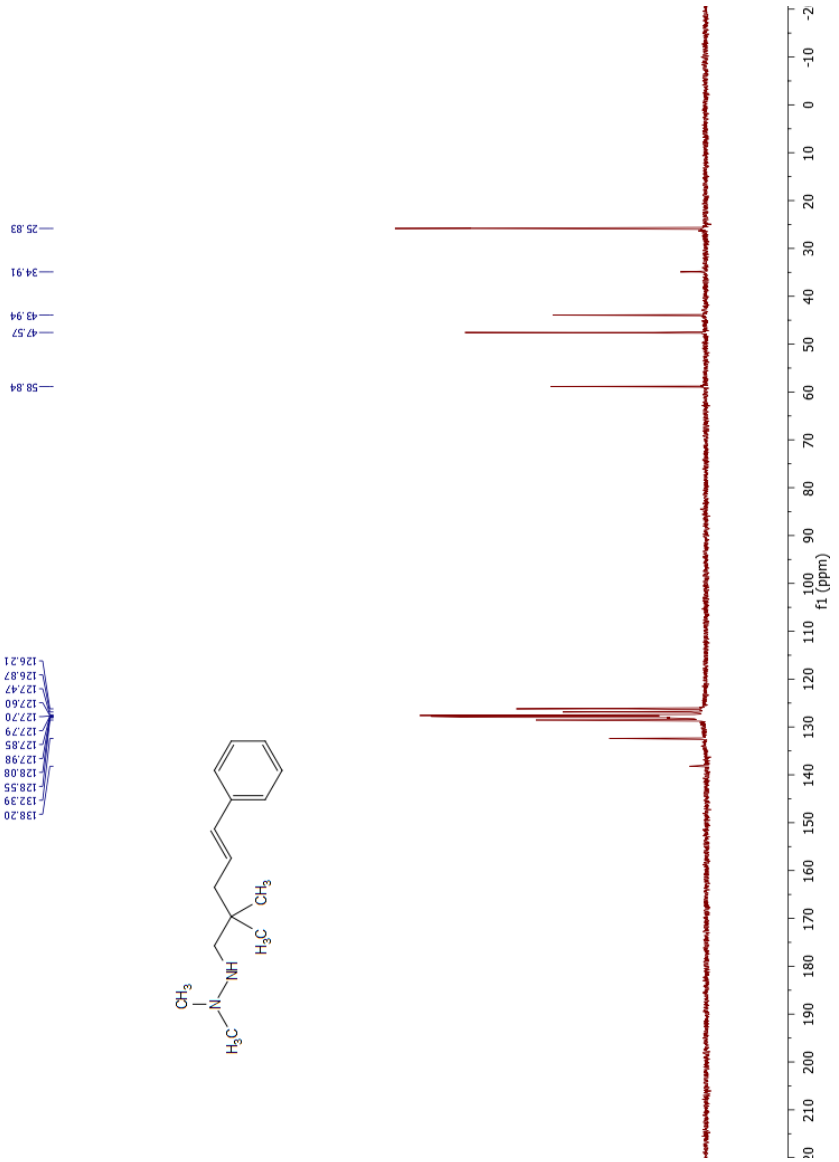
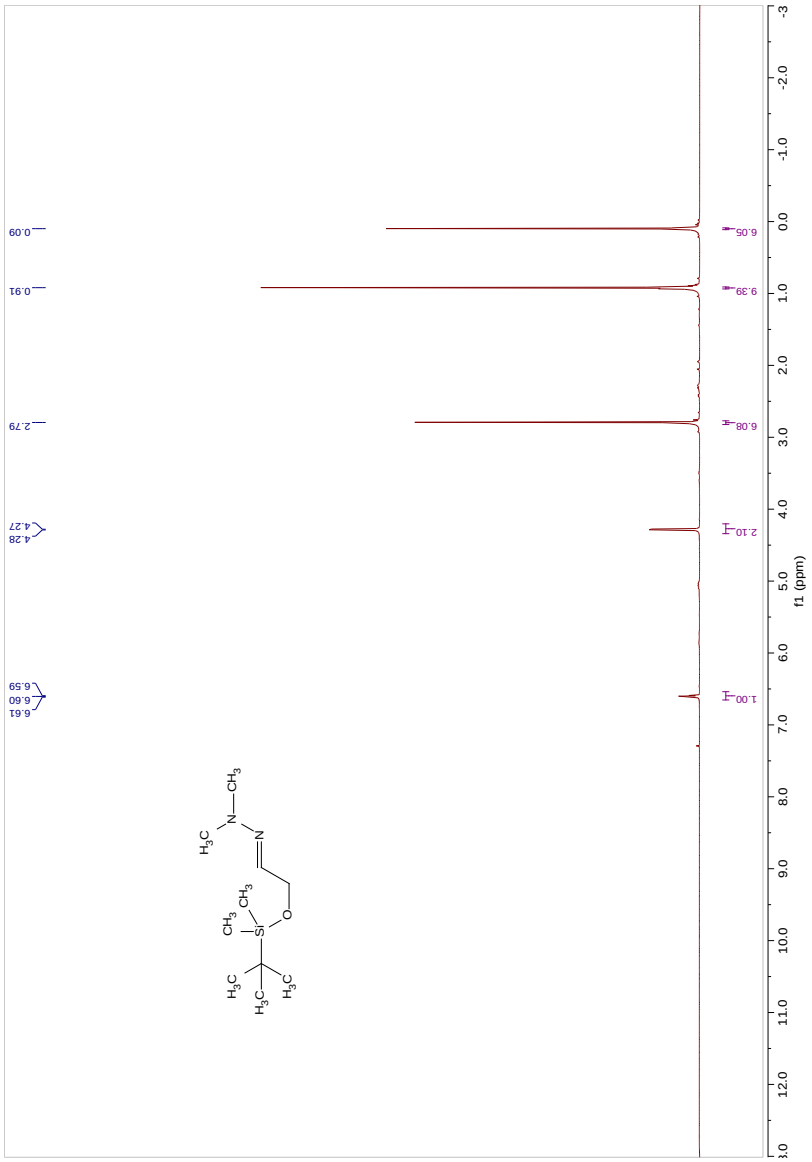
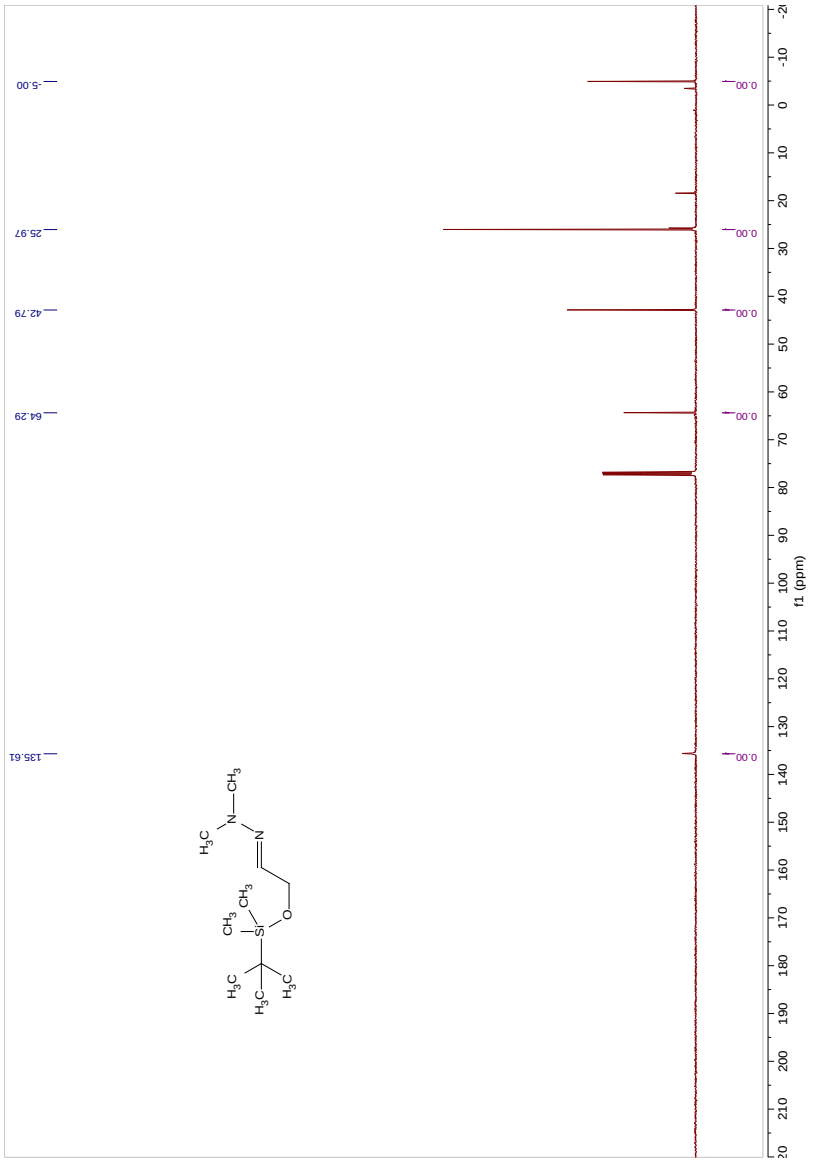
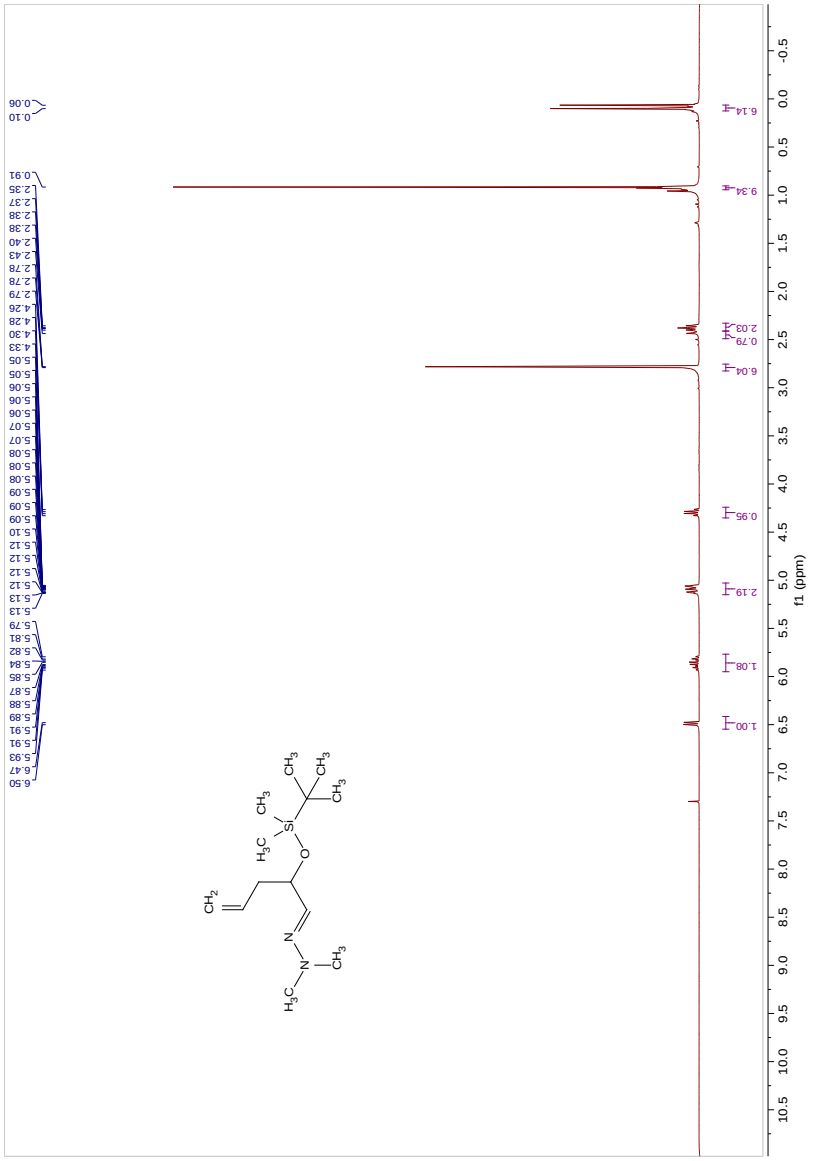
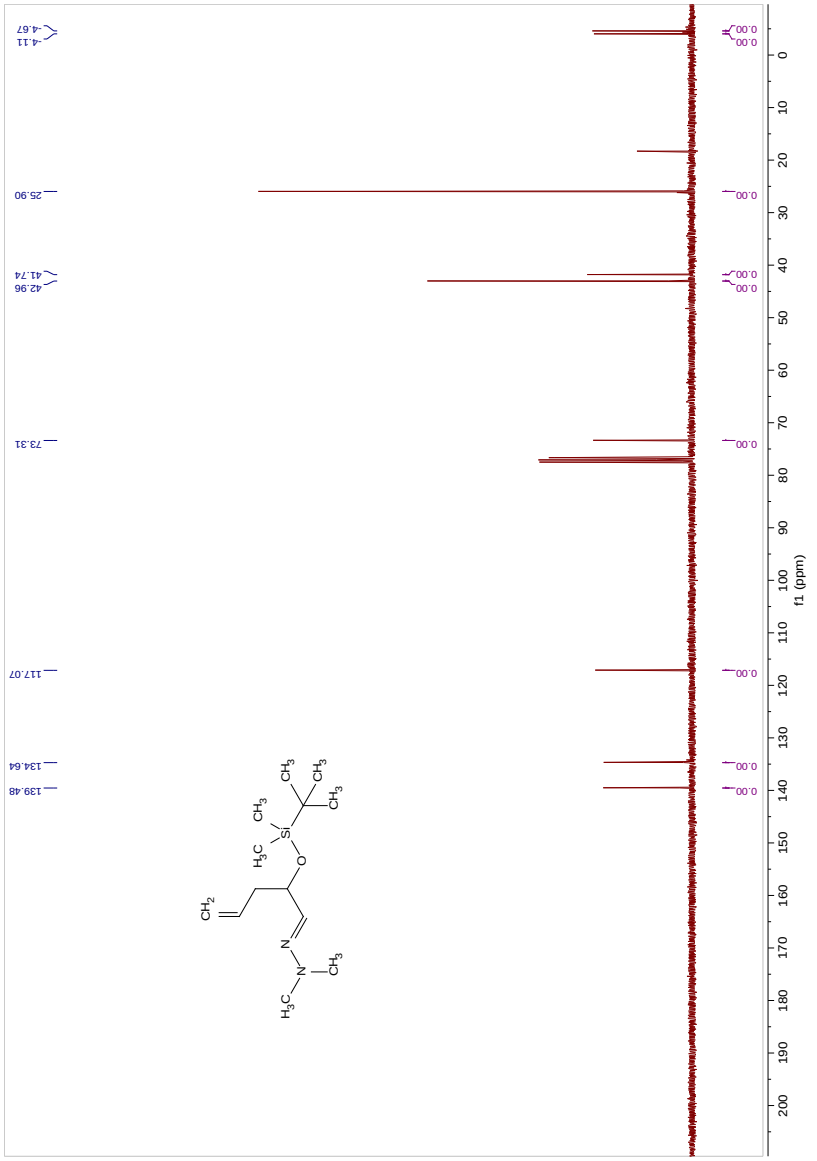
7.17
7.18
7.19
7.19
7.25
7.27
7.28
7.28
7.41
7.42
7.43
CH3
N
H3C
NH
CH3
H3C

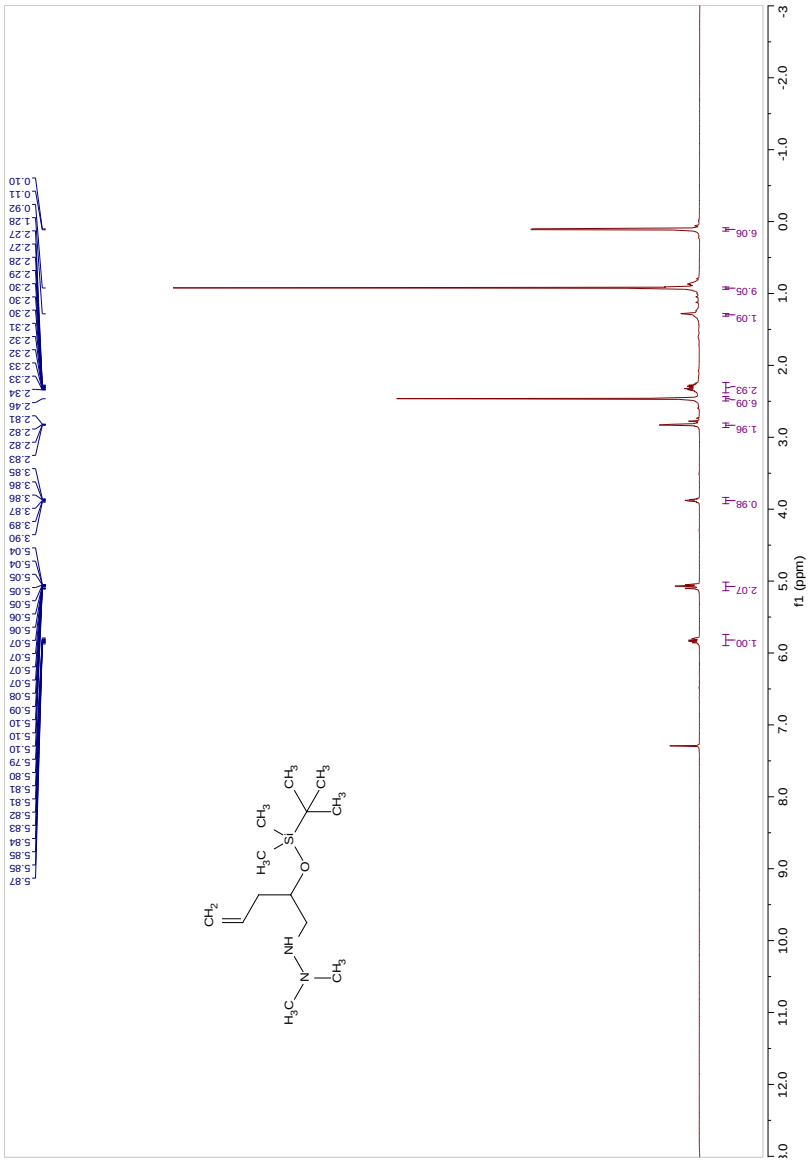

138.20
132.39
128.55
128.08
127.98
127.85
127.79
127.70
127.60
127.47
126.87
126.21
58.84
47.57
43.94
34.91
25.83
f1 (ppm)

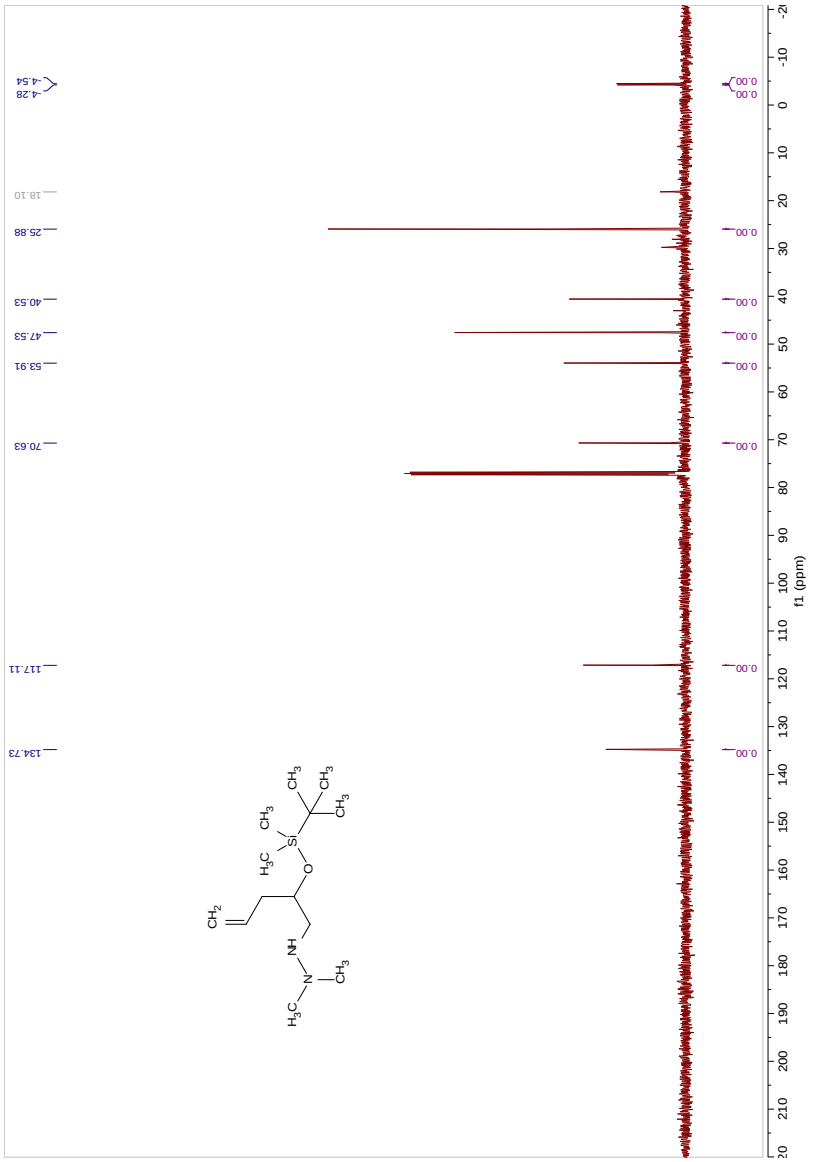

0.09
0.91
2.79
4.28
4.27
6.61
6.60
6.59
6.05
9.39
6.08
2.10
1.00
f1 (ppm)

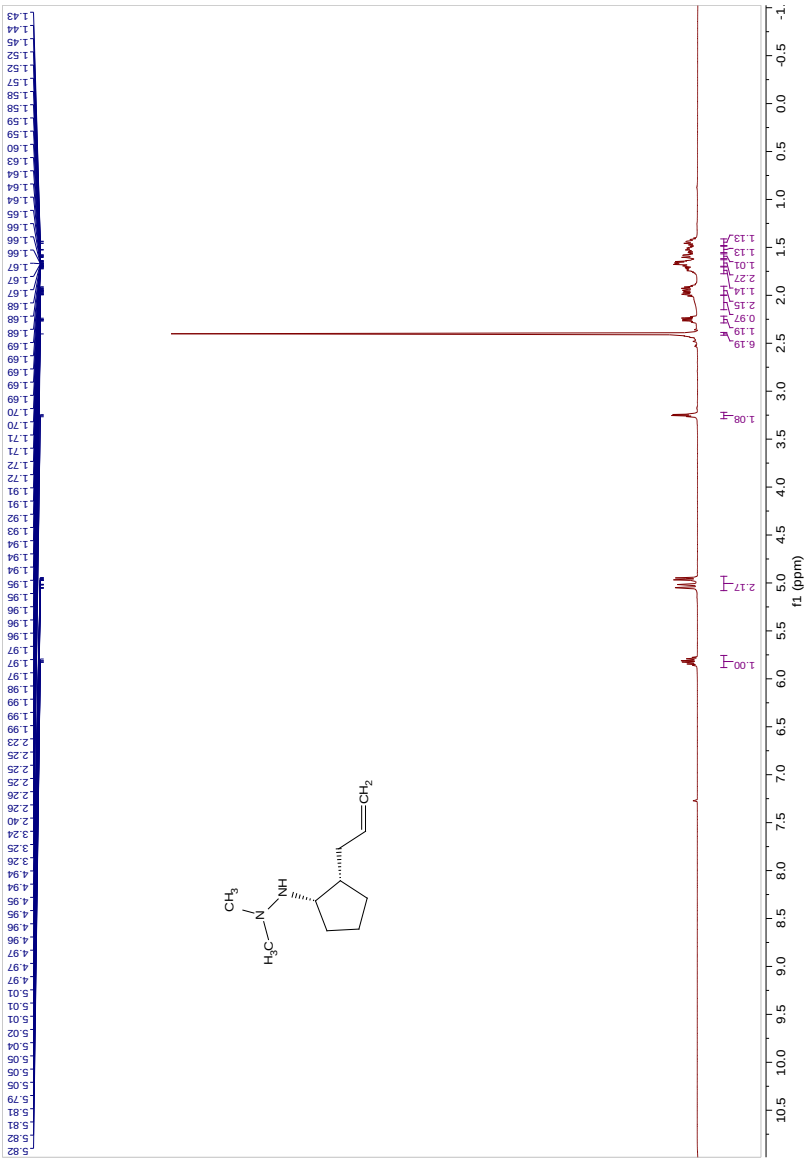

-5.00
25.97
42.79
64.29
135.61
0.00
f1 (ppm)

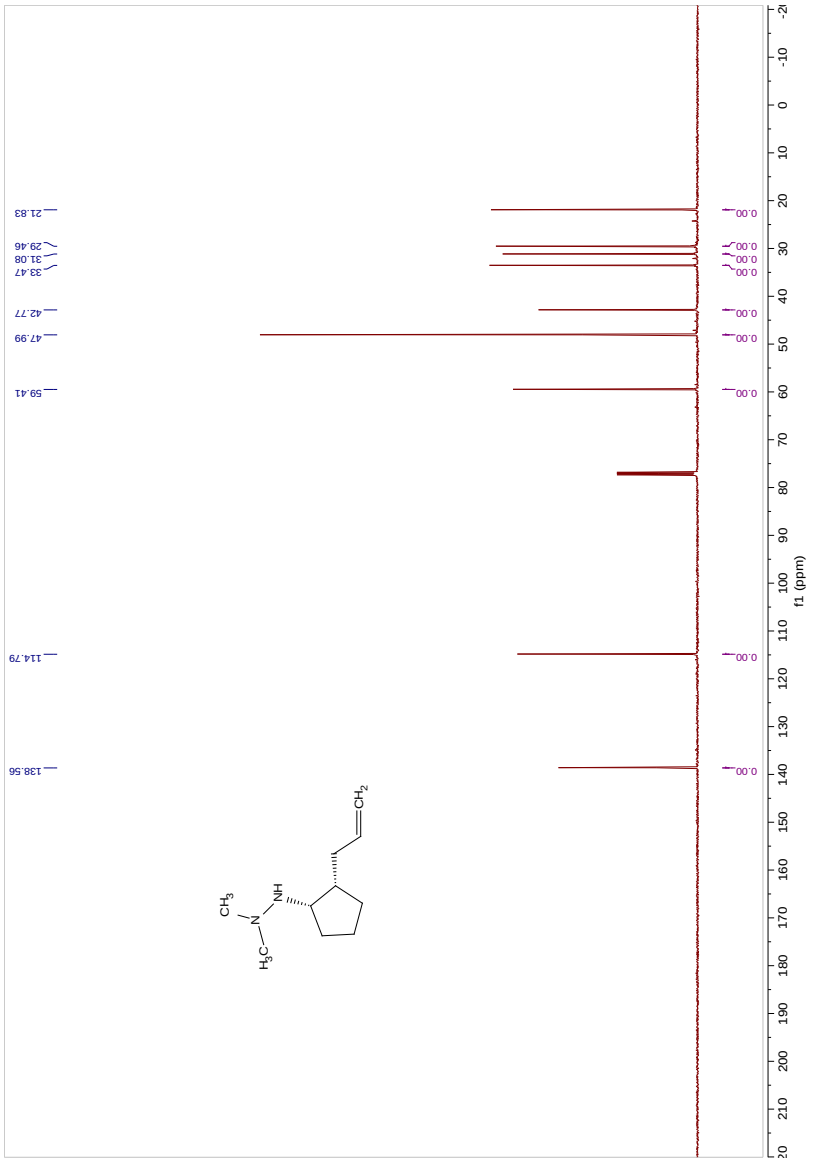

0.10
0.06
0.91
2.35
2.37
2.38
2.38
2.40
2.43
2.78
2.78
2.79
4.26
4.28
4.30
4.33
5.05
5.05
5.06
5.06
5.06
5.07
5.07
5.08
5.08
5.08
5.09
5.09
5.09
5.10
5.12
5.12
5.12
5.12
5.13
5.13
5.79
5.81
5.82
5.84
5.85
5.87
5.88
5.89
5.91
5.91
5.93
6.47
6.50
6.14
9.34
2.03
0.79
6.04
0.95
2.19
1.08
1.00
f1 (ppm)
CH2
Si
O
N
N
CH3
H3C

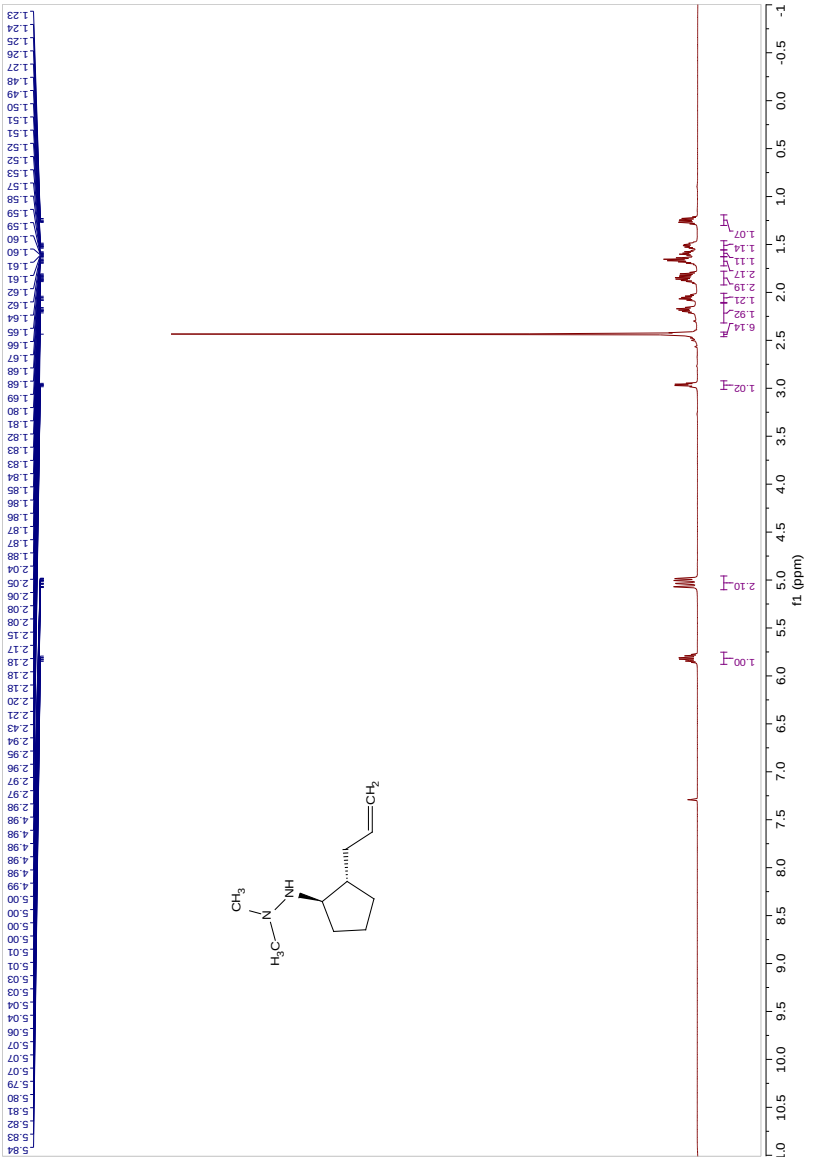

-4.67
-4.11
25.90
42.96
41.74
73.31
117.07
134.64
139.48
f1 (ppm)

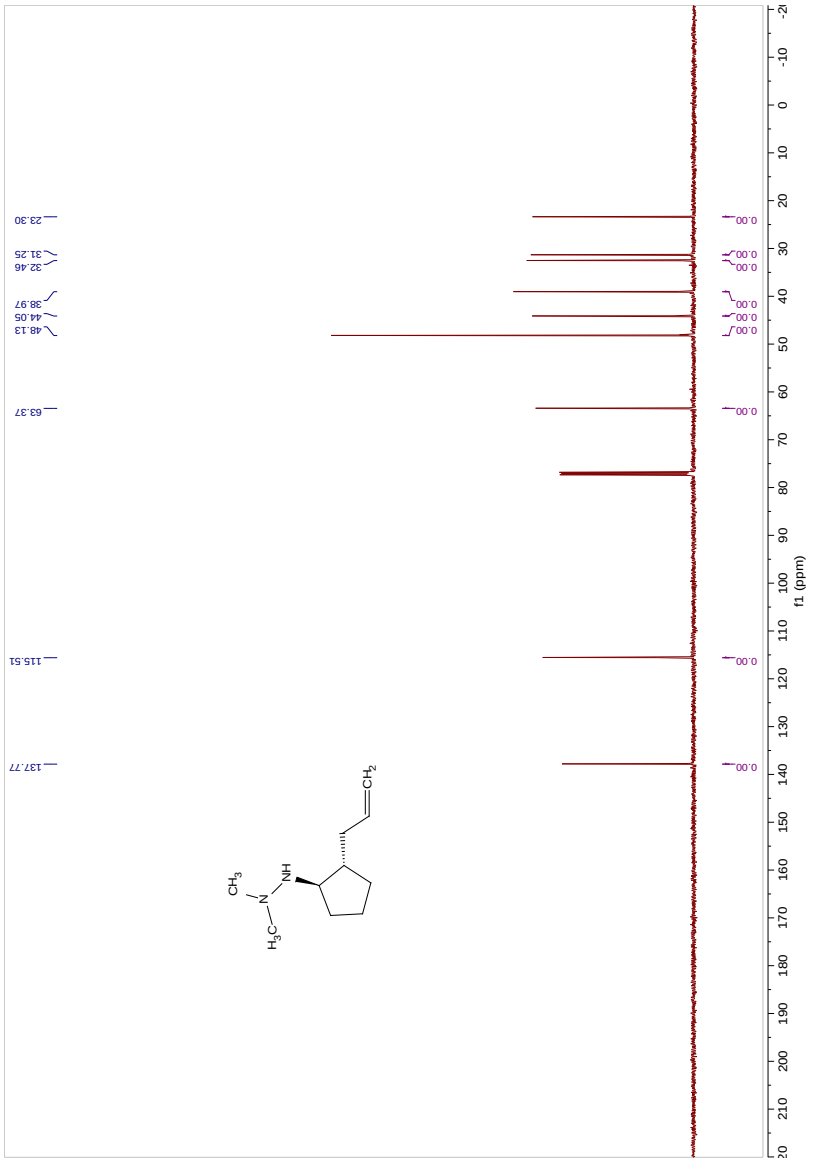

f1 (ppm)
6.06
9.05
1.09
6.09
2.93
1.96
0.98
2.07
1.00

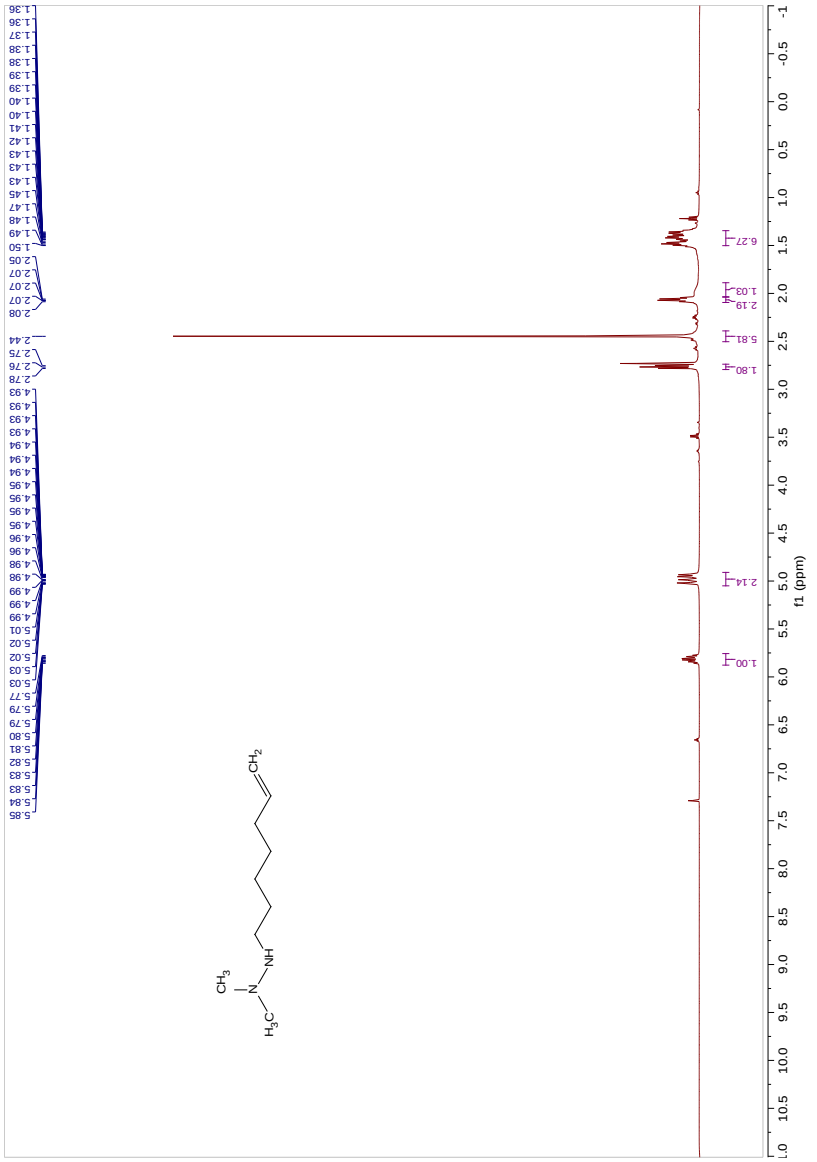

-4.54
-4.28
18.10
25.88
40.53
47.53
53.91
70.63
117.11
134.73
0.00
f1 (ppm)

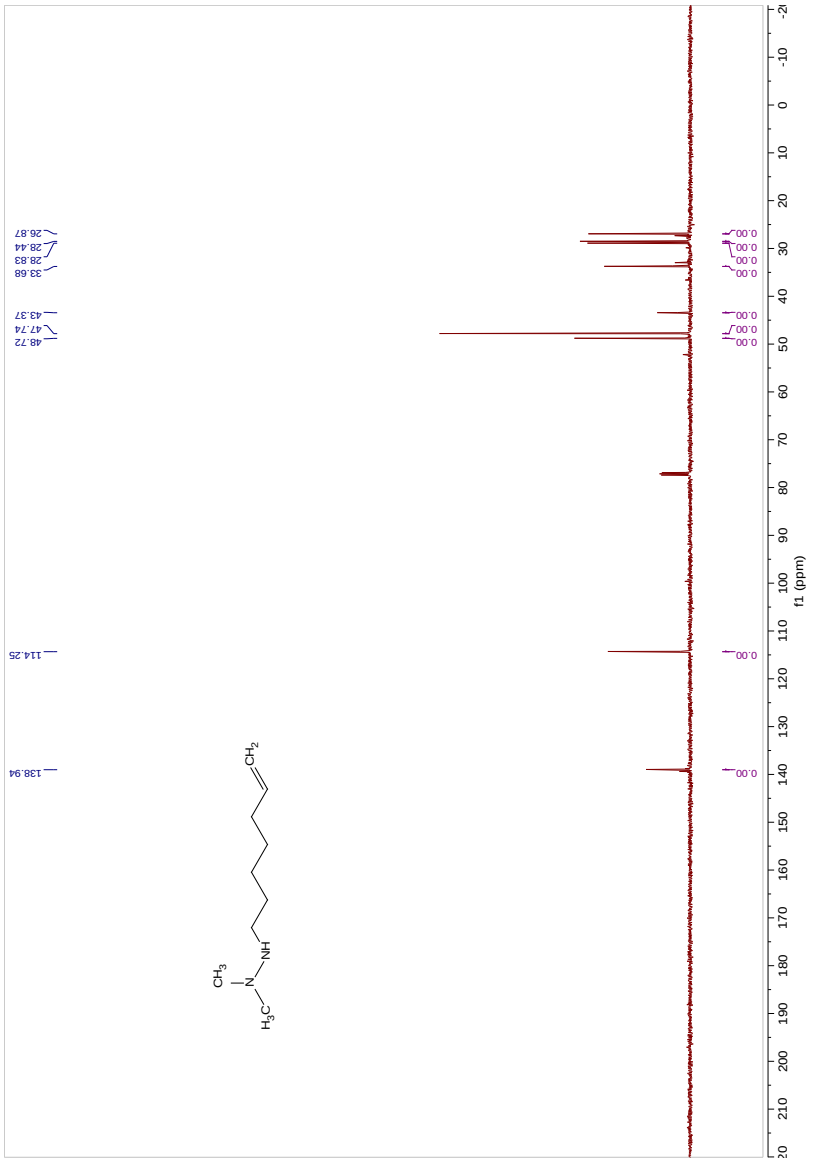

f1 (ppm)
CH3
N
NH
H3C
CH2

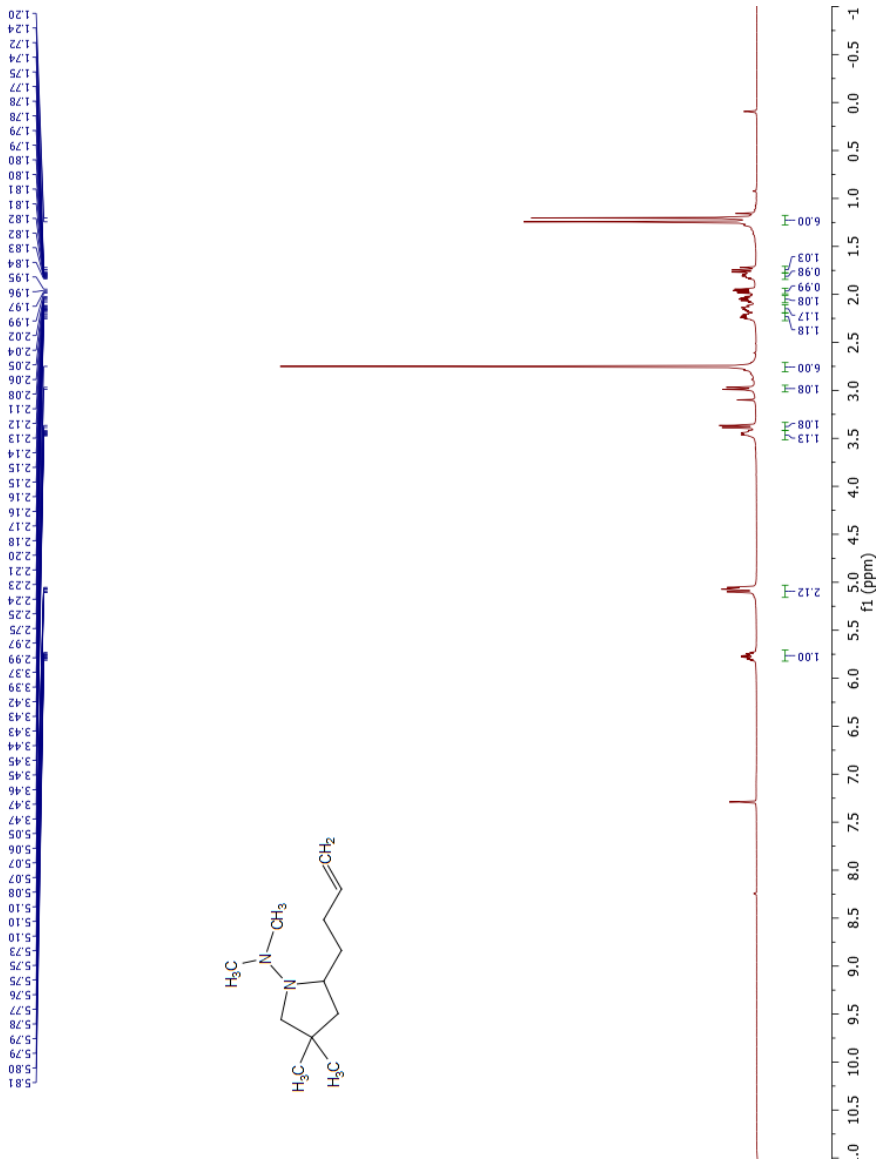

21.83
29.46
31.08
33.47
42.77
47.99
59.41
114.79
138.56
0.00
f1 (ppm)
CH3
N
NH
H3C
CH2

