Chapter-5

Chemoselective deprotection of N-Allylic amines using DDQ
Chemoselective Deprotection of *N*-Allylic Amines using DDQ

5.1. Introduction

Protecting groups often play a crucial role in many complex synthetic strategies. The proper selection of efficient protecting groups, as well as the search of selective deprotection methodologies, still remains crucial issues in modern organic chemistry.¹ These processes are particularly relevant in the chemistry of amines since they generally constitute unavoidable steps in a great variety of organic transformations including the synthesis of natural products and other polyfunctional complex molecules.¹ In particular, among the plethora of alternatives, the use of allyl moieties for the protection of amines is becoming more and more popular as methods of amines into carbamates or to a lesser extent into amides. In contrast to classical protecting groups such as Boc (tert-butoxycarbonyl), FMOC (9-fluorenylemethyl carbamate), tosylamide *etc.*, allyl groups remain inert under both acidic and basic conditions. But as reported later on, they can be cleaved upon treatment with strong bases.²

5.2. Review of Literature

The *N*-deallylation methodologies can be roughly classified into two groups according to their mechanistic features.³ The methods belonging to the first group procedures are based on nucleophilic substitution reactions, where the amine unit 2 becomes a leaving group (Scheme 1, path A). The second group procedures are based on the isomerization of the allylamine into an enamine 4, which is subsequently cleaved upon acidic hydrolysis (Scheme 1, path B).

![Scheme 1: Strategies used for deprotection of *N*-allylamines](image_url)
Early reports demonstrated that allylamines can be isomerized into enamines upon treatment with strong bases. However, basic conditions are rather tough and generally cannot be used under catalytic conditions. The use of a stoichiometric amount of a strong base is incompatible with base-sensitive functional groups. Alternatively, the migration of the double bond can be performed under milder conditions involving transition metals catalysis (essentially Pd and Rh) or free-radical processes. Among the latter, new procedures involving Grubbs-type catalysts also have emerged. A few of them are reviewed.

**Caperelli et al. (1997)**

Caperelli et al. have used NaOH at 50 °C in DMSO to deprotect the N-crotylthymine moiety in a carbocyclic analog of 2-deoxyribonucleoside 6, where migration of the double bond occurs concomitantly to the hydrolysis of resulting enamines. The N-propargyl group can also be removed by refluxing in 1 N NaOH (Scheme 2).

**Charles et al. (1983)**

Charles et al. performed deallylation upon treatment with chloroformate providing a two-step procedure to release secondary amines. The first step leads to a carbamate 9, which is cleaved upon heating at reflux in methanol (Scheme 3). Vinyl and trichloroethyl chloroformates are among the best reagents for this purpose since their oxygenated moieties are very good leaving groups. It should be noted that N-debenzylation is faster under these experimental conditions than N-deallylation.
Guibé et al. (1993)\textsuperscript{10}

Guibé et al. has developed a very efficient method for the deprotection of monoallylamines and diallylamines based on a Pd(0) catalyst and $N,N$-dimethylbarbituric acid (NDMBA) (Scheme 4).\textsuperscript{10} The number of recorded examples suggests that this is probably the most efficient and widely employed procedure. It is also possible to cleave the $N$-allyl group selectively in the presence of an $\alpha$-branched allylic chain \textbf{14}. (Scheme 5)\textsuperscript{11}

\begin{center}
\begin{tikzpicture}
  \node (a) at (0,0) {\includegraphics[width=0.4\textwidth]{scheme_4.png}};
  \node[scale=0.8] at (2,-2) {Scheme 4};
\end{tikzpicture}
\end{center}

\begin{center}
\begin{tikzpicture}
  \node (a) at (0,0) {\includegraphics[width=0.4\textwidth]{scheme_5.png}};
  \node[scale=0.8] at (2,-2) {Scheme 5};
\end{tikzpicture}
\end{center}

Nagakura et al. (1997)\textsuperscript{12}

Nagakura et al. modified Pd(0) protocol by sulfinic acids or their salts have been used in the presence of a catalytic amount of [Pd(PPh$_3$)$_4$] (Scheme 6). This procedure is efficient to cleave both C–N and C–O allylic bonds.

\begin{center}
\begin{tikzpicture}
  \node (a) at (0,0) {\includegraphics[width=0.4\textwidth]{scheme_6.png}};
  \node[scale=0.8] at (2,-2) {Scheme 6};
\end{tikzpicture}
\end{center}
The procedure involving \([\text{Pd}(\text{PPh}_3)_4]\) in dichloromethane or in a THF/MeOH mixture in the presence of \(\text{ArSO}_2\text{Na}\) allows the cleavage of allyl, methallyl, crotyl, and cinnamyl ethers, and the cleavage of allyloxycarbonyl (alloc) derivatives and allyl esters as well.

**Chandrasekhar et al. (2001)**\(^{13}\)

Chandrasekhar et al. demonstrated that association of \([\text{Pd}(\text{PPh}_3)_4]\) with poly(methylhydrosiloxane) (PMHS) in the presence of \(\text{ZnCl}_2\) has cleaved allyl ethers, allyl esters, and allylamines. \(\text{N}-\text{Benzyl}, \text{N}-\text{Boc},\) and \(\text{N}-\text{Cbz}\) derivatives were found to be stable under these reaction conditions (Scheme 7).

![Scheme 7](image)

**Alcaide et al. (2001)**\(^7\)

Alcaide et al. have reported the catalytic deprotection of allylic amines by using Grubbs’ carbene. The deallylation mechanism involves ruthenium-catalyzed isomerization followed by hydrolysis of the enamine intermediate. The treatment of tertiary allylamine in the presence of 5 mol % \(\text{Cl}_2(\text{Cy}_3\text{P})_2\text{Ru=CHPh}\) in toluene at 110 °C for 3 h gave deallylated products (Scheme 8). Tertiary allylamines bearing a variety of substituents were smoothly deallylated by Grubbs' carbene to give the corresponding \(\text{N}\)-deprotected amines.

![Scheme 8](image)

**Hauzawa et al. (1993)**\(^{14}\)

Hauzawa et al. achieved the cleavage of \(\text{N}\)-Allylamines by treatment with one equivalent of zirconocene at room temperature (Scheme 9). Both allyl ethers and allylamines are cleaved
under these peculiar conditions, but since the rate constants for the two processes are quite different, it is possible to cleave the C–O bond selectively without breaking the C–N bond.

Davies et al. (2003)\textsuperscript{15}

Davies et al. have reported N-deallylation using Wilkinson’s catalyst in aqueous acetonitrile. This method is probably among the most frequently used because of its ability to differentiate between different protecting groups of amines. It is possible to deprotect the N-allyl group in the presence of an α-branched allylic chain and in the presence of N-benzyl nitrogen protecting groups (Scheme 10).

Marquet, et al.\textsuperscript{16} showed that in some cases, RhCl\textsubscript{3}·H\textsubscript{2}O, used under the same conditions as Wilkinson’s catalyst, leads to very good results, and this procedure has been claimed to be superior because of its better reproducibility (Scheme 11).
Ogasawara et al. (1998)\(^ {17}\)

Ogasawara et al. demonstrated the deprotection of a series of allylic tertiary amines, including aliphatic, benzylic, aromatic, and heteroaromatic compounds which is catalyzed by dichlorobis(diphenylphosphanyl) propane nickel \([\text{NiCl}_2(\text{dppp})]\) in the presence of DIBAL, at 0 °C in toluene (Scheme 12). It is worth noting that the reaction is chemoselective. The allyl group is removed selectively and the prenyl group is recovered unchanged.

![Scheme 12](image)

Meyer et al. (1999)\(^ {6d}\)

Meyer et al. employed the Birch reduction conditions to \(N\)-allylpyrrole derivatives for \(N\)-allyl deprotection (Scheme 13). It should be noted that \(O\)-allyl, \(O\)-benzyl, and \(N\)-benzyl derivatives are all cleaved under these conditions.