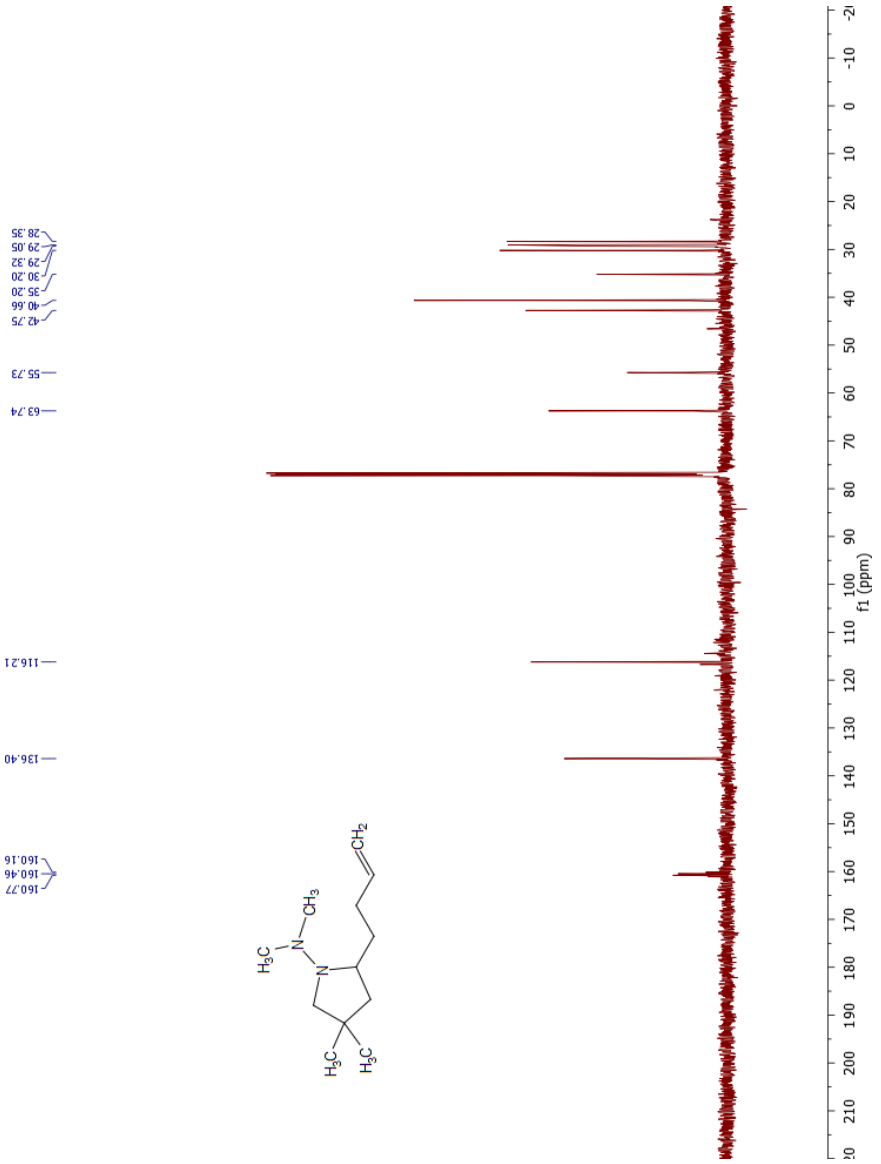

f1 (ppm)
1.00
2.10
1.02
6.14
1.92
1.21
2.19
2.17
1.11
1.14
1.07
CH2
NH
N
CH3
H3C

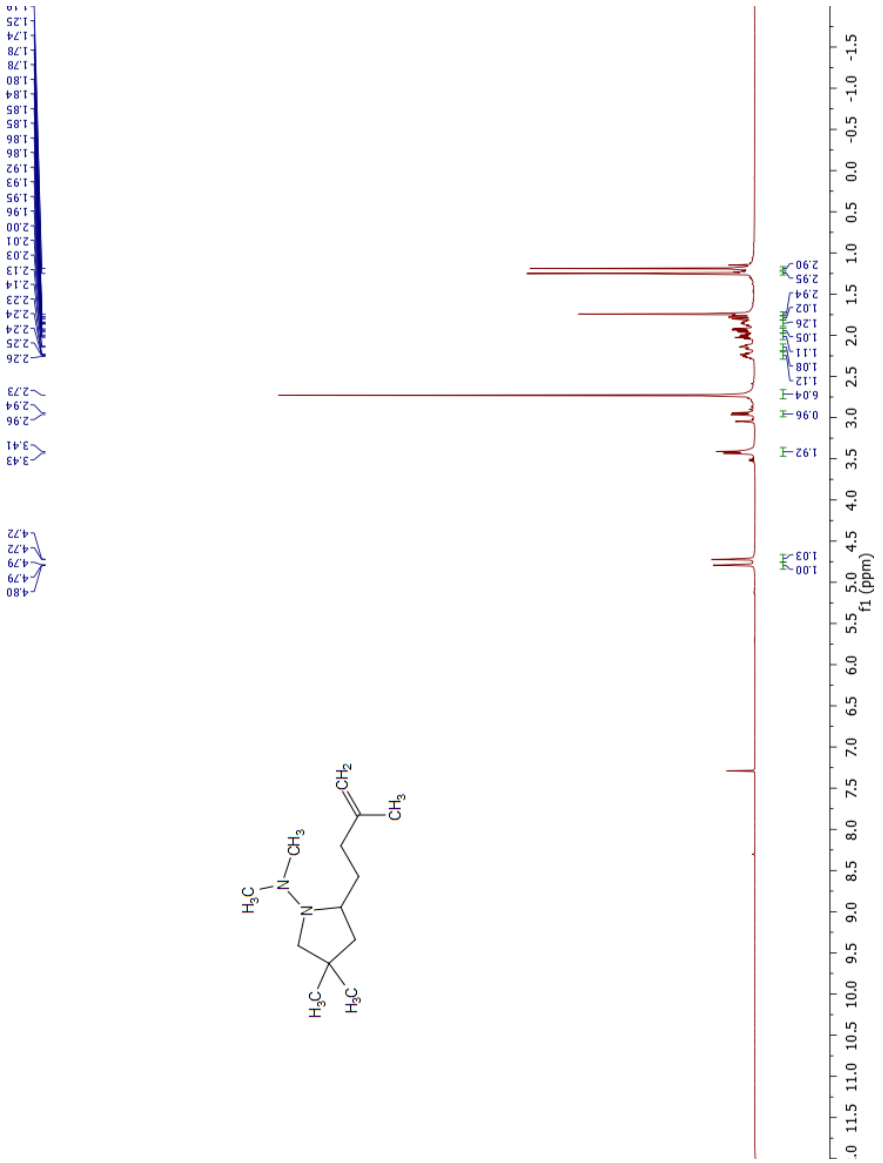

23.30
31.25
32.46
38.97
44.05
48.13
63.37
115.51
137.77
0.00
f1 (ppm)

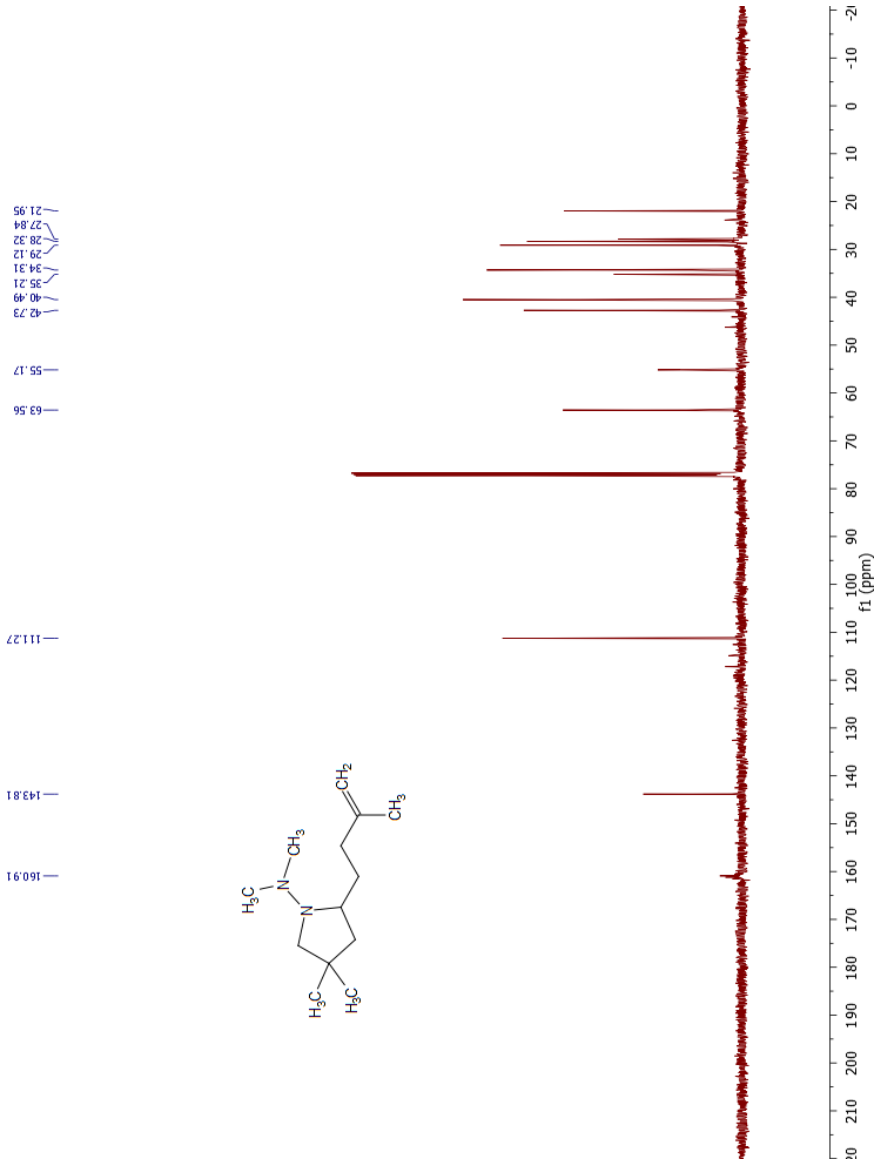

f1 (ppm)
6.27
1.03
2.19
5.81
1.80
2.14
1.00
CH2
NH
N
CH3
H3C

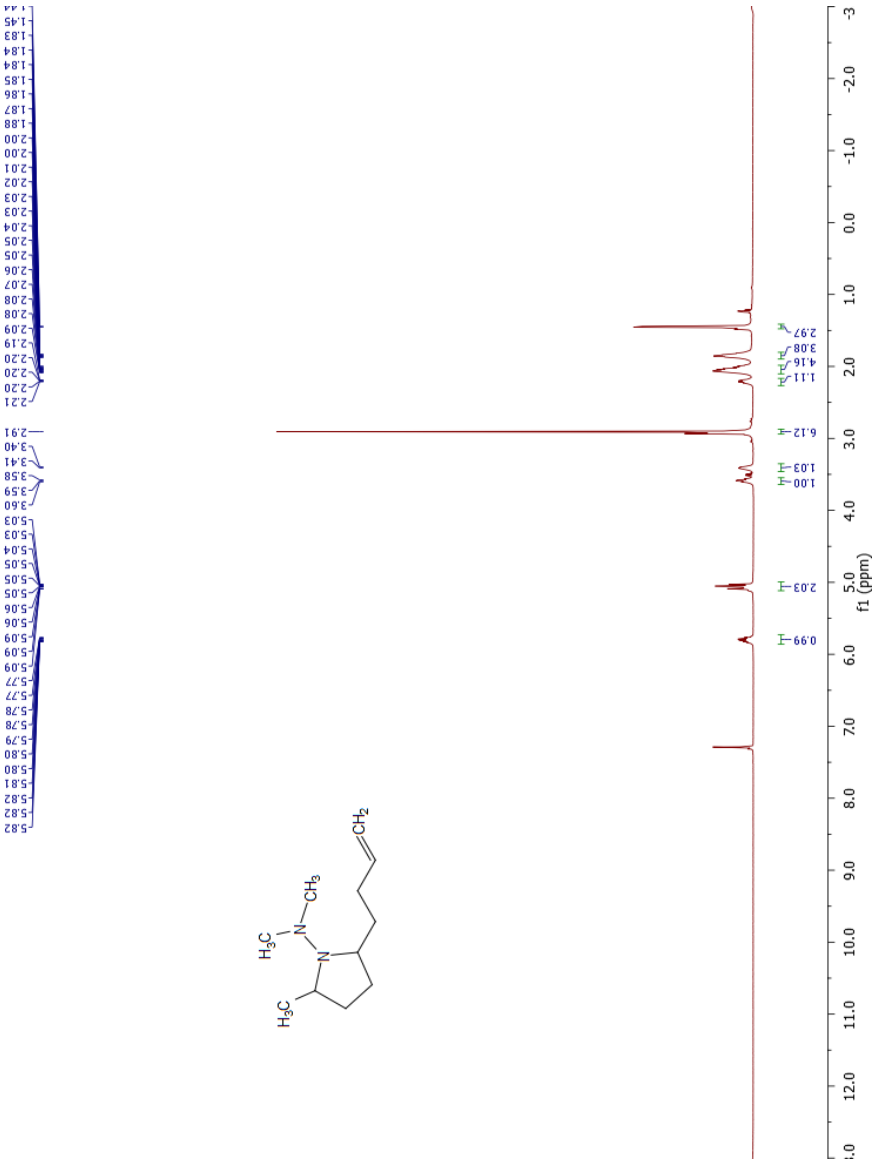

138.94
114.25
48.72
47.74
43.37
33.68
28.83
28.44
26.87
0.00
f1 (ppm)

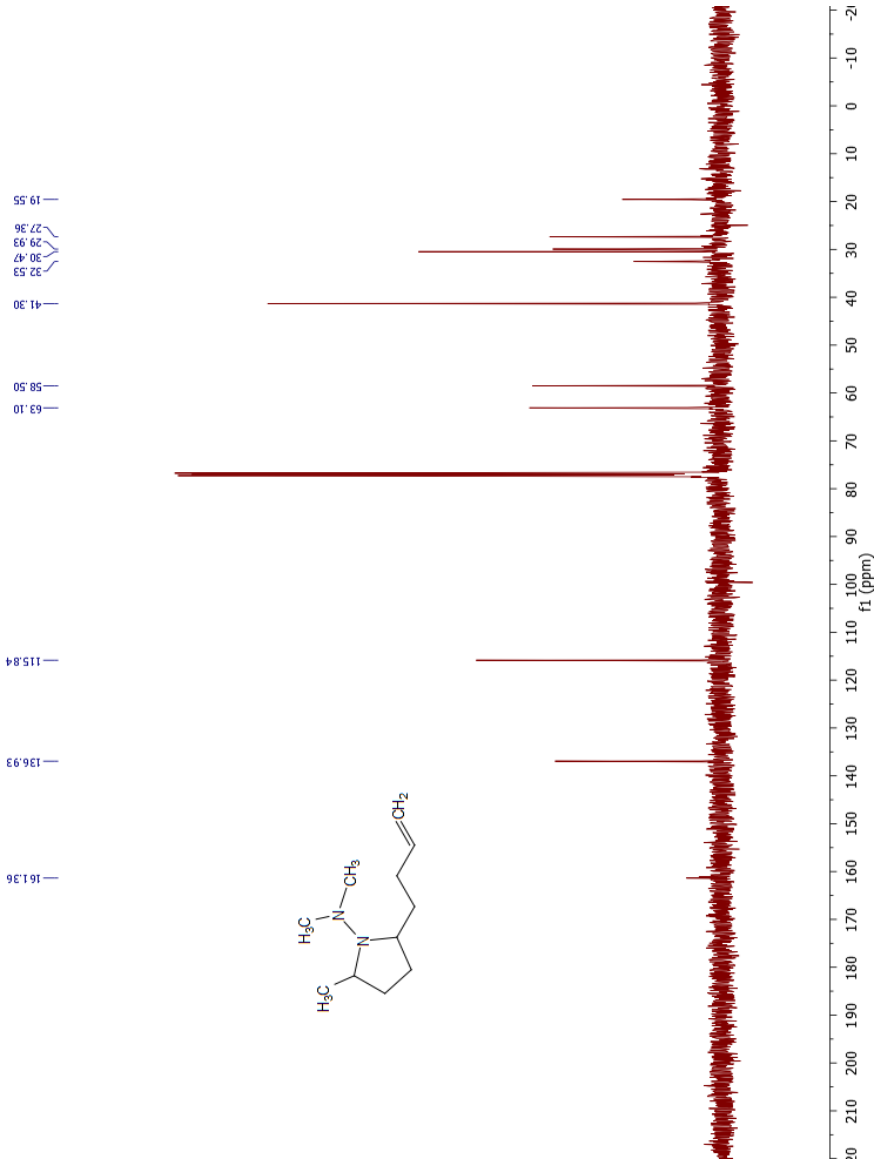

H3C
N
CH3
N
CH2
H3C
H3C
f1 (ppm)

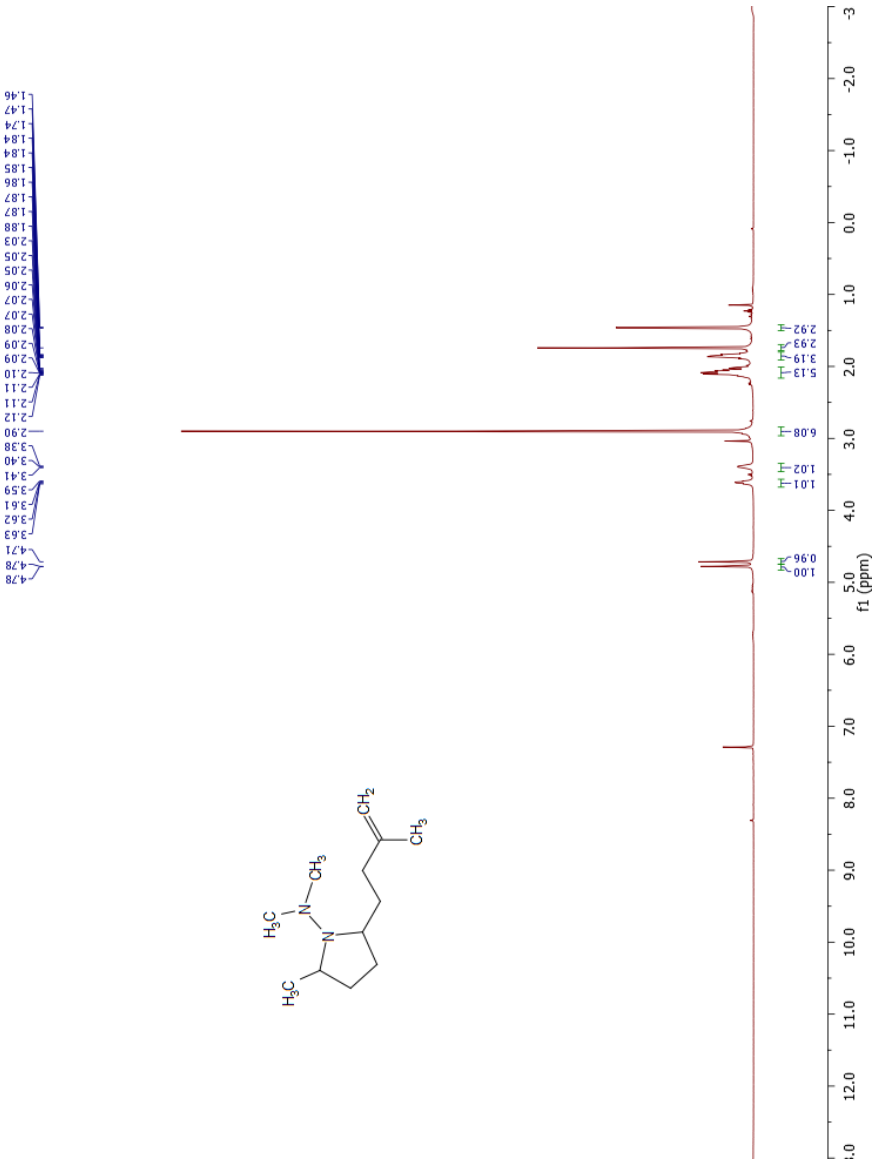

28.35
29.05
29.32
30.20
35.20
40.66
42.75
55.73
63.74
116.21
136.40
160.16
160.46
160.77
f1 (ppm)

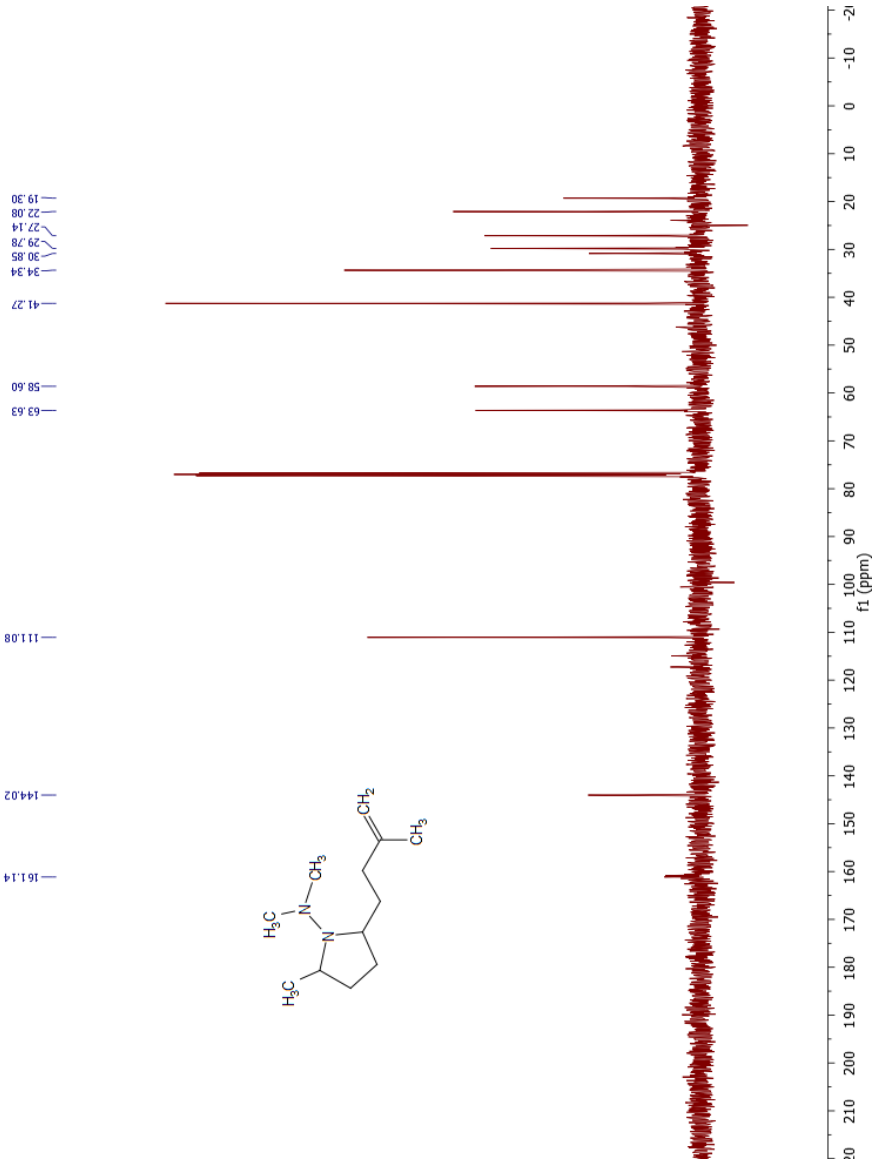

f1 (ppm)

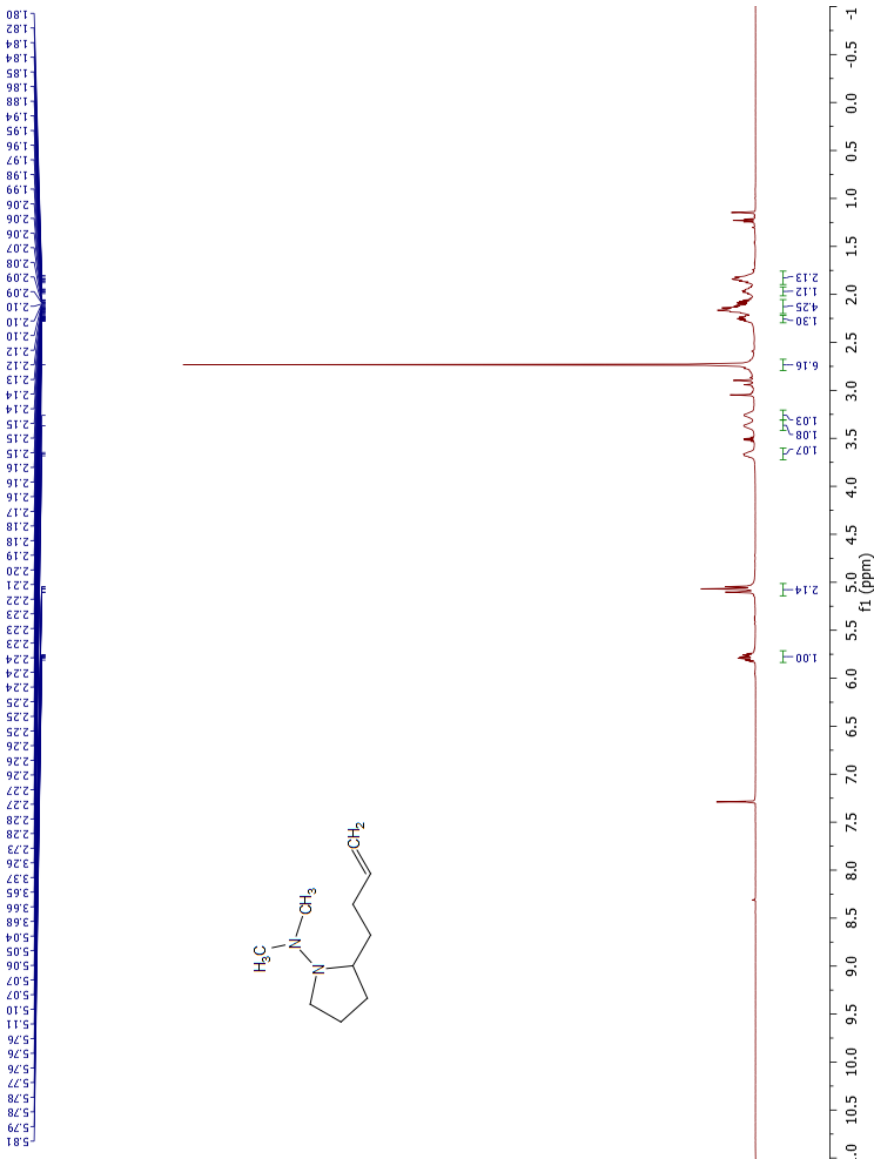

160.91
143.81
111.27
63.56
55.17
42.73
40.49
35.21
34.31
29.12
28.32
27.84
21.95
f1 (ppm)

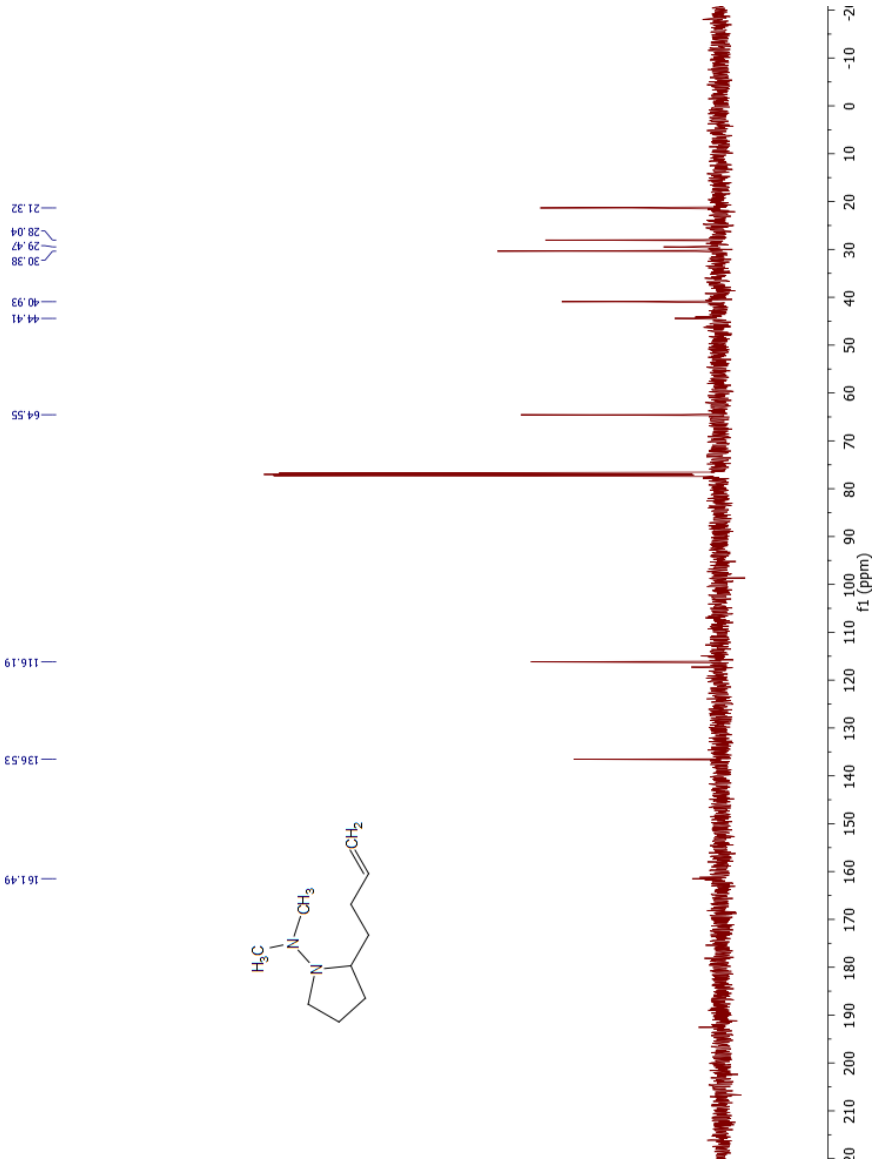

f1 (ppm)
H3C
N
CH3
N
H3C
CH2

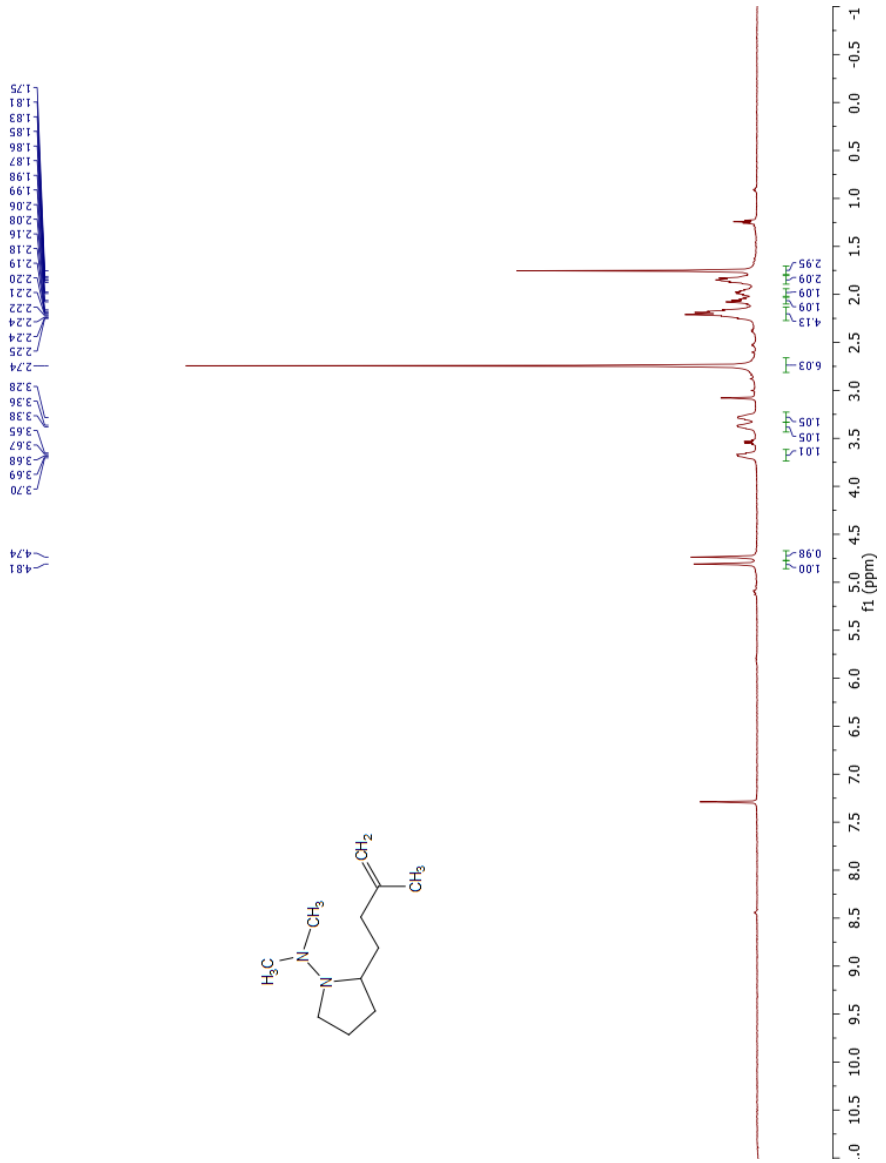

19.55
27.36
29.93
30.47
32.53
41.30
58.50
63.10
115.84
136.93
161.36
f1 (ppm)

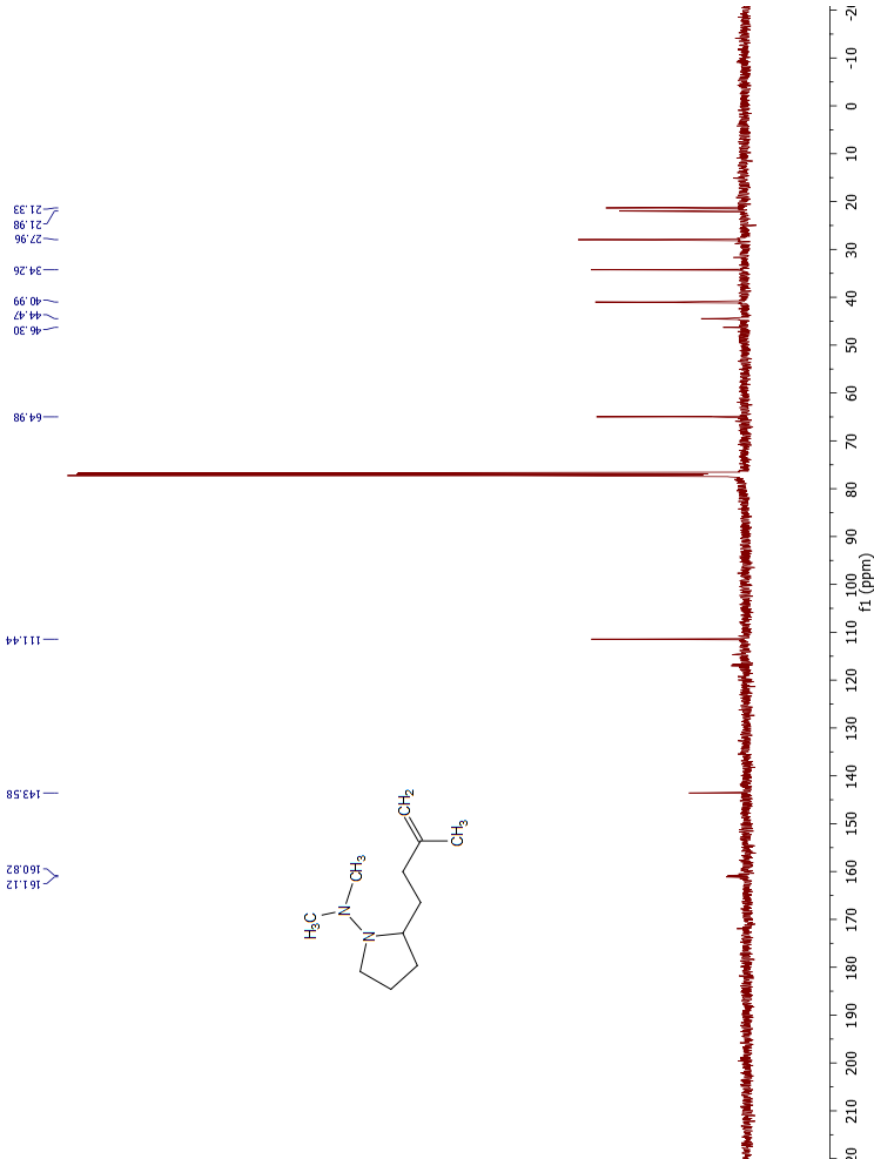

1.46
1.47
1.74
1.84
1.84
1.85
1.86
1.87
1.87
1.88
2.03
2.05
2.05
2.06
2.07
2.07
2.08
2.09
2.09
2.10
2.11
2.11
2.12
2.90
3.38
3.40
3.41
3.59
3.61
3.62
3.63
4.71
4.78
4.78
5.13
3.19
2.93
2.92
6.08
1.01
1.02
1.00
0.96
f1 (ppm)
H3C
N
CH3
N
H3C
CH2
CH3

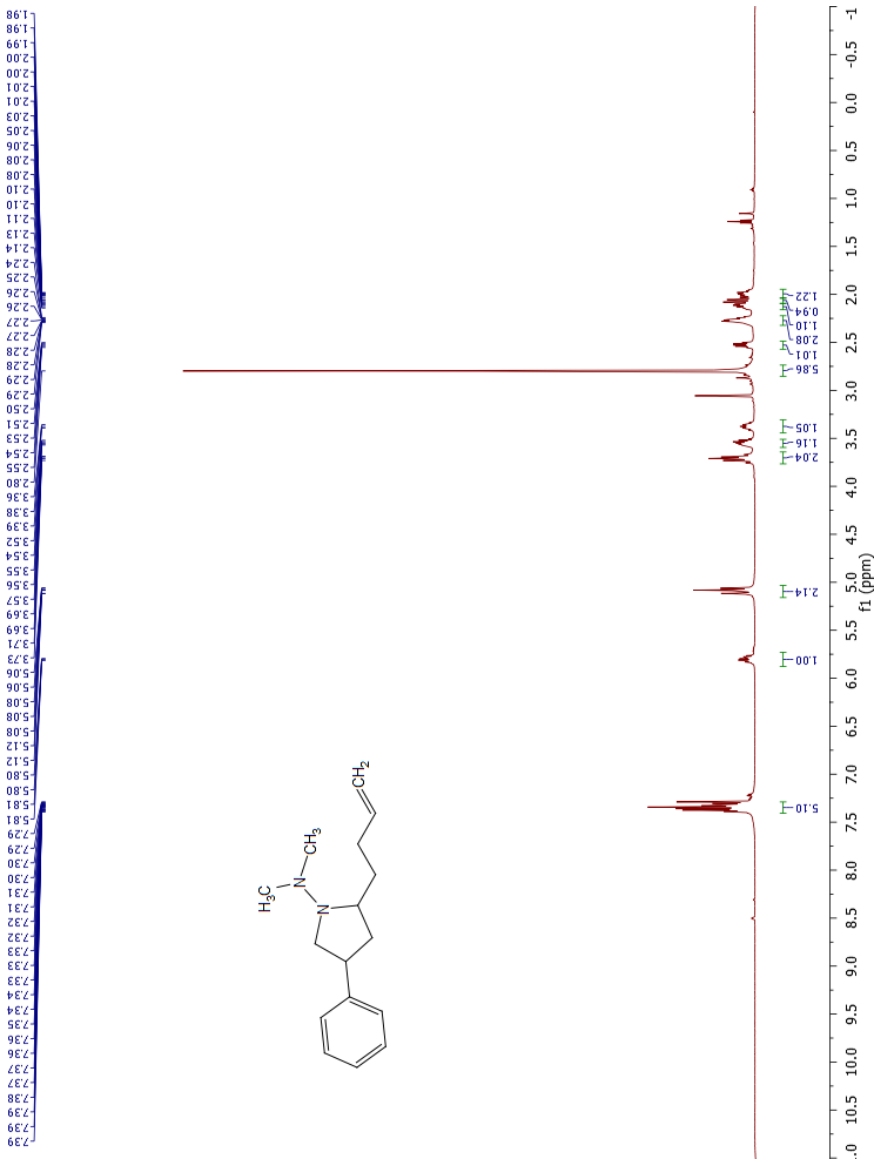

19.30
22.08
27.14
29.78
30.85
34.34
41.27
58.60
63.63
111.08
144.02
161.14
f1 (ppm)

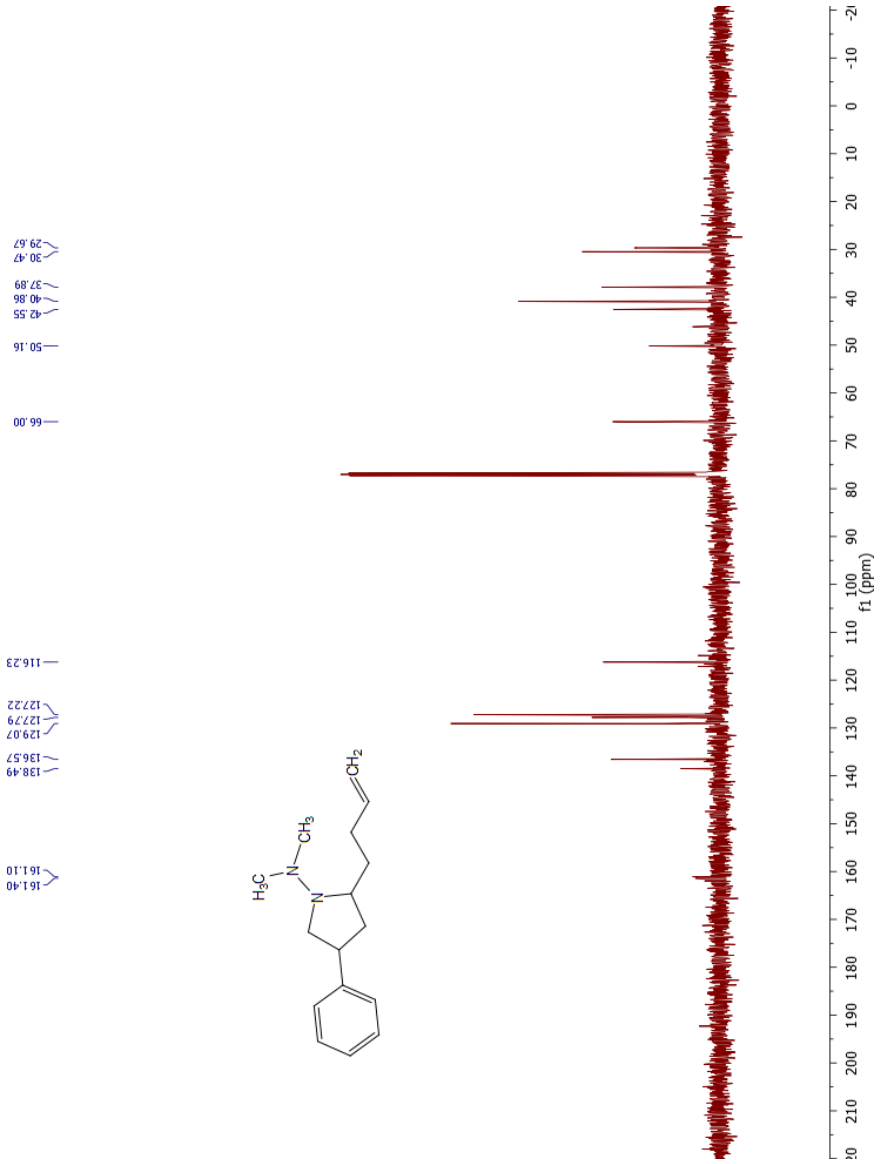

f1 (ppm)
H3C
N
CH3
N
CH2

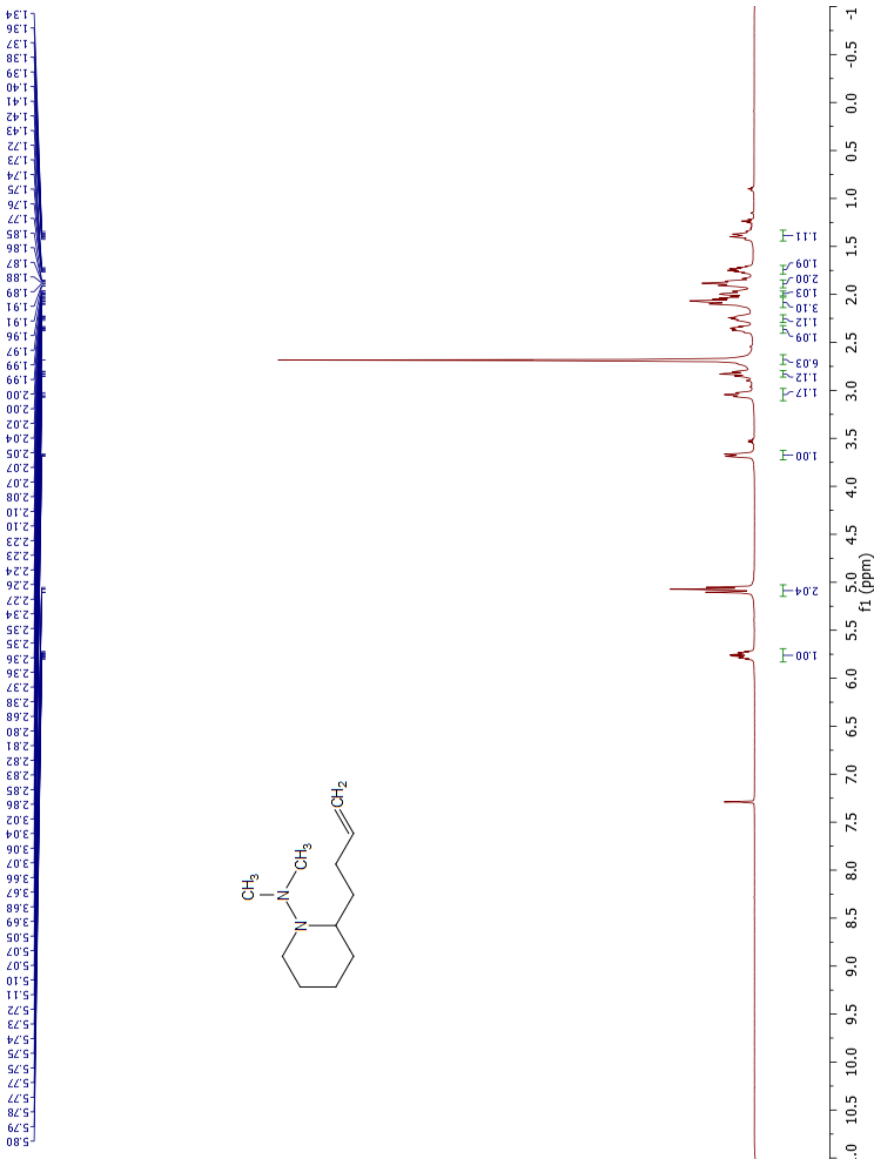

21.32
28.04
29.47
30.38
40.93
44.41
64.55
116.19
136.53
161.49
H_3C
N
CH_3
N
CH_2
f1 (ppm)

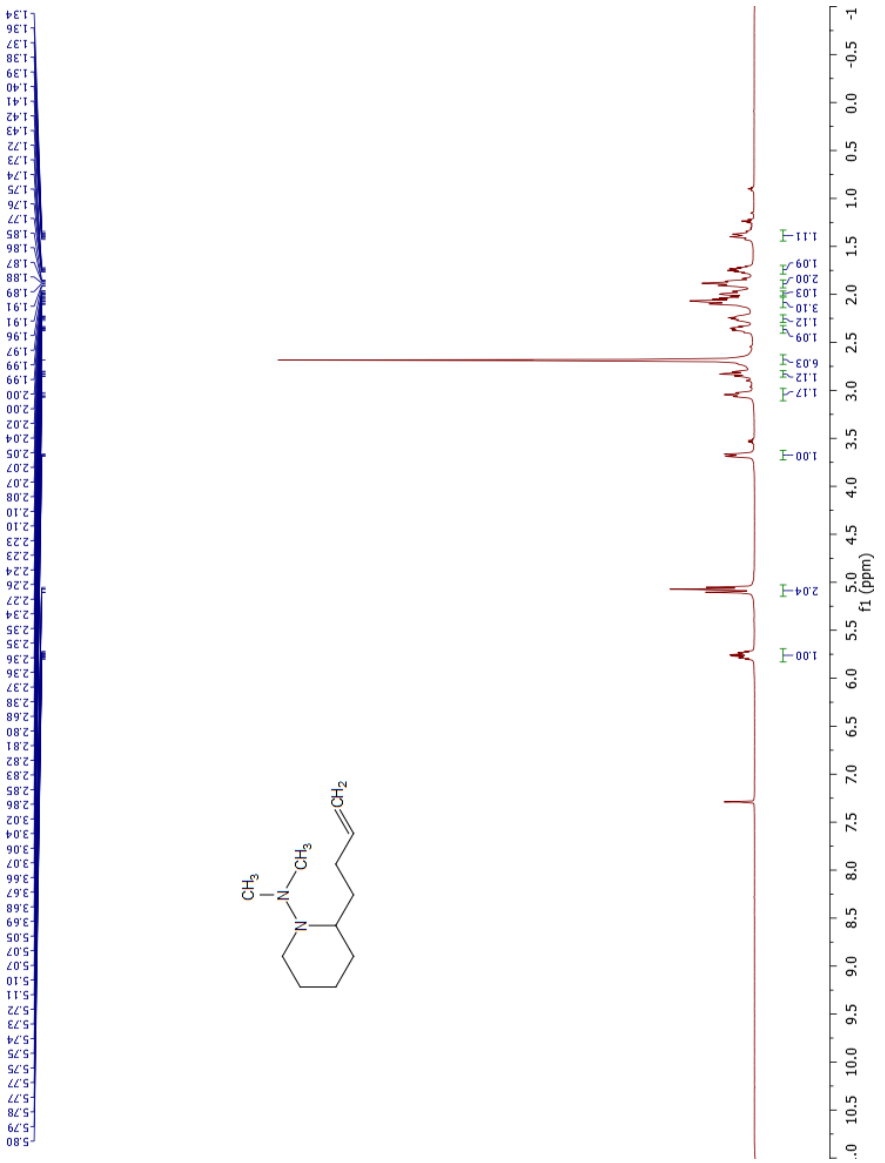

1.75
1.81
1.83
1.85
1.86
1.87
1.98
1.99
2.06
2.08
2.16
2.18
2.19
2.20
2.21
2.22
2.24
2.24
2.25
2.74
3.28
3.36
3.38
3.65
3.67
3.68
3.69
3.70
4.74
4.81
0.98
1.00
1.05
1.05
1.01
6.03
1.09
1.09
2.09
2.95
f1 (ppm)
H3C
N
CH3
N
CH2
CH3

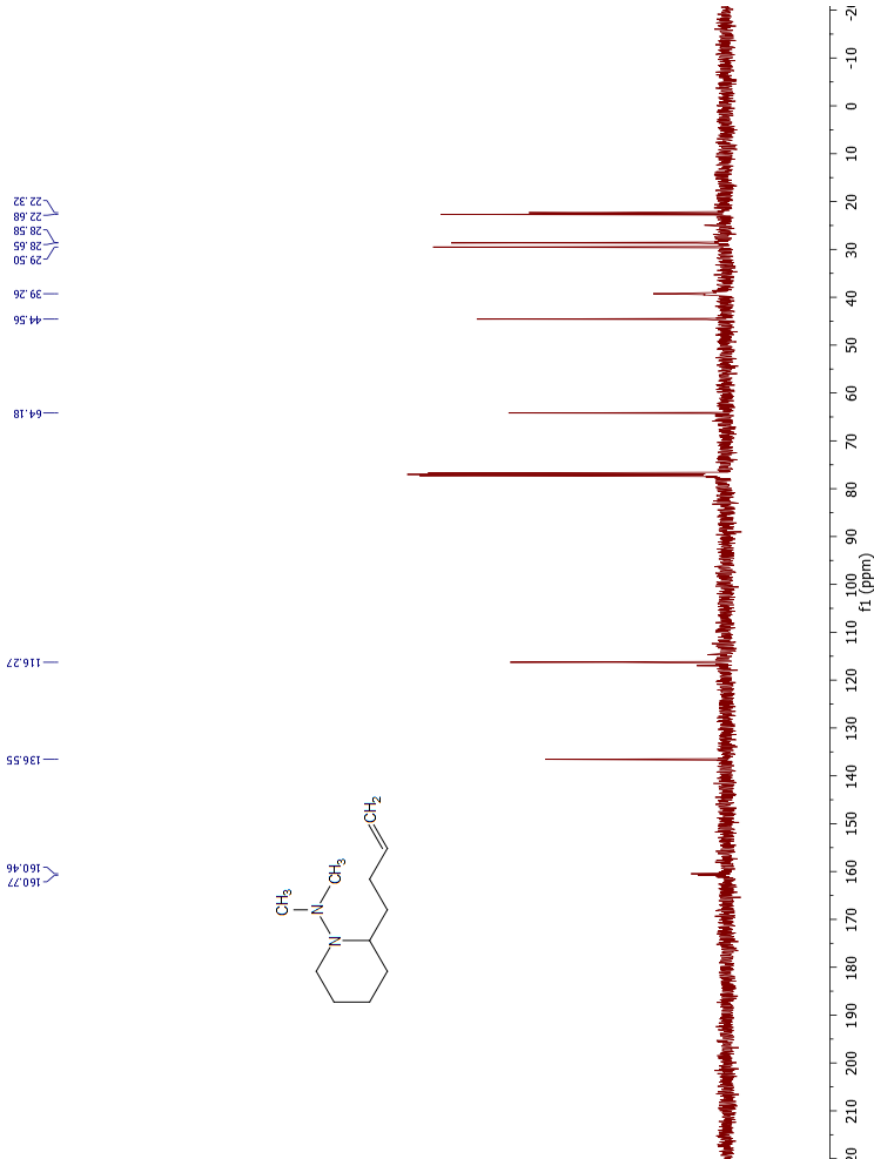

21.33
21.98
27.96
34.26
40.99
44.47
46.30
64.98
111.44
143.58
160.82
161.12
f1 (ppm)
H3C
N
CH3
N
CH2
CH3

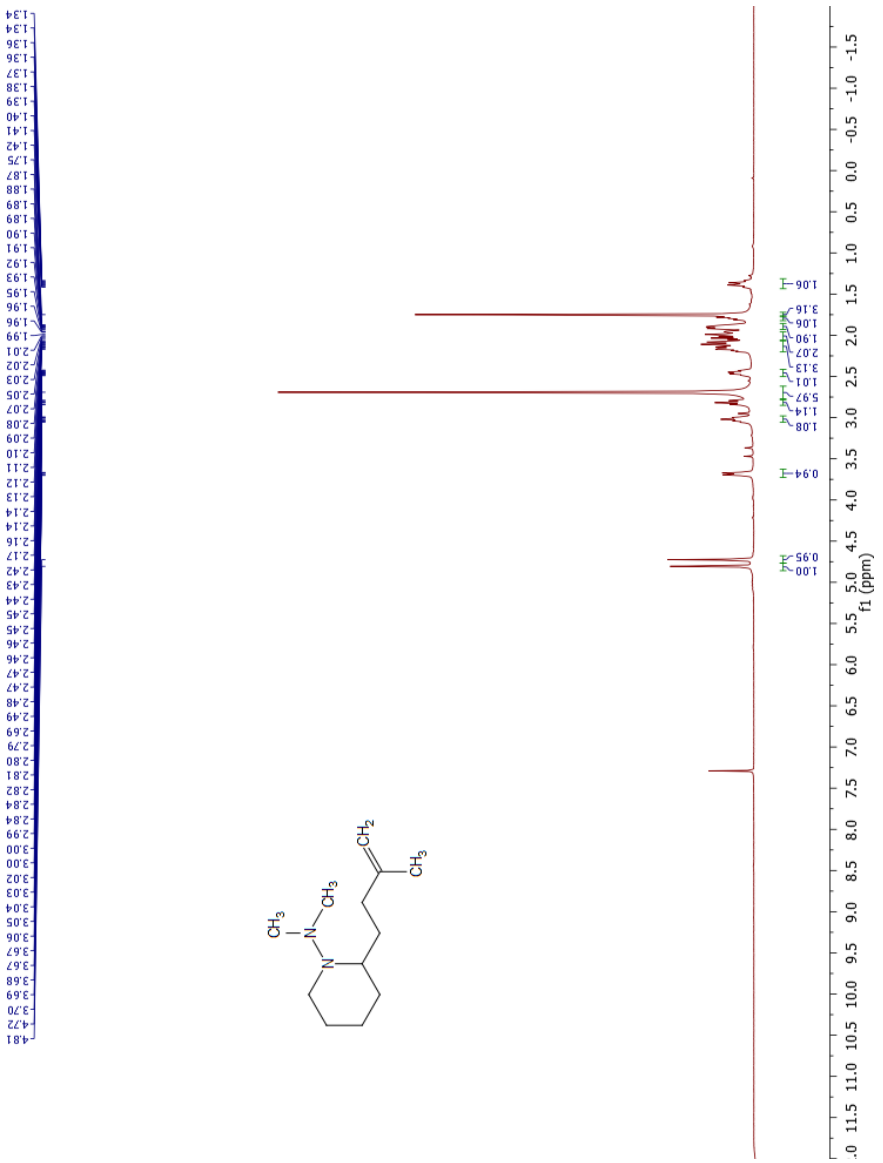

f1 (ppm)
5.10
1.00
2.14
1.05
1.16
2.04
5.86
1.01
2.08
1.10
0.94
1.22
H3C
N
CH3
N
CH2

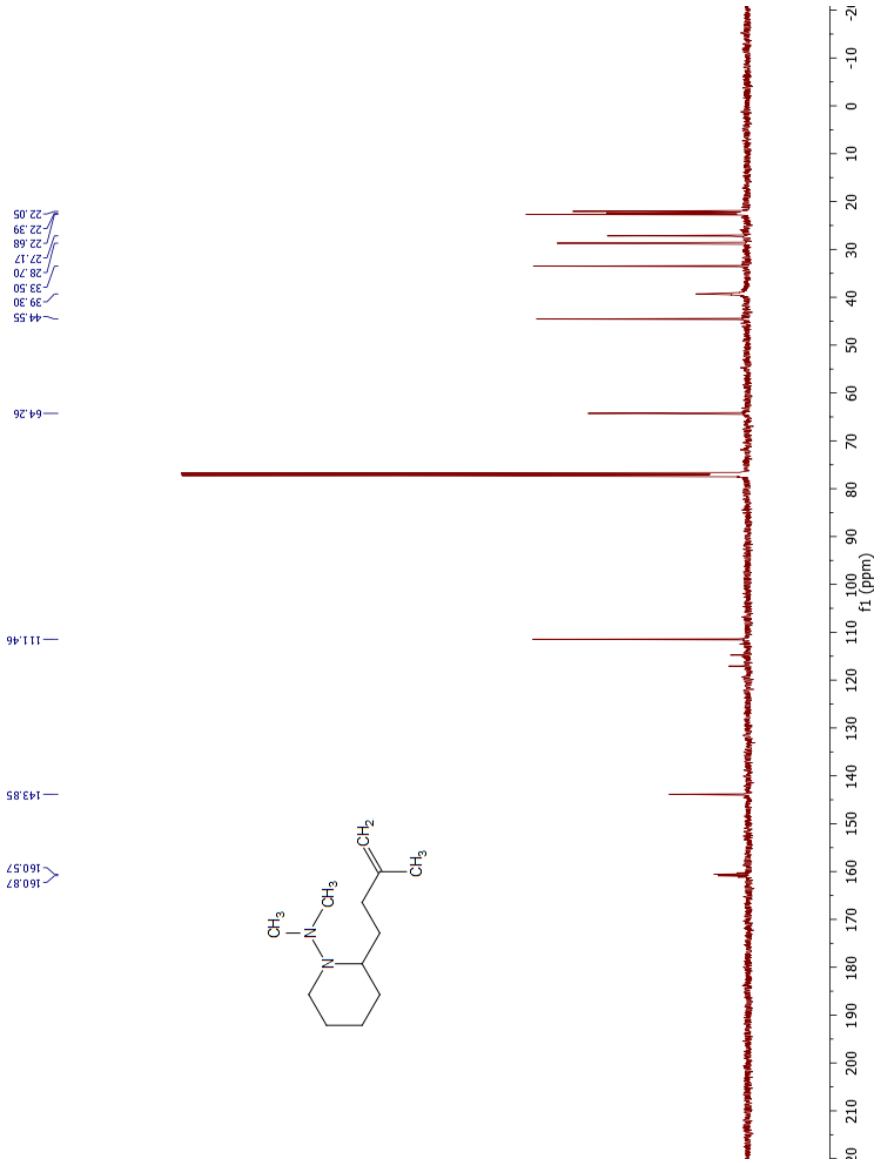

29.67
30.47
37.89
40.86
42.55
50.16
66.00
116.23
127.22
127.79
129.07
136.57
138.49
161.10
161.40
CH2
CH3
H3C
N
N
f1 (ppm)

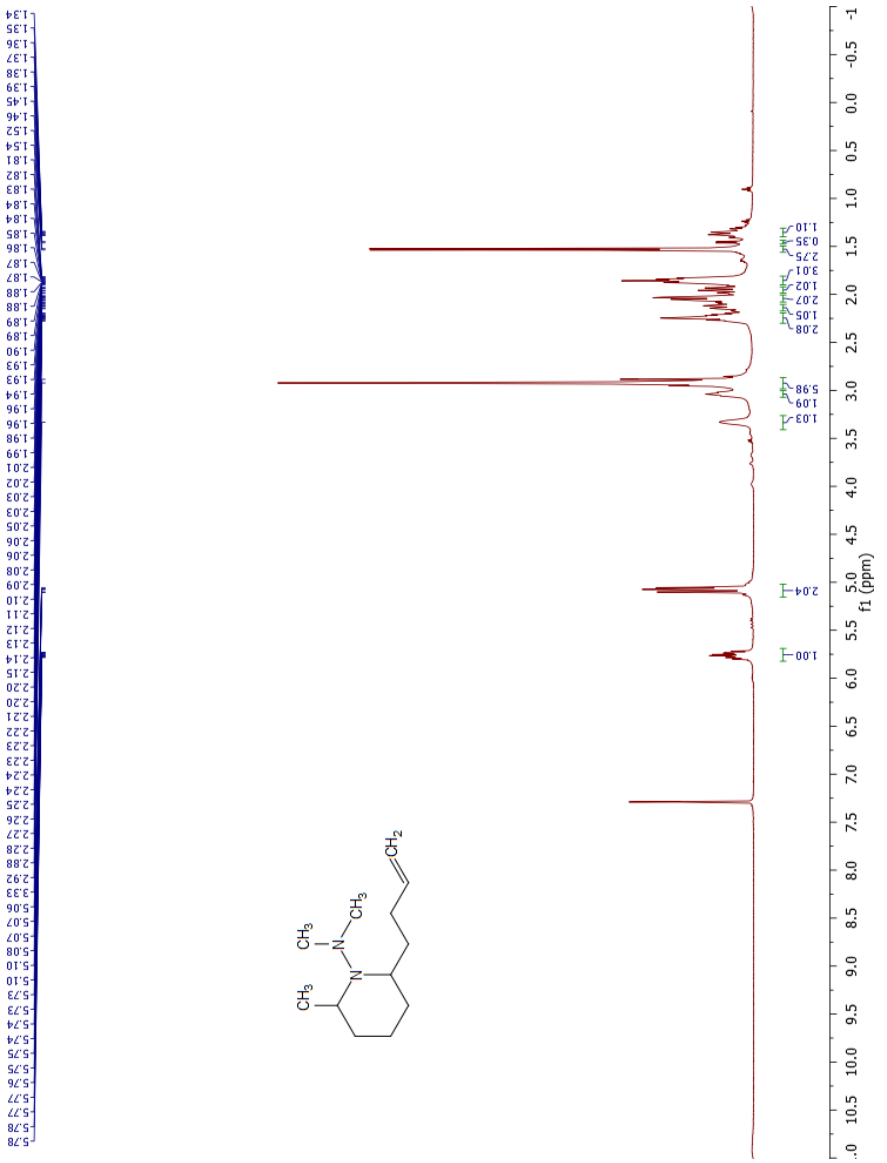

CH3
N
N
CH3
CH2
f1 (ppm)

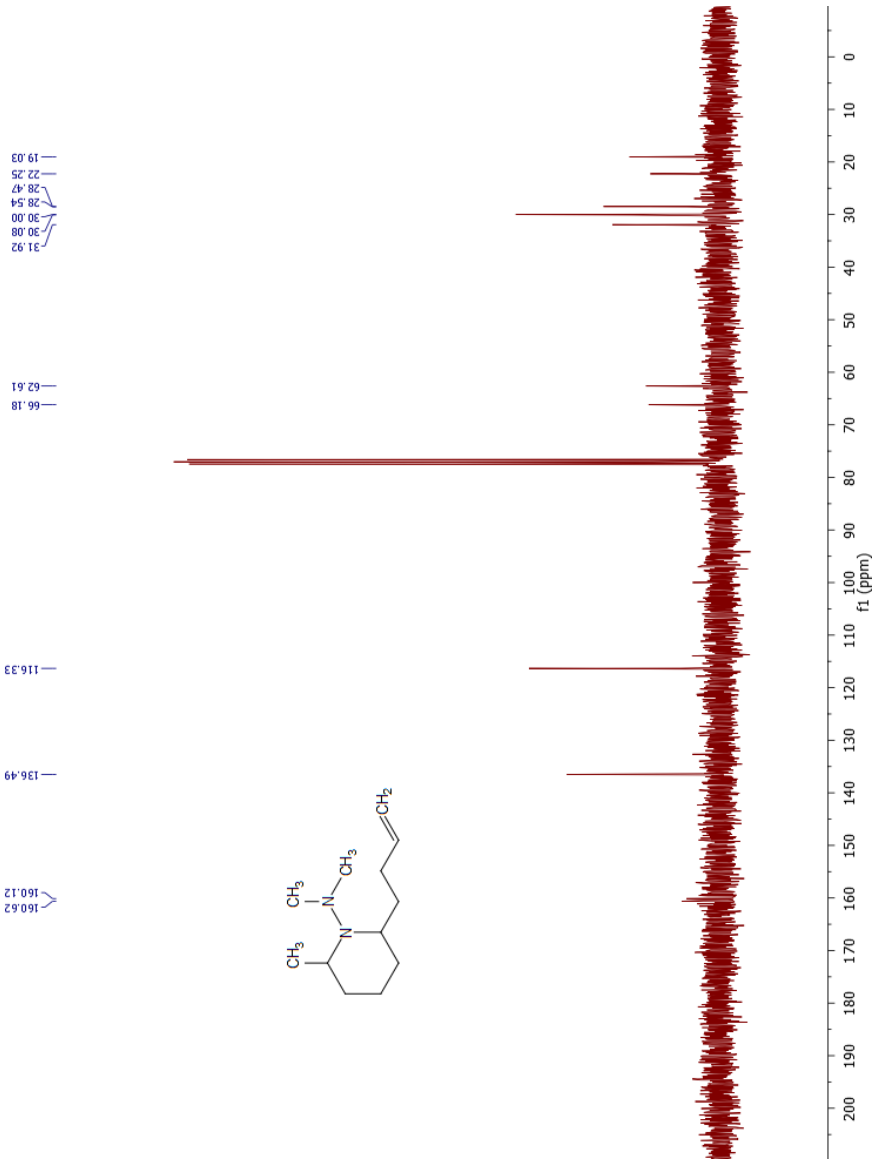

CH3
N
N
CH3
CH2
f1 (ppm)

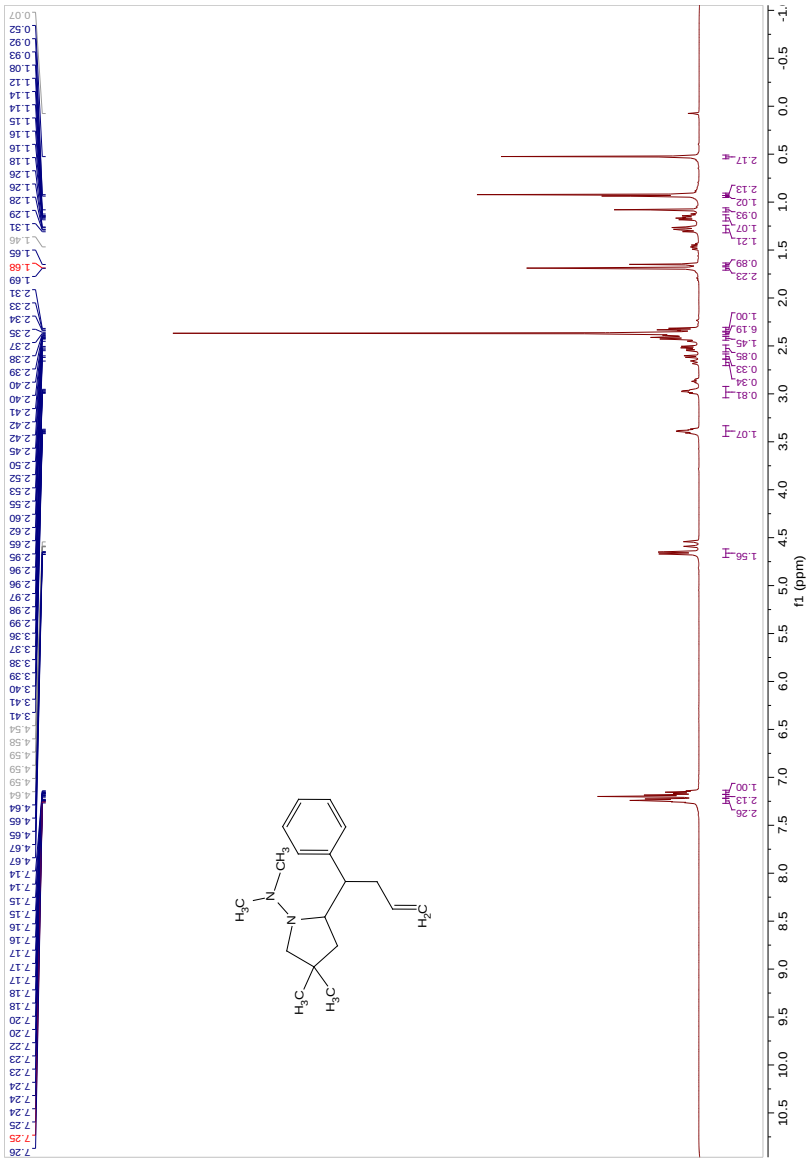

22.32
22.68
28.58
28.65
29.50
39.26
44.56
64.18
116.27
136.55
160.77
160.46
CH3
N
CH3
N
CH2
f1 (ppm)

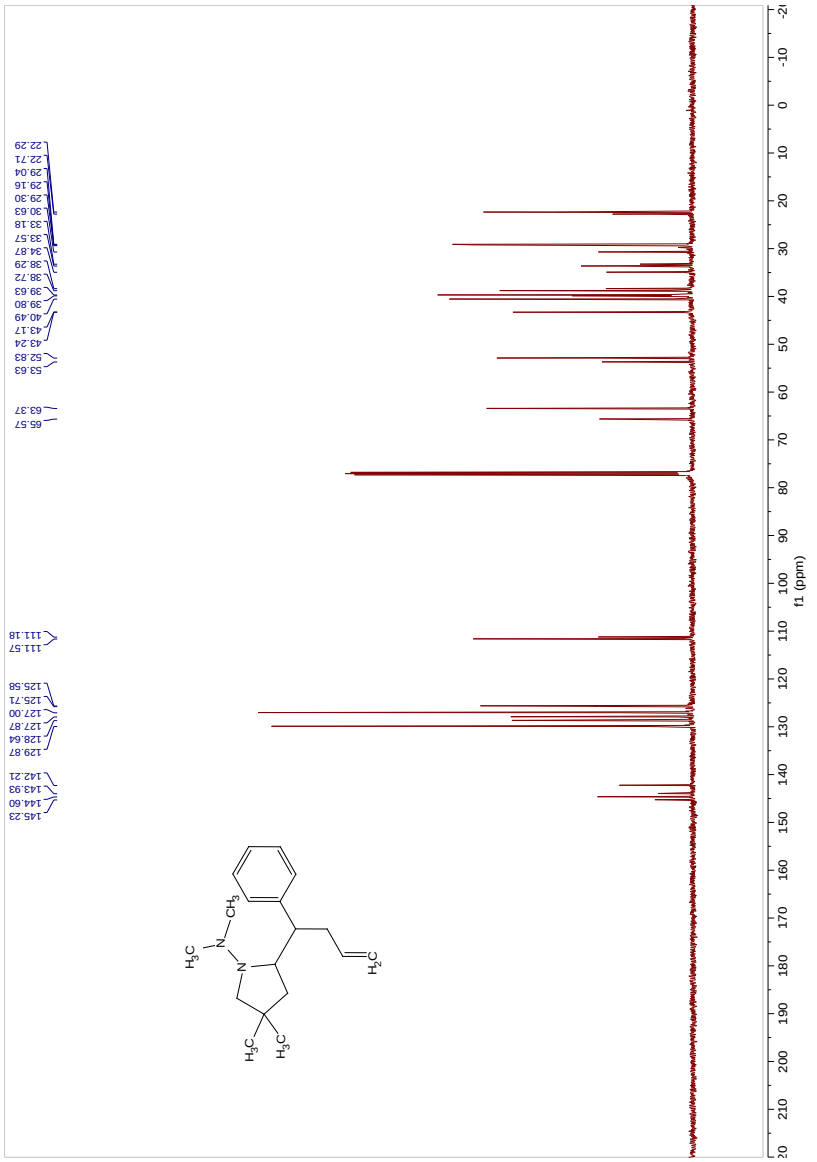

f1 (ppm)

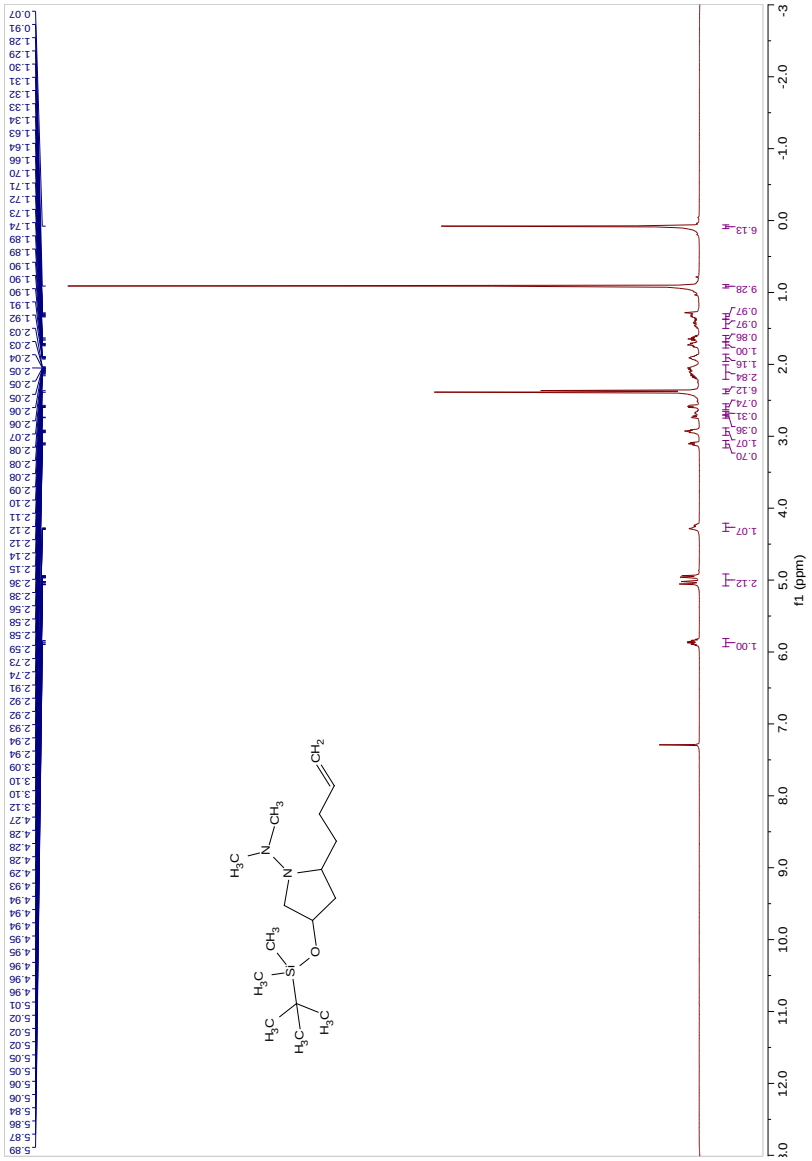

22.05
22.39
22.68
27.17
28.70
33.50
39.30
44.55
64.26
111.46
143.85
160.87
160.57
f1 (ppm)

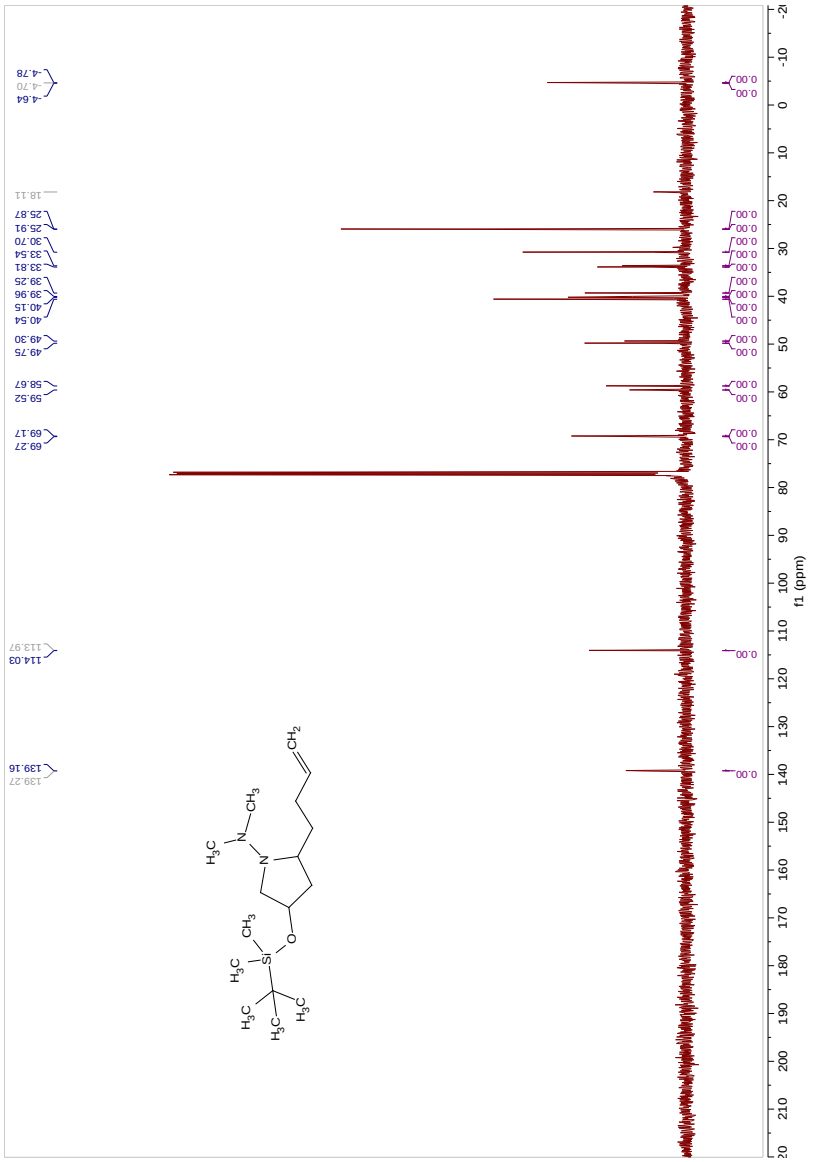

CH3
N
CH3
N
CH3
CH2
1.00
2.04
1.03
5.98
1.09
2.08
1.05
2.07
1.02
3.01
2.75
0.35
1.10
f1 (ppm)

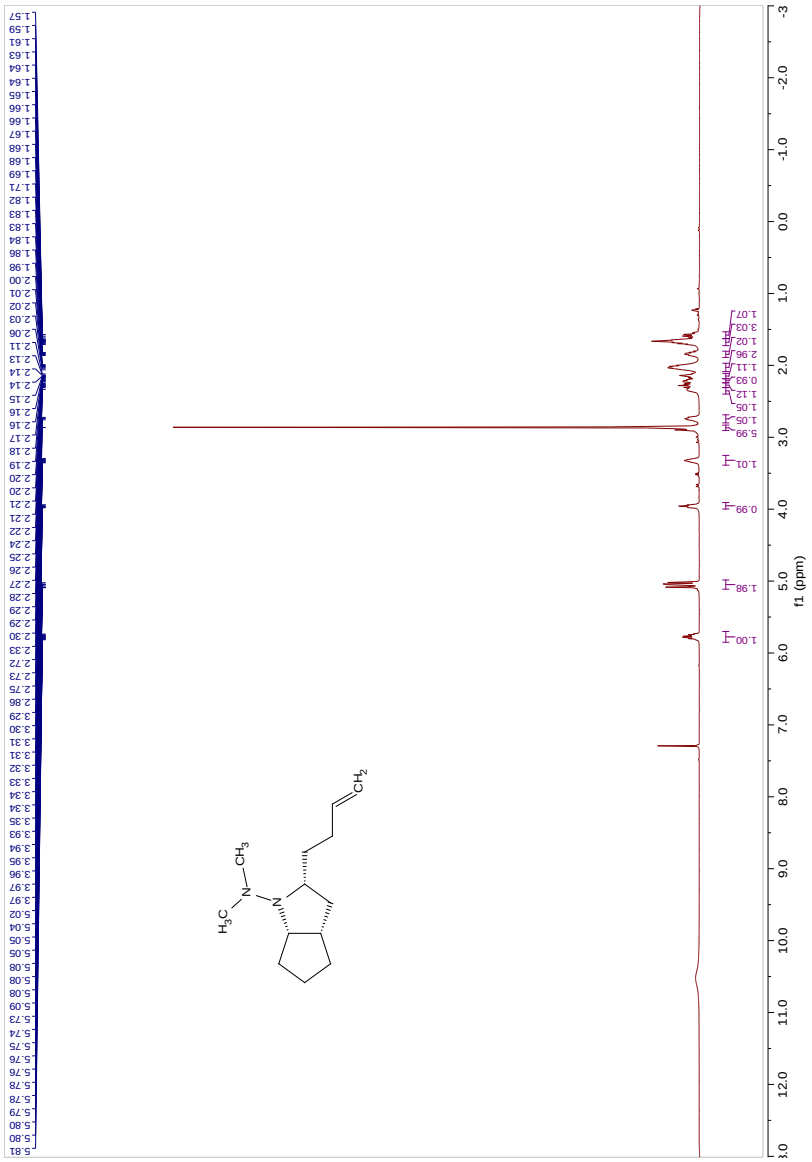

19.03
22.25
28.47
28.54
30.00
30.08
31.92
62.61
66.18
116.33
136.49
160.12
160.62
CH3
N
CH3
N
CH3
CH2
f1 (ppm)