![Scheme 13](image)

Nayak et al. (2001)\(^ {6b}\)

Nayak et al. applied low-valent titanium (LVT) to amines to cleave C–N bonds by electron transfer. This methodology, which allows the allyl chain cleaved faster than the benzyl group under such conditions, although yields are moderate. Substantial improvement of the yield can be achieved by adding an inorganic salt such as KCl to the reaction medium (Scheme 14). The cleavage of allyl- and benzylationines is slower than the cleavage of the corresponding ethers.
Bertrand et al. (2002)\textsuperscript{6e}

Bertrand et al. reported a 1,3-hydrogen shift leading to an enamine by the thiyl radical. Subsequent hydrolytic treatment allows primary or secondary amines to be released. The reaction can be performed in the presence of either a stoichiometric or a catalytic amount of thiol. These conditions apply to allyl, crotyl, prenyl, and cinnamyl derivatives, although prenyl groups are cleaved slightly faster. The prenyl group can be removed selectively in the presence of \(\alpha\)-branched allylic groups (Scheme 15).

\[
\begin{align*}
\text{Ph} & \text{N} \quad \text{TiCl}_3\text{-Li-THF} \\
\text{Bn} & \quad \text{KCl, 60 °C} \\
\text{32} & \quad 18 \text{ h, 80\%} \\
\text{Ph} & \text{NH} \quad \text{Bn} \\
\text{33} & \end{align*}
\]

Scheme 14

5.3. Present work

Objective

2,3-Dichloro-5,6-dicyano-1,4-benzoquinone (DDQ)\textsuperscript{18} is a powerful oxidizing agent and has proved to be a versatile reagent for various synthetic organic transformations. Apart from its well-known applications as a dehydrogenating and oxidizing agent, in recent years it has found number of other applications including C–C, C–O and C–N bond-formation reactions and deprotection of various functional groups including cleavage of linker molecules from its solid support.\textsuperscript{19}
During one of our on-going project directed toward the asymmetric synthesis of natural products and derivatives of biological interest, we have observed a clean cleavage of $N$-allyl amine in compound 37 instead of expected PMB ether deprotection with DDQ in CH$_2$Cl$_2$-H$_2$O mixture (Scheme 16).

Armstrong et al. has reported a similar incident during their total synthesis of Motuporin (Nodularin-V). They observed that allylic NHBoc in 39 was converted to a ketone 40 during attempted PMB cleavage (Scheme 17).

A careful literature survey has revealed that DDQ has previously never been utilised effectively for $N$-deallylation of amines.

5.4. Results and Discussion

The choice of protecting groups is one of the decisive factors in the successful realization of a complex, demanding synthetic project. The protecting groups used influence the length and efficiency of the synthesis and are often responsible for its success or failure. The allyl moiety is a protecting group that permits orthogonal protection strategies with a wide range of protecting groups. It is readily removable and its compatibility with a range of other functional groups, the allyl protecting group has become established in protecting group
chemistry and is finding increasing application in the synthesis of complex natural products.\textsuperscript{23}

It is undeniable that transition-metal-catalyzed methods\textsuperscript{5} are the most widely admitted methods for allyl group deprotection. But selectivity can still be a problem, since $O$-allyl derivatives are cleaved faster than $N$-allyl derivatives in most cases. Reductive metals are not selective either.\textsuperscript{6} An important drawback of the $\pi$-allyl–palladium methodology is the requirement of stoichiometric amounts of a nucleophilic compound, which acts as the allyl group scavenger. Selectivity is also a problem with chloroformate-mediated processes\textsuperscript{9}, which are capable of cleaving different types of $N$–$C$ bonds. New procedures involving Grubbs-type catalysts are also emerged in recent years.\textsuperscript{7} But still selectivity remains the problem with these methods. Therefore we were interested in the development of an alternative $N$-deallylation method that can smoothly provide free amines.

The high oxidation potential ($E_0$) of 2,3-dichloro-5,6-dicyanobenzoquinone (DDQ) has resulted in the extensive use of this compound as a dehydrogenating agent in organic synthesis.\textsuperscript{24} Even though $O$-allyl ethers are oxidatively cleaved in the presence of DDQ\textsuperscript{25}, this reaction has not been developed further into a method of synthetic interest for the cleavage of $N$-allylic bonds.\textsuperscript{26} The examples of the quinone mediated oxidation of amines are limited. In general, primary and secondary aliphatic amines undergo nucleophilic displacement reactions with halogen-containing quinone oxidants, whereas aliphatic tertiary amines are known to react by way of a charge transfer complex to give enamines.\textsuperscript{27} Our studies shows that DDQ mediated $N$-deallylation of amine could be a promising methodology in organic synthesis. The mild cleavage condition broadens the synthetic applications of $N$-allyl amines and the high selectivity observed in the presence of other functionalities extends its utility as an orthogonal protecting group.

Our studies began with the reaction of a series of allyl substrates on aliphatic, alicyclic and benzylic amines. From the literature, we learned that $O$-allylic ethers are easily deprotected at room temperature by 1.2 equivalent of 2,3-dichloro-5,6-dicyanoquinone (DDQ) in a solvent mixture of $\text{CH}_2\text{Cl}_2$-$\text{H}_2\text{O}$ (9:1).\textsuperscript{25} This solvent system has an additional merit, that is, weakly acidic DDQH$_2$ (2,3-dichloro-5,6-dicyanohydroquinone) precipitated from the
solution as the reaction proceeded because DDQH₂ is almost insoluble in both dichloromethane and water, and the reaction medium was consequently kept almost neutral all through the reaction. This is sometimes very important in the case of substrates bearing acid-sensitive functional and protecting groups.

We performed the reactions choosing compound 41 as a model substrate (Scheme 18). The DDQ which recrystallized from toluene-hexane solvent mixture was used in all oxidative deallylation reactions. The reaction conditions we initially identified were mild (1.2 equiv DDQ, non-dried solvent, open to air and room temperature). DDQ was added to a solution of 41 in dichloromethane-water (9:1) (table 1, entry 1). and the resulting dark red solution stirred at room temperature overnight, during which time a pale yellow hydroquinone derivative was precipitated. The reaction proceeded without difficulty.

<table>
<thead>
<tr>
<th>Entry</th>
<th>Solvent system</th>
<th>DDQ (Equivalent)</th>
<th>Reaction time (hrs.)</th>
<th>Deprotection of 41 in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CH₂Cl₂-H₂O (9:1)</td>
<td>1.2</td>
<td>12</td>
<td>92</td>
</tr>
<tr>
<td>2</td>
<td>CH₂Cl₂-H₂O (97:3)</td>
<td>1.2</td>
<td>22</td>
<td>70</td>
</tr>
<tr>
<td>3</td>
<td>CH₂Cl₂</td>
<td>1.2</td>
<td>48</td>
<td>trace</td>
</tr>
<tr>
<td>4</td>
<td>Hexane-H₂O (9:1)</td>
<td>1.2</td>
<td>24</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>Dioxane-H₂O (9:1)</td>
<td>1.2</td>
<td>10</td>
<td>Complex mixture</td>
</tr>
<tr>
<td>6</td>
<td>THF-H₂O (9:1)</td>
<td>1.2</td>
<td>12</td>
<td>Complex mixture</td>
</tr>
<tr>
<td>7</td>
<td>Toluene-H₂O (9:1)</td>
<td>1.2</td>
<td>36</td>
<td>45</td>
</tr>
<tr>
<td>8</td>
<td>CHCl₃-H₂O (9:1)</td>
<td>1.2</td>
<td>24</td>
<td>60</td>
</tr>
<tr>
<td>9</td>
<td>EtOAc-H₂O (9:1)</td>
<td>1.2</td>
<td>12</td>
<td>Complex mixture</td>
</tr>
<tr>
<td>10</td>
<td>MeOH-H₂O (9:1)</td>
<td>1.2</td>
<td>6</td>
<td>Complex mixture</td>
</tr>
<tr>
<td>11</td>
<td>CCl₄-H₂O (9:1)</td>
<td>1.2</td>
<td>24</td>
<td>20</td>
</tr>
<tr>
<td>12</td>
<td>MeCN-H₂O (9:1)</td>
<td>1.2</td>
<td>14</td>
<td>85</td>
</tr>
</tbody>
</table>

Table 1: Oxidative cleavage of compound 41 with DDQ in various solvents at room temperature
The IR spectrum of 41 exhibits a characteristic sharp band of medium intensity at 1641 cm\(^{-1}\) (C=C stretching vibration). This band is useful for monitoring the deprotection reaction of \(N\)-allyl amine. It was found that correct work-up of the reactions was very important. The optimised procedure involved extraction with several portions of \(\text{CH}_2\text{Cl}_2\) and washing with saturated sodium bicarbonate solution, followed by loading the residual solution (after removal of the volatiles) directly onto a short basic alumina flash column, eluting with hexane–\(\text{CH}_2\text{Cl}_2\) afforded a nearly quantitative yield of \(N\)-deallylated secondary amines 42 (table 1, entry 1).