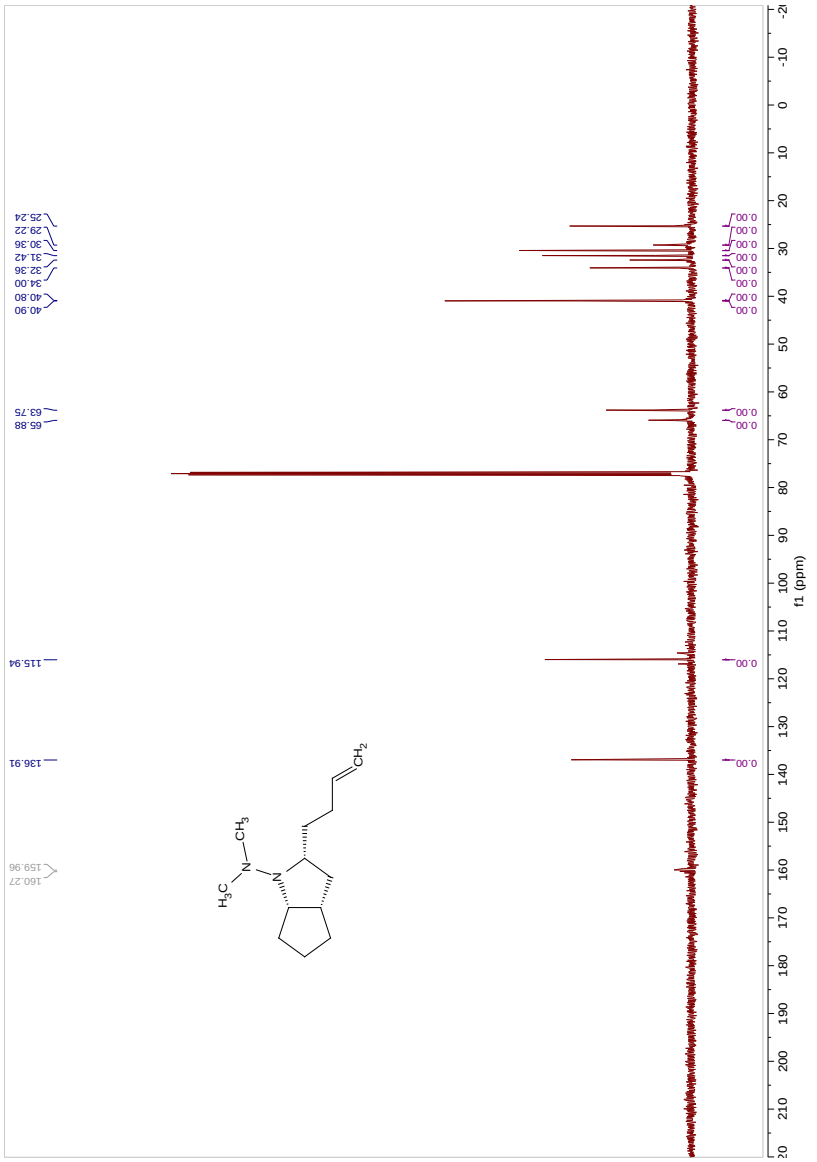

f1 (ppm)
H3C
N
CH3
N
H2C
H3C
H3C

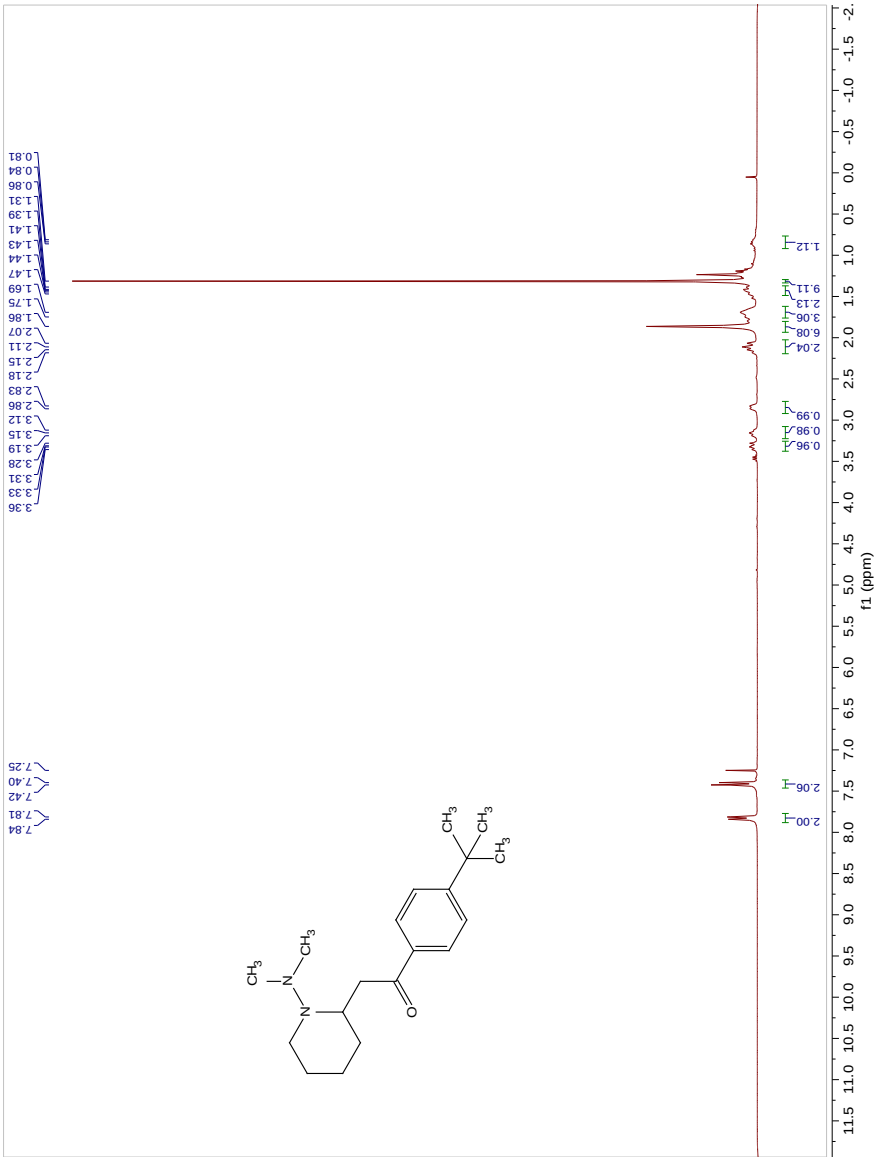

22.29
22.71
29.04
29.16
29.30
30.63
33.18
33.57
34.87
38.29
38.72
39.63
39.80
40.49
43.17
43.24
52.83
53.63
63.37
65.57
111.18
111.57
125.58
125.71
127.00
127.87
128.64
129.87
142.21
143.93
144.60
145.23
f1 (ppm)

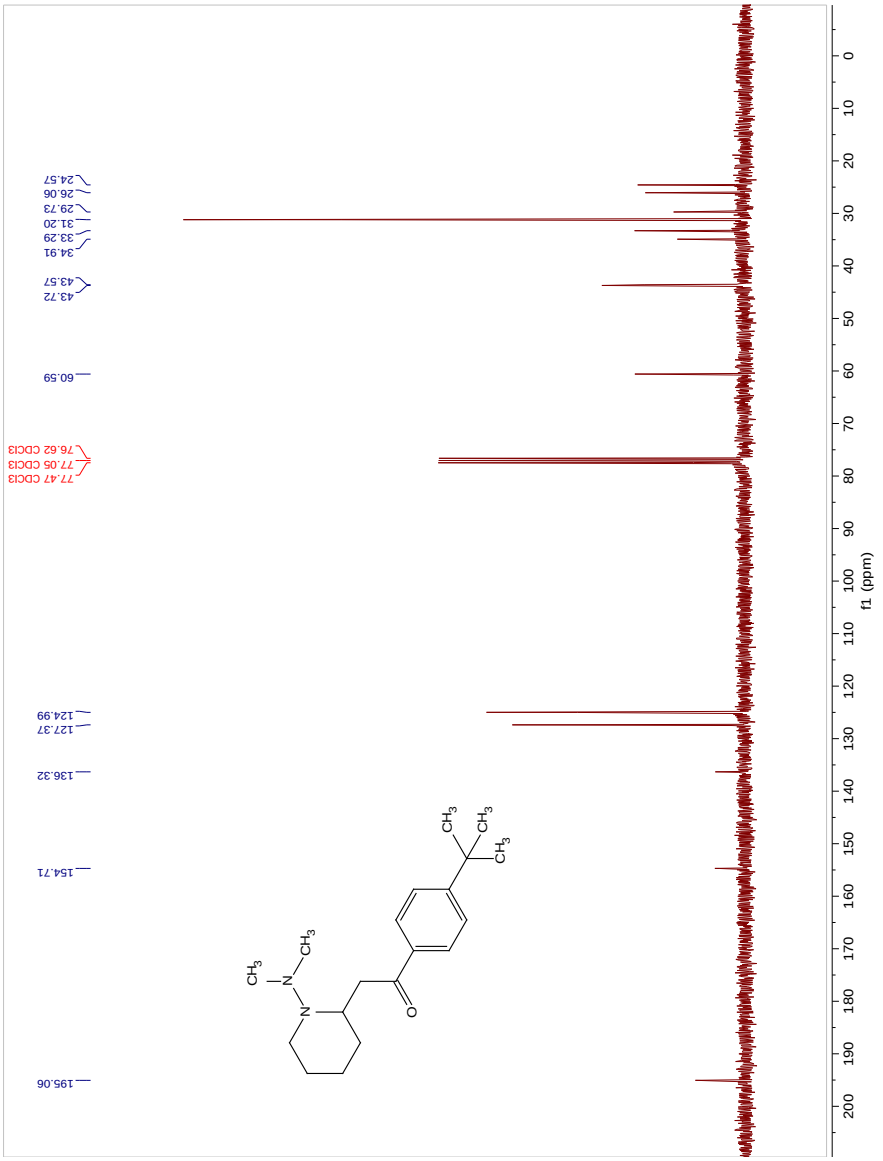

f1 (ppm)

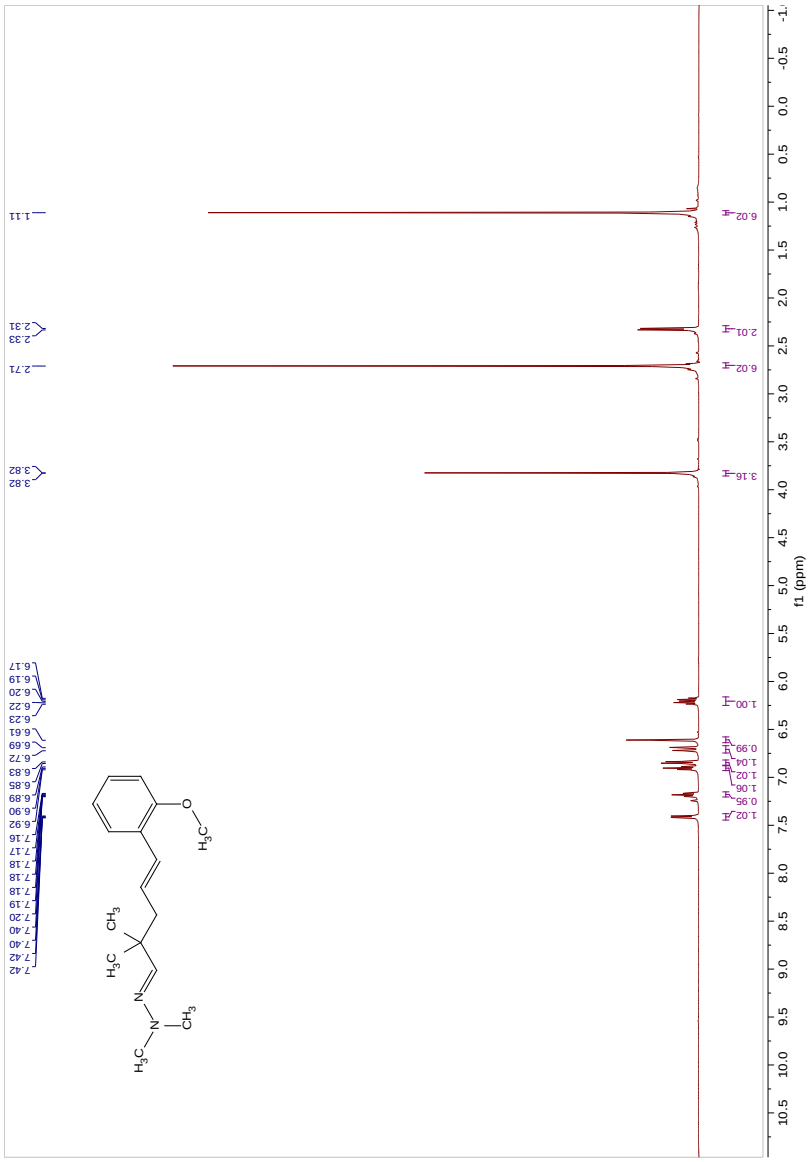

-4.64
-4.70
-4.78
18.11
25.87
25.91
30.70
33.54
33.81
39.25
39.96
40.15
40.54
49.30
49.75
58.67
59.52
69.17
69.27
113.97
114.03
139.27
139.16
f1 (ppm)

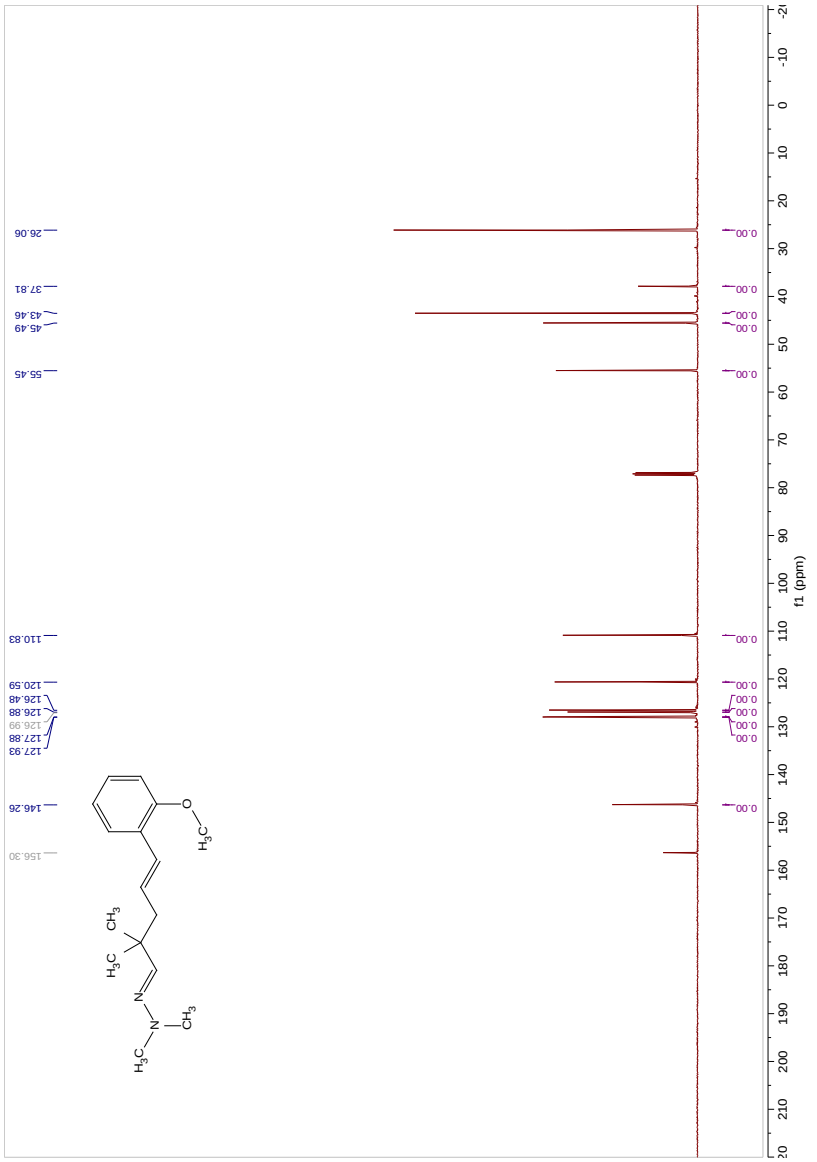

f1 (ppm)
1.07
3.03
1.02
2.96
1.11
0.93
1.12
1.05
1.05
5.99
1.01
0.99
1.98
1.00
H_3C
CH_3
N
N
CH_2

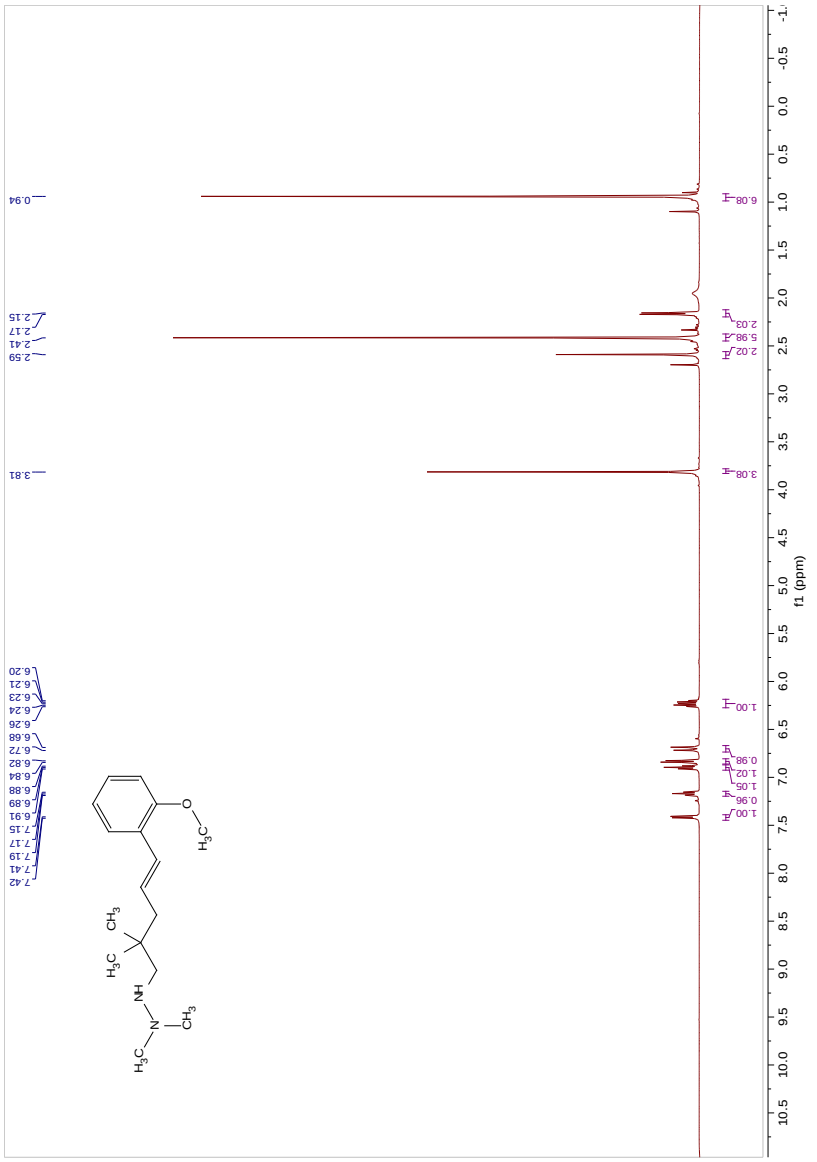

160.27
159.96
136.91
115.94
65.88
63.75
40.90
40.80
34.00
32.36
31.42
30.36
29.22
25.24
0.00
f1 (ppm)
H3C
CH3
N
N
CH2

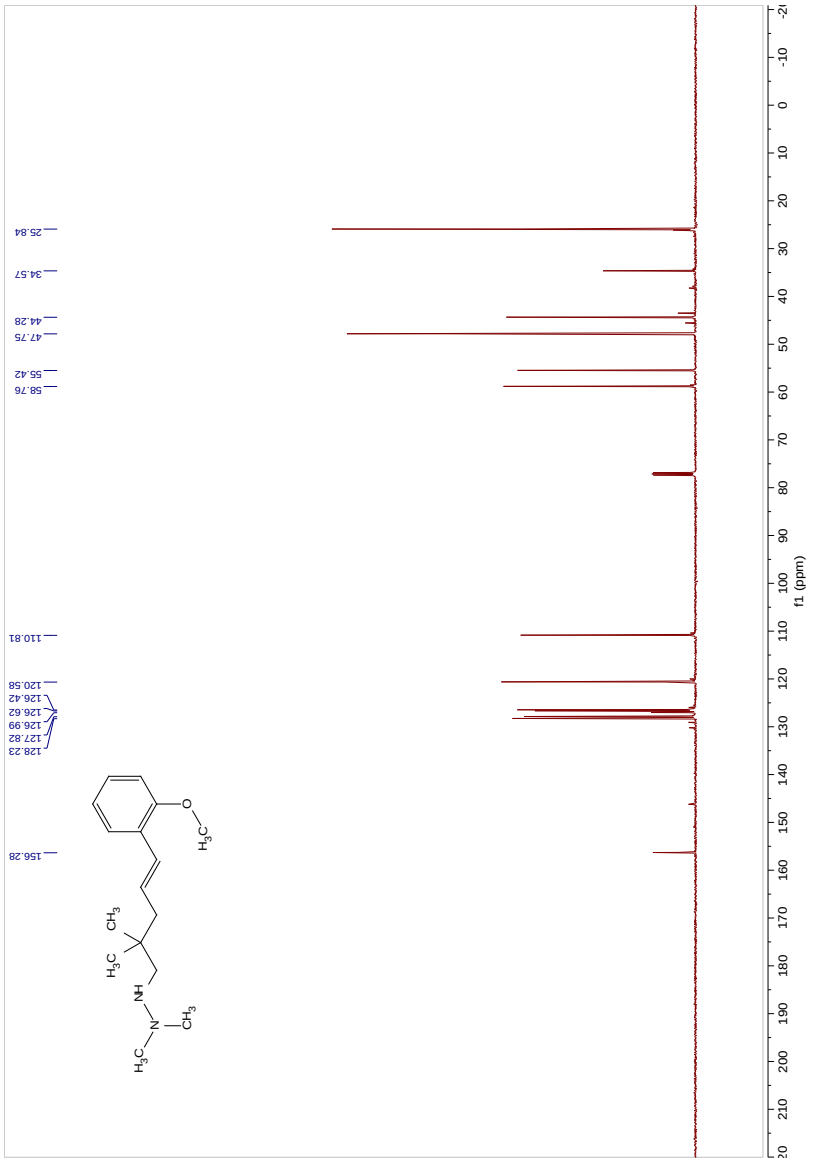

0.81
0.84
0.86
1.31
1.39
1.41
1.43
1.44
1.47
1.69
1.75
1.86
2.07
2.11
2.15
2.18
2.83
2.86
3.12
3.15
3.19
3.28
3.31
3.33
3.36
7.25
7.40
7.42
7.81
7.84
1.12
9.11
2.13
3.06
6.08
2.04
0.99
0.98
0.96
2.06
2.00
f1 (ppm)

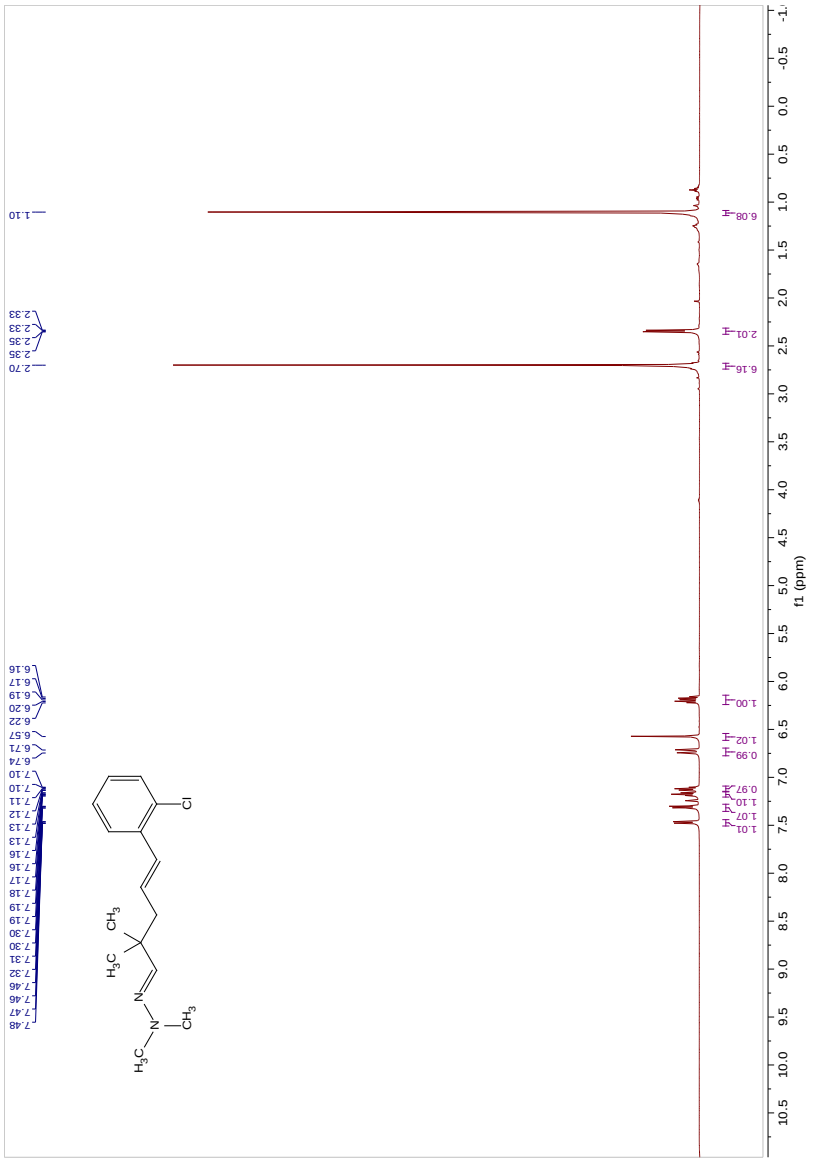

195.06
154.71
136.32
127.37
124.99
77.47 CDCl3
77.05 CDCl3
76.62 CDCl3
60.59
43.57
43.72
34.91
33.29
31.20
29.73
26.06
24.57
f1 (ppm)

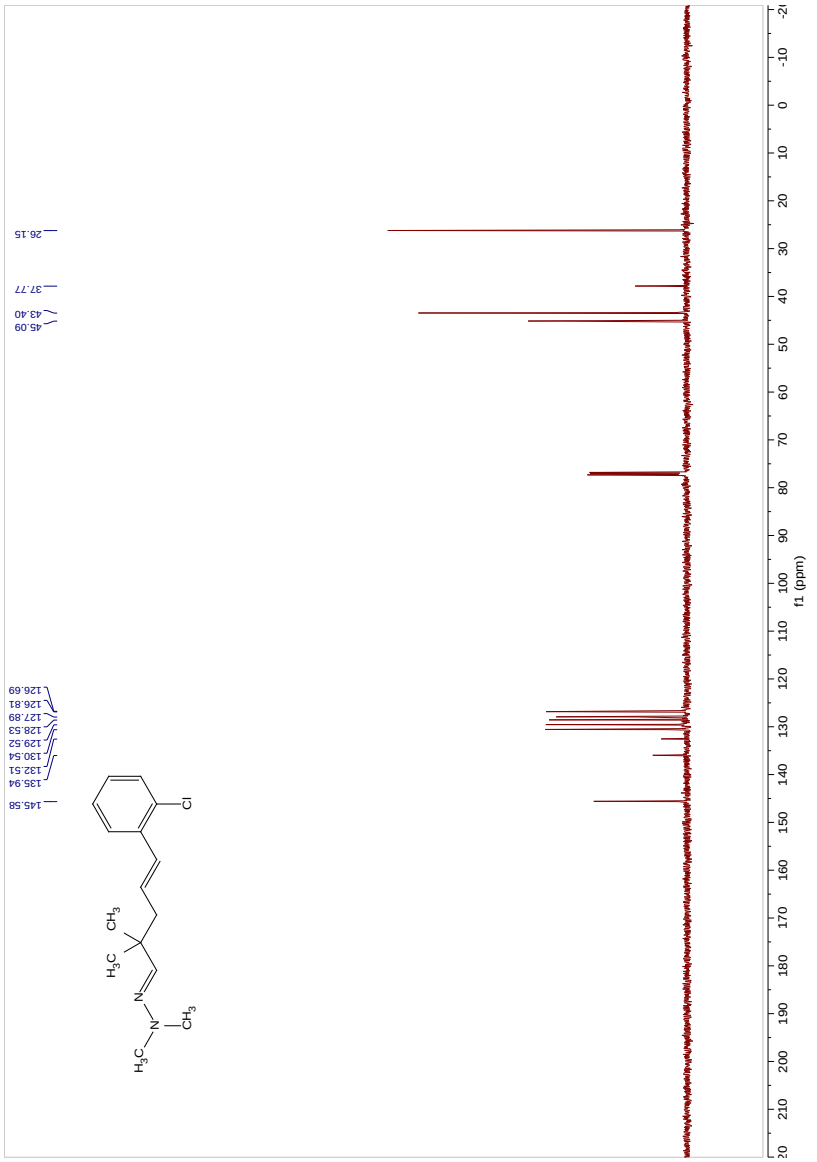

f1 (ppm)
1.11
2.31
2.33
2.71
3.82
3.82
6.17
6.19
6.20
6.22
6.23
6.61
6.69
6.72
6.83
6.85
6.89
6.90
6.92
7.16
7.17
7.18
7.18
7.18
7.19
7.20
7.40
7.40
7.42
7.42
6.02
2.01
6.02
3.16
1.00
0.99
1.04
1.02
1.06
0.95
1.02
O
H3C
CH3
H3C
N
N
CH3
H3C

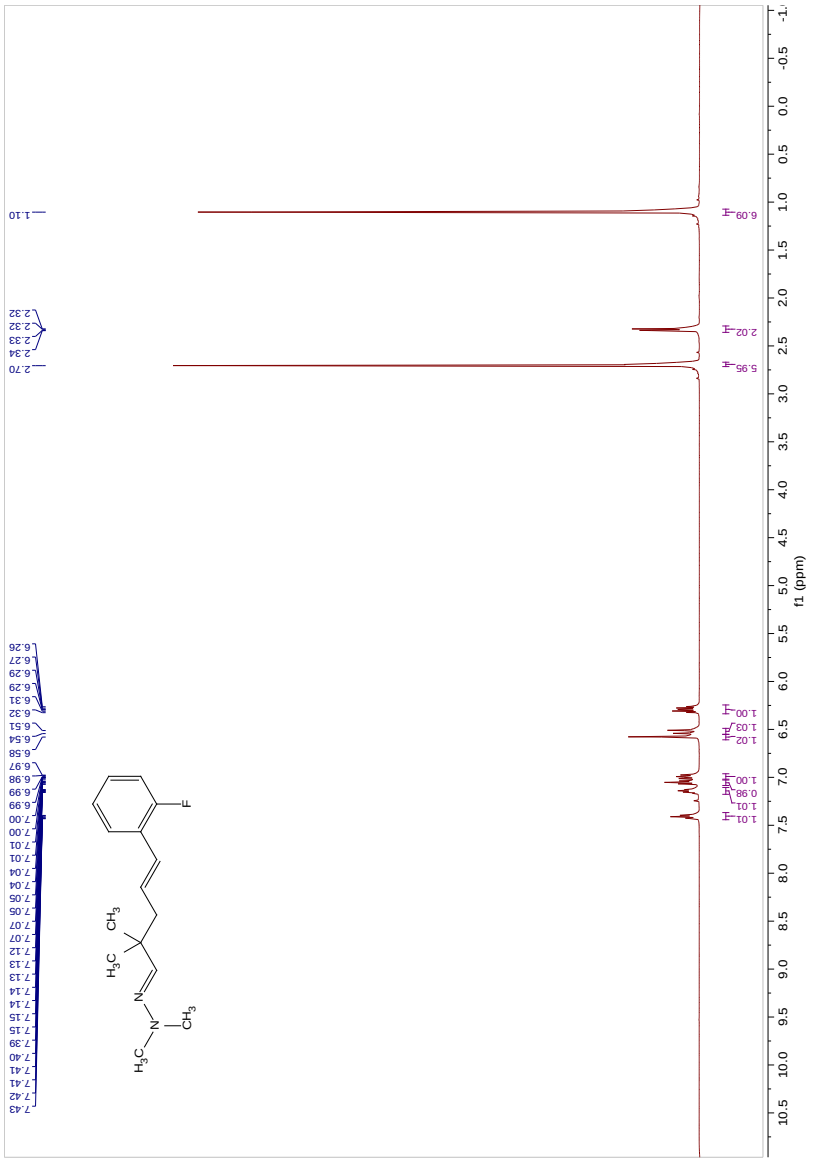

26.06
37.81
43.46
45.49
55.45
110.83
120.59
126.48
126.88
126.99
127.88
127.93
146.26
156.30
0.00
f1 (ppm)

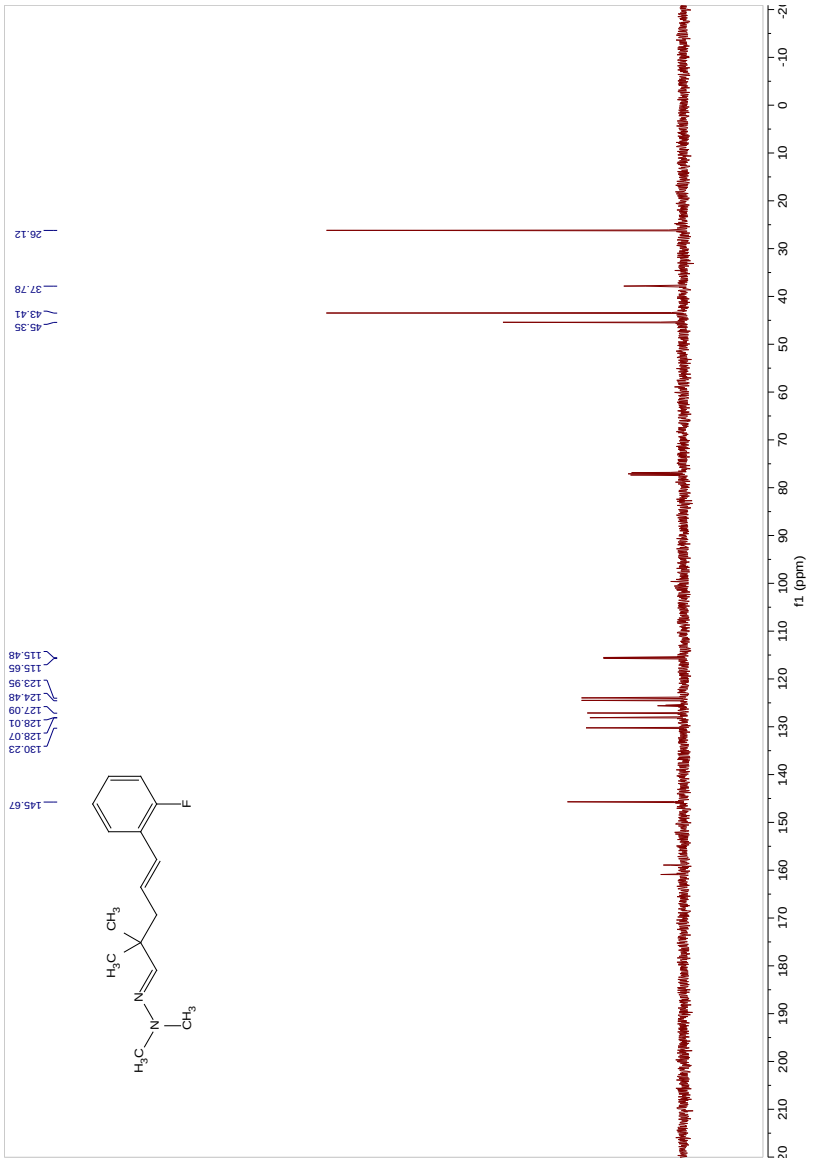

0.94
2.15
2.17
2.41
2.59
3.81
6.20
6.21
6.23
6.24
6.26
6.68
6.72
6.82
6.84
6.88
6.89
6.91
7.15
7.17
7.19
7.41
7.42
6.08
2.03
5.98
2.02
3.08
1.00
0.98
1.02
1.05
0.96
1.00
f1 (ppm)

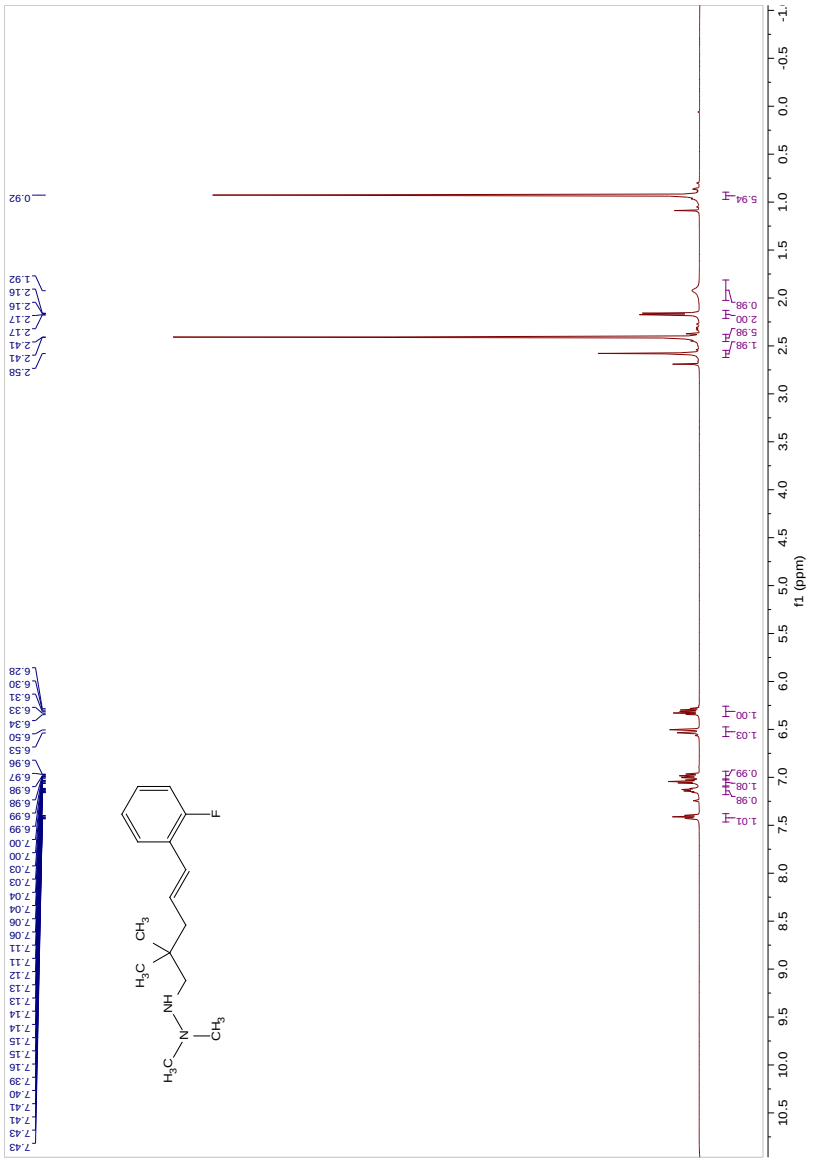

25.84
34.57
44.28
47.75
55.42
58.76
110.81
120.58
126.42
126.62
126.99
127.82
128.23
156.28
f1 (ppm)

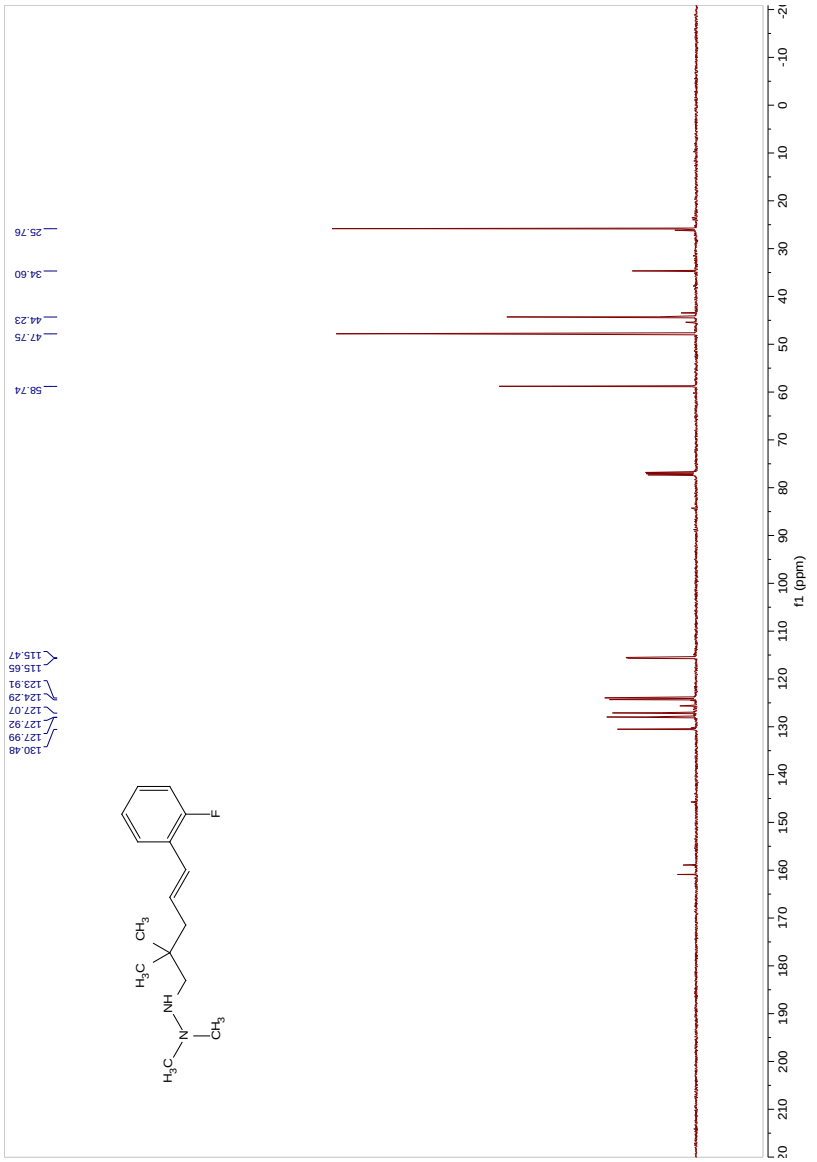

f1 (ppm)
Cl
CH3
H3C
N
N
CH3
H3C


26.15
37.77
43.40
45.09
126.69
126.81
127.89
128.53
129.52
130.54
132.51
135.94
145.58
Cl
CH3
H3C
N
N
CH3
H3C
f1 (ppm)


f1 (ppm)
F
CH3
H3C
N
N
CH3
H3C


26.12
37.78
43.41
45.35
115.48
115.65
123.95
124.48
127.09
128.01
128.07
130.23
145.67
F
CH3
H3C
N
N
CH3
H3C
f1 (ppm)


f1 (ppm)
F
CH3
H3C
NH
N
CH3
H3C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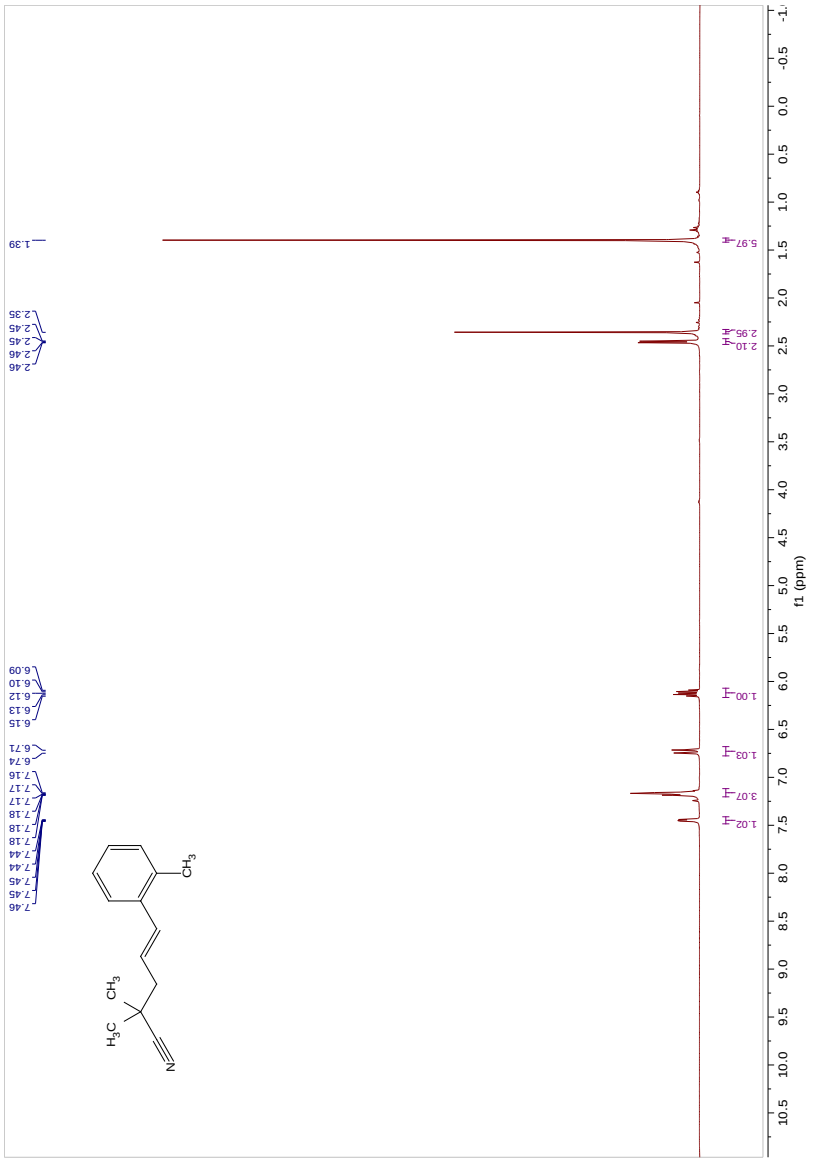
34.60
44.23
47.75
58.74
115.47
115.65
123.91
124.29
127.07
127.92
127.99
130.48
F
CH3
H3C
NH
N
CH3
H3C
f1 (ppm)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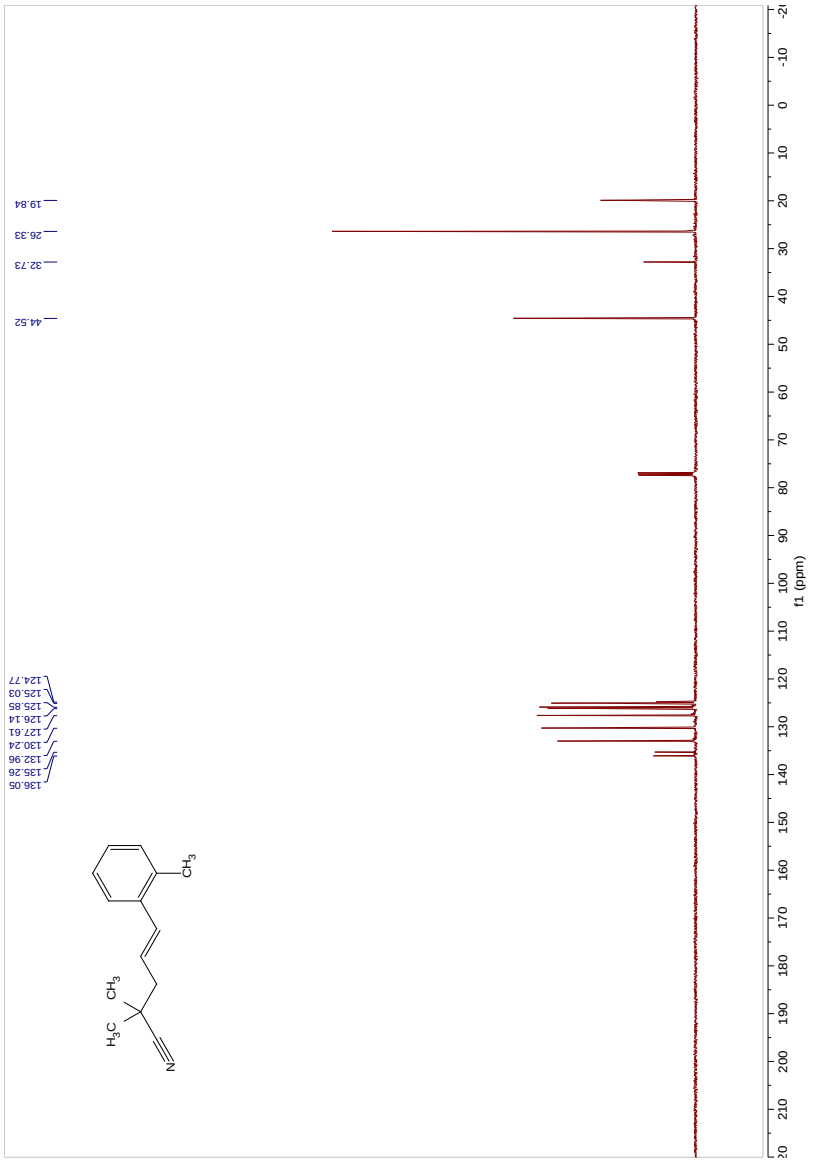
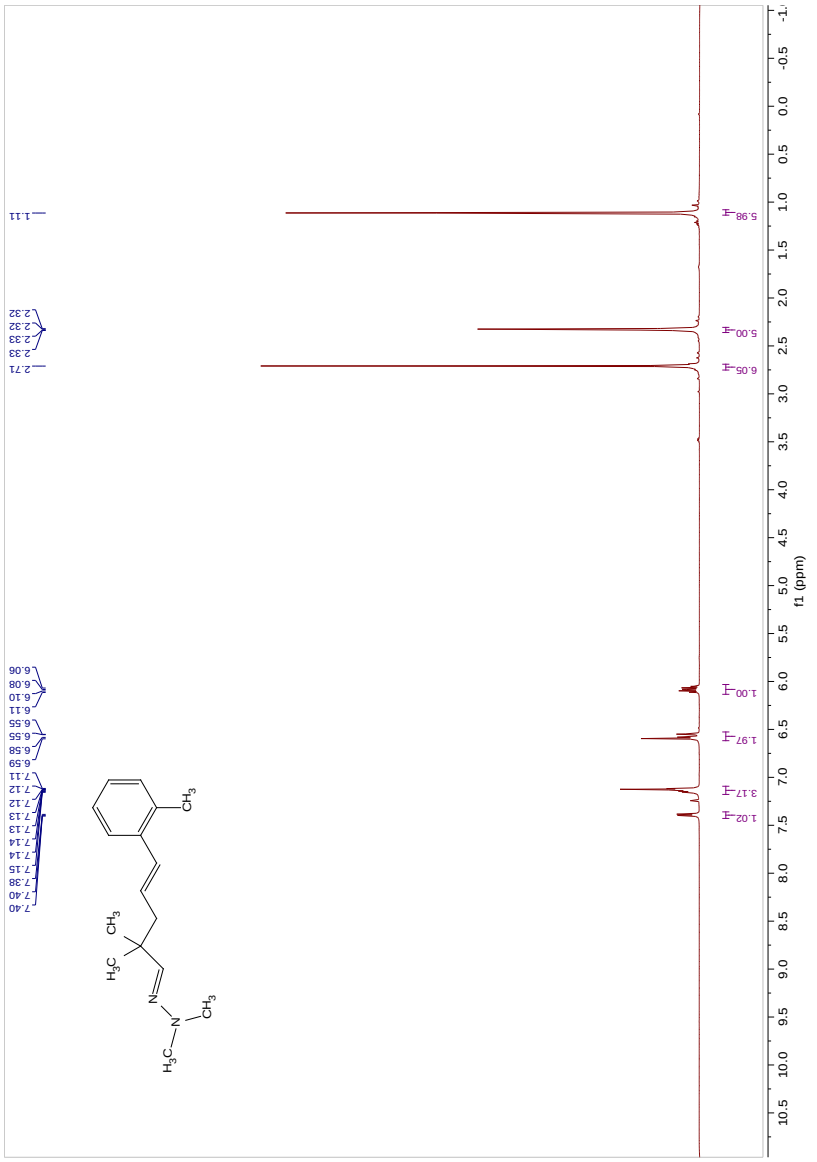
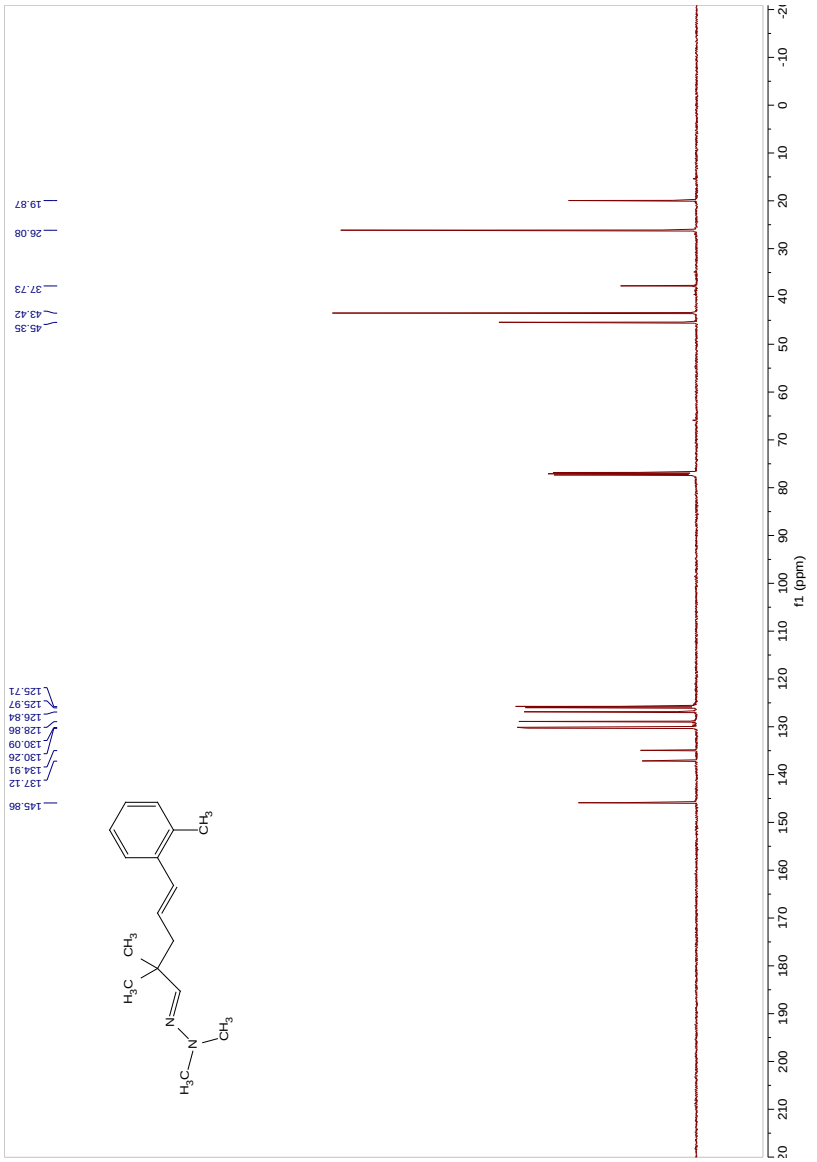
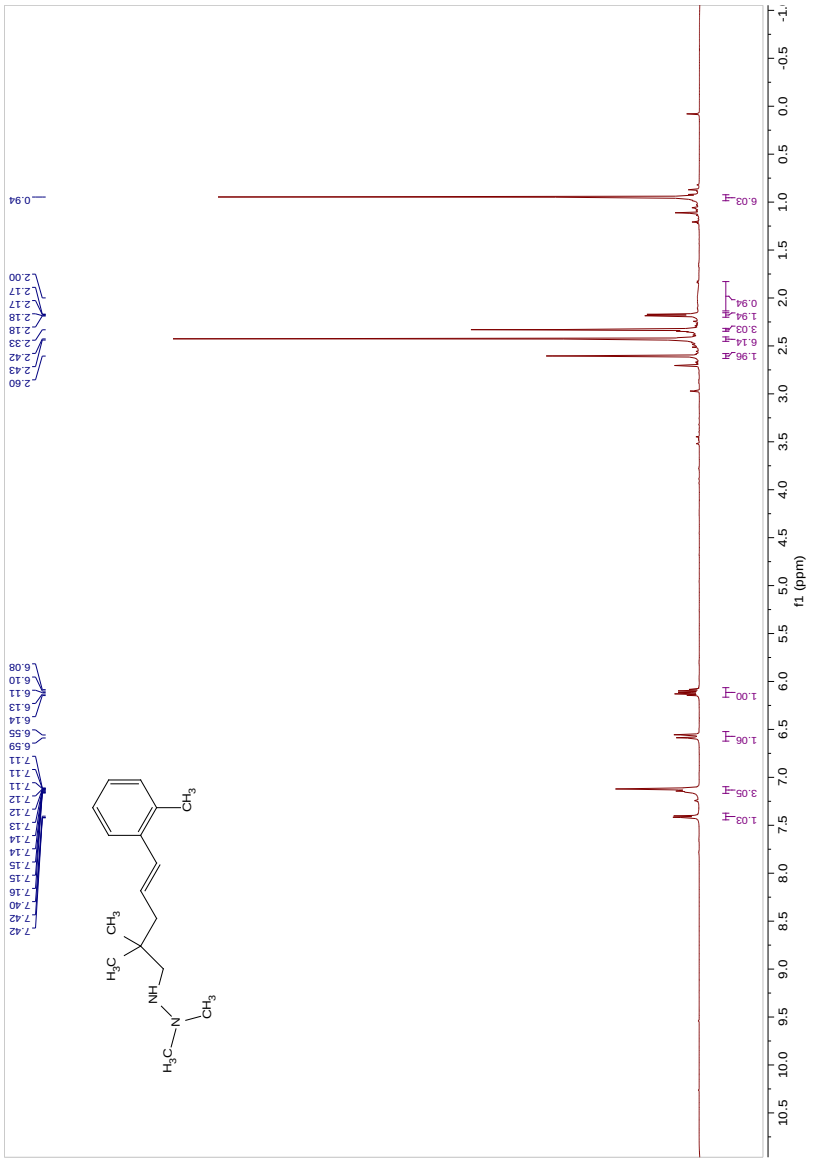
2.35
2.45
2.45
2.46
2.46
6.09
6.10
6.12
6.13
6.15
6.71
6.74
7.16
7.17
7.17
7.18
7.18
7.18
7.44
7.44
7.45
7.45
7.46
5.97
2.95
2.10
1.00
1.03
3.07
1.02
CH3
H3C
CH3
N
f1 (ppm)


19.84
26.33
32.73
44.52
124.77
125.03
125.85
126.14
127.61
130.24
132.96
135.26
136.05
CH3
CH3
H3C
N
f1 (ppm)


1.11
2.32
2.33
2.33
2.71
6.06
6.08
6.10
6.11
6.55
6.56
6.58
6.59
7.11
7.12
7.12
7.13
7.13
7.14
7.14
7.15
7.38
7.40
7.40
5.98
5.00
6.05
1.00
1.97
3.17
1.02
f1 (ppm)


19.87
26.08
37.73
43.42
45.35
125.71
125.97
126.84
128.86
130.09
130.26
134.91
137.12
145.86
CH3
H3C
CH3
N
N
CH3
H3C
f1 (ppm)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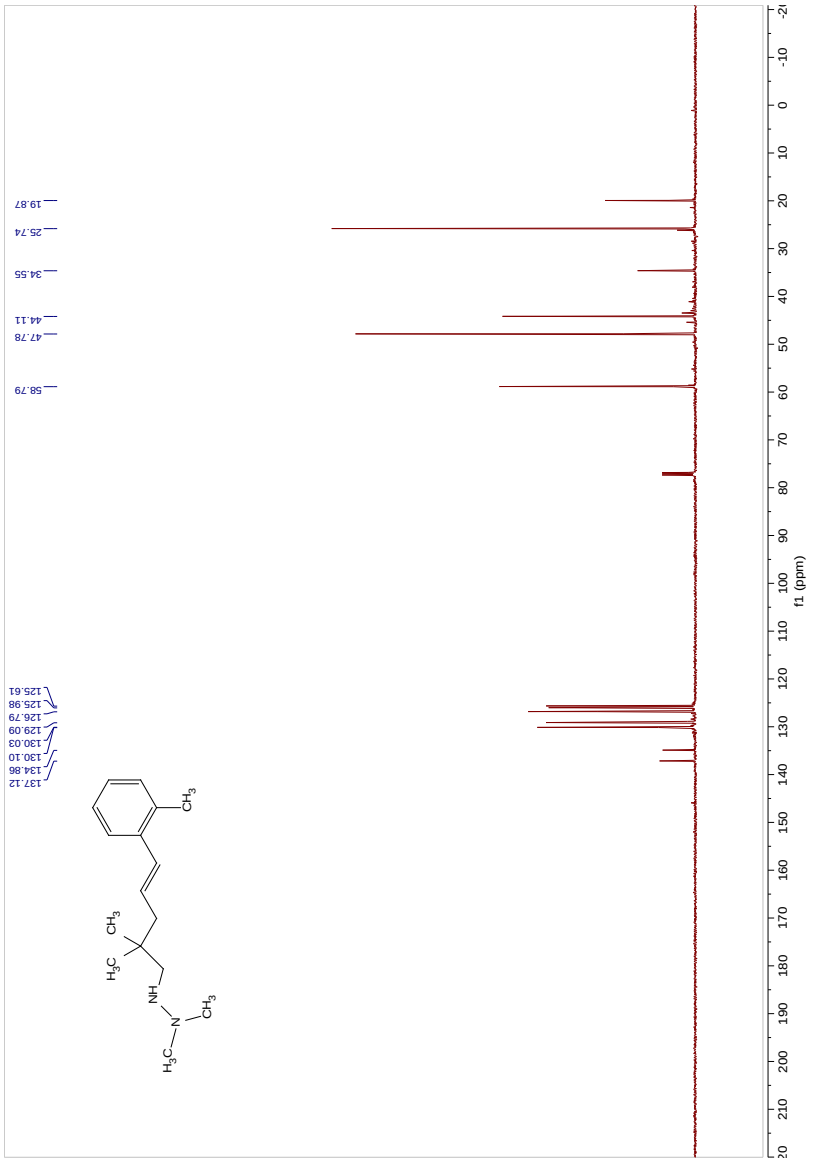
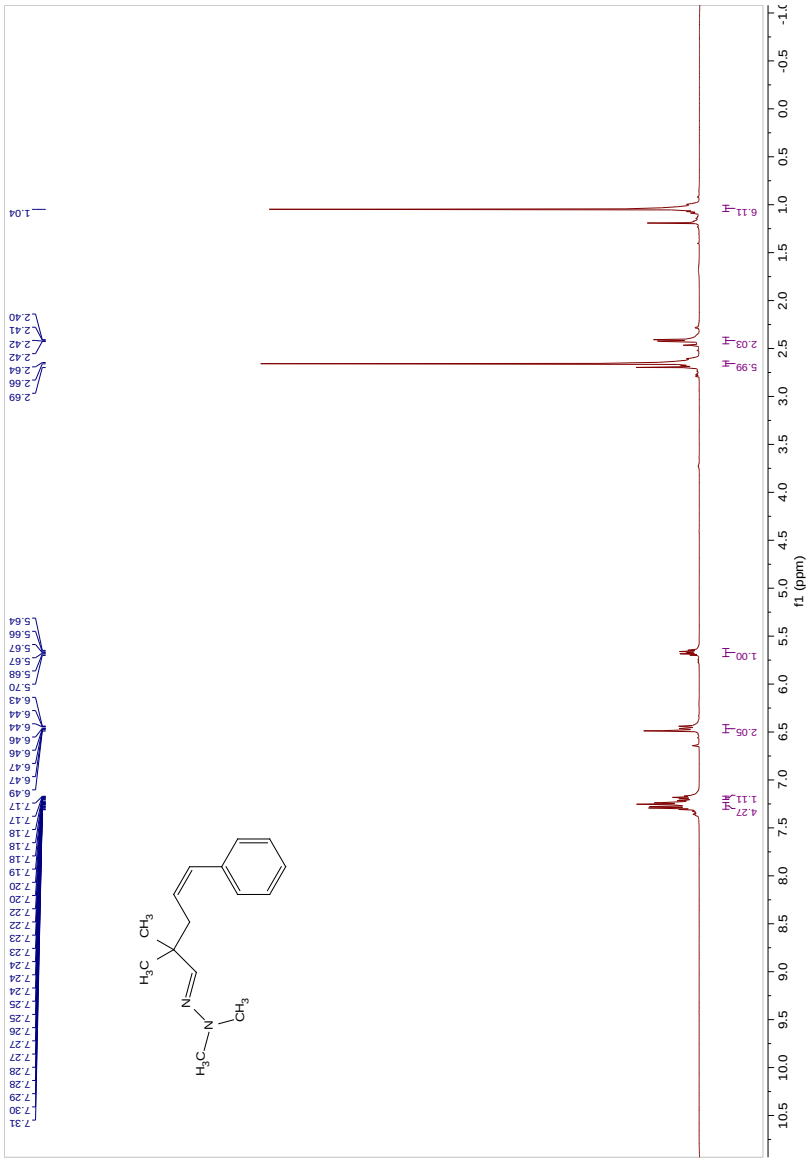
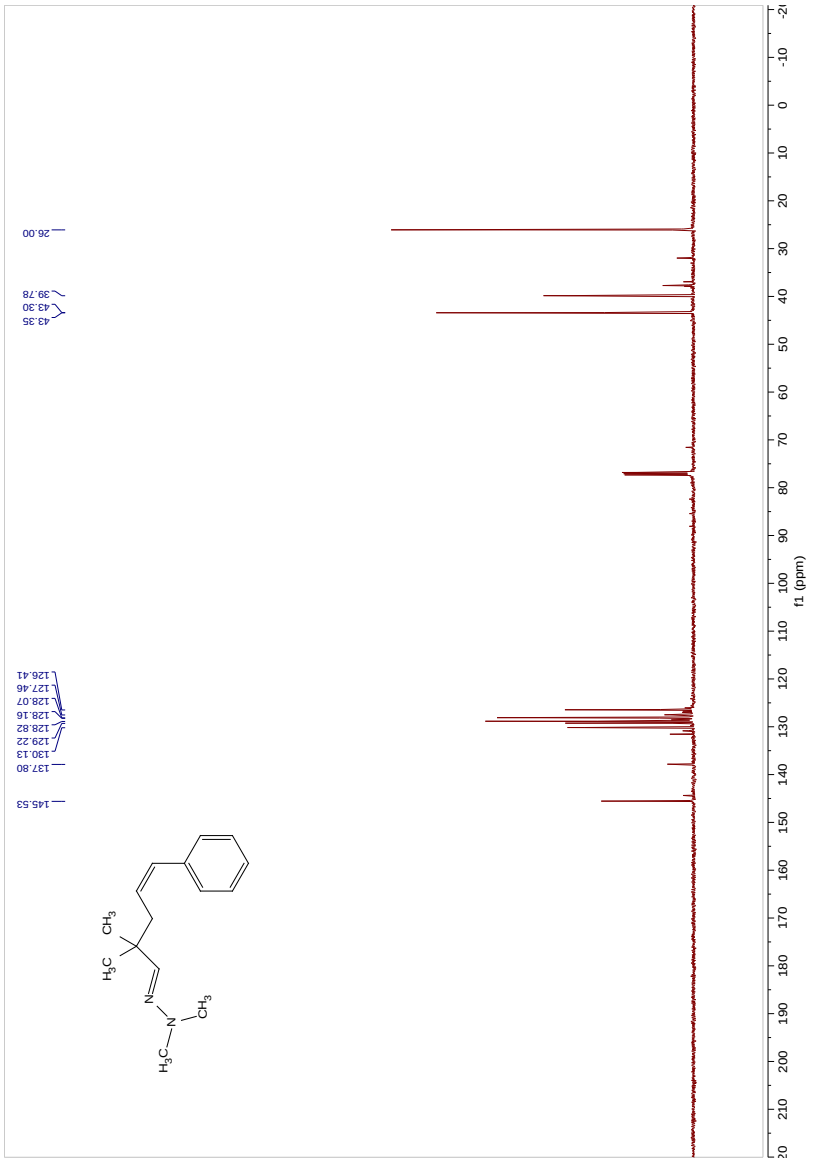
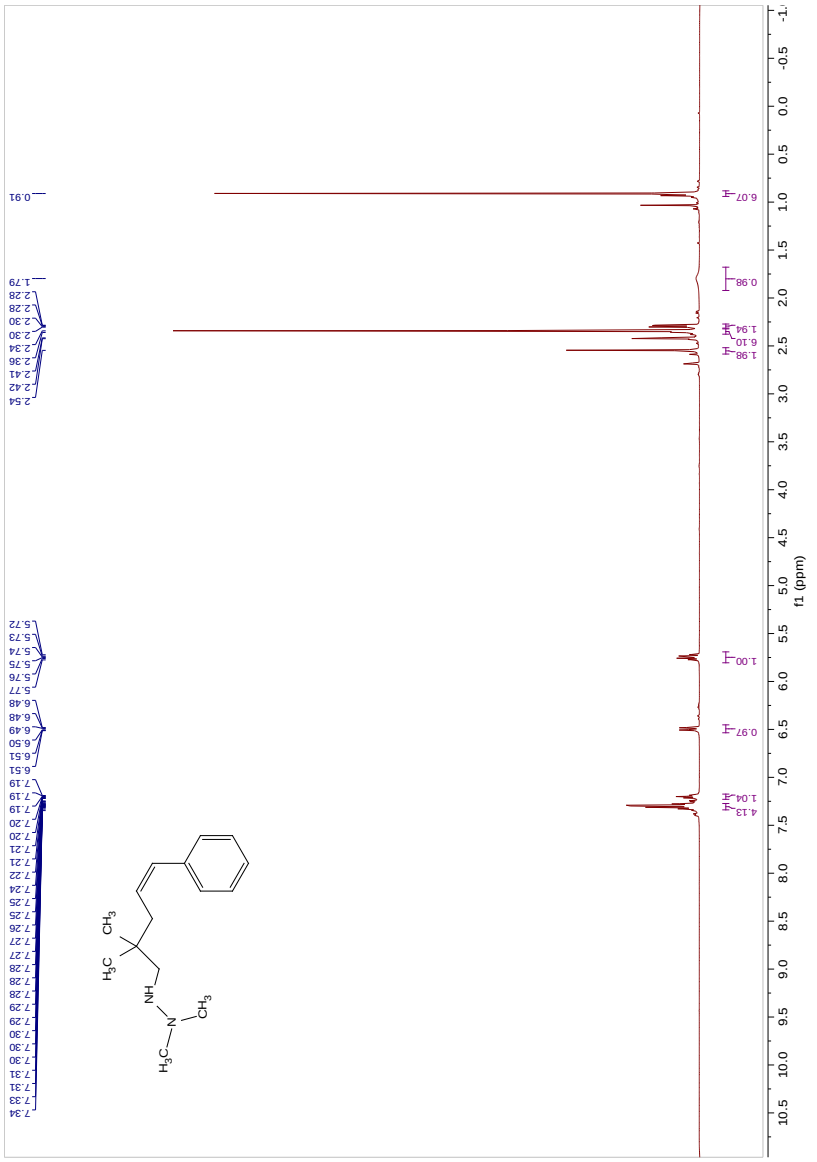
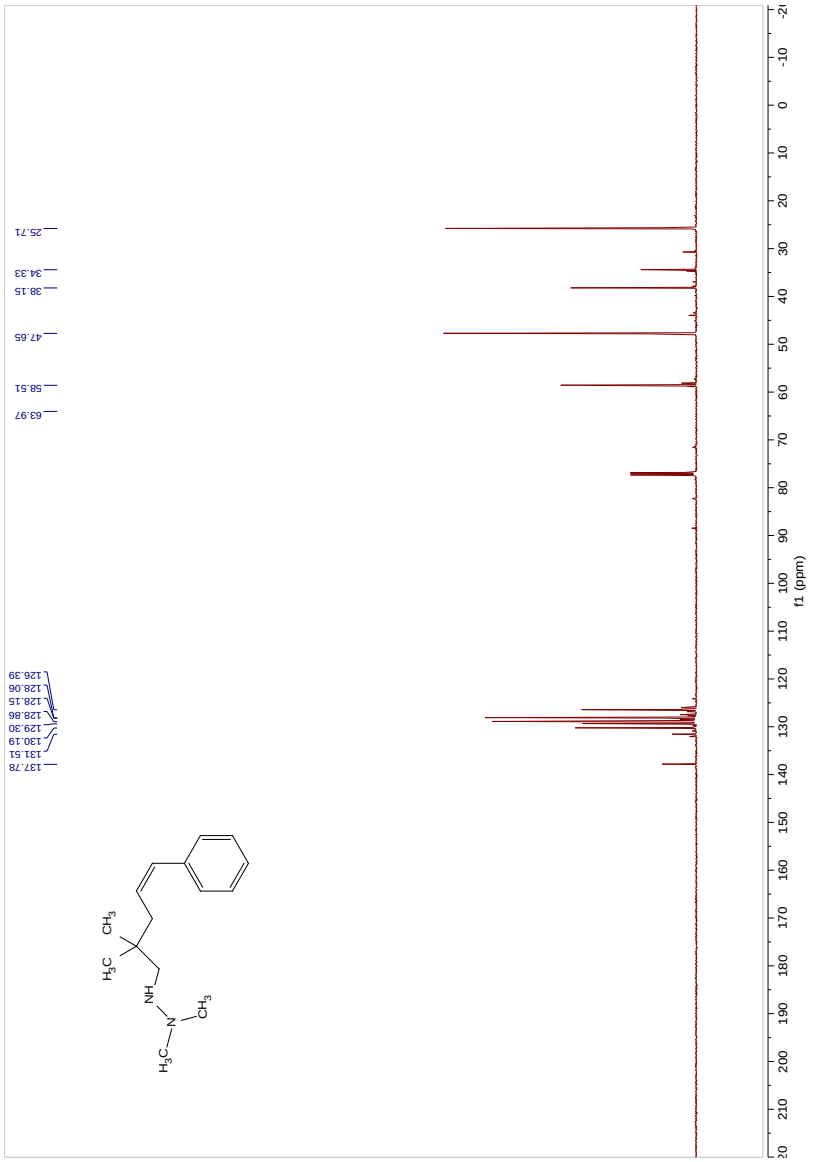
2.00
2.17
2.17
2.18
2.18
2.33
2.42
2.43
2.60
6.08
6.10
6.11
6.13
6.14
6.55
6.59
7.11
7.11
7.11
7.12
7.12
7.13
7.14
7.14
7.15
7.15
7.16
7.40
7.42
7.42
6.03
0.94
1.94
3.03
6.14
1.96
1.00
1.06
3.05
1.03
f1 (ppm)

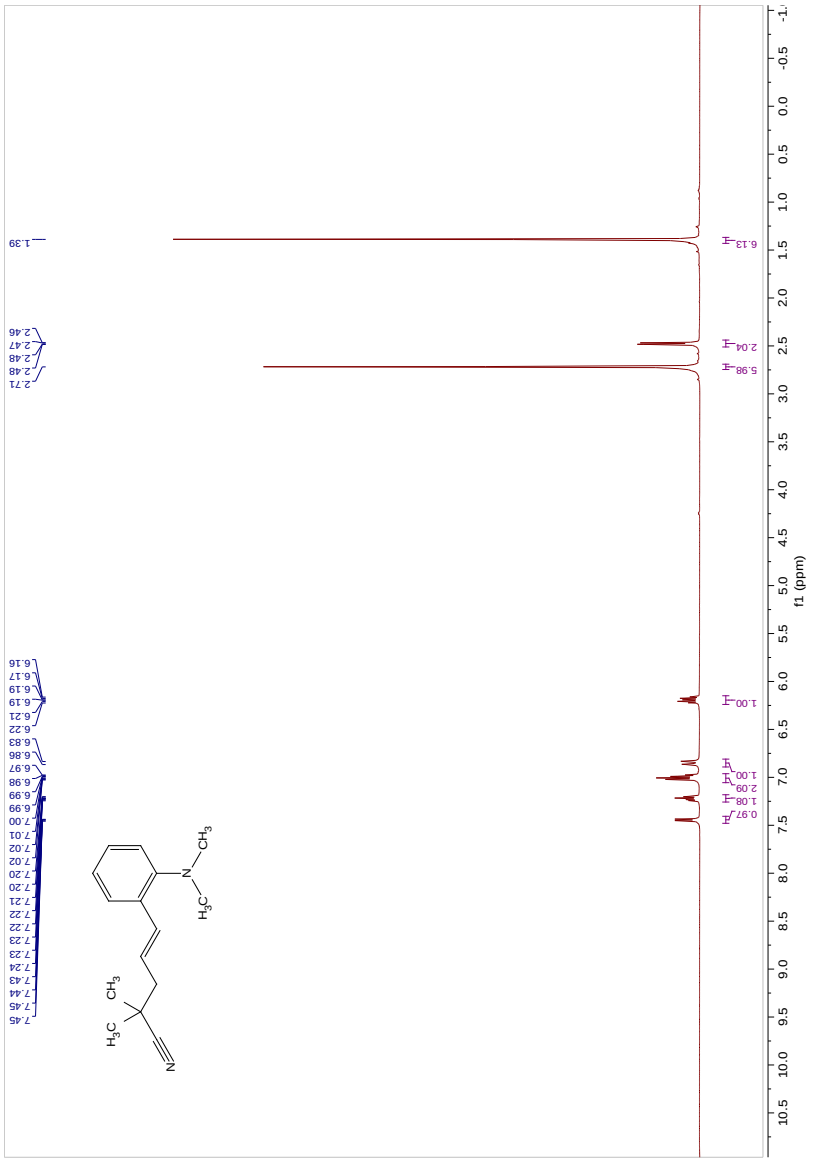

19.87
25.74
34.55
44.11
47.78
58.79
125.61
125.98
126.79
129.09
130.03
130.10
134.86
137.12
f1 (ppm)

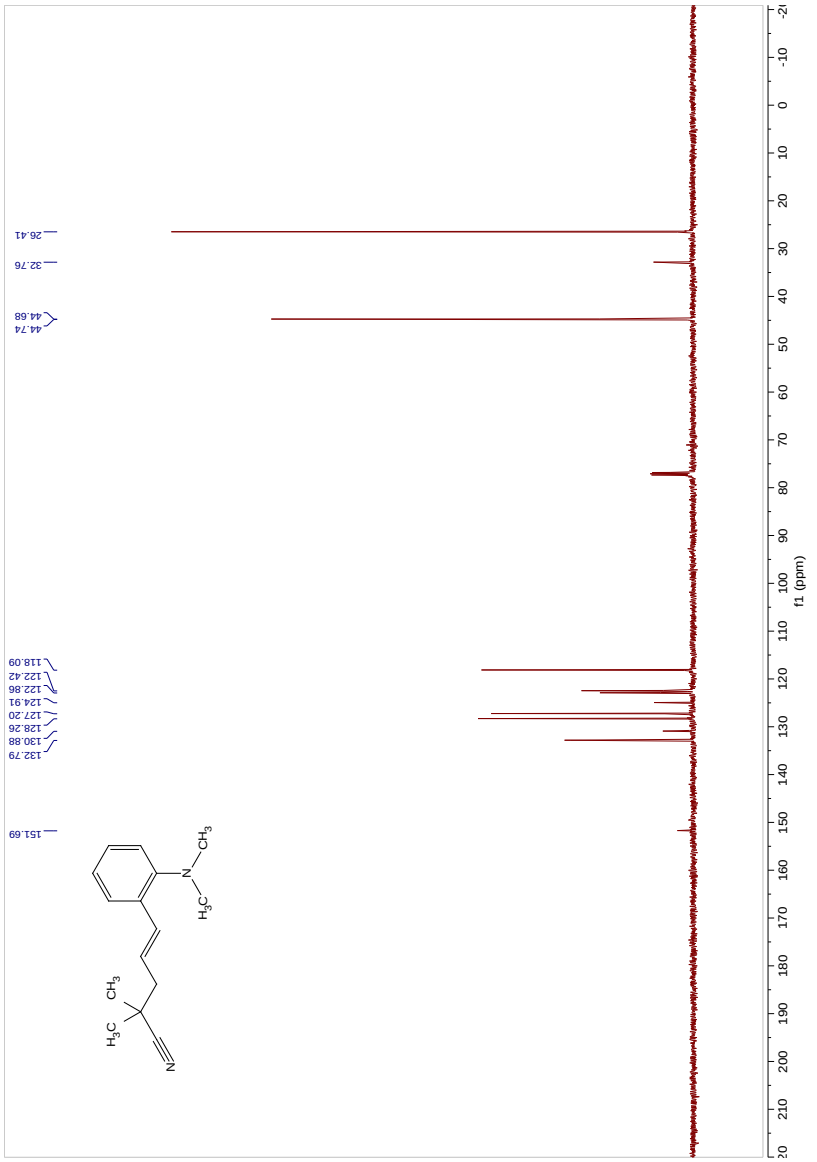

f1 (ppm)
6.11
2.03
5.99
1.00
2.05
4.27
1.11
1.04
2.40
2.41
2.42
2.42
2.64
2.66
2.69
5.64
5.66
5.67
5.67
5.68
5.70
6.43
6.44
6.44
6.46
6.46
6.47
6.47
6.49
7.17
7.17
7.18
7.18
7.18
7.19
7.20
7.20
7.22
7.22
7.23
7.23
7.24
7.24
7.24
7.25
7.25
7.26
7.27
7.27
7.28
7.28
7.29
7.30
7.31
H3C
CH3
N
N
CH3
H3C


26.00
43.35
43.30
39.78
126.41
127.46
128.07
128.16
128.82
129.22
130.13
137.80
145.53
f1 (ppm)


f1 (ppm)
6.07
0.98
1.94
6.10
1.98
1.00
0.97
1.04
4.13
0.91
1.79
CH3
H3C
NH
N
CH3
H3C


25.71
34.33
38.15
47.65
58.51
63.97
126.39
128.06
128.15
128.86
129.30
130.19
131.51
137.78
f1 (ppm)


1.39
2.46
2.47
2.48
2.48
2.71
6.13
2.04
5.98
1.00
0.97
1.08
2.09
1.00
f1 (ppm)