This reaction is only achieved in the presence of water. Decrease of the water ratio somewhat lowered the yields and increased the reaction time (table 1, entry 2). In the absence of water, most of compound 41 was recovered (table 1, entry 3). The reaction was studied in a variety of solvents and results are summarized in table 1. No desired deallylation product was observed when the reaction was carried out in hexane-water (table 1, entry 4). The reaction could proceed in THF, toluene, \(\text{CHCl}_3\), \(\text{MeOH}\), \(\text{CCl}_4\), \(\text{MeCN}\), \(\text{EtOAc}\) and dioxane (table 1, entries 5–12). However, considerable amounts of undesired products were formed in THF, \(\text{MeOH}\), \(\text{EtOAc}\) and dioxane (table 1, entries 5, 6, 9 and 10). The rate of the reaction became slower when \(\text{CHCl}_3\), \(\text{CCl}_4\) or toluene were used as the solvents (table 1, entries 7, 8 and 11). Interestingly, the speed and yield of the reaction in \(\text{MeCN}\) were comparable with those in \(\text{CH}_2\text{Cl}_2\) (table 1, entry 12). Based on the above investigations; \(\text{CH}_2\text{Cl}_2\) was preferred as the reaction media from the practical point of view.

A stoichiometric amount of DDQ would be sufficient for this oxidation, but the reactions progressed slowly, probably because of competitive aqueous decomposition of DDQ.\(^{19b}\) To circumvent this problem, the DDQ was added in small portions in every twenty minutes (3–4 portions) and this helped us to achieve high yields. Variation in the number of equivalents of DDQ was then assayed. Usually 20\% excess of DDQ brought about a large reduction in reaction time (table 2, entries 1 and 2). Starting material was reclaimed when less than 1 equivalent of DDQ was used (table 2, entry 3). When the concentration of the reaction mixture was examined between 0.4 and 0.02 M, the best combination of rate and ease of handling was found at 0.1 M of substrate. Attempt to conduct the reaction at lower
temperature than room temperature slow down the reaction considerably (table 2, entry 4). A further increase of temperature above room temperature did a significantly faster conversion, but the yield of deallylated amine was just a little lower (table 2, entry 5).

<table>
<thead>
<tr>
<th>Entry</th>
<th>Reaction conditions</th>
<th>Reaction time (hrs)</th>
<th>Deprotection of 41 in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.2 equiv. DDQ, CH₂Cl₂-H₂O (9:1) r.t.</td>
<td>12</td>
<td>92</td>
</tr>
<tr>
<td>2</td>
<td>1 equiv. DDQ, CH₂Cl₂-H₂O (9:1) r.t.</td>
<td>18</td>
<td>80</td>
</tr>
<tr>
<td>3</td>
<td>0.8 equiv. DDQ, CH₂Cl₂-H₂O (9:1) r.t.</td>
<td>20</td>
<td>45</td>
</tr>
<tr>
<td>4</td>
<td>1.2 equiv. DDQ, CH₂Cl₂-H₂O (9:1) 0 °C</td>
<td>24</td>
<td>35</td>
</tr>
<tr>
<td>5</td>
<td>1.2 equiv. DDQ, MeCN-H₂O (9:1) 70 °C</td>
<td>6</td>
<td>78</td>
</tr>
</tbody>
</table>

Table 2: Oxidative cleavage of compound 41 with DDQ in various reaction conditions

With the optimized reaction conditions established, various substrates were subjected to this deallylation reaction (Table 3). The reaction proceeded without any difficulty. Regardless of the aliphatic, alicyclic, or benzylic allyl amine substrates used to give the corresponding secondary amines in satisfactory yields with specific removal of the N-allyl group. During this study, N-benzyl (NBn), N-t-butyl carbamate (NBoc) and N-Tosylimide (NTs) groups were found to be stable to the reaction conditions (table 3, entries 1, 4, 9, 10, 11 and 14). Indeed, some selective deprotection of N-allyl group in the presence of N-PMB group could be achieved under certain conditions (table 3, entries 5, 6 and 7). Deallylation of N-Tosyl and N-Boc protected amine systems (table 3, entries 9, 10 and 11) required longer reaction time and higher equivalents of oxidant DDQ (1.5-2.5 equiv.). It has been observed that N-cinnamyl and N-prenyl systems (table 3, entries 13 and 14) deprotected much faster than N-allyl substrates. But cleavage of N- prpargyl amine 63 (table 3, entry 12) resulted a complex reaction mixture.
Table 3: Oxidative cleavage of various N-allyl amines with DDQ in CH₂Cl₂-H₂O (9:1) at room temperature

<table>
<thead>
<tr>
<th>Entry</th>
<th>Substrate</th>
<th>Product</th>
<th>Reaction time (hrs.)</th>
<th>% Yield</th>
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<td>18</td>
<td>85</td>
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<td>3</td>
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<td>18</td>
<td>90</td>
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<td>55</td>
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<td>Entry</td>
<td>Substrate</td>
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<td>% Yield</td>
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<td>-------</td>
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<td>Substrate</td>
<td>Product</td>
<td>Reaction time (hrs.)</td>
<td>% Yield</td>
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<tr>
<td>12</td>
<td><img src="image" alt="image" /> 63</td>
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<td><img src="image" alt="image" /> 46</td>
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<td>95</td>
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<td>17</td>
<td><img src="image" alt="image" /> 69</td>
<td><img src="image" alt="image" /> 66</td>
<td>48</td>
<td>A mixture of 66:67</td>
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</table>
Extrapolation of the deprotection of tertiary allyl amines to secondary allyl amines is not obvious. Even through secondary amine N-cinnamylcyclohexanamine 68 gave cyclohexanamine 67 in 65 % yields (table 3, entry 16), conversion of N-allylcyclohexanamine 66 to cyclohexanamine 67 under the same reaction condition was very slow (table 3, entry 15). When N,N-diallylcyclohexanamine 69 was treated under the same procedure (table 3, entry 17), we got a mixture of compounds 66:67 even after 2 days, suggesting that secondary N-allylamines would require stronger reaction conditions to be cleaved.

Mechanism of the reaction is not very clear to us. Mechanistically, the oxidation/deprotection N-allyl amine with DDQ must follow the same pathway as that involved in the cleavage of prenyl ethers, cinnamyl ethers or OPMB, which has been well studied. A possible mechanism is shown in Scheme 19.

![Scheme 19](image)

The reaction must proceed by hydride abstraction from the activated methylene of 70 by DDQ followed by trapping the iminium ion 72 by water giving a hemiaminal 73 which decomposes to give a 2° amine, DDQH₂ and acrylaldehyde 75. A heteroatom such as nitrogen, oxygen, or sulfur atom located at the α-position activates the adjacent allylic sp³ C-H bond and further stabilizes the in situ formed intermediate.

The oxidative cation formation appears to proceed (Scheme 19) through a sequence of radical cation formation followed by hydrogen atom abstraction. DDQ is a well-known electron acceptor and forms charge transfer (CT) complexes with a variety of donors. When a solution of N-allyl amine was combined with DDQ, we usually observed a immediate colour changes in reaction mixture that is likely a charge-transfer complex formation.
Even through DDQ is a mild and efficient oxidant, it has some disadvantage like removal of its by-product (2,3-dichloro-5,6-dicyanohydroquinone-DDQH₂) is sometimes cumbersome. In order to overcome these difficulties, Sharma et al. have reported a method for regeneration of DDQ using Mn(OAc)₃ as reoxidant.³¹. We tested this method during the cleavage of compound 41, but failed to see any initial promising result.

The preparation of tert-N-allyl amines derivatives used in this study deserves some comment. As previously reported in the literature³², the direct allylation of the amino group with allyl bromide in the presence of a base (diisopropylamine in toluene, NaH in THF or K₂CO₃ in MeCN) afforded most of tert-N-allyl amines.

5.5. Conclusion

The use of DDQ in dichloromethane–water provides a mild and efficient one-step deallylation of tertiary N-allyl amines. The new method is well suited to selective deprotection of a wide variety of orthogonally protected tertiary amine derivatives, and its application permits novel manipulation of more complex allyl protecting groups. Application of the present method to secondary amines and use of catalytic amount of DDQ in reactions are currently underway in our group.