26.41
32.76
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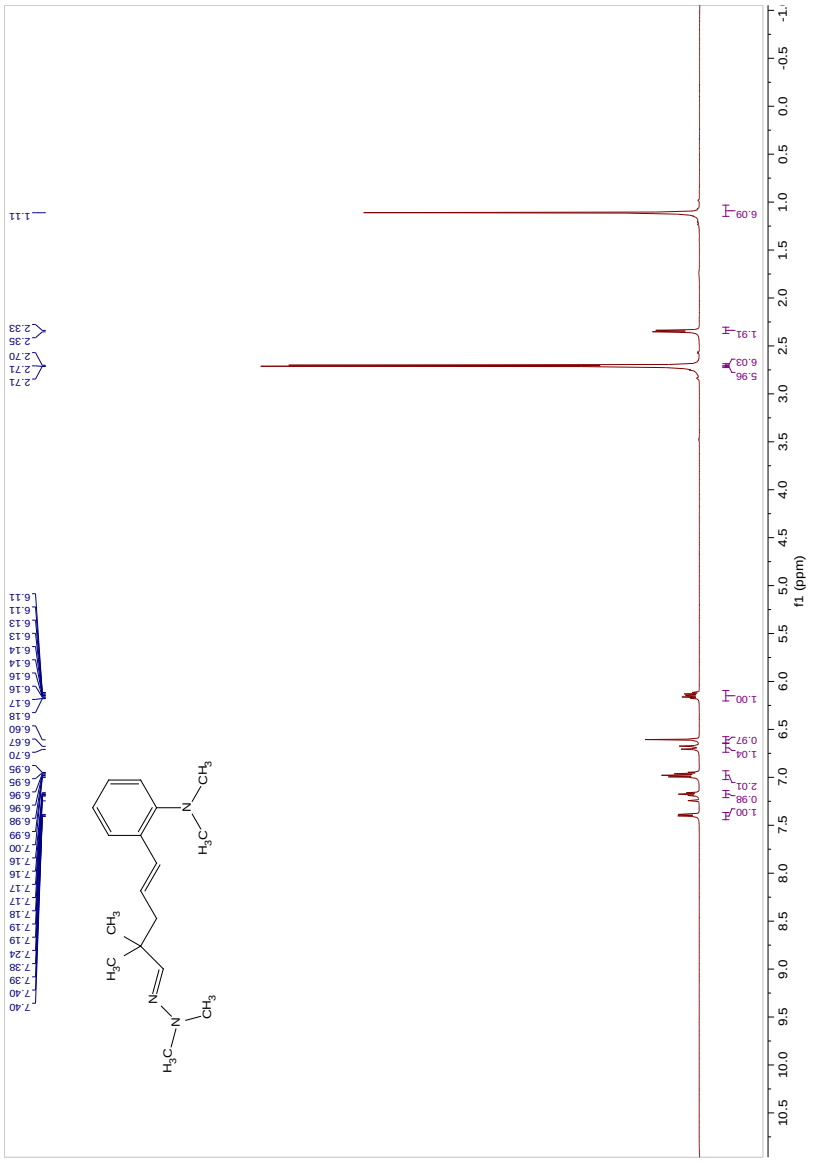
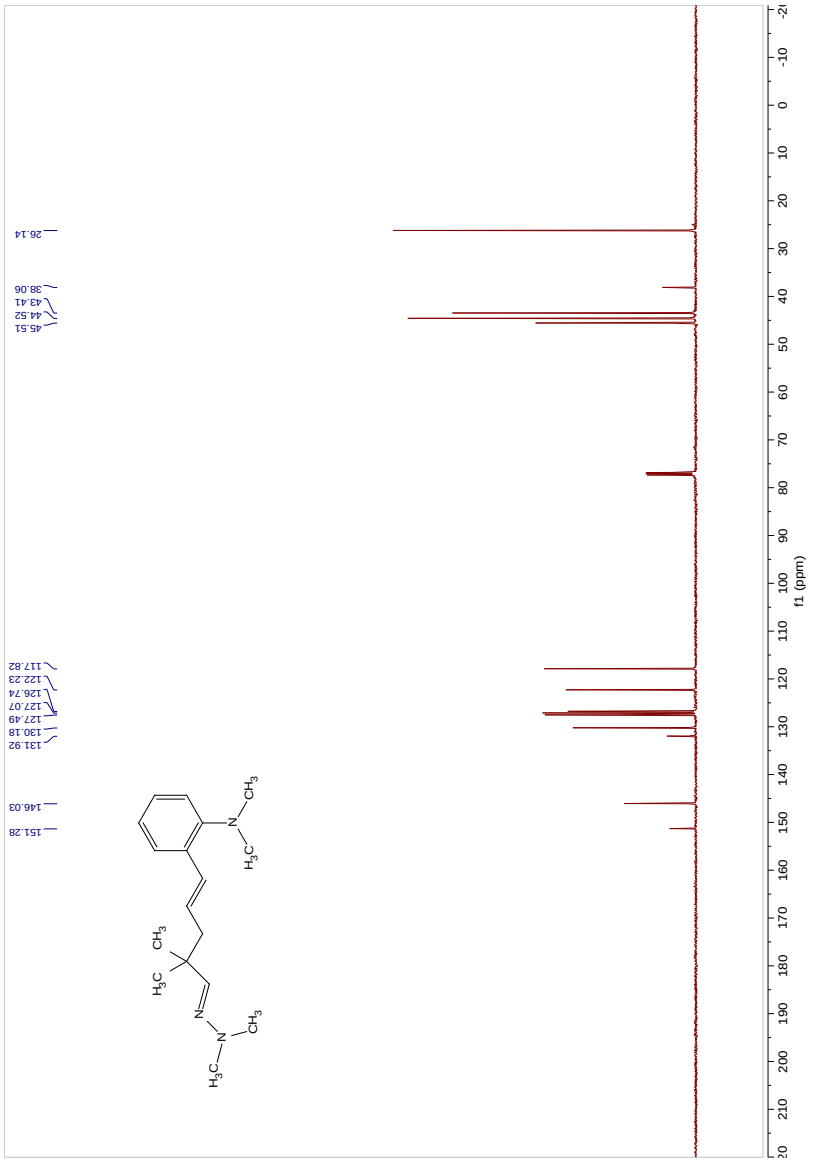
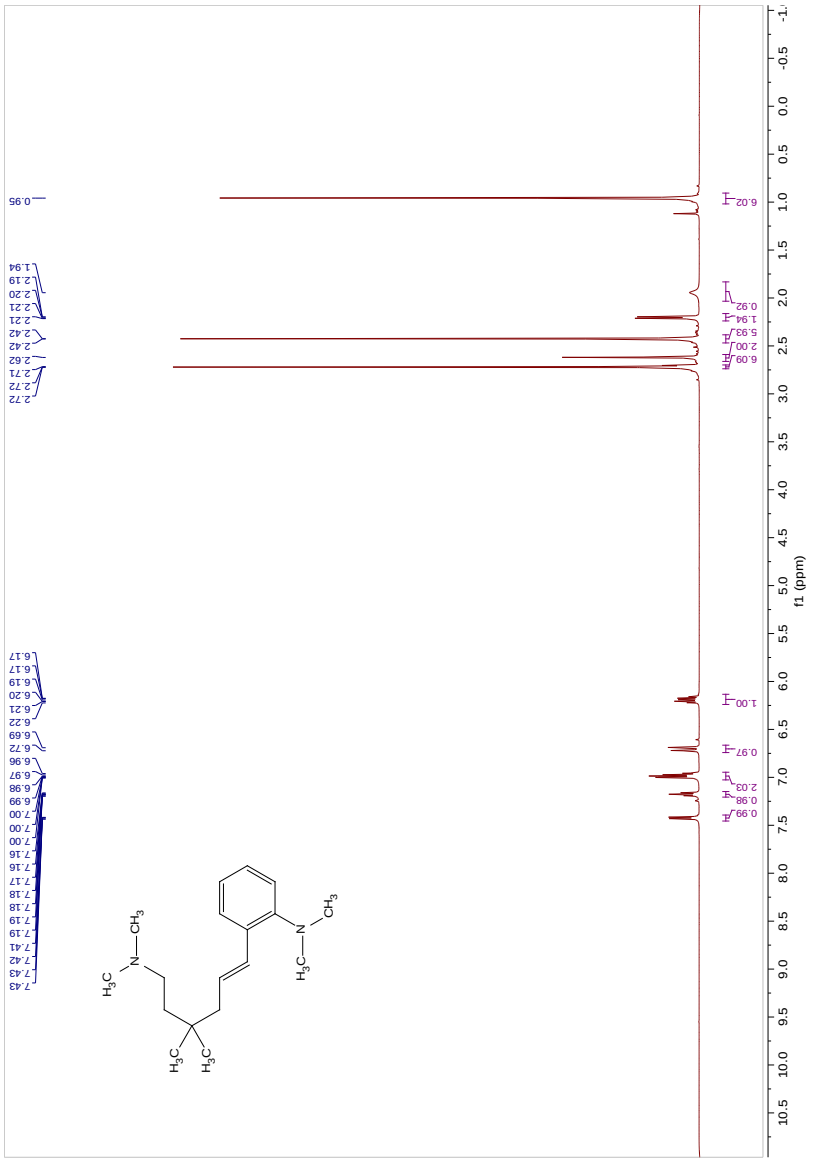
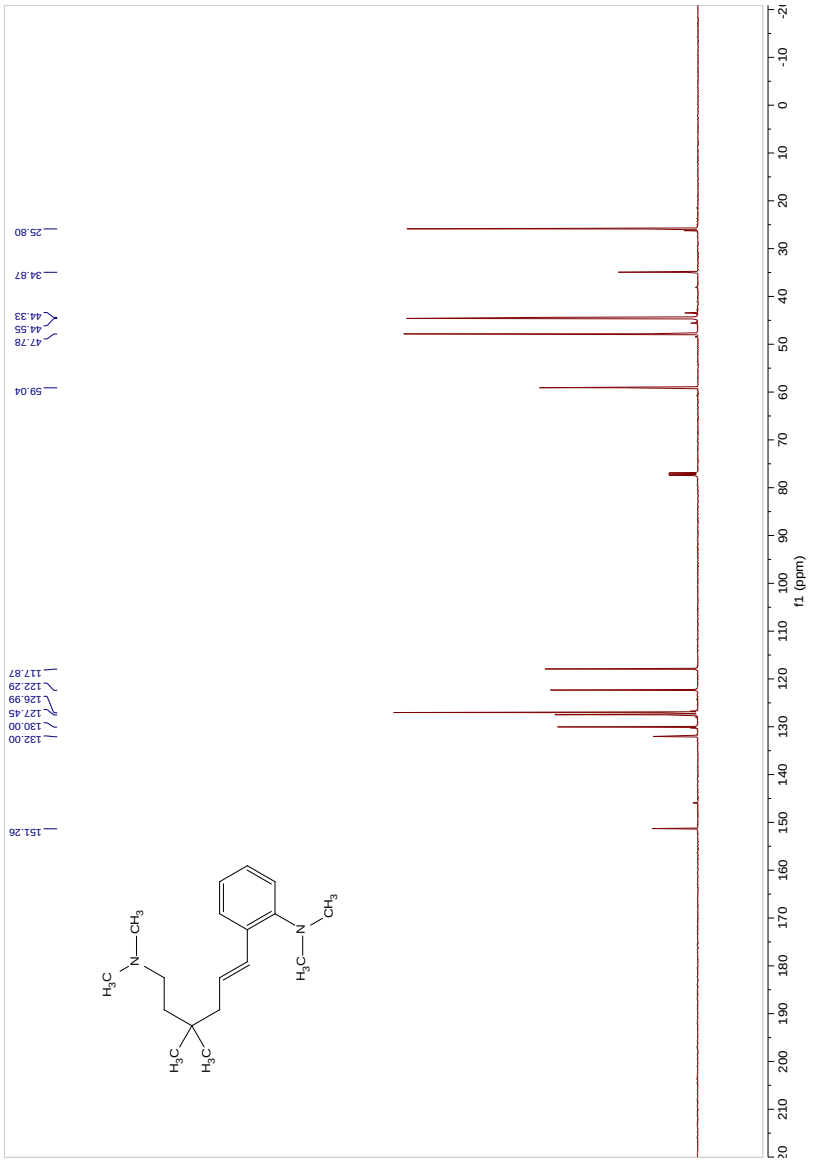
44.74
118.09
122.42
122.86
124.91
127.20
128.26
130.88
132.79
151.69
f1 (ppm)


f1 (ppm)
6.09
1.91
5.96
6.03
1.00
0.97
1.04
2.01
0.98
1.00
1.11
2.33
2.35
2.70
2.71
2.71
6.11
6.11
6.13
6.13
6.14
6.14
6.16
6.16
6.17
6.18
6.60
6.67
6.70
6.95
6.95
6.96
6.96
6.98
6.99
7.00
7.16
7.16
7.17
7.17
7.18
7.19
7.19
7.24
7.38
7.39
7.40
7.40
N
CH3
H3C
N
CH3
CH3
H3C
N
N
CH3
H3C


26.14
38.06
43.41
44.52
45.51
117.82
122.23
126.74
127.07
127.49
130.18
131.92
146.03
151.28
f1 (ppm)


f1 (ppm)
H3C
N
CH3
H3C
H3C
H3C
N
CH3


25.80
34.87
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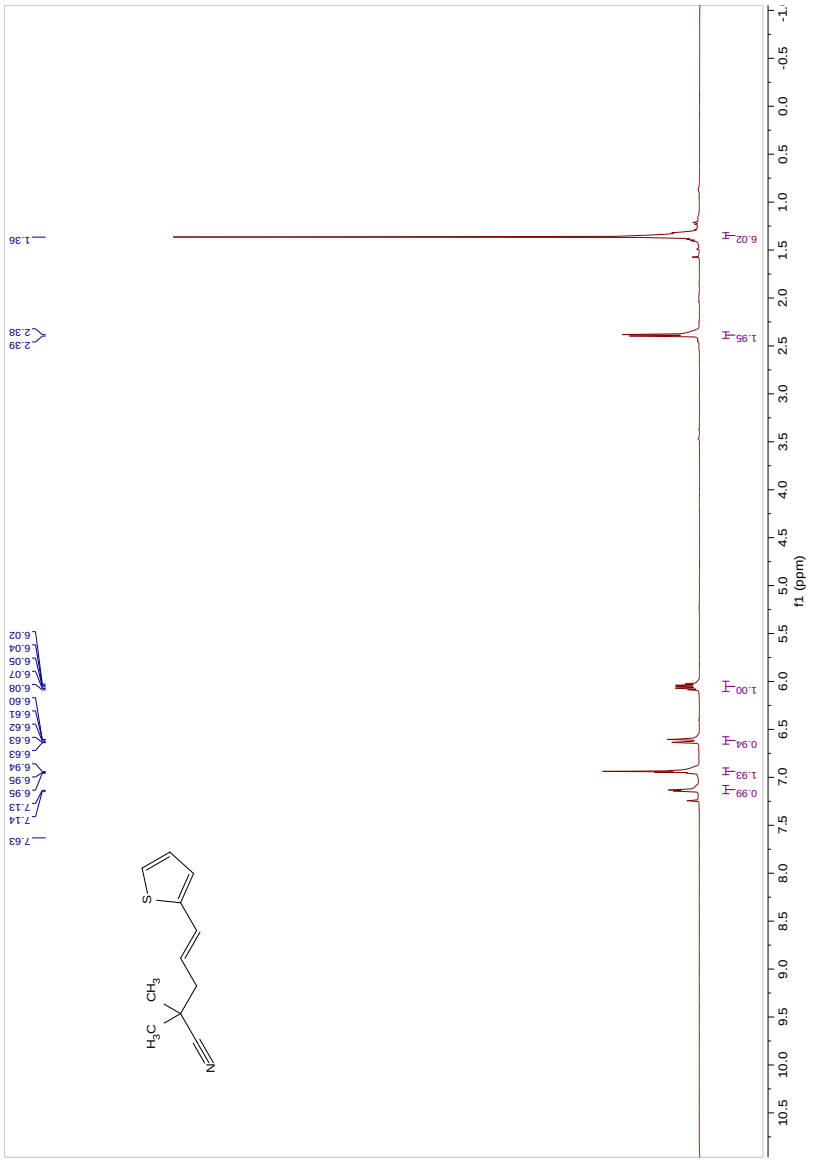
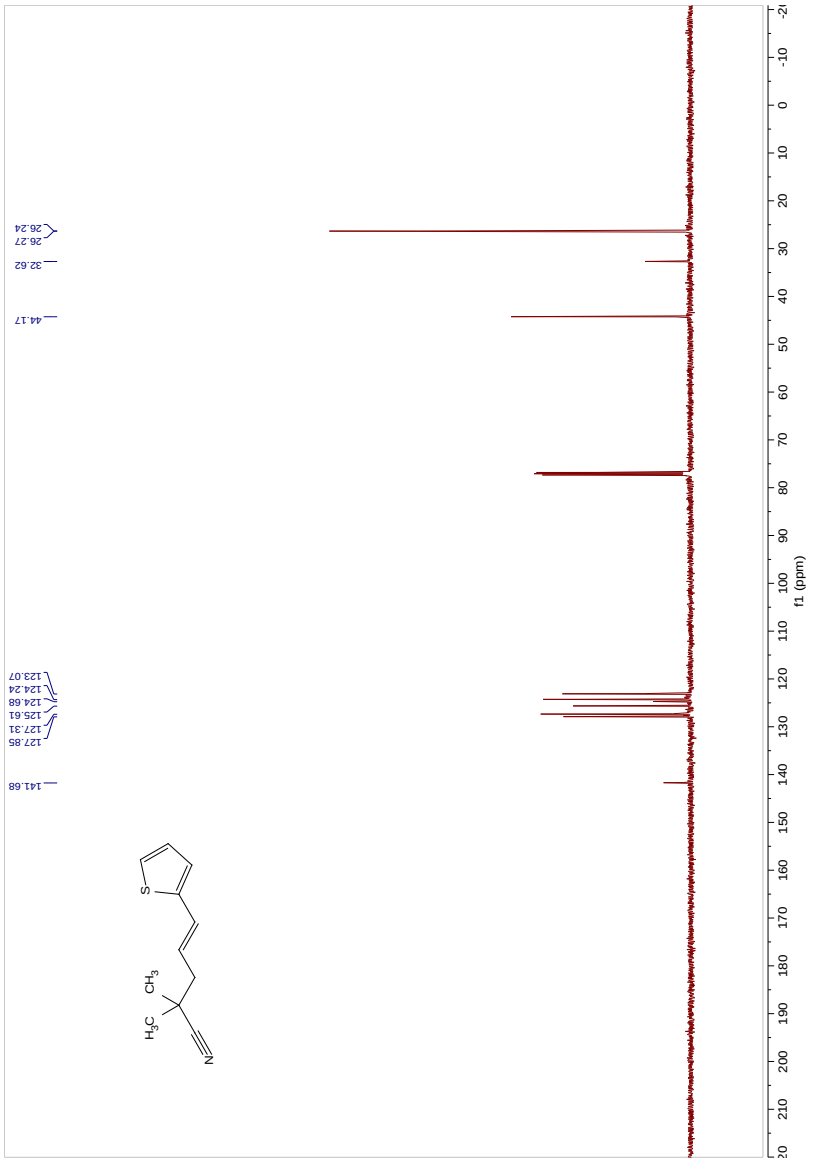
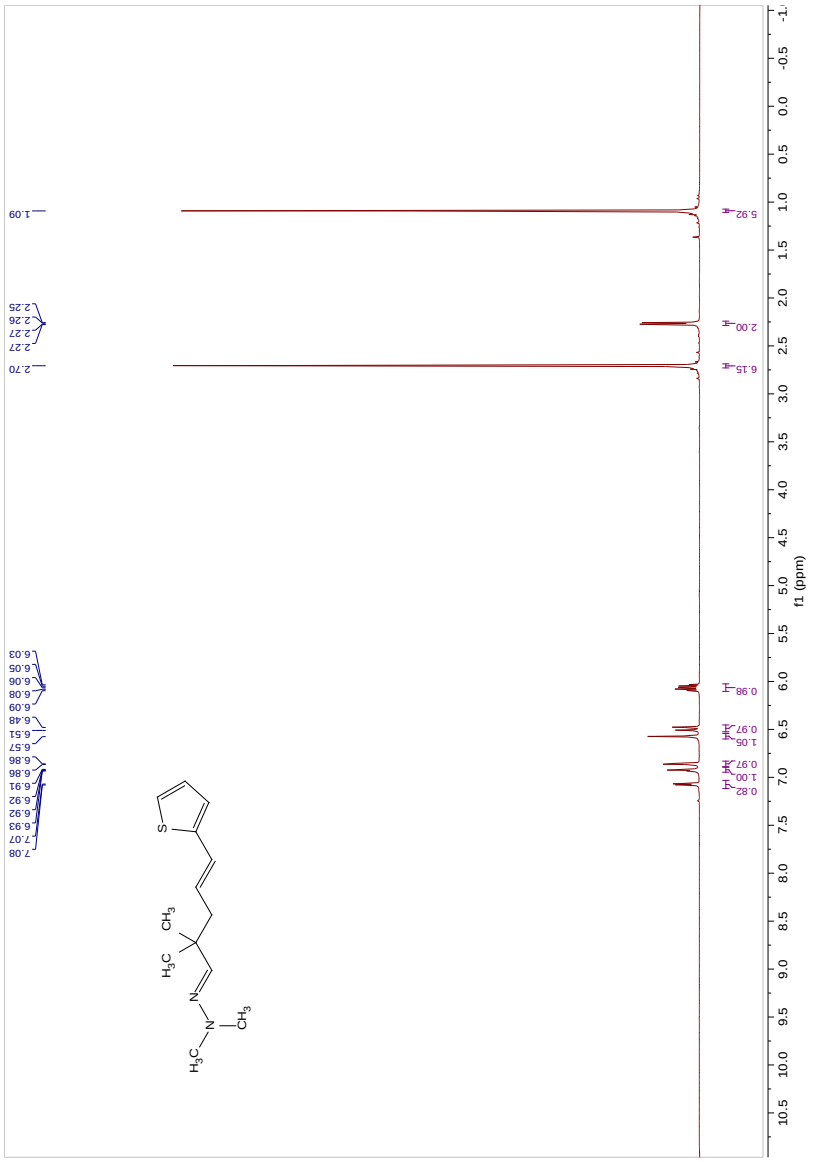
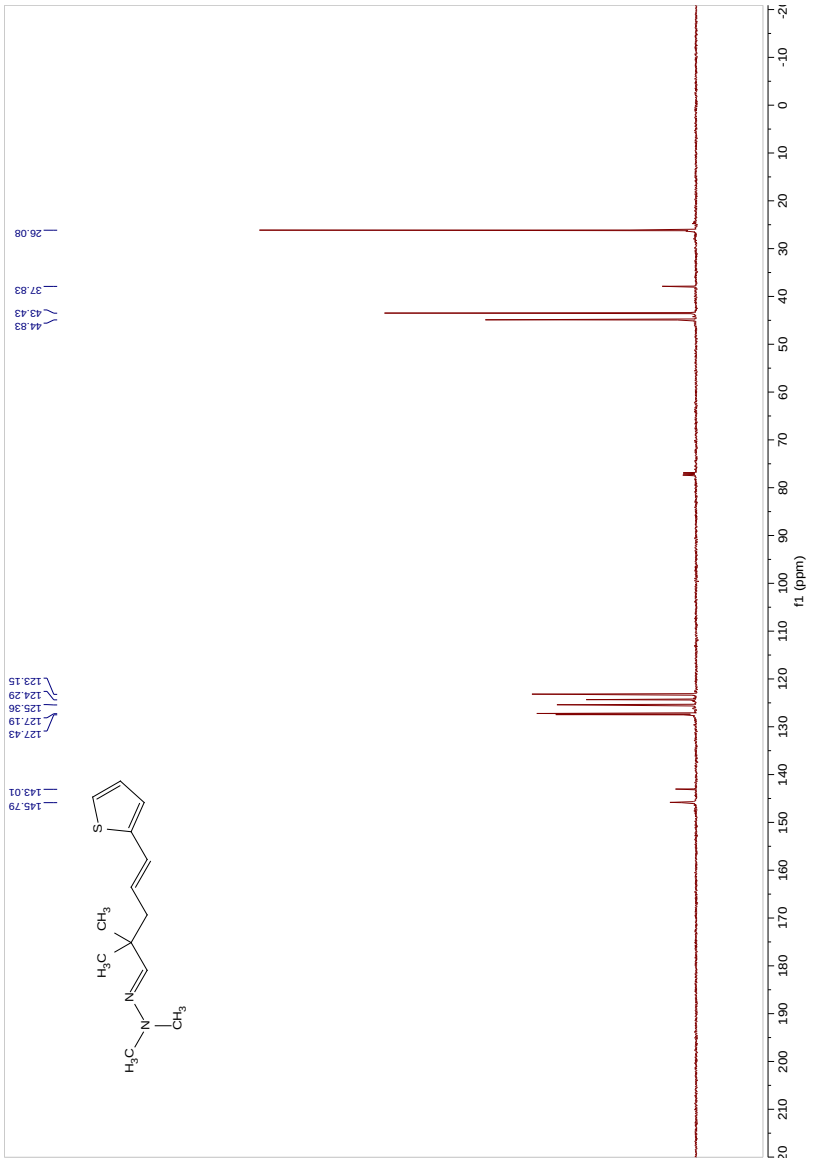
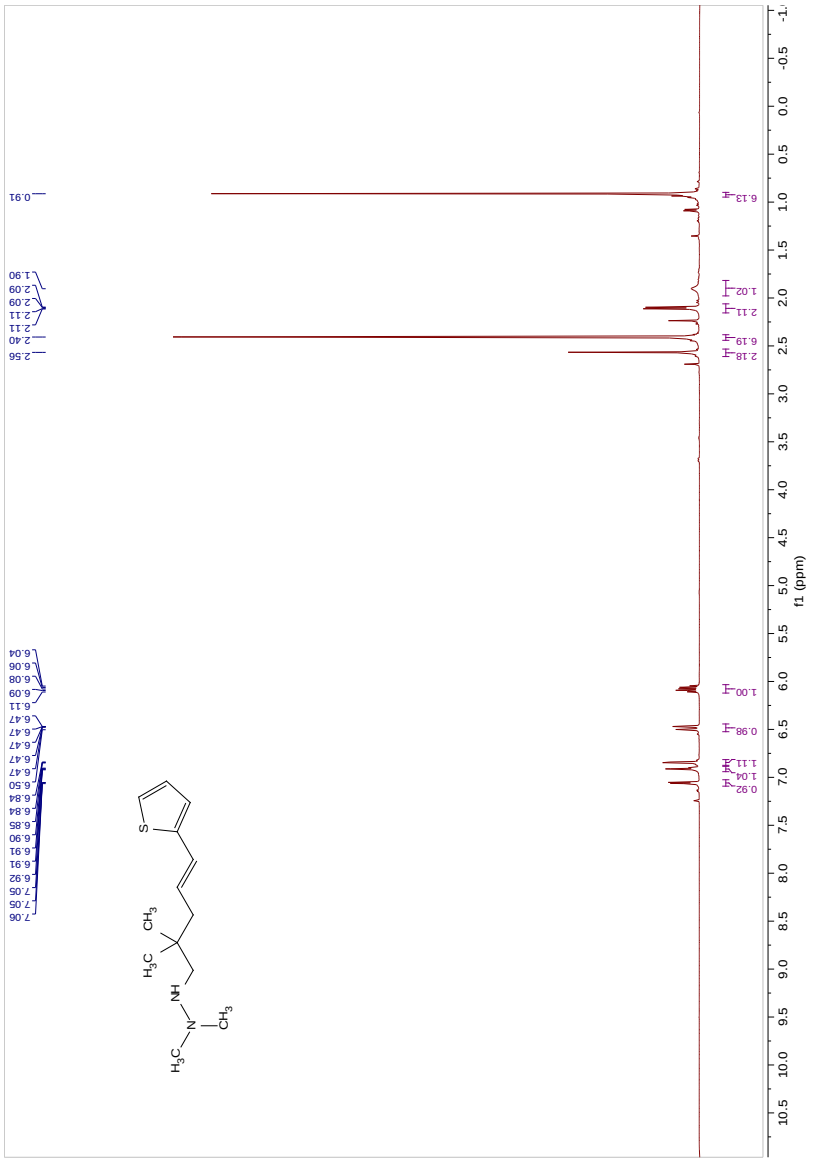
44.55
47.78
59.04
117.87
122.29
126.99
127.45
130.00
132.00
151.26
f1 (ppm)

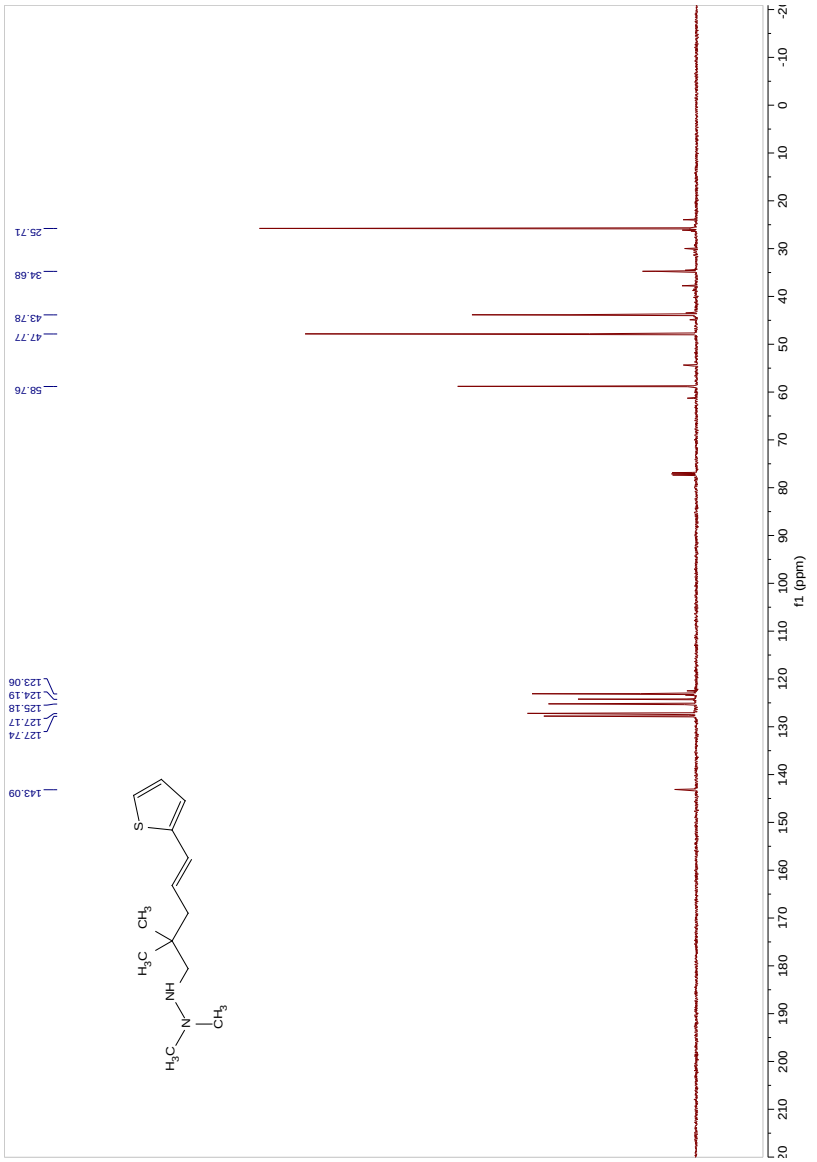

1.36
2.39
2.38
6.08
6.07
6.05
6.04
6.02
6.60
6.61
6.62
6.63
6.63
6.94
6.95
6.95
7.13
7.14
7.63
6.02
1.95
1.00
0.94
1.93
0.99
f1 (ppm)
S
CH3
H3C
N

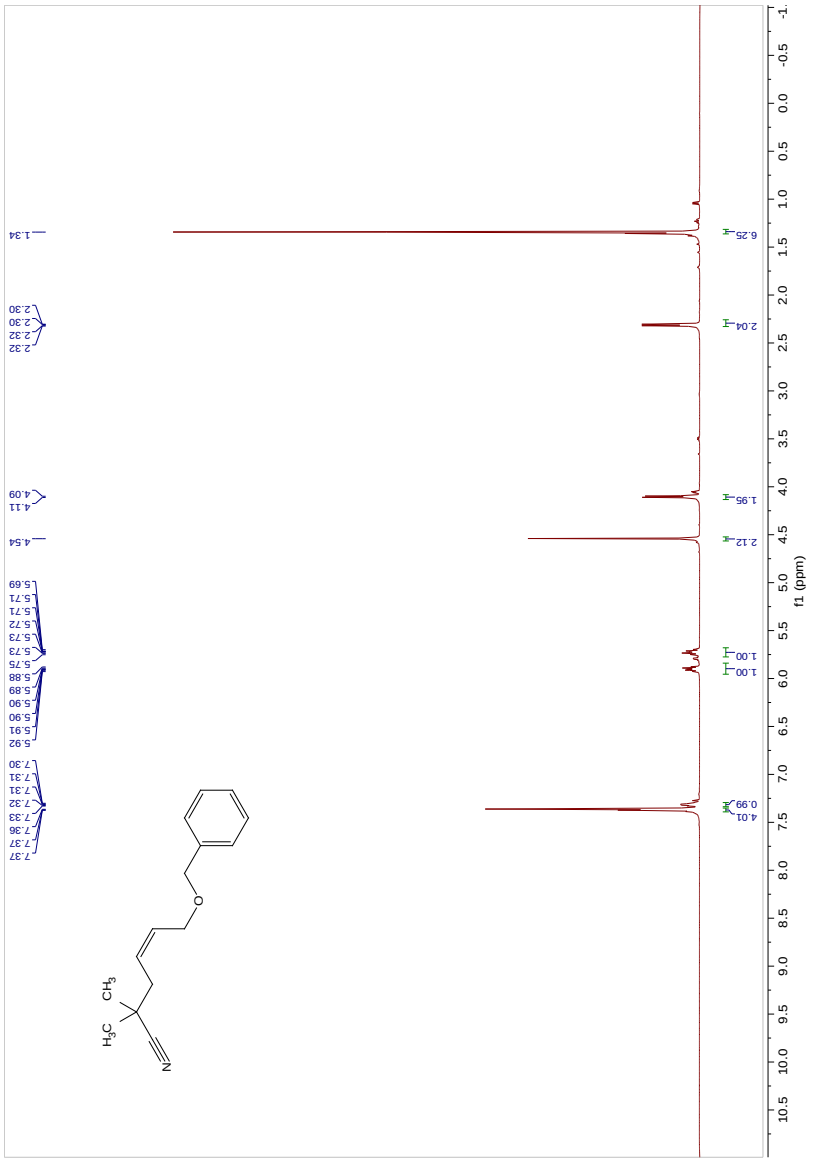

26.24
26.27
32.62
44.17
123.07
124.24
124.68
125.61
127.31
127.85
141.68
S
CH3
H3C
N
f1 (ppm)


1.09
2.25
2.26
2.27
2.27
2.70
6.03
6.05
6.06
6.08
6.09
6.48
6.51
6.57
6.86
6.86
6.91
6.92
6.92
6.93
7.07
7.08
5.92
2.00
6.15
0.98
0.97
1.05
0.97
1.00
0.82
f1 (ppm)


26.08
37.83
43.43
44.83
123.15
124.29
125.36
127.19
127.43
143.01
145.79
f1 (ppm)


f1 (ppm)
S
CH3
H3C
NH
N
CH3
H3C


25.71
34.68
43.78
47.77
58.76
123.06
124.19
125.18
127.17
127.74
143.09
S
CH3
H3C
NH
N
CH3
H3C
f1 (ppm)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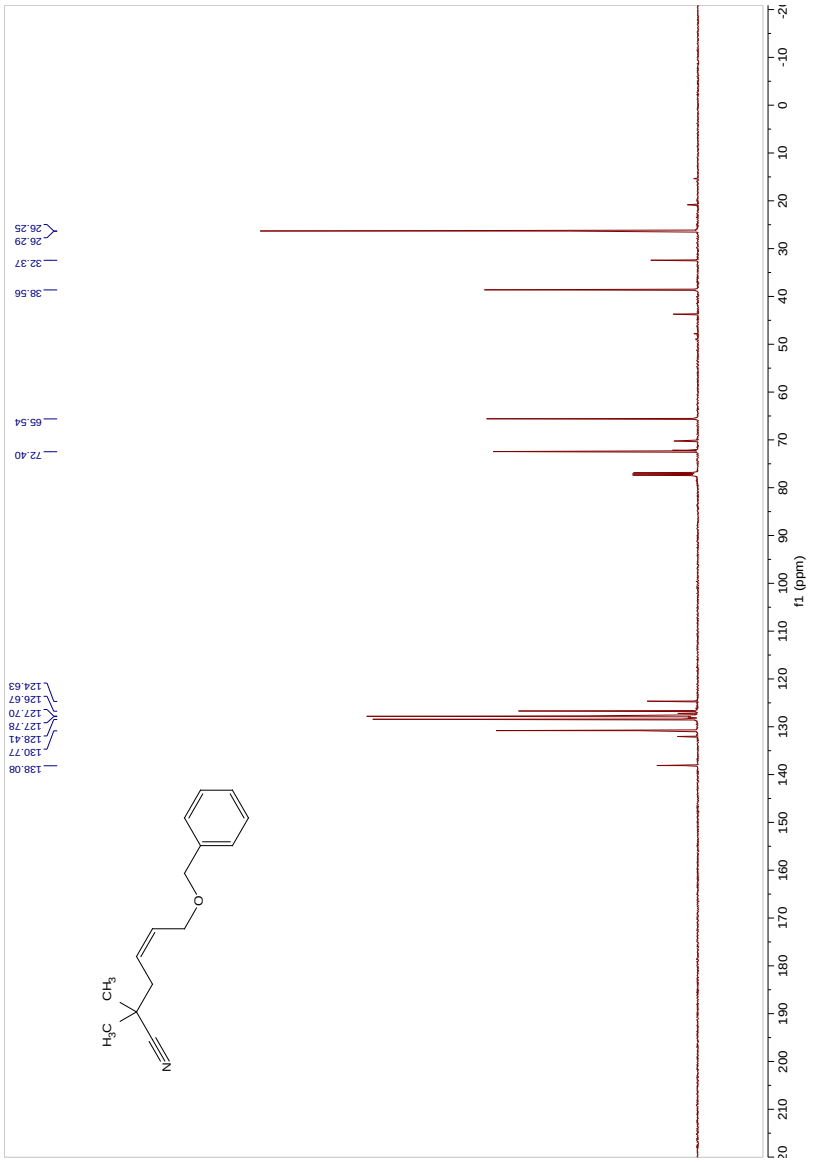
2.30
2.30
2.32
2.32
4.09
4.11
4.54
5.69
5.71
5.71
5.72
5.73
5.73
5.75
5.88
5.89
5.90
5.90
5.91
5.92
7.30
7.31
7.31
7.32
7.33
7.36
7.37
7.37
6.25
2.04
1.95
2.12
1.00
1.00
4.01
0.99
f1 (ppm)
H3C
CH3
N
O


26.25
26.29
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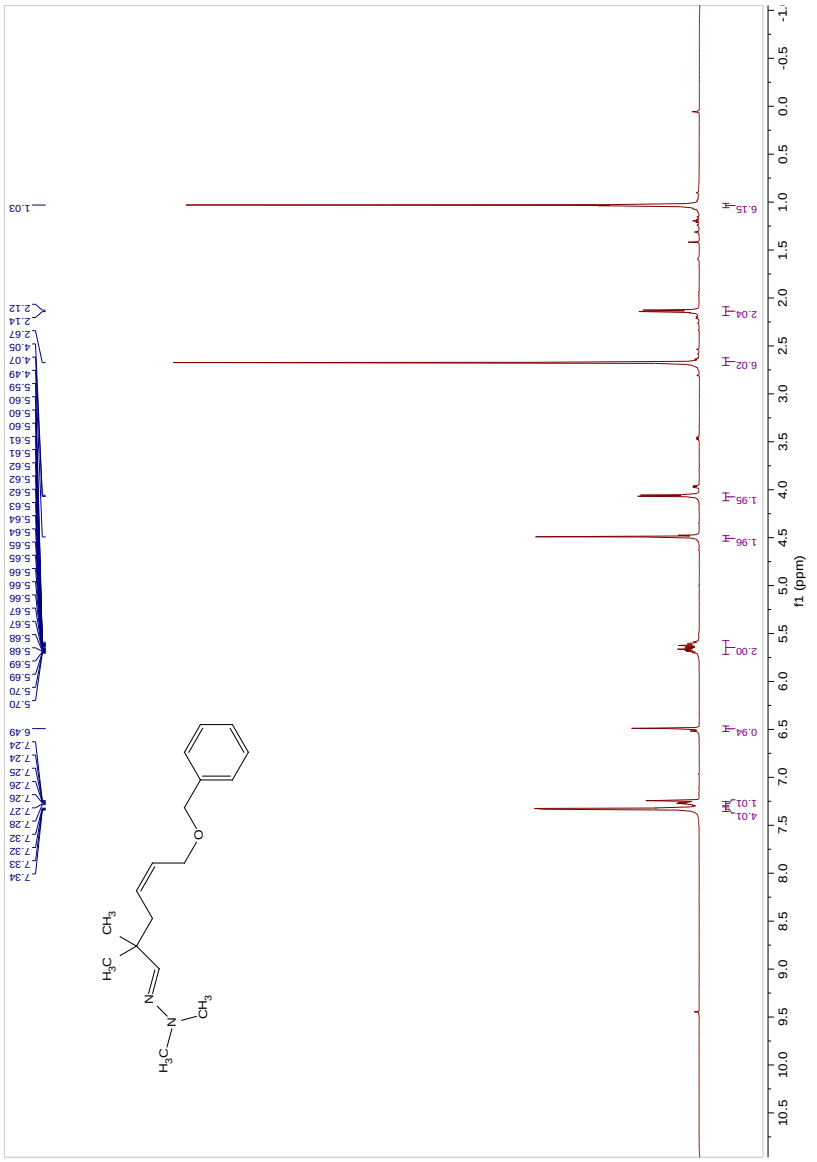
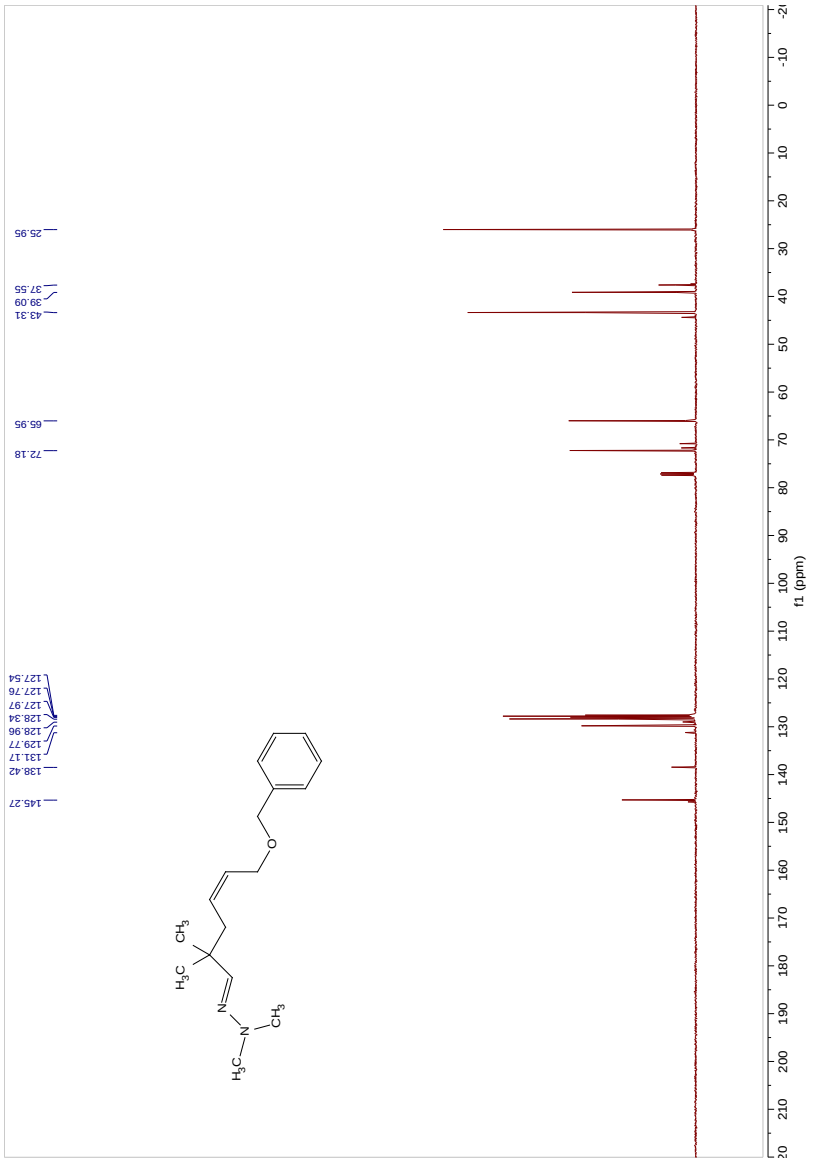
72.40
124.63
126.67
127.70
127.78
128.41
130.77
138.08
f1 (ppm)


1.03
2.12
2.14
2.67
4.05
4.07
4.49
5.59
5.60
5.60
5.60
5.61
5.61
5.62
5.62
5.62
5.63
5.64
5.64
5.65
5.65
5.66
5.66
5.66
5.67
5.67
5.68
5.68
5.69
5.69
5.70
5.70
6.49
7.24
7.24
7.25
7.26
7.26
7.27
7.28
7.32
7.32
7.33
7.34
6.15
2.04
6.02
1.95
1.96
2.00
0.94
1.01
4.01
f1 (ppm)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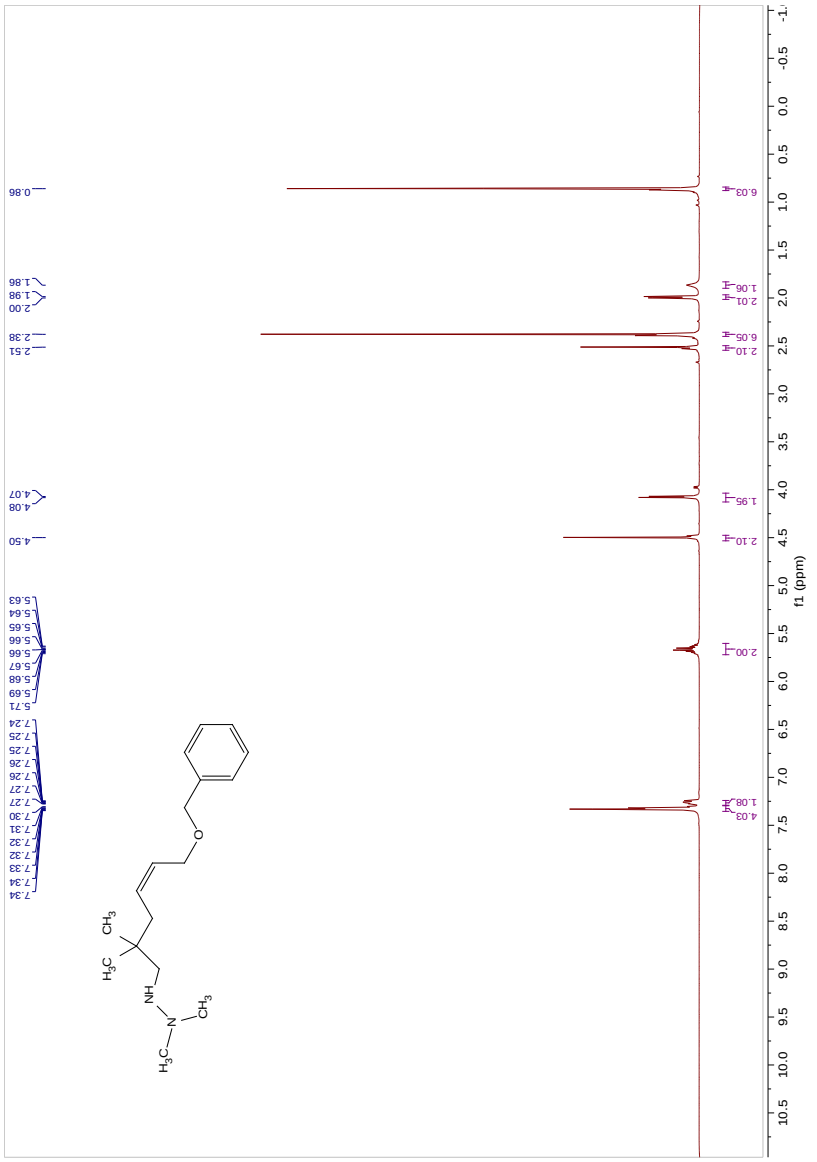
37.55
39.09
43.31
65.95
72.18
127.54
127.76
127.97
128.34
128.96
129.77
131.17
138.42
145.27
f1 (ppm)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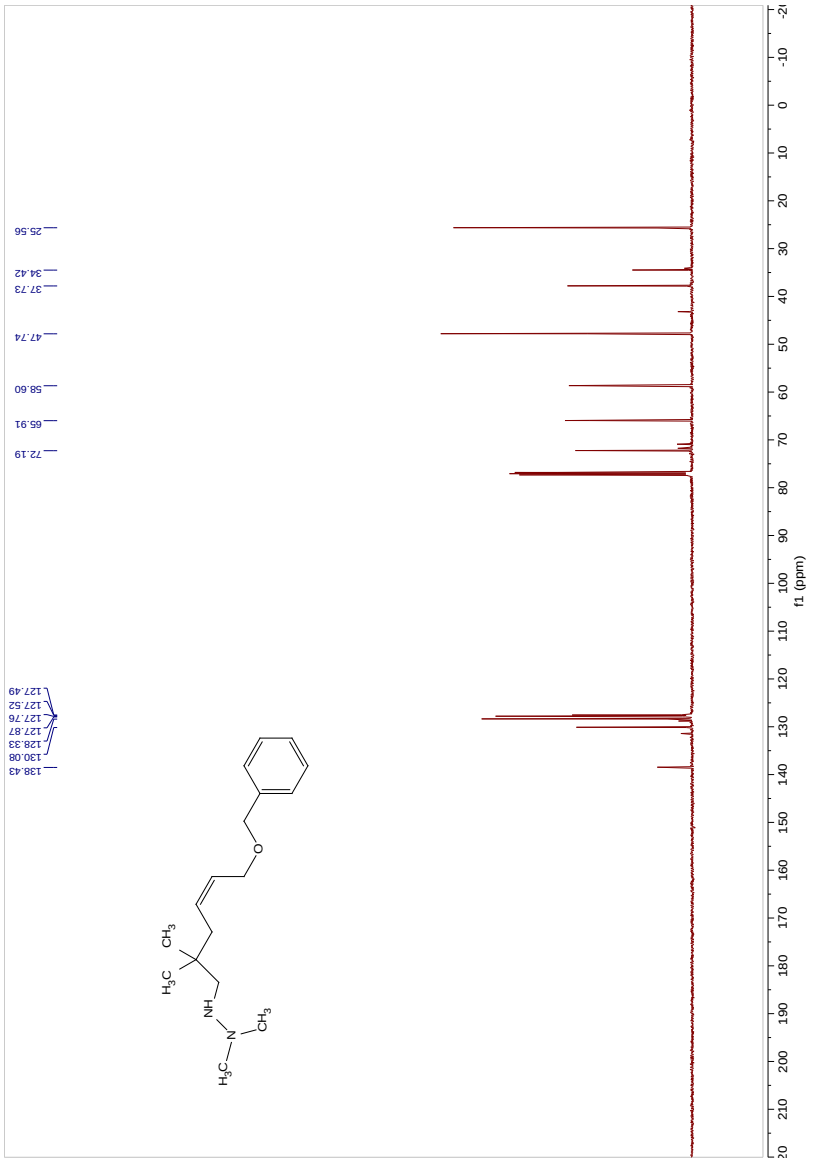
1.86
1.98
2.00
2.38
2.51
4.07
4.08
4.50
5.63
5.64
5.65
5.66
5.66
5.67
5.68
5.69
5.71
7.24
7.25
7.25
7.26
7.26
7.27
7.27
7.30
7.31
7.32
7.32
7.33
7.34
7.34
6.03
1.06
2.01
6.05
2.10
1.95
2.10
2.00
4.03
1.08
f1 (ppm)
CH3
H3C
NH
N
CH3
H3C
O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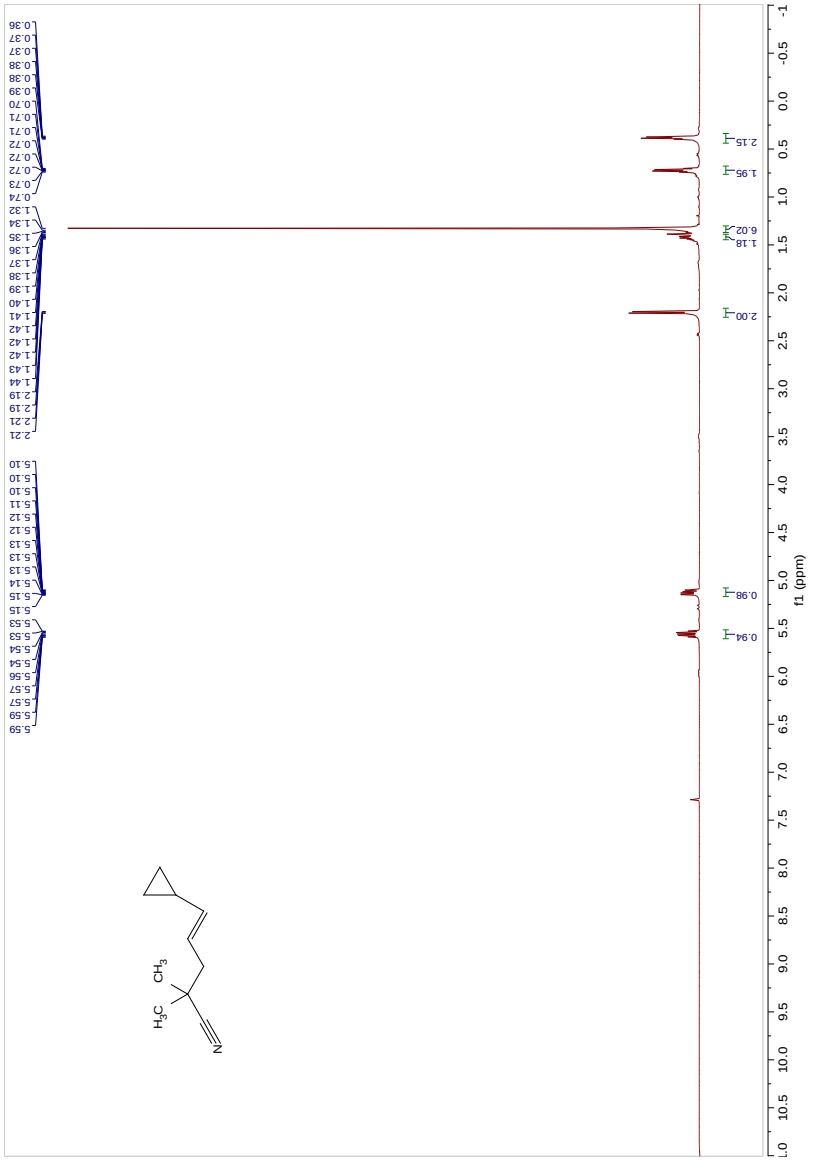
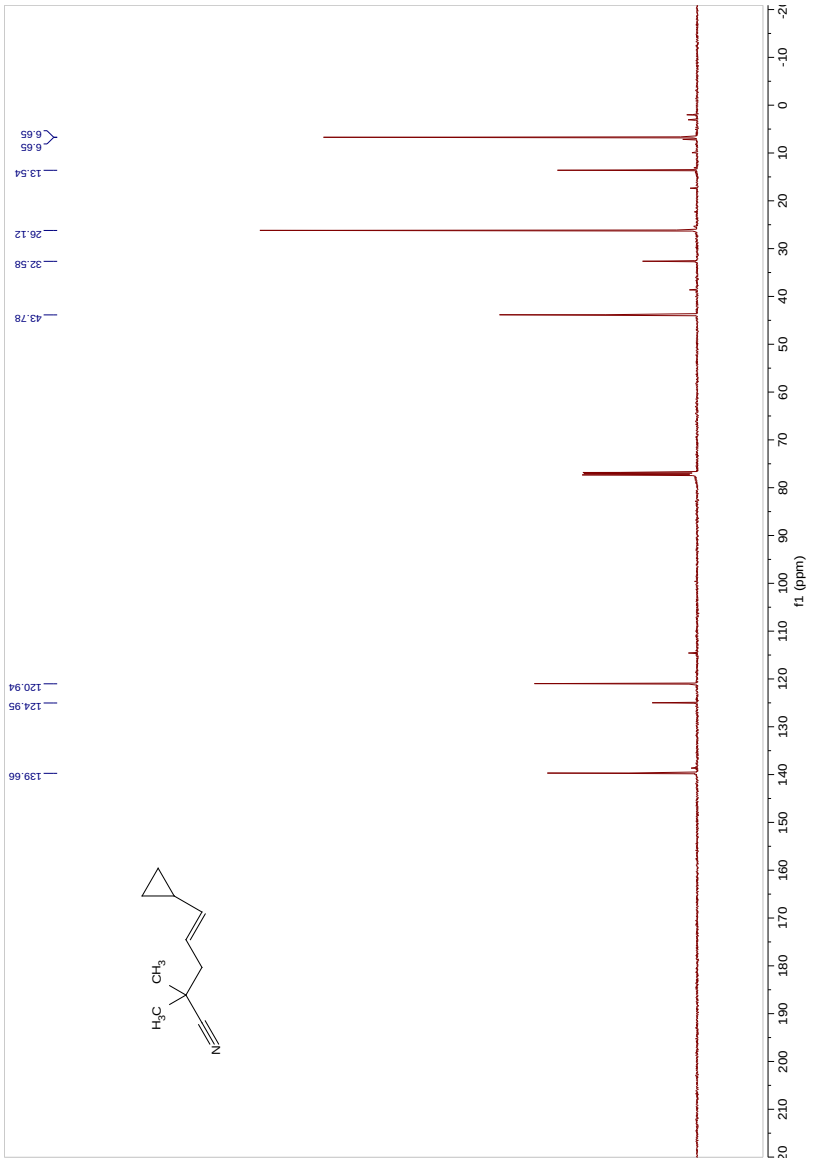
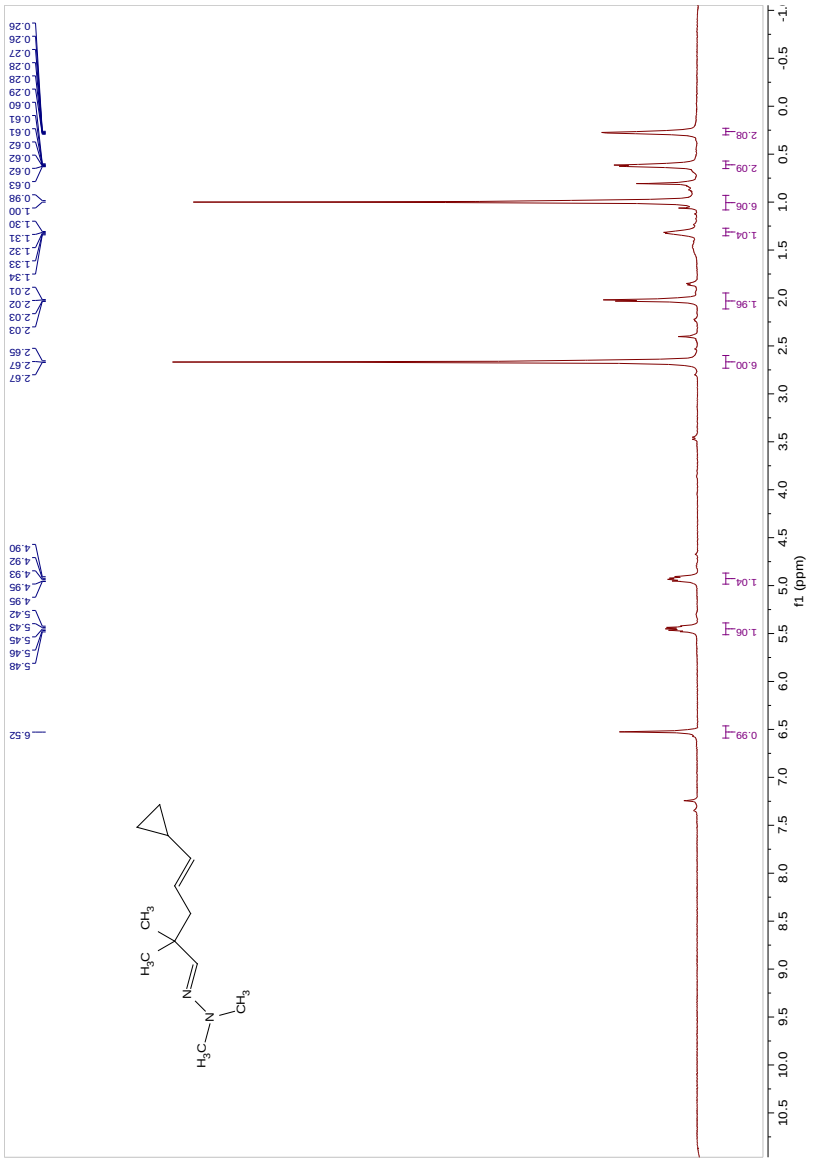
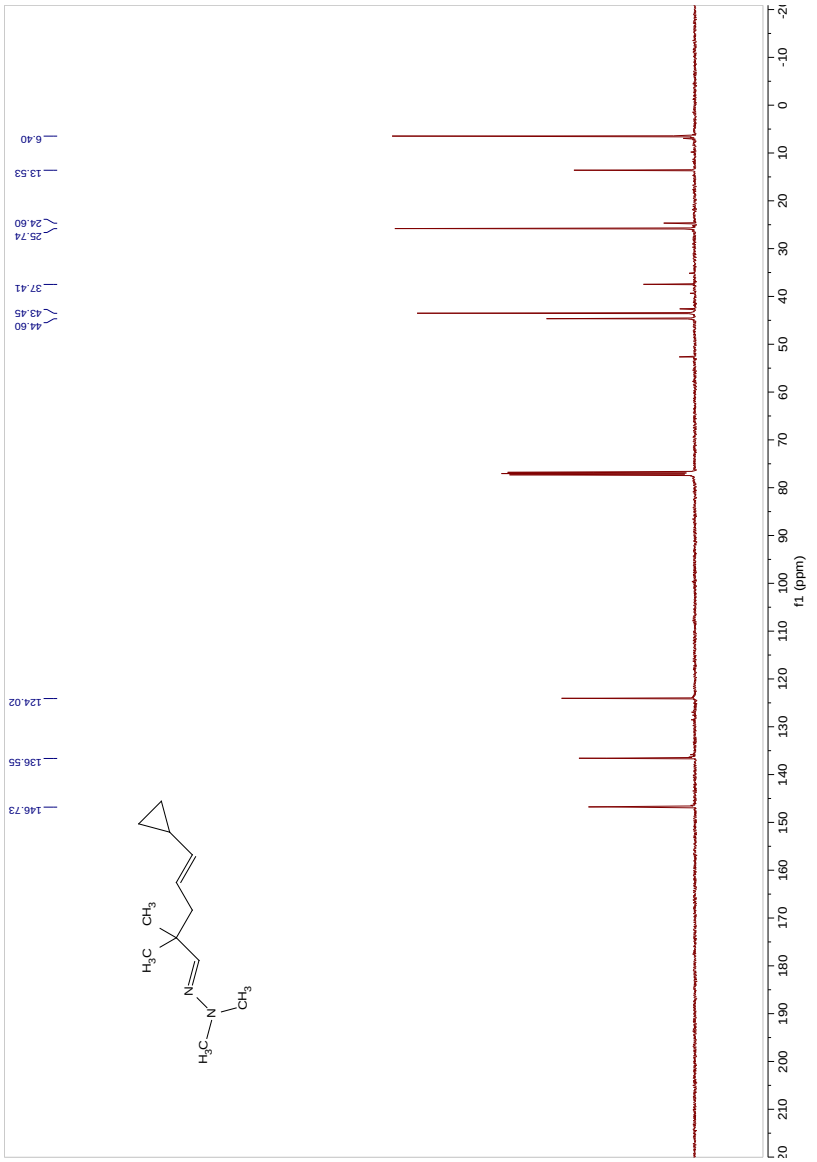
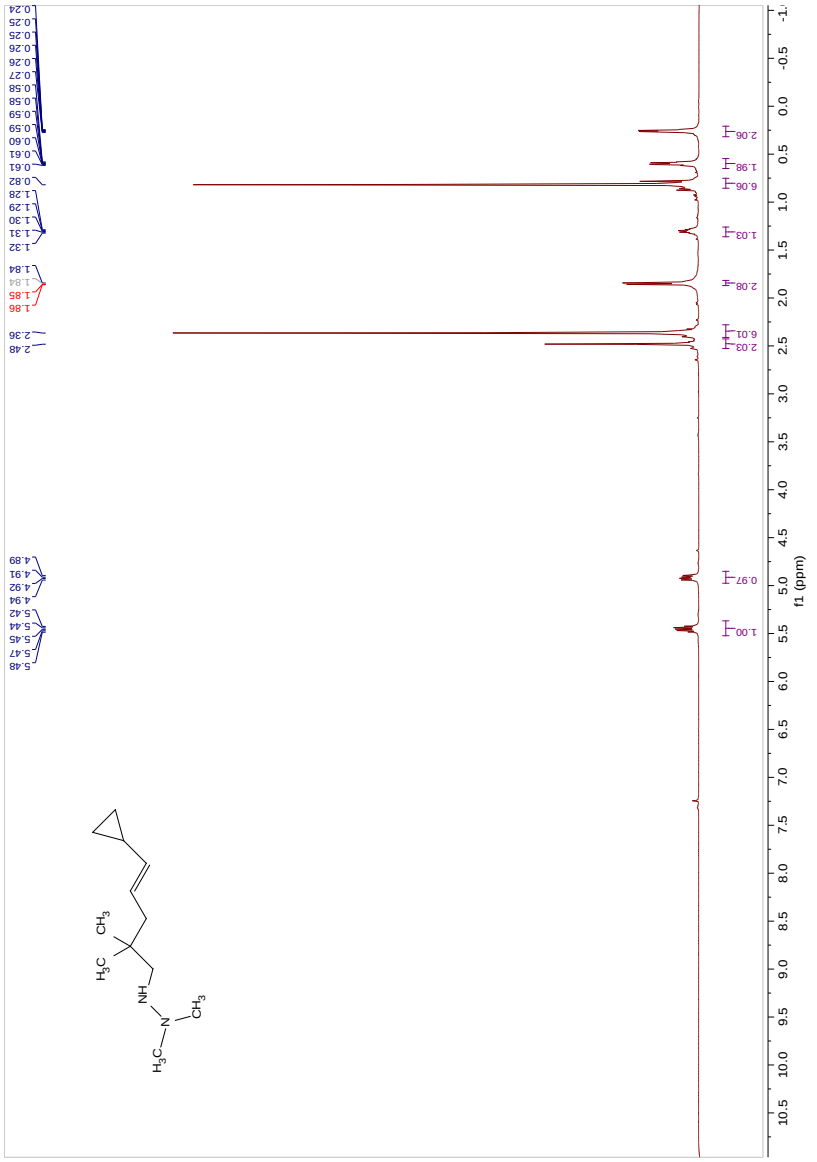
34.42
37.73
47.74
58.60
65.91
72.19
127.49
127.52
127.76
127.87
128.33
130.08
138.43
f1 (ppm)

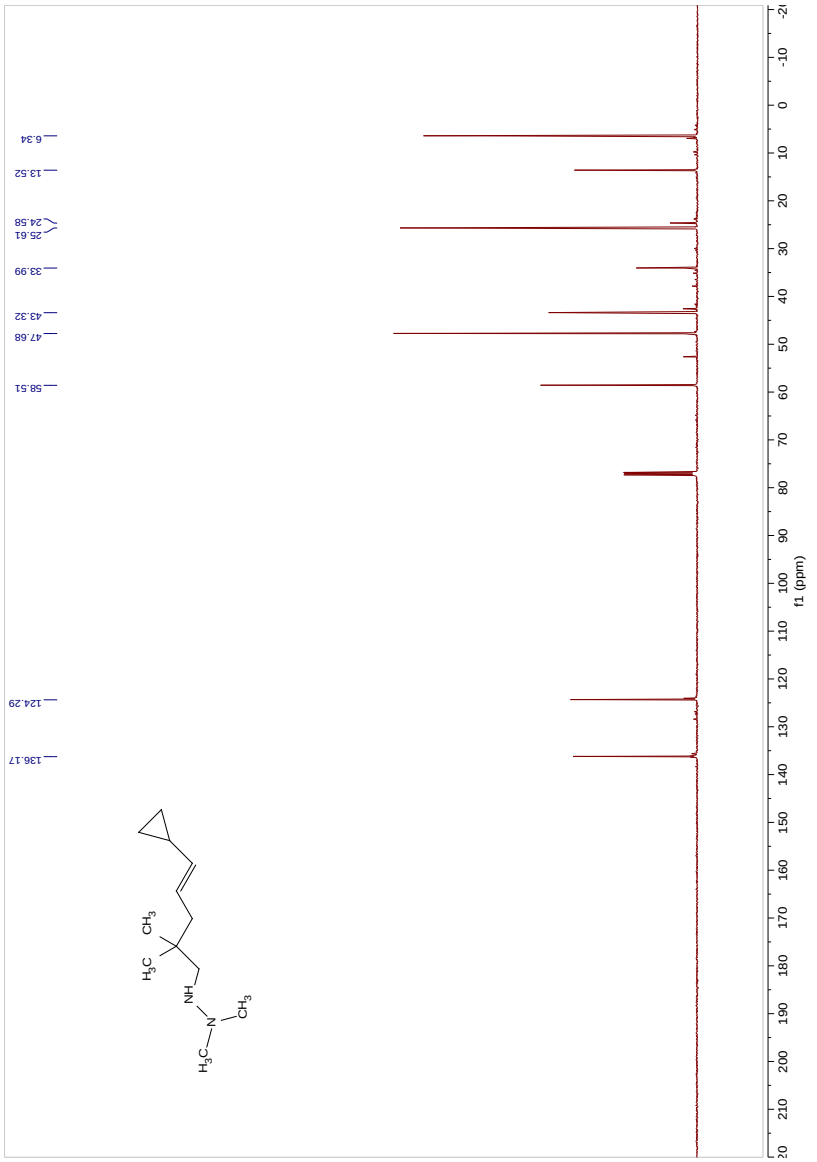

f1 (ppm)
2.15
1.95
6.02
1.18
2.00
0.98
0.94
H3C
CH3
N

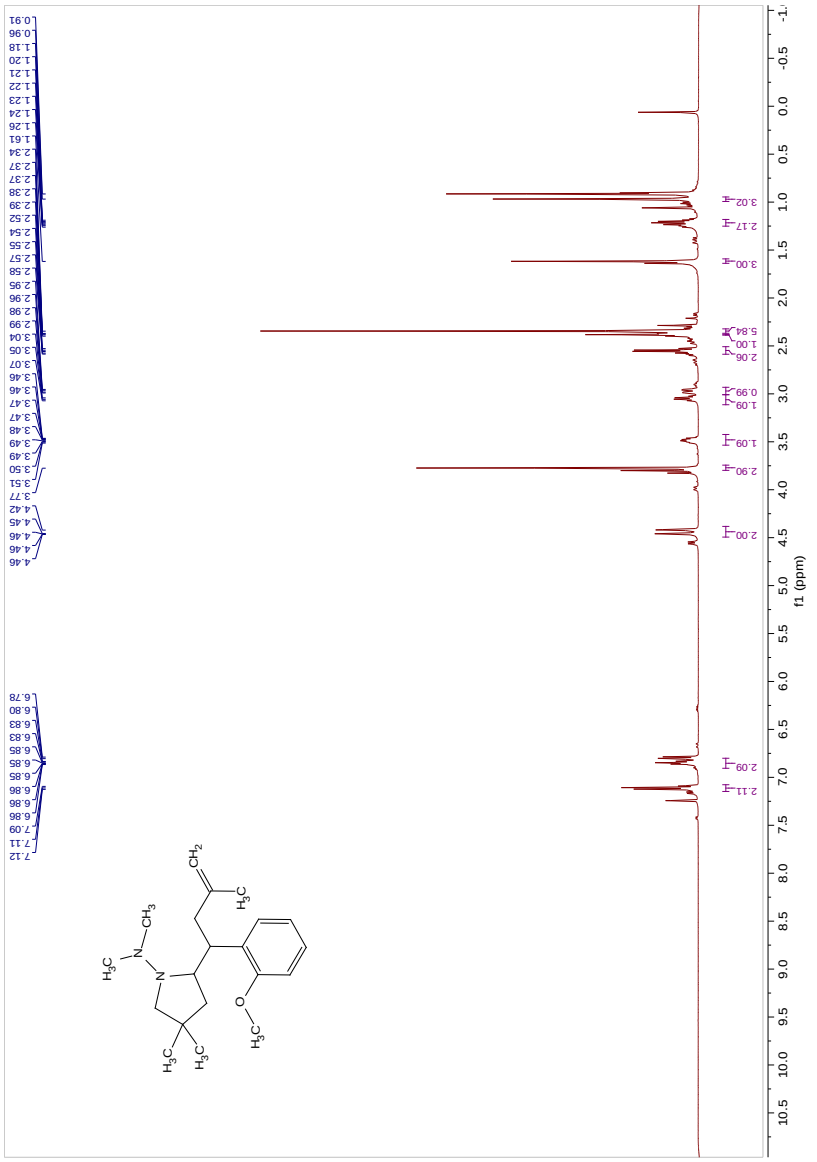

6.65
6.65
13.54
26.12
32.58
43.78
120.94
124.95
139.66
f1 (ppm)
H3C
CH3
N

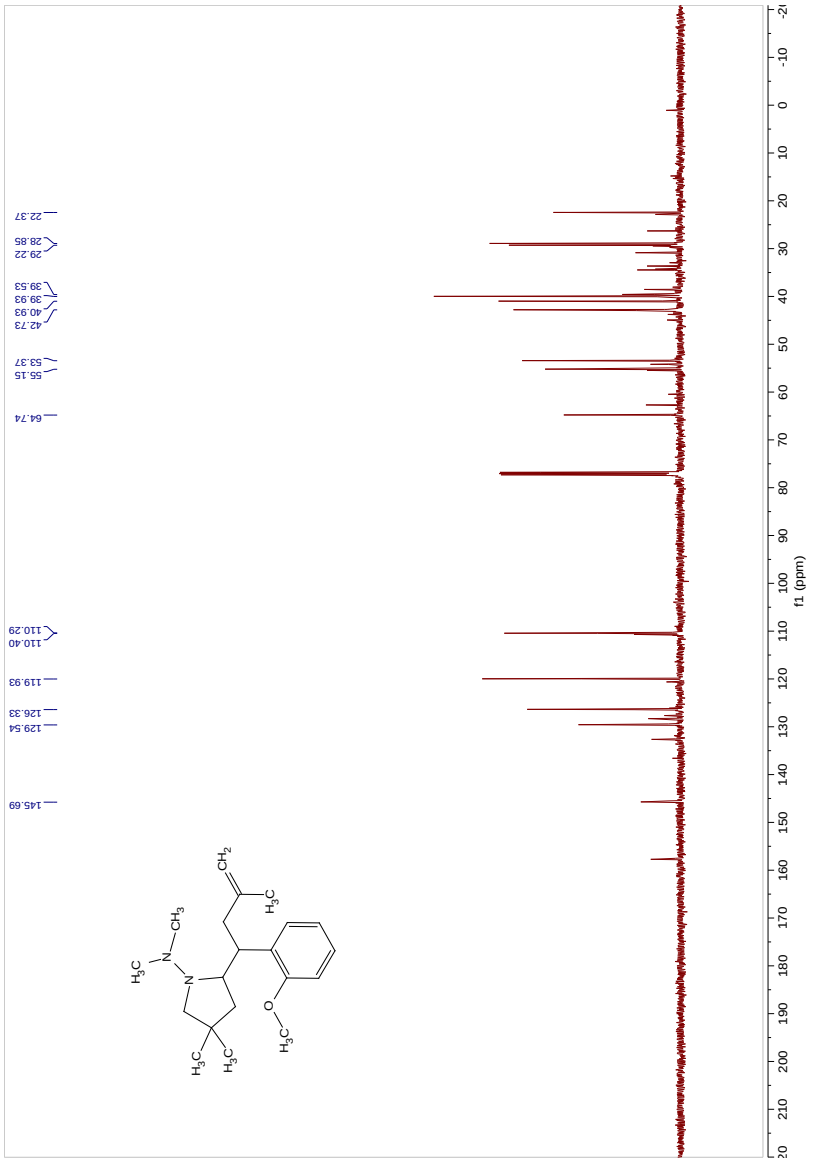

f1 (ppm)
2.08
2.09
6.06
1.04
1.96
6.00
1.04
1.06
0.99
6.52
4.90
4.92
4.93
4.95
4.95
5.42
5.43
5.45
5.46
5.48
2.67
2.67
2.65
2.03
2.02
2.03
2.01
1.34
1.33
1.32
1.31
1.30
1.00
0.98
0.63
0.62
0.62
0.62
0.61
0.61
0.60
0.29
0.28
0.28
0.27
0.26
0.26
CH3
H3C
N
N
CH3
H3C

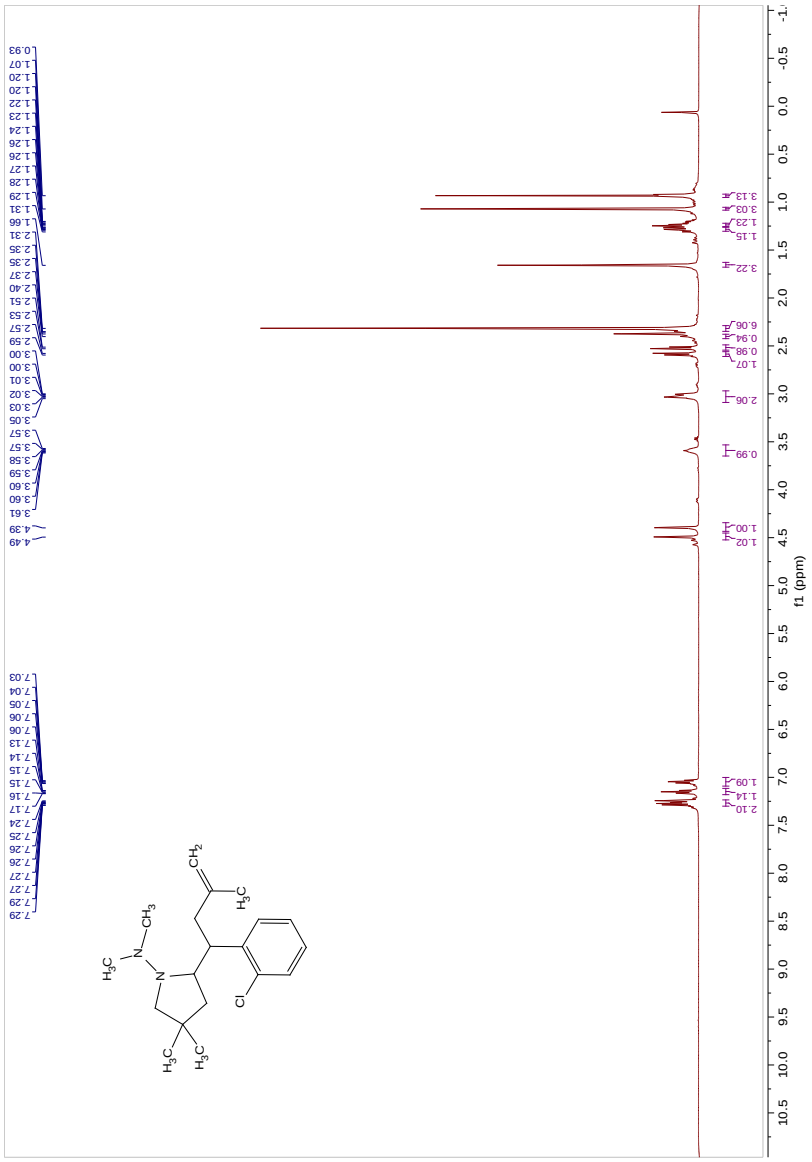

6.40
13.53
24.60
25.74
37.41
43.45
44.60
124.02
136.55
146.73
f1 (ppm)

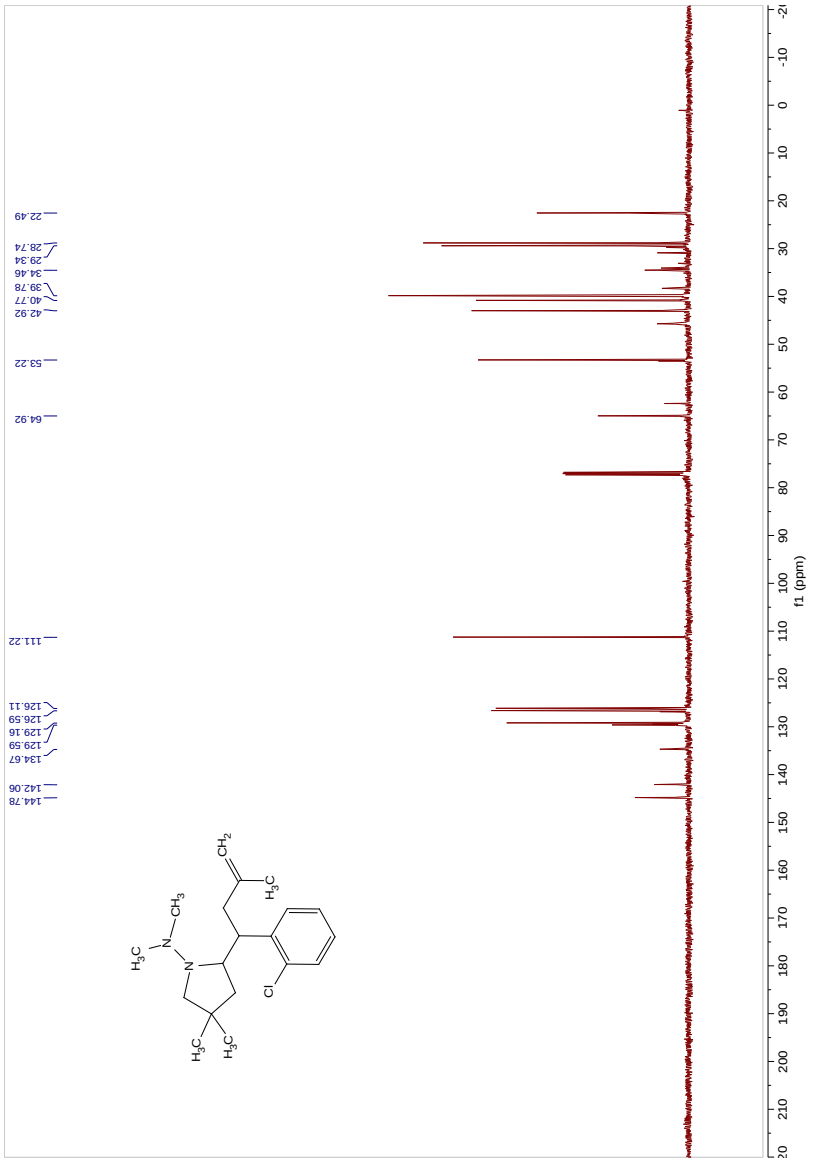

0.24
0.25
0.25
0.26
0.26
0.27
0.58
0.58
0.59
0.59
0.60
0.61
0.61
0.82
1.28
1.29
1.30
1.31
1.32
1.84
1.84
1.86
2.36
2.48
4.89
4.91
4.92
4.94
5.42
5.44
5.45
5.47
5.48
2.06
1.98
6.06
1.03
2.08
6.01
2.03
0.97
1.00
f1 (ppm)
H3C
CH3
NH
N
CH3
H3C

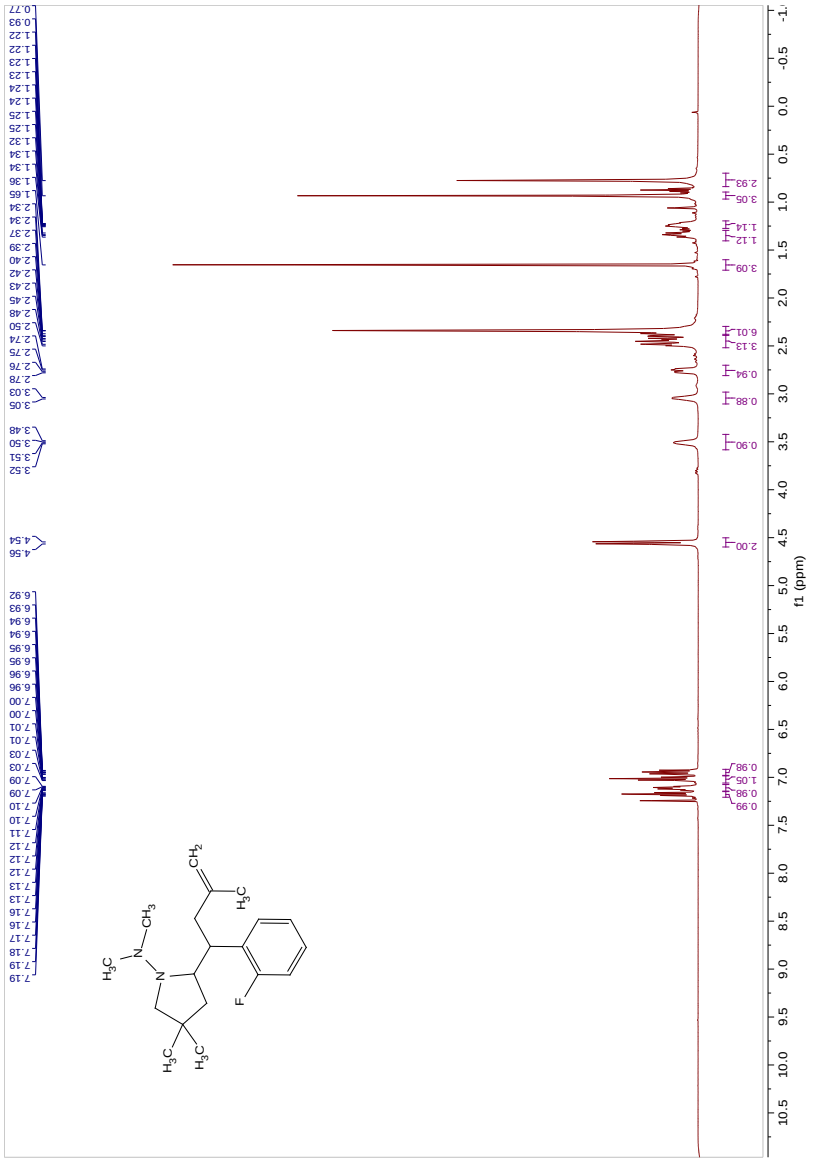

6.34
13.52
24.58
25.61
33.99
43.32
47.68
58.51
124.29
136.17
f1 (ppm)