5.6. Experimental Section

**General Experimental Procedure for the Oxidative Cleavage of N-allyl amine:**

To a stirred solution of the N-allyl amine (1 mmol) dissolved in 9 mL of CH₂Cl₂ and 1 mL of water, DDQ (1.2 equiv.) were added intermittently in 3-4 portions. Reaction progress was monitored by TLC. Upon consumption of the N-allyl amine, 2,3-dichloro-5,6-dicyanohydroquinone/DDQH₂ was filtered. A saturated NaHCO₃ solution was added to the filtrate and the aqueous phase was extracted twice with CH₂Cl₂. Drying over Na₂SO₄, evaporation to dryness gave a material that was purified by flash column chromatography using neutral or basic Alumina as stationary phase and petroleum ether–CH₂Cl₂ as eluent. The compounds were characterized by comparison with authentic samples and by spectral data.
Chapter 5

N-Allyl-N-benzyl-1-((4-methoxybenzyl)oxy)-1-phenylpent-4-en-2-amine (37)

\[
\begin{align*}
\text{Mol. Formula: } & \text{C}_{29}\text{H}_{33}\text{NO}_2 \\
\text{IR (CHCl}_3, \text{cm}^{-1}): & \nu_{\text{max}} 3069, 3029, 3003, 2956, 2933, 1676, 1642, 1598, 1500, 1460, 1246, 1036, 818. \\
\text{H NMR (200 MHz, CDCl}_3): & \delta 2.36-2.44 (m, 2H), 3.04-3.16 (m, 2H), 3.30-3.37 (m, 1H), 3.60 (s, 2H), 3.86 (s, 3H), 4.25-4.33 (m, 1H), 4.67 (s, 2H), 4.98-5.13 (m, 4H), 5.63-5.87 (m, 2H), 6.91-6.95 (d, J=8.7 Hz, 2H), 7.19-7.42 (m, 12H) ppm. \\
\text{C NMR (50 MHz, CDCl}_3): & \delta 30.5, 53.3, 54.1, 55.0, 63.6, 70.1, 80.5, 113.6, 115.1, 116.2, 126.4, 127.0, 127.1, 127.8, 128.0, 128.5, 129.3, 130.3, 137.6, 138.2, 140.4, 141.3, 159.0 ppm. \\
\text{Analysis Calcd.:} & \text{C, 81.46; H, 7.78; N, 3.28; Found: C, 81.45; H, 7.73; N, 3.26.}
\end{align*}
\]

N-Benzyl-1-((4-methoxybenzyl)oxy)-1-phenylpent-4-en-2-amine (38)

\[
\begin{align*}
\text{Yield: } & 78\% \\
\text{Mol. Formula: } & \text{C}_{26}\text{H}_{29}\text{NO}_2 \\
\text{IR (CHCl}_3, \text{cm}^{-1}): & \nu_{\text{max}} 3439, 3067, 3025, 3001, 2954, 2933, 1676, 1597, 1503, 1464, 1249, 1136, 816. \\
\text{H NMR (200 MHz, CDCl}_3): & \delta 2.23-2.43 (m, 2H), 2.89 (brs, 1H), 3.58-3.60 (m, 1H), 3.73 (s, 2H), 3.81 (s, 3H), 4.20-4.26 (m, 1H), 4.48 (s, 2H), 5.04-5.12 (m, 2H), 5.72-5.92 (m, 1H), 6.85-6.90 (d, J=8.7 Hz, 2H), 7.16-7.38 (m, 12H) ppm. \\
\text{C NMR (50 MHz, CDCl}_3): & \delta 33.6, 50.9, 55.2, 61.1, 70.4, 81.4, 113.7, 117.4, 127.2, 127.6, 127.8, 128.3, 128.5, 129.5, 129.6, 130.3, 135.5, 139.4, 159.2 ppm. \\
\text{Analysis Calcd.:} & \text{C, 80.59; H, 7.54; N, 3.61; Found: C, 80.58; H, 7.51; N, 3.58.}
\end{align*}
\]
**N-allyl-N-benzylcyclohexanamine (41)**

![Chemical Structure](image)

**Mol. Formula:** C\textsubscript{16}H\textsubscript{23}N

**IR** (CHCl\textsubscript{3}, cm\textsuperscript{-1}): \( \nu_{\text{max}} 3081, 3063, 2928, 2853, 1641, 1602, 1493, 1450, 1416, 1263, 1122, 915, 735, 697. 

**\(^1\text{H NMR}\)** (200 MHz, CDCl\textsubscript{3}): \( \delta 1.16-1.36 \text{ (m, 5H)}, 1.64-1.77 \text{ (m, 1H)}, 1.82-1.87 \text{ (m, 4H)}, 2.55-2.59 \text{ (m, 1H)}, 3.11-3.15 \text{ (dt, } J = 6.1, 1.3 \text{ Hz, 2H)}, 3.63 \text{ (s, 2H)}, 5.07-5.21 \text{ (m, 2H)}, 5.77-5.93 \text{ (ddt, } J = 17.2, 10.1, 6.1 \text{ Hz, 1H)}, 7.24-7.39 \text{ (m, 5H) ppm.}

**\(^{13}\text{C NMR}\)** (50 MHz, CDCl\textsubscript{3}): \( \delta 26.1, 26.4, 28.9, 53.0, 53.5, 58.6, 115.8, 126.3, 127.9, 128.3, 137.7, 141.3 \text{ ppm.}

**Analysis:** Calcd.: C, 83.79; H, 10.11; N, 6.11; Found: C, 83.71; H, 10.14; N, 6.09.

**N-benzylcyclohexanamine (42)**

![Chemical Structure](image)

**Yield:** 92%

**Mol. Formula:** C\textsubscript{13}H\textsubscript{19}N

**IR** (CHCl\textsubscript{3}, cm\textsuperscript{-1}): \( \nu_{\text{max}} 3435, 3071, 3065, 2980, 2933, 2854, 1580, 1455, 1372, 1264, 1212, 1119, 758. 

**\(^1\text{H NMR}\)** (200 MHz, CDCl\textsubscript{3}): \( \delta 1.10-1.23 \text{ (m, 5H)}, 1.57-1.60 \text{ (m, 1H)}, 1.69-1.72 \text{ (m, 2H)}, 1.89-1.92 \text{ (d, } J = 11.8 \text{ Hz, 2H)}, 2.17 \text{ (brs, 1H)}, 2.46-2.50 \text{ (m, 1H)}, 3.79 \text{ (s, 2H)}, 7.21-7.23 \text{ (m, 1H)}, 7.27-7.30 \text{ (m, 4H) ppm.}

**\(^{13}\text{C NMR}\)** (50 MHz, CDCl\textsubscript{3}): \( \delta 24.9, 26.0, 33.2, 50.7, 56.0, 126.8, 128.1, 128.3, 140.3 \text{ ppm.}

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Analysis: **Calcd.**: C, 82.48; H, 10.12; N, 7.40; **Found**: C, 82.58; H, 10.11; N, 7.38.

**N-ALLYL-N-PENTYLCYCLOHEXANAMINE (43)**

![Chemical Structure](image)

**Mol. Formula**: C\textsubscript{14}H\textsubscript{27}N

**IR** (CHCl\textsubscript{3}, cm\textsuperscript{-1}): \( \nu_{\text{max}} \) 2931, 2857, 2796, 1640, 1444, 1384, 1271, 1114, 989, 891.

**\(^1\text{H NMR}\)** (200 MHz, CDCl\textsubscript{3}): \( \delta \) 0.88-0.92 (m, 3H), 1.13-1.39 (m, 9H), 1.66-1.75 (m, 4H), 1.99-2.03 (m, 3H), 2.44-2.54 (m, 1H), 2.92 (br, 2H), 3.01-3.04 (d, \( J=6.1 \) Hz, 2H), 5.00-5.16 (m, 1H), 5.24-5.31 (t, \( J=7.1 \) Hz, 1H), 5.70-5.90 (m, 1H) ppm.

**\(^{13}\text{C NMR}\)** (50 MHz, CDCl\textsubscript{3}): \( \delta \) 14.0, 22.3, 26.3, 27.3, 28.6, 30.4, 32.2, 52.5, 55.8, 57.9, 115.2, 138.0 ppm.

Analysis **Calcd.**: C, 80.31; H, 13.00; N, 6.69; **Found**: C, 80.29; H, 13.07; N, 6.65.

**N-PENTYLCYCLOHEXANAMINE (44)**

![Chemical Structure](image)

**Yield**: 85%

**Mol. Formula**: C\textsubscript{11}H\textsubscript{23}N

**IR** (CHCl\textsubscript{3}, cm\textsuperscript{-1}): \( \nu_{\text{max}} \) 3567, 2932, 2853, 2798, 1444, 1384, 1275, 1124, 889.

**\(^1\text{H NMR}\)** (200 MHz, CDCl\textsubscript{3}): \( \delta \) 0.83-0.91 (m, 3H), 1.11-1.15 (m, 4H), 1.29-1.33 (m, 5H), 1.73-1.97 (m, 4H), 2.00-2.04 (m, 3H), 2.43-2.52 (m, 1H), 2.99-3.02 (m, 2H), 3.86 (brs, 1H) ppm.

**\(^{13}\text{C NMR}\)** (50 MHz, CDCl\textsubscript{3}): \( \delta \) 13.6, 21.7, 25.6, 25.9, 28.7, 29.7, 30.7, 31.5, 49.5, 54.4 ppm.
Analysis Calcd.: C, 78.03; H, 13.69; N, 8.27; Found: C, 78.08; H, 13.61; N, 8.34.

N- Allyl-N-cyclohexylcyclohexanamine (45)

Mol. Formula: C_{15}H_{27}N

IR (CHCl₃, cm⁻¹): ν_max 2929, 2853, 2712, 2666, 1729, 1625, 1449, 1271, 1116, 912, 756.

¹H NMR (200 MHz, CDCl₃): δ 1.03-1.06 (m, 2H), 1.15-1.25 (m, 8H), 1.56-1.59 (br, 2H), 1.69-1.74 (m, 8H), 2.52-2.57 (m, 2H), 3.18-3.20 (d, J=5.8 Hz, 2H), 4.95-4.98 (d, J=10.1 Hz, 1H), 5.10-5.15 (dd, J=17.1, 1.8 Hz, 1H), 5.77-5.85 (m, 1H) ppm.

¹³C NMR (50 MHz, CDCl₃): δ 26.2, 26.3, 31.7, 49.2, 57.6, 114.2, 140.4 ppm.

Analysis Calcd.: C, 81.38; H, 12.29; N, 6.33; Found: 81.33; H, 12.31; N, 6.35.

Dicyclohexylamine (46)

Yield: 90%

Mol. Formula: C_{12}H_{23}N

IR (CHCl₃, cm⁻¹): ν_max 3357, 2928, 2853, 2713, 1728, 1605, 1578, 1449, 1295, 1159, 758.

¹H NMR (200 MHz, CDCl₃): δ 1.09-1.24 (m, 10H), 1.58-1.71 (m, 3H), 1.73-1.74 (m, 4H), 1.87-1.90 (m, 3H), 2.59-2.65 (m, 2H), 3.75 (brs, 1H) ppm.

¹³C NMR (50 MHz, CDCl₃): δ 26.7, 26.3, 34.8, 52.8 ppm.
Chapter 5

\[ N\text{-Allyl-N-(4-methylbenzyl)cyclohexanamine (47)} \]

\[
\begin{align*}
\text{Mol. Formula: } & C_{17}H_{25}N \\
\text{IR } (\text{CHCl}_3, \text{ cm}^{-1}): & \nu_{\text{max}} 3021, 2937, 2851, 1738, 1644, 1601, 1483, 1457, 1416, 1278, 913. \\
\text{\textsuperscript{1}H NMR } (200 MHz, \text{CDCl}_3): & 1.14-1.35 (m, 5H), 1.63-1.68 (m, 1H), 1.80-1.90 (m, 4H), 2.38 (s, 3H), 2.56-2.63 (m, 1H), 3.15-3.18 (d, \textit{J}=6.1 \text{ Hz}, 2\text{H}), 3.63 (s, 2\text{H}), 5.06-5.12 (dd, \textit{J}=10.1, 1.9 \text{ Hz}, 1\text{H}), 5.16-5.25 (dd, \textit{J}=17.2, 1.8 \text{ Hz}, 1\text{H}), 5.87-5.97 (m, 1\text{H}), 7.13-7.17 (d, \textit{J}=7.6 \text{ Hz}, 2\text{H}), 7.27-7.31 (d, \textit{J}=7.6 \text{ Hz}, 2\text{H}) \text{ ppm}. \\
\text{\textsuperscript{13}C NMR } (50 MHz, \text{CDCl}_3): & \delta 21.0, 26.1, 26.4, 28.9, 52.9, 53.2, 58.5, 115.7, 128.2, 128.7, 135.8, 137.9, 138.2 \text{ ppm}. \\
\text{Analysis Calcd.: } & C, 83.89; H, 10.35; N, 5.75; \textbf{Found: } C, 83.84; H, 10.36; N, 5.81. \\
\end{align*}
\]

\[ N\text{-}(4\text{-Methylbenzyl)cyclohexanamine (48)} \]

\[
\begin{align*}
\text{Yield: } & 80\% \\
\text{Mol. Formula: } & C_{14}H_{21}N \\
\text{IR } (\text{CHCl}_3, \text{ cm}^{-1}): & \nu_{\text{max}} 3498, 3022, 2939, 2856, 1739, 1601, 1489, 1434, 1415, 1271, 1135, 945. \\
\text{\textsuperscript{1}H NMR } (200 MHz, \text{CDCl}_3): & \delta 1.09-1.28 (m, 4\text{H}), 1.73-1.78 (m, 2\text{H}), 1.89-1.94 (m, 4\text{H}), 2.35 (s, 3\text{H}), 2.42-2.56 (m, 1\text{H}), 3.77 (s, 2\text{H}), 4.63 (s, 1\text{H}), 7.12-7.24 (m, 4\text{H}) \text{ ppm}. \\
\end{align*}
\]
$^{13}$C NMR (50 MHz, CDCl$_3$): $\delta$ 20.9, 24.8, 26.0, 33.2, 50.4, 55.8, 127.9, 128.9, 136.2, 137.4 ppm.

Analysis Calcd.: C, 82.70; H, 10.41; N, 6.89; Found: C, 82.72; H, 10.45; N, 6.81.

$N$-Allyl-$N$-(4-methoxybenzyl)cyclohexanamine (49)

![Structure of 49](image)

Mol. Formula: C$_{17}$H$_{25}$NO

IR (CHCl$_3$, cm$^{-1}$): $\nu_{\text{max}}$ 3073, 3002, 2929, 2853, 1699, 1640, 1611, 1509, 1450, 1246, 1167, 1038, 913, 817, 758

$^1$H NMR (200 MHz, CDCl$_3$): $\delta$ 1.07-1.27 (m, 5H), 1.56-1.61 (m, 1H), 1.73-1.82 (m, 4H), 2.48-2.53 (m, 1H), 3.06-3.10 (dt, $J$=6.1, 1.3 Hz, 2H), 3.53 (s, 2H), 3.77 (s, 3H), 4.99-5.05 (ddt, $J$=10.1, 2.2, 1.2 Hz, 1H), 5.08-5.17 (m, 1H), 5.73-5.89 (ddt, $J$= 16.9, 10.4, 6.2 Hz, 1H), 6.79-6.84 (d, $J$=8.7 Hz, 2H), 7.21-7.26 (m, 2H) ppm.

$^{13}$C NMR (50 MHz, CDCl$_3$): $\delta$ 26.0, 26.4, 28.8, 52.8(2C) 55.0, 58.4, 113.3, 115.7, 129.3, 133.0, 137.7, 158.2 ppm.

Analysis Calcd.: C, 78.72; H, 9.71; N, 5.40; Found: C, 78.75; H, 9.70; N, 5.34.

$N$-(4-Methoxybenzyl)cyclohexanamine (50)

![Structure of 50](image)

Yield: 55%

Mol. Formula: C$_{14}$H$_{21}$NO
**IR (CHCl₃, cm⁻¹):** ν max 3435, 3073, 3001, 2931, 2854, 1700, 1612, 1508, 1450, 1245, 1169, 1037, 819, 753.

**¹H NMR (200 MHz, CDCl₃):** δ 0.97-1.26 (m, 5H), 1.35-1.42 (m, 1H), 1.52-1.80 (m, 4H), 2.44-2.56 (m, 1H), 3.52 (s, 2H), 3.73 (s, 3H), 4.16 (brs, 1H), 6.75-6.80 (d, J= 8.6 Hz, 2H), 7.20-7.23 (m, 2H) ppm.

**¹³C NMR (50 MHz, CDCl₃):** δ 23.2, 25.5, 29.6, 49.9, 55.6, 57.5, 112.9, 126.5, 130.2, 157.8 ppm.

**Analysis Calcd.:** C, 76.67; H, 9.65; N, 6.39; **Found:** C, 76.66; H, 9.61; N, 6.40.

---

**N-Allyl-N-(4-methoxybenzyl)hexadecan-1-amine (51)**

![Chemical structure](attachment:image.png)

**Mol. Formula:** C₂₇H₄₇NO

**IR (CHCl₃, cm⁻¹):** ν max 3073, 2975, 2853, 1728, 1642, 1612, 1511, 1645, 1248, 1170, 1039, 914, 818, 759.

**¹H NMR (200 MHz, CDCl₃):** δ 0.86-0.92 (m, 3H), 1.17-1.34 (m, 28H), 2.36-2.44 (m, 2H), 3.04-3.07 (d, J= 6.3 Hz, 2H), 3.51 (s, 2H), 3.81 (s, 3H), 5.11-5.22 (m, 2H), 5.82-5.96 (ddt, J= 17, 10.3, 6.4 Hz, 1H), 6.83-6.87 (m, 2H), 7.22-7.27 (m, 2H) ppm.

**¹³C NMR (50 MHz, CDCl₃):** δ 14.0, 22.6, 26.9, 27.3, 29.3, 29.5, 29.6, 31.9, 53.2, 55.1, 56.5, 57.2, 113.4, 116.9, 129.9, 131.6, 136.1, 158.4 ppm.

**Analysis Calcd.:** C, 80.74; H, 11.79; N, 3.49; **Found:** C, 80.69; H, 11.77; N, 3.5.
**N-(4-Methoxybenzyl)hexadecan-1-amine (52)**

![Chemical Structure](image)

**Yield:** 50%

**Mol. Formula:** C\textsubscript{24}H\textsubscript{43}NO

**IR (CHCl\textsubscript{3}, cm\textsuperscript{-1}):** ν\textsubscript{max} 3478, 3071, 2975, 2852, 1728, 1612, 1511, 1645, 1248, 1171, 1039, 817, 760.

**\textsuperscript{1}H NMR (200 MHz, CDCl\textsubscript{3}):** δ 0.87-0.93 (m, 3H), 1.37-1.35 (m, 29H), 2.49-2.57 (m, 2H), 3.61(s, 2H), 3.82 (s, 3H), 6.84-6.88 (m, 2H), 7.23-7.28 (m, 2H) ppm.

**\textsuperscript{13}C NMR (50 MHz, CDCl\textsubscript{3}):** δ 12.3, 20.9, 25.1, 25.6, 27.6, 27.8, 27.9, 30.2, 51.5, 53.4, 55.5, 111.7, 128.2, 129.9, 156.7 ppm.

**Analysis Calcd.:** C, 79.72; H, 11.99; N, 3.87; **Found:** C, 79.74; H, 11.95; N, 3.92.

**N-Allyl-N-(4-methoxybenzyl)aniline (53)**

![Chemical Structure](image)

**Mol. Formula:** C\textsubscript{17}H\textsubscript{19}NO

**IR (CHCl\textsubscript{3}, cm\textsuperscript{-1}):** ν\textsubscript{max} 3061, 3003, 2931, 3834, 1725, 1642, 1598, 1500, 1460, 1266, 1036, 921, 818, 747.

**\textsuperscript{1}H NMR (200 MHz, CDCl\textsubscript{3}):** δ 3.84 (s, 3H), 4.03-4.05 (d, J= 14.5 Hz, 2H), 4.54 (s, 2H), 5.19-5.21 (t, J= 1.8 Hz, 1H), 5.25-5.28 (m, 1H), 5.84-6.02 (m, 1H), 6.70-6.71 (m, 1H), 6.79-6.80 (m, 2H), 6.89-6.93 (m, 2H), 7.20-7.21 (m, 2H), 7.24-7.28 (m, 2H) ppm.

**\textsuperscript{13}C NMR (50 MHz, CDCl\textsubscript{3}):** δ 52.7, 53.2, 55.1, 112.3, 113.8, 116.16, 116.3, 127.6, 129.0, 130.6, 133.6, 148.8, 158.4 ppm.
Chapter 5

Analysis Calcd.: C, 80.60; H, 7.56; N, 5.53%; Found: C, 80.63; H, 7.54; N, 5.50%.

N-(4-Methoxybenzyl)aniline (54)

Yield: 35%

Mol. Formula: C₁₄H₁₅NO

IR (CHCl₃, cm⁻¹): νₘₐₓ 3419, 3061, 3002, 2934, 3834, 1725, 1596, 1501, 1460, 1266, 1036, 816.

¹H NMR (200 MHz, CDCl₃): δ 3.82 (s, 3H), 4.24 (brs, 1H), 4.41 (s, 2H), 6.71-6.77 (m, 3H), 6.89-6.90 (m, 2H), 7.17-7.27 (m, 4H) ppm.

¹³C NMR (50 MHz, CDCl₃): δ 49.2, 55.1, 112.3, 113.8, 115.0, 127.6, 129.0, 132.3, 148.8, 158.4 ppm.

Analysis Calcd.: C, 78.84; H, 7.09; N, 6.57; Found: C, 78.81; H, 7.11; N, 6.59.

N-Allyl-N-pentylaniline (55)

Mol. Formula: C₁₄H₂₁N

IR (CHCl₃, cm⁻¹): νₘₐₓ 3056, 3007, 2931, 2796, 1749, 1642, 1443, 1384, 1270, 1071, 1039, 914, 891.

¹H NMR (200 MHz, CDCl₃): δ 0.93-0.95 (m, 3H), 1.33-1.35 (m, 4H), 1.44-1.49 (m, 2H), 2.29 (m, 2H), 3.01-3.04 (d, J= 6.1 Hz, 2H), 5.00-5.16 (m, 2H), 5.24-5.31 (t, J= 7.1 Hz, 1H), 5.70-5.87 (m, 1H), 6.61-6.72 (m, 3H), 7.16-7.27 (m, 2H) ppm.
\[^{13}\text{C NMR}\] (50 MHz, CDCl\(_3\)): \(\delta\) 13.9, 22.3, 30.8, 32.1, 52.3, 55.5, 112.1, 115.8, 125.4, 128.8, 133.6, 149.1 ppm.

**Analysis Calcd.:** C, 82.70; H, 10.41; N, 6.89; **Found:** C, 82.73; H, 10.45; N, 6.84.

**N-Pentylaniline (56)**

![N-Pentylaniline](attachment:image)

**Yield:** 75%

**Mol. Formula:** C\(_{11}\)H\(_{17}\)N

**IR** (CHCl\(_3\), cm\(^{-1}\)):

\(\nu_{\text{max}}\) 3414, 3049, 3006, 2931, 1750, 1443, 1384, 1271, 1074, 1040, 890.

\[^{1}\text{H NMR}\] (200 MHz, CDCl\(_3\)): \(\delta\) 0.90-0.96 (m, 3H), 1.33-1.49 (m, 3H), 1.61-1.71 (m, 2H), 2.06-2.11 (m, 1H), 2.92 (m, 2H), 4.10 (brs, 1H), 6.58-6.72 (m, 3H), 6.96-7.27 (m, 2H) ppm.

\[^{13}\text{C NMR}\] (50 MHz, CDCl\(_3\)): \(\delta\) 14.0, 22.4, 31.0, 32.0, 49.8, 112.8, 127.3, 129.1, 148.6 ppm.

**Analysis Calcd.:** C, 80.93; H, 10.50; N, 8.58; **Found:** C, 80.89; H, 10.54; N, 8.5.

**tert-Butyl allyl(cyclohexyl)carbamate (57)**

![tert-Butyl allyl(cyclohexyl)carbamate](attachment:image)

**Mol. Formula:** C\(_{14}\)H\(_{25}\)NO\(_2\)

**IR** (CHCl\(_3\), cm\(^{-1}\)):

\(\nu_{\text{max}}\) 2986, 2931, 2821, 2713, 1720, 1658, 1647, 1454, 1416, 1263, 912.

\[^{1}\text{H NMR}\] (200 MHz, CDCl\(_3\)): \(\delta\) 1.02-1.05 (m, 1H), 1.28-1.29 (m, 4H), 1.41 (s, 9H), 1.56-1.59 (m, 1H), 1.66-1.73 (m, 4H), 3.67 (brs, 2H), 3.90 (brs, 1H), 4.99-5.08 (m, 2H), 5.72-5.76 (m, 1H) ppm.
\[ ^{13}\text{C NMR} \text{ (50 MHz, CDCl}_3\text{): } \delta \text{ 25.4, 25.8, 28.3, 31.0, 45.1, 54.8, 79.1, 114.9, 136.3, 155.3 ppm.} \]

**Analysis Calcd.:** C, 70.25; H, 10.53; N, 5.85; **Found:** C, 70.29; H, 10.51; N, 5.85.

**tert-Butyl cyclohexylcarbamate (58)**

Yield: 80%

**Mol. Formula:** C\(_{11}\)H\(_{21}\)NO\(_2\)

**IR** (CHCl\(_3\), cm\(^{-1}\)): \( \nu_{\text{max}} \text{ 3356, 2984, 2934, 2822, 2713, 1720, 1658, 1452, 1416, 1263, 830.} \)

**\(^1\text{H NMR} \text{ (200 MHz, CDCl}_3\text{): } \delta \text{ 1.05-1.36 (m, 5H), 1.44 (s, 9H), 1.58-1.71 (m, 3H), 1.90-1.95 (m, 2H), 3.39-3.42 (m, 1H), 4.43 (brs, 1H) ppm.} \)**

**\(^{13}\text{C NMR} \text{ (50 MHz, CDCl}_3\text{): } \delta \text{ 24.8, 25.4, 28.3, 33.4, 49.3, 78.8, 155.1 ppm.} \)**

**Analysis Calcd.:** C, 66.29; H, 10.62; N, 7.03; **Found:** C, 66.25; H, 10.64; N, 7.07.

**tert-Butyl allyl(phenyl)carbamate (59)**

**Mol. Formula:** C\(_{14}\)H\(_{19}\)NO\(_2\)

**IR** (CHCl\(_3\), cm\(^{-1}\)): \( \nu_{\text{max}} \text{ 3073, 3041, 3027, 2976, 2851, 1730, 1658, 1454, 1416, 1264, 913.} \)

**\(^1\text{H NMR} \text{ (200 MHz, CDCl}_3\text{): } \delta \text{ 1.41 (s, 9H), 4.31-4.33 (m, 2H), 5.14-5.24 (m, 2H), 5.83-5.92 (m, 1H), 7.02-7.08 (m, 2H), 7.17-7.21 (m, 1H), 7.23-7.58 (m, 2H) ppm.} \)**
\( ^{13}\text{C NMR} \) (50 MHz, CDCl\(_3\)): \( \delta \) 28.3, 49.0, 80.1, 117.7, 126.6, 128.8, 129.7, 130.9, 143.4, 155.5 ppm.

**Analysis Calcd.:** C, 72.07; H, 8.21; N, 6.00; **Found:** C, 72.03; H, 8.24; N, 5.98.

*tert*-Butyl phenylcarbamate (60)

![tert-Butyl phenylcarbamate (60)](image)

**Yield:** 74%

**Mol. Formula:** C\(_{11}\)H\(_{15}\)NO\(_2\)

**IR (CHCl\(_3\), cm\(^{-1}\)):** \( \nu_{\text{max}} \) 3416, 3073, 3040, 3023, 2976, 2841, 1728, 1658, 1454, 1415, 1261, 937.

\( ^{1}\text{H NMR} \) (200 MHz, CDCl\(_3\)): \( \delta \) 1.41 (s, 9H), 4.48 (brs, 1H), 6.91-6.97 (m, 2H), 7.06-7.10 (m, 1H), 7.41-7.47 (m, 2H) ppm.

\( ^{13}\text{C NMR} \) (50 MHz, CDCl\(_3\)): \( \delta \) 28.3, 79.13, 122.4, 127.0, 128.9, 137.9, 152.3 ppm.

**Analysis Calcd.:** C, 68.37; H, 7.82; N, 7.25; **Found:** C, 68.30; H, 7.85; N, 7.23.

*N*-Allyl-*N*-cyclohexyl-4-methylbenzenesulfonamide (61)

![*N*-Allyl-*N*-cyclohexyl-4-methylbenzenesulfonamide (61)](image)

**Mol. Formula:** C\(_{16}\)H\(_{25}\)NO\(_2\)S

**IR (CHCl\(_3\), cm\(^{-1}\)):** \( \nu_{\text{max}} \) 3063, 3042, 3027, 2986, 2941, 2819, 2713, 1720, 1639, 1454, 1420, 1251, 1142, 1030, 914.
\[ ^1H\text{ NMR} \ (200\ \text{MHz, CDCl}_3) : \delta\ 1.09-1.23\ (m,\ 5H),\ 1.57-1.60\ (m,\ 1H),\ 1.69-1.72\ (m,\ 4H), \ 2.39\ (s,\ 3H),\ 2.56-2.63\ (m,\ 1H),\ 3.15-3.18\ (d,\ J= 6.1\ \text{Hz},\ 2H),\ 5.06-5.12\ (dd,\ J= 10.1,\ 1.9\ \text{Hz},\ 1H),\ 5.16-5.25\ (dd,\ J= 17.3,\ 1.7\ \text{Hz},\ 1H),\ 5.81-5.97\ (m,\ 1H),\ 7.25-7.27\ (d,\ J= 8\ \text{Hz},\ 2H), \ 7.73-7.75\ (d,\ J=8.1\ \text{Hz},\ 2H)\ \text{ppm.} \]

\[ ^{13}C\text{ NMR} \ (50\ \text{MHz, CDCl}_3) : \delta\ 21.4,\ 25.4,\ 25.8,\ 28.3,\ 49.3,\ 55.1,\ 115.2,\ 125.7,\ 127.3,\ 127.6,\ 137.1,\ 140.6\ \text{ppm.} \]

Analysis Calcd.: C, 65.49; H, 7.90; N, 4.77; Found: C, 65.43; H, 7.92; N, 4.74.

\textit{N-Cyclohexyl-4-methylbenzenesulfonamide (62)}

\begin{center}
\begin{tikzpicture}
\node at (0,0) {
\begin{tikzpicture}
\node at (0,0) {N};
\node at (1,0) {Ts};
\node at (0.5,-0.5) {H};
\end{tikzpicture}
\end{tikzpicture}
\end{center}

Yield: 60%

\textbf{Mol. Formula}: C_{13}H_{19}NO_2S

\textbf{IR (CHCl}_3, \text{cm}^{-1}) : \nu_{\text{max}}\ 3412,\ 3063,\ 3042,\ 3027,\ 2986,\ 2941,\ 2819,\ 2713,\ 1720,\ 1454,\ 1420,\ 1250,\ 1140,\ 1032.

\[ ^1H\text{ NMR} \ (200\ \text{MHz, CDCl}_3) : \delta\ 1.13-1.26\ (m,\ 5H),\ 1.49-1.52\ (m,\ 1H),\ 1.61-1.65\ (m,\ 2H), \ 1.73-1.75\ (m,\ 2H),\ 2.43\ (s,\ 3H),\ 3.09-3.16\ (m,\ 1H),\ 4.67\ (brs,\ 1H),\ 7.28-7.30\ (d,\ J= 8.1\ \text{Hz},\ 2H),\ 7.76-7.78\ (d,\ J= 8.3\ \text{Hz},\ 2H)\ \text{ppm.} \]

\[ ^{13}C\text{ NMR} \ (50\ \text{MHz, CDCl}_3) : \delta\ 21.4,\ 24.9,\ 26.0,\ 33.2,\ 50.7,\ 128.1,\ 128.3,\ 137.5,\ 141.3\ \text{ppm.} \]

Analysis Calcd.: C, 61.63; H, 7.56; N, 5.53; Found: C, 61.64; H, 7.58; N, 5.51.
$N$-Cyclohexyl-$N$-(prop-2-yn-1-yl)cyclohexanamine (63)

Mol. Formula: $C_{15}H_{25}N$

IR (CHCl$_3$, cm$^{-1}$): $\nu$ max 3264, 2929, 2857, 2702, 2666, 1729, 1447, 1271, 1116, 1013, 747.

$^1$H NMR (200 MHz, CDCl$_3$): $\delta$ 1.16-1.28 (m, 9H), 1.55-1.58 (br, 2H), 1.72-1.82 (m, 9H), 2.10 (s, 1H), 2.71-2.76 (m, 2H), 3.44 (s, 2H) ppm.

$^{13}$C NMR (50 MHz, CDCl$_3$): $\delta$ 25.9, 26.1, 30.9, 34.6, 57.1, 70.8, 83.5 ppm.

Analysis Calcd.: C, 82.13; H, 11.49; N, 6.39; Found: C, 82.16; H, 11.45; N, 6.37.

$N$-Cyclohexyl-$N$-(3-methylbut-2-en-1-yl)cyclohexanamine (64)

Mol. Formula: $C_{17}H_{31}N$

IR (CHCl$_3$, cm$^{-1}$): $\nu$ max 2929, 2853, 2701, 2666, 1729, 1662, 1447, 1271, 1116, 916.

$^1$H NMR (200 MHz, CDCl$_3$): $\delta$ 0.97-1.19 (m, 10H), 1.50-1.52 (m, 2H), 1.53 (s, 3H), 1.60-1.65 (m, 8H), 1.78 (s, 3H), 2.46-2.50 (m, 2H), 3.12-3.13 (d, $J= 6.5$ Hz, 2H), 5.14-5.27 (m, 1H) ppm.

$^{13}$C NMR (50 MHz, CDCl$_3$): $\delta$ 18.4, 25.5, 26.3, 26.5, 26.8, 27.0, 31.9, 35.1, 44.5, 53.2, 58.3, 127.1, 132.4 ppm.

Analysis Calcd.: C, 81.86; H, 12.53; N, 5.62; Found: C, 81.84; H, 12.54; N, 5.63.
**tert-Butyl cinnamyl(cyclohexyl)carbamate (65)**

![Chemical Structure](image)

**Mol. Formula:** C_{20}H_{29}NO_{2}

**IR** (CHCl₃, cm⁻¹): v max 3074, 3027, 2976, 2930, 2851, 2806, 1730, 1658, 1647, 1454, 1416, 1261, 912.

**¹H NMR** (200 MHz, CDCl₃): δ 0.99-1.25 (m, 4H), 1.37 (s, 9H), 1.64-1.70 (m, 4H), 1.83-1.89 (m, 2H), 2.58-2.73 (m, 1H), 3.69-3.72 (dd, J = 6.1, 0.9 Hz, 2H), 6.17-6.28 (m, 1H), 6.32-6.49 (m, 1H), 7.14-7.34 (m, 5H) ppm.

**¹³C NMR** (50 MHz, CDCl₃): δ 25.5, 26.6, 28.8, 32.6, 49.4, 58.1, 79.8, 126.7, 127.7, 128.9, 129.3, 131.4, 137.6, 154.0 ppm.

**Analysis Calcd.:** C, 76.15; H, 9.27; N, 4.44; **Found:** C, 76.11; H, 9.28; N, 4.42.

**N-Alllylcyclohexanamine (66)**

![Chemical Structure](image)

**Mol. Formula:** C_{9}H_{17}N

**IR** (CHCl₃, cm⁻¹): v max 3430, 2977, 2929, 2851, 2806, 1730, 1642, 1450, 1416, 1261, 914, 758.

**¹H NMR** (200 MHz, CDCl₃): δ 1.25-1.41 (m, 4H), 1.49-1.74 (m, 6H), 2.41-2.52 (m, 1H), 3.80-3.92 (m, 2H), 4.45 (brs, 1H), 5.04-5.22 (m, 2H), 5.69-5.89 (m, 1H) ppm.

**¹³C NMR** (50 MHz, CDCl₃): δ 24.0, 24.3, 26.9, 50.8, 56.8, 114.1, 135.4 ppm.

**Analysis Calcd.:** C, 77.63; H, 12.31; N, 10.06; **Found:** C, 77.61; H, 12.29; N, 10.09.
**N-Cinnamylecyclohexanamine (68)**

**Mol. Formula:** C\(_{15}\)H\(_{21}\)N

**IR** (CHCl\(_3\), cm\(^{-1}\)): \(\nu_{\text{max}}\) 3430, 3074, 3027, 2977, 2929, 2851, 2806, 1730, 1655, 1454, 1416, 1261, 914.

**\(^1\)H NMR** (200 MHz, CDCl\(_3\)): \(\delta\) 0.98-1.24 (m, 5H), 1.59-1.69 (m, 4H), 1.82-1.86 (m, 2H), 2.39-2.51 (m, 1H), 3.35-3.38 (dd, \(J = 6.1, 0.9\) Hz, 2H), 6.20-6.31 (m, 1H), 6.41-6.49 (m, 1H), 7.14-7.33 (m, 5H) ppm.

**\(^{13}\)C NMR** (50 MHz, CDCl\(_3\)): \(\delta\) 24.9, 26.0, 33.4, 48.78, 56.0, 126.0, 127.1, 128.3, 128.7, 130.8, 130.8, 137.0 ppm.

**Analysis Calcd.:** C, 83.67; H, 9.83; N, 6.50; **Found:** C, 83.68; H, 9.80; N, 6.53.

**N,N-Diallylecyclohexanamine (69)**

**Mol. Formula:** C\(_{12}\)H\(_{21}\)N

**IR** (CHCl\(_3\), cm\(^{-1}\)): \(\nu_{\text{max}}\) 2976, 2929, 2854, 2806, 1728, 1642, 1450, 1416, 1261, 915, 758.

**\(^1\)H NMR** (200 MHz, CDCl\(_3\)): \(\delta\) 1.15-1.25 (m, 5H), 1.57-1.64 (m, 1H), 1.76-1.79 (m, 4H), 2.48-2.58 (m, 1H), 3.10-3.11 (t, \(J = 1.3\) Hz, 2H), 3.13-3.14 (t, \(J = 1.3\) Hz, 2H), 5.04-5.05 (m, 1H), 5.09-5.11 (m, 2H), 5.18-5.20 (m, 1H), 5.74-5.91 (m, 2H) ppm.

**\(^{13}\)C NMR** (50 MHz, CDCl\(_3\)): \(\delta\) 26.0, 26.3, 28.9, 52.8, 58.8, 116.1, 137.4 ppm.

**Analysis Calcd.:** C, 80.38; H, 11.81; N, 7.81; **Found:** C, 80.37; H, 11.80; N, 7.83.

5.7. Spectra
Chapter 5

$^1$H-NMR of compound 37 in CDCl$_3$

$^{13}$C-NMR of compound 37 in CDCl$_3$
\( ^1 \text{H-NMR of compound 38 in CDCl}_3 \)

\( ^{13} \text{C-NMR of compound 38 in CDCl}_3 \)
Chapter 5

$^{1}H$-NMR of compound 41 in CDCl$_3$

$^{13}C$-NMR of compound 41 in CDCl$_3$
Chapter 5

$^1$H-NMR of compound 42 in CDCl$_3$

$^{13}$C-NMR of compound 42 in CDCl$_3$
Chapter 5

$^{1}H$-NMR of compound 43 in CDCl$_3$

$^{13}C$-NMR of compound 43 in CDCl$_3$
$^1$H-NMR of compound 44 in CDCl$_3$
Chapter 5

$^1$H-NMR of compound 45 in CDCl$_3$

$^{13}$C-NMR of compound 45 in CDCl$_3$
Chapter 5

$^1$H-NMR of compound 46 in CDCl₃

$^{13}$C-NMR of compound 46 in CDCl₃
Chapter 5

\[ ^1\text{H-NMR of compound 47 in CDCl}_3 \]

\[ ^1\text{C-NMR of compound 47 in CDCl}_3 \]
Chapter 5

$^{1}H$-NMR of compound 48 in CDCl$_3$

$^{13}C$-NMR of compound 48 in CDCl$_3$
Chapter 5

$^1$H-NMR of compound 49 in CDCl$_3$

$^{13}$C-NMR of compound 49 in CDCl$_3$
Chapter 5

$^1$H-NMR of compound 50 in CDCl$_3$

$^{13}$C-NMR of compound 50 in CDCl$_3$
Chapter 5

$^1$H-NMR of compound 51 in CDCl$_3$

$^{13}$C-NMR of compound 51 in CDCl$_3$
Chapter 5

$^{1}$H-NMR of compound 52 in CDCl$_3$

$^{13}$C-NMR of compound 52 in CDCl$_3$
Chapter 5

$^1$H-NMR of compound 53 in CDCl$_3$

$^{13}$C-NMR of compound 53 in CDCl$_3$
Chapter 5

$^{1}H$-NMR of compound 54 in CDCl$_3$

$^{13}C$-NMR of compound 54 in CDCl$_3$
Chapter 5

$^1$H-NMR of compound 55 in CDCl$_3$

$^{13}$C-NMR of compound 55 in CDCl$_3$
1H-NMR of compound 56 in CDCl₃

13C-NMR of compound 56 in CDCl₃
Chapter 5

$^1$H-NMR of compound 57 in CDCl$_3$

$^{13}$C-NMR of compound 57 in CDCl$_3$
\(^1\)H-NMR of compound 58 in CDCl\(_3\)

\(^1\)C-NMR of compound 58 in CDCl\(_3\)
Chapter 5

$^1$H-NMR of compound 59 in CDCl$_3$

$^{13}$C-NMR of compound 59 in CDCl$_3$
Chapter 5

\[ ^1H\text{-NMR of compound 60 in CDCl}_3 \]

\[ ^{13}C\text{-NMR of compound 60 in CDCl}_3 \]
Chapter 5

\[ ^1H\text{-NMR of compound 61 in CDCl}_3 \]

\[ ^{13}C\text{-NMR of compound 61 in CDCl}_3 \]
Section from Chapter 5

$^{1}$H-NMR of compound 62 in CDCl$_3$

$^{13}$C-NMR of compound 62 in CDCl