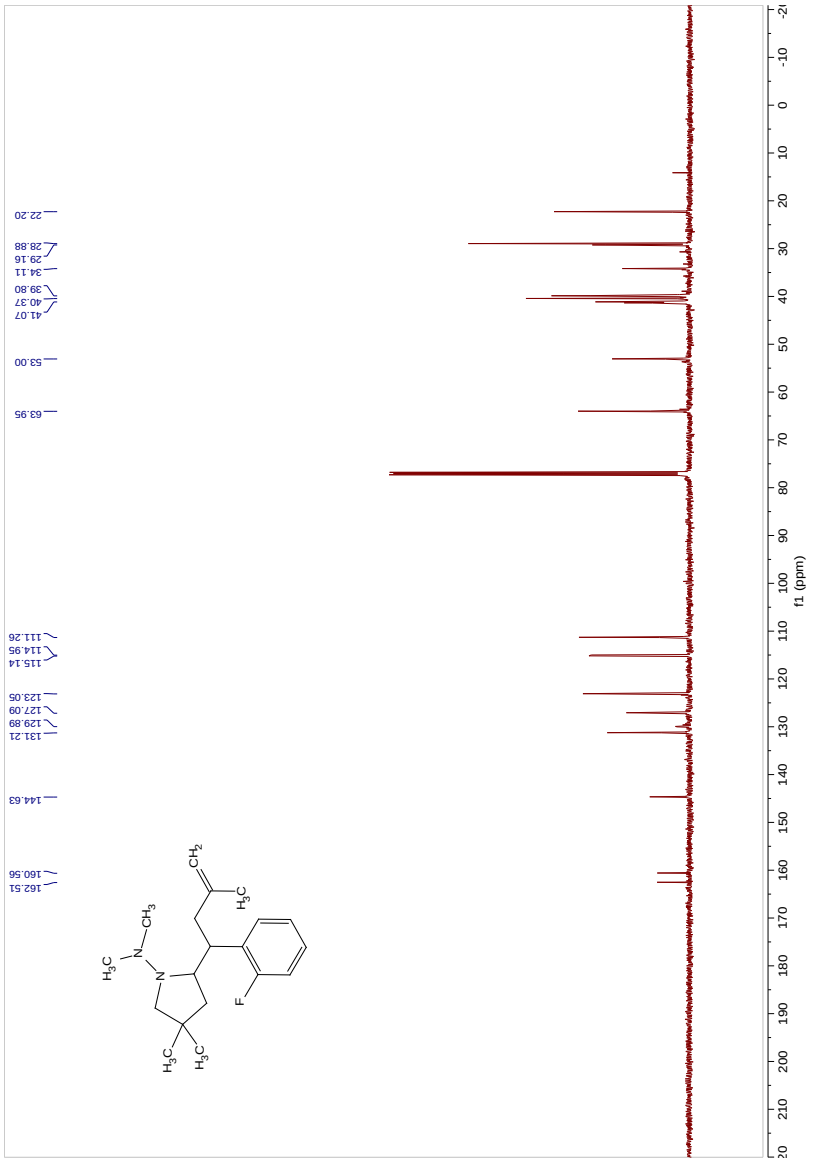

f1 (ppm)
3.02
2.17
3.00
5.84
1.00
2.06
0.99
1.09
1.09
2.90
2.00
2.09
2.11
H3C
N
CH3
CH2
O
CH3

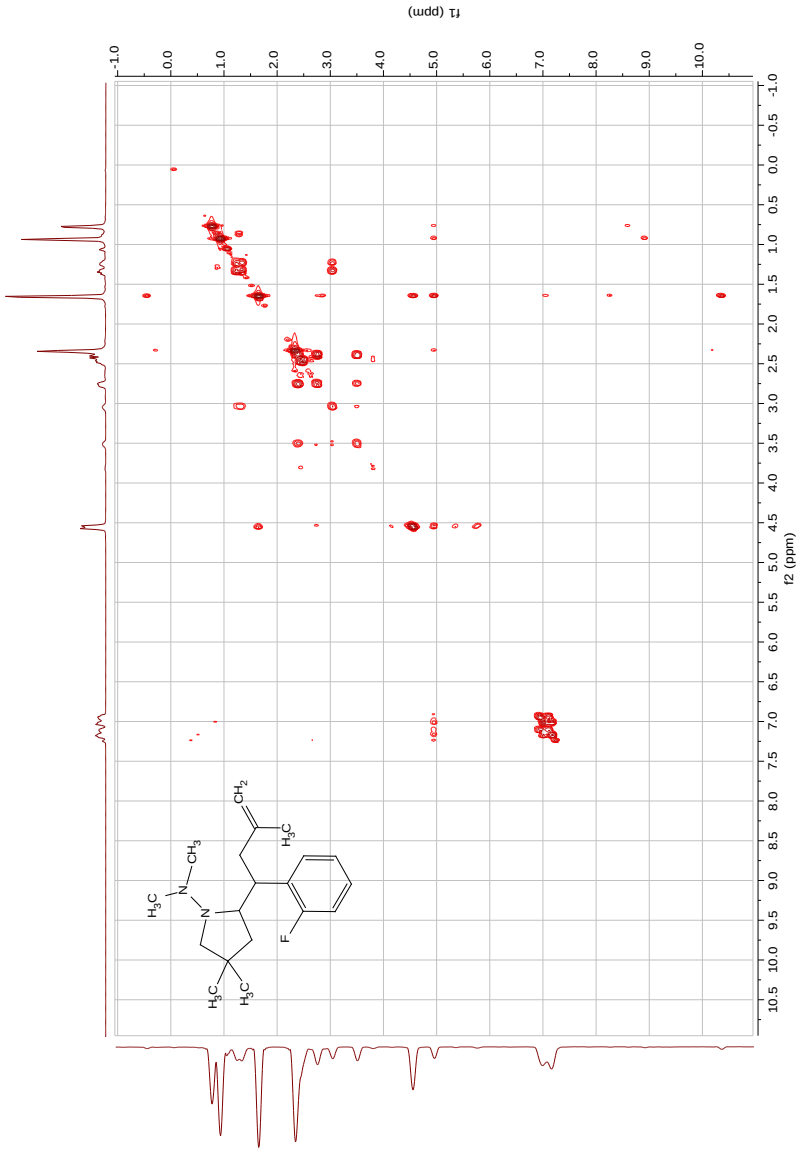

22.37
28.85
29.22
39.53
39.93
40.93
42.73
53.37
55.15
64.74
110.40
110.29
119.93
126.33
129.54
145.69
f1 (ppm)

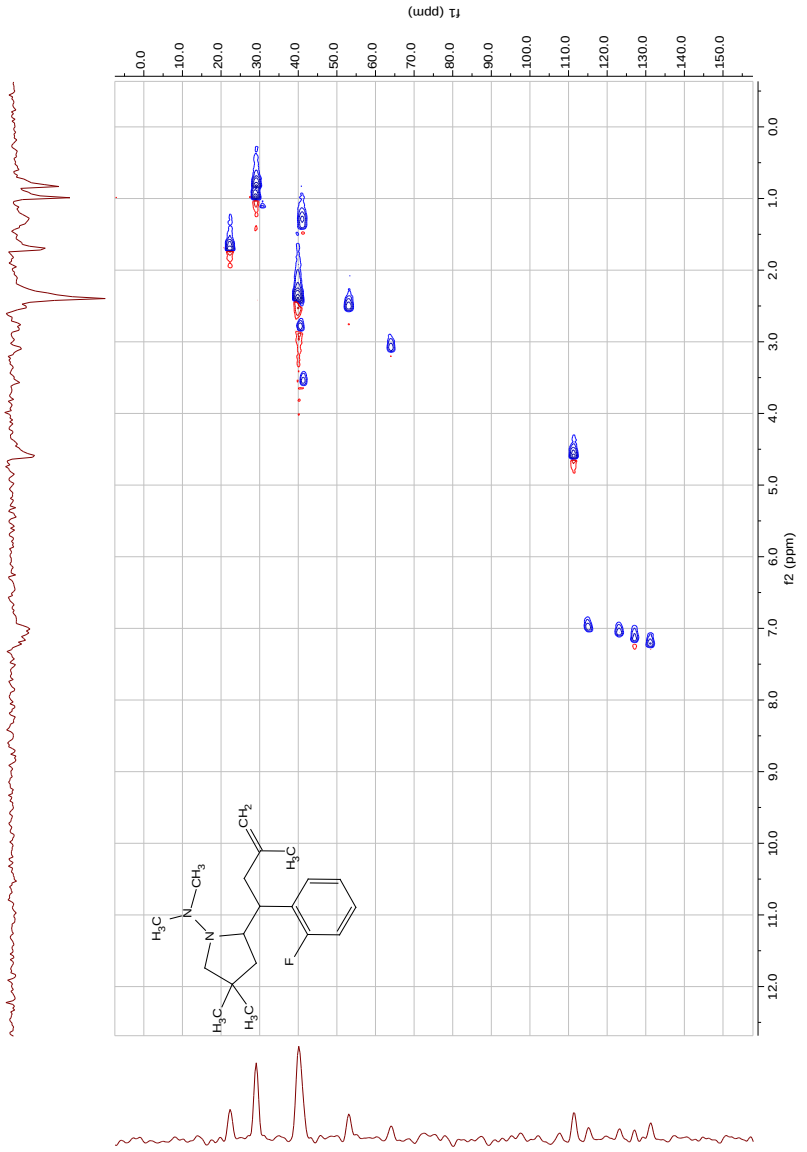

f1 (ppm)
3.13
3.03
1.23
1.15
3.22
6.06
0.94
0.98
1.07
2.06
0.99
1.00
1.02
1.09
1.14
2.10
H3C
N
CH3
H3C
N
CH2
H3C
Cl
H3C

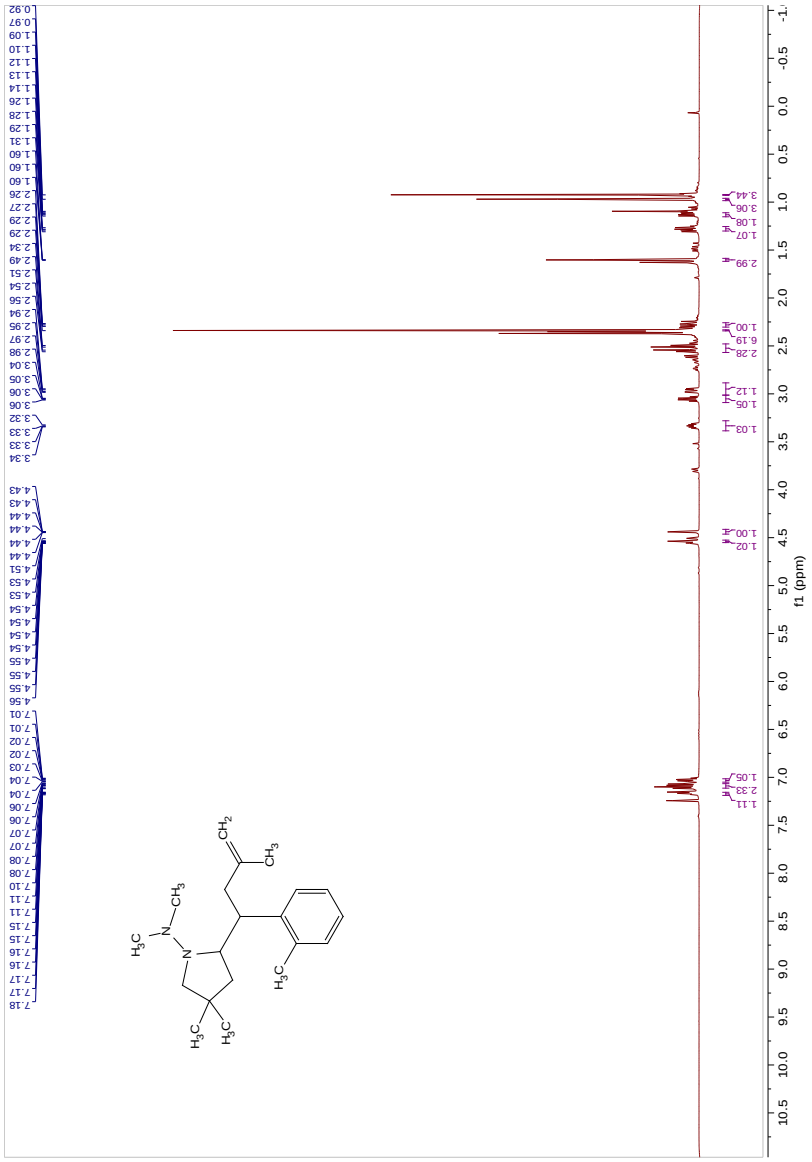

22.49
28.74
29.34
34.46
39.78
40.77
42.92
53.22
64.92
111.22
126.11
126.59
129.16
129.59
134.67
142.06
144.78
f1 (ppm)

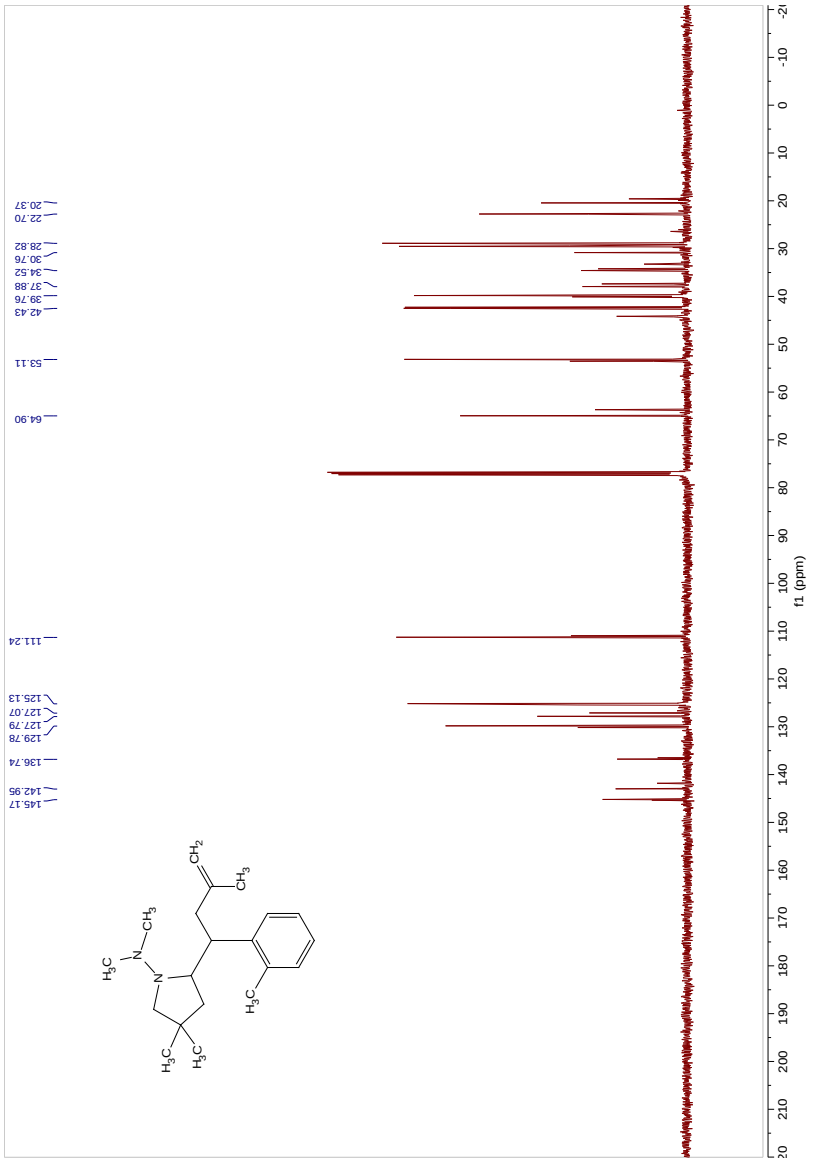

f1 (ppm)
H3C
CH3
N
N
H3C
H3C
CH2
H3C
F

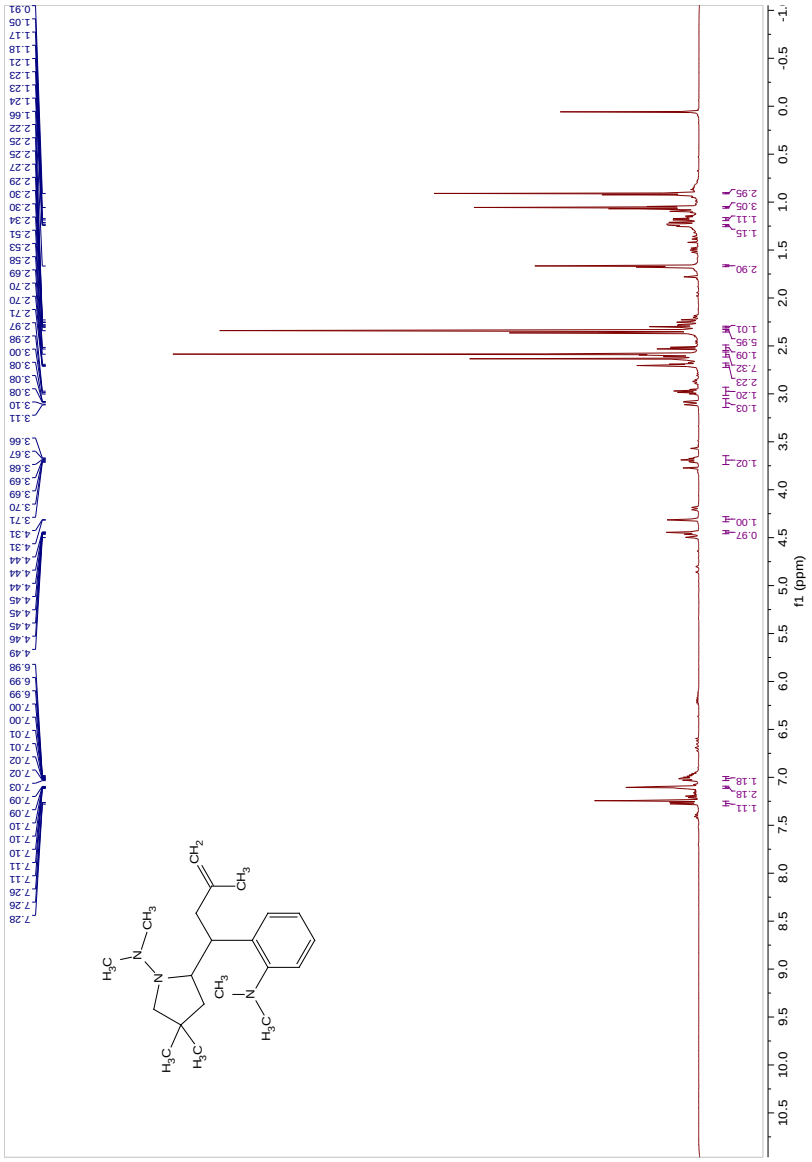

22.20
28.88
29.16
34.11
39.80
40.37
41.07
53.00
63.95
111.26
114.95
115.14
123.05
127.09
129.89
131.21
144.63
160.56
162.51
f1 (ppm)

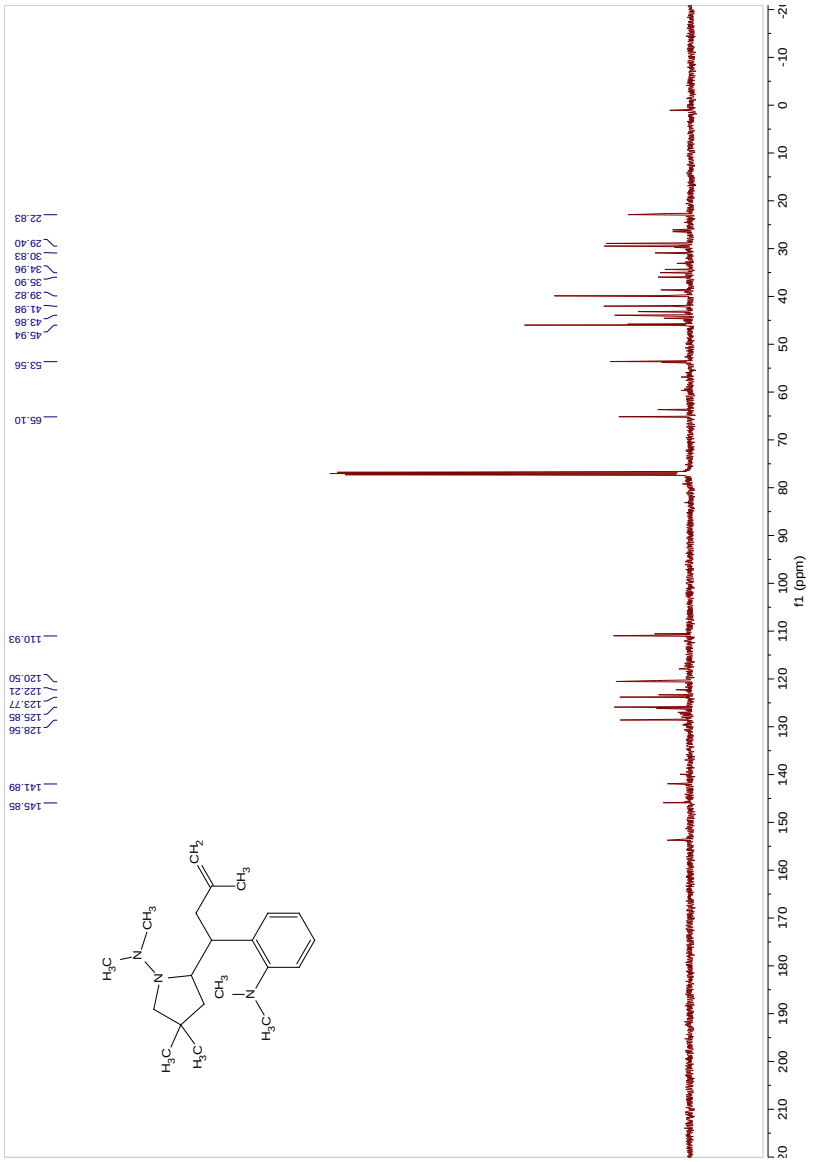

f1 (ppm)
f2 (ppm)
F
N
N
CH3
CH2
H3C
H3C
H3C
H3C

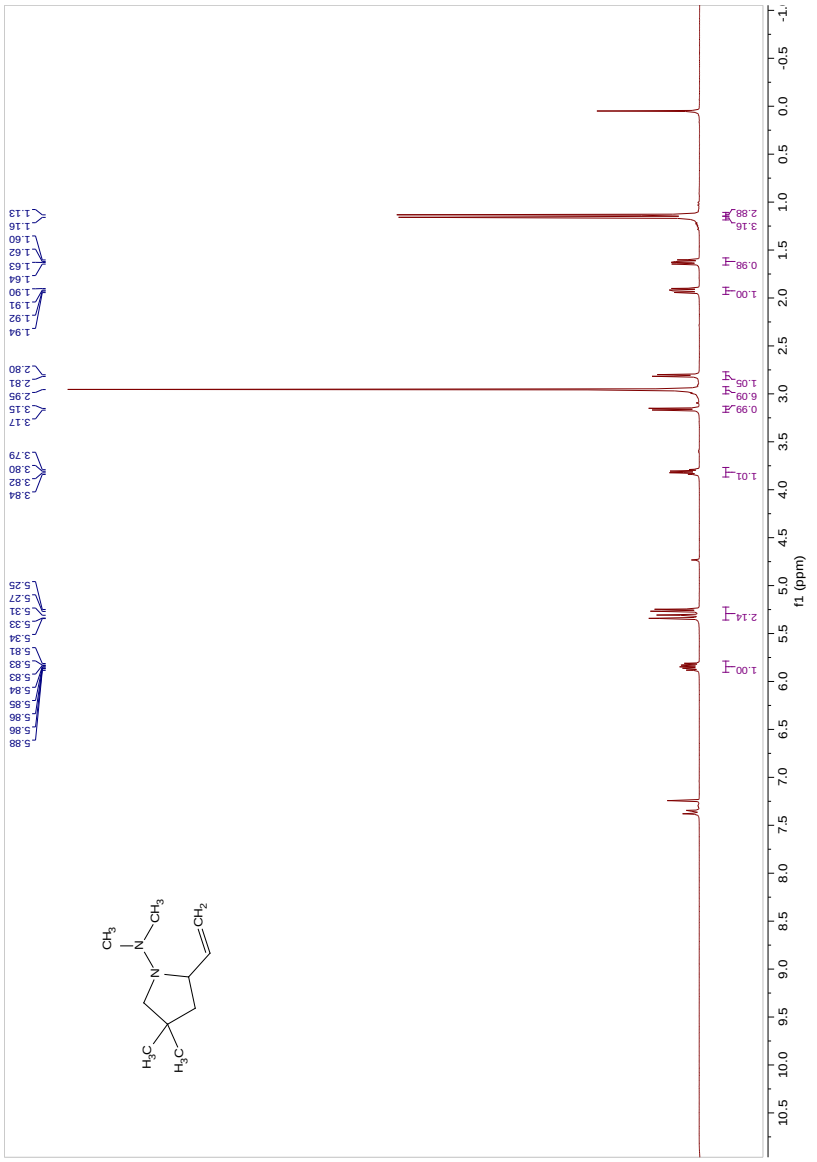

f1 (ppm)
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
110.0
120.0
130.0
140.0
150.0
f2 (ppm)
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
H3C
CH3
N
N
H3C
H3C
CH2
H3C
F

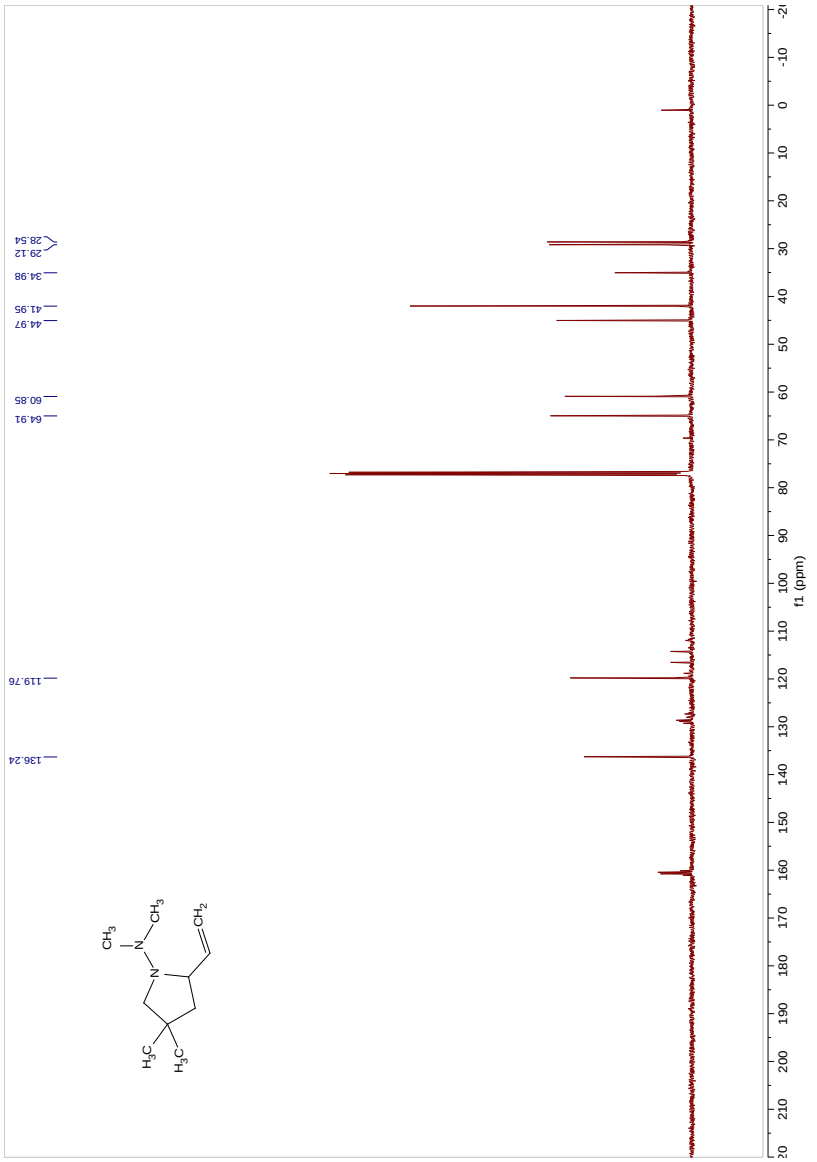

f1 (ppm)
CH2
CH3
H3C
N
CH3
H3C
H3C

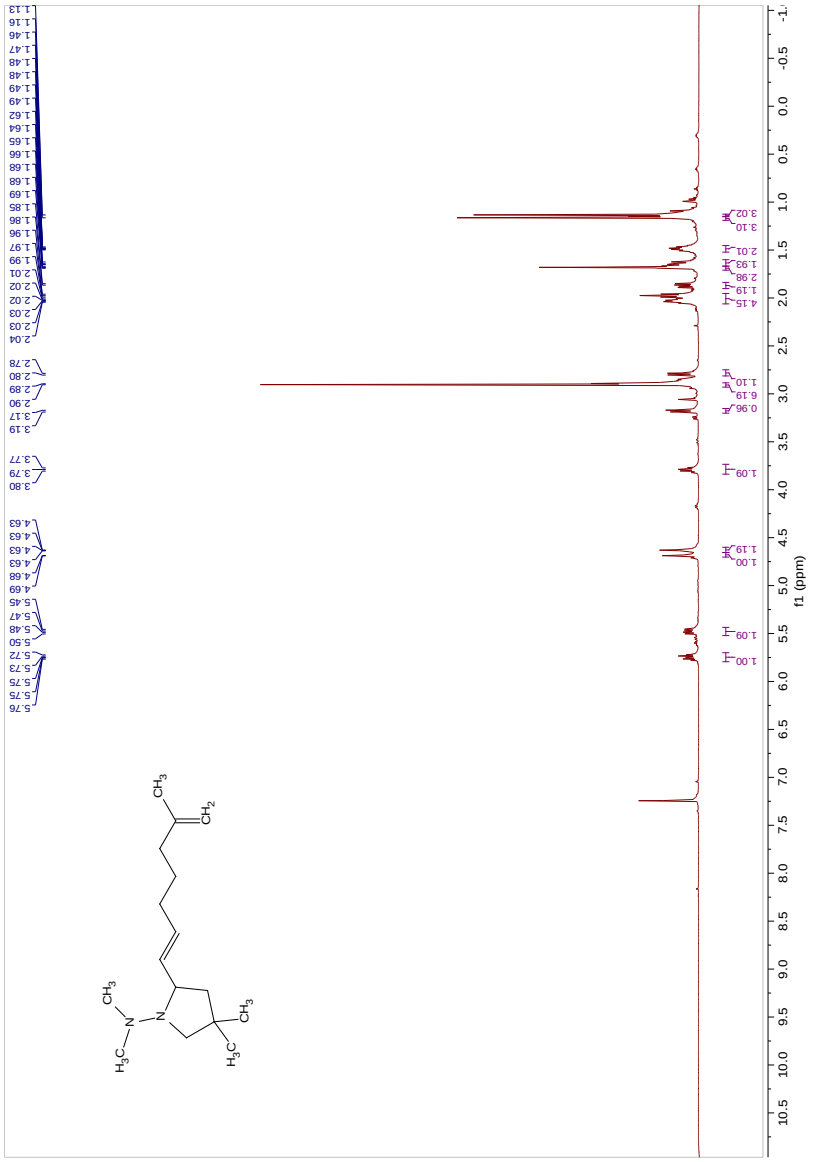

20.37
22.70
28.82
30.76
34.52
37.88
39.76
42.43
53.11
64.90
111.24
125.13
127.07
127.79
129.78
136.74
142.95
145.17
f1 (ppm)

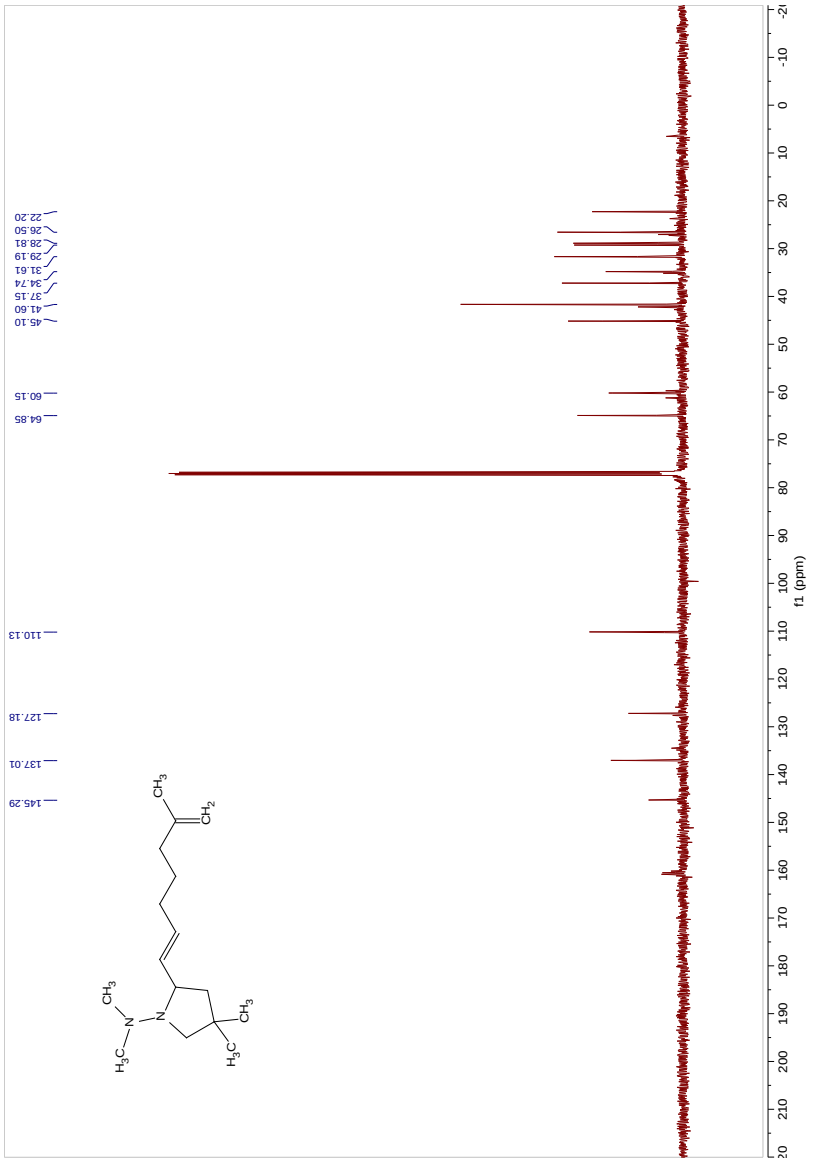

f1 (ppm)

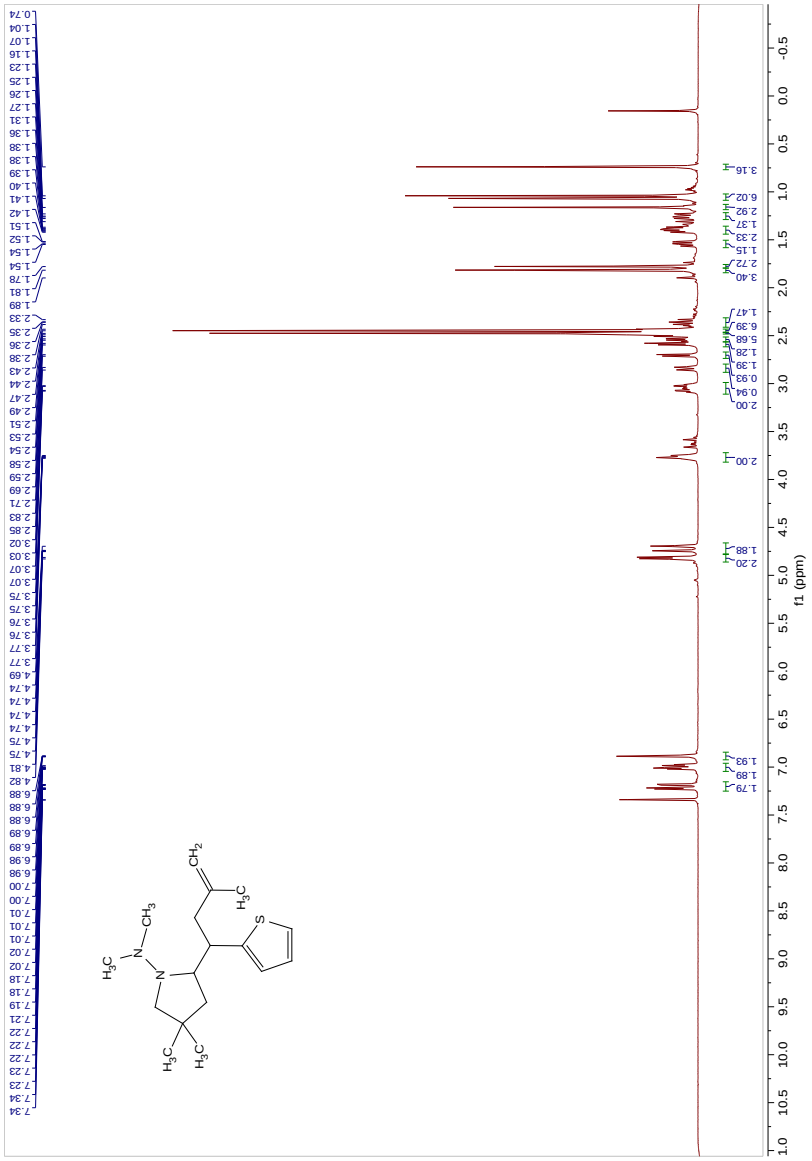

22.83
29.40
30.83
34.96
35.90
39.82
41.98
43.86
45.94
53.56
65.10
110.93
120.50
122.21
123.77
125.85
128.56
141.89
145.85
f1 (ppm)

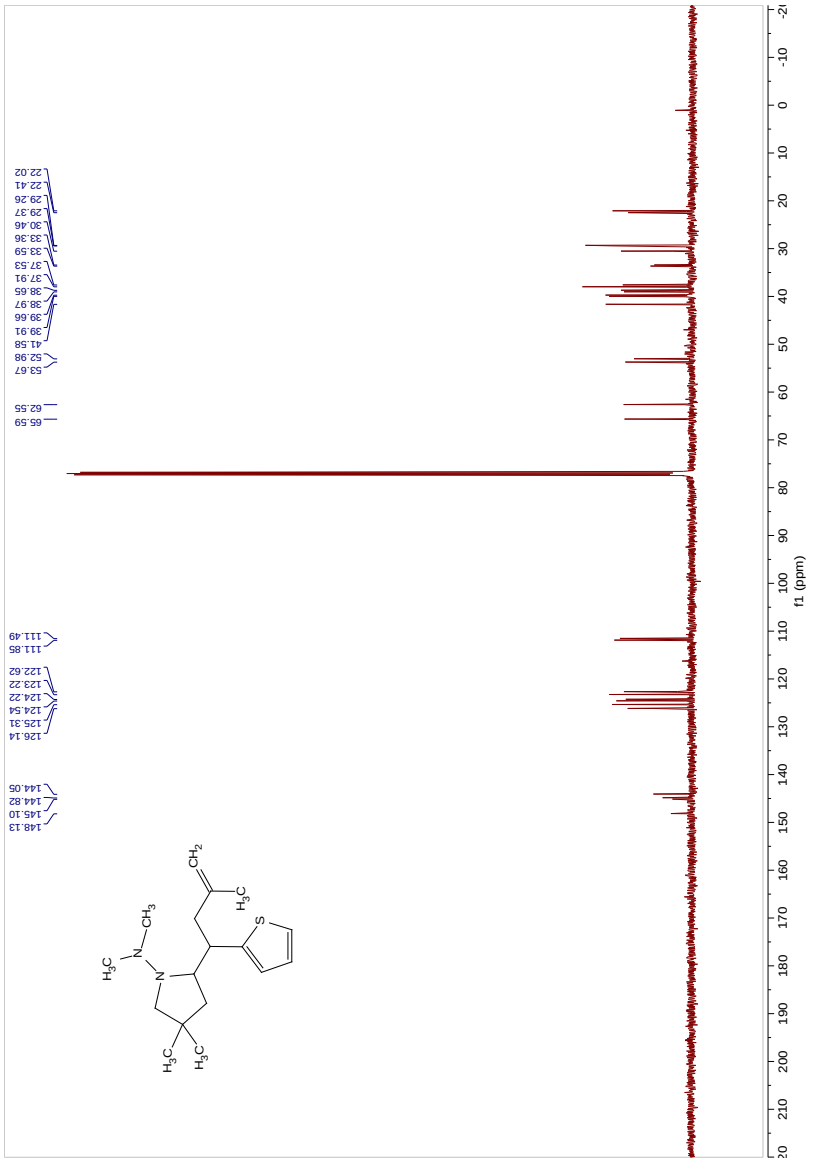

1.13
1.16
1.60
1.62
1.63
1.64
1.90
1.91
1.92
1.94
2.80
2.81
2.95
3.15
3.17
3.79
3.80
3.82
3.84
5.25
5.27
5.31
5.33
5.34
5.81
5.83
5.83
5.84
5.85
5.86
5.86
5.88
3.16
2.88
0.98
1.00
1.05
6.09
0.99
1.01
2.14
1.00
f1 (ppm)


28.54
29.12
34.98
41.95
44.97
60.85
64.91
119.76
136.24
f1 (ppm)


f1 (ppm)
CH3
CH2
N
N
CH3
H3C
CH3
H3C


22.20
26.50
28.81
29.19
31.61
34.74
37.15
41.60
45.10
60.15
64.85
110.13
127.18
137.01
145.29
f1 (ppm)


f1 (ppm)


22.02
22.41
29.26
29.37
30.46
33.36
33.59
37.53
37.91
38.65
38.97
39.66
39.91
41.58
52.98
53.67
62.55
65.59
111.49
111.85
122.62
123.22
124.22
124.54
125.31
126.14
144.05
144.82
145.10
148.13
f1 (ppm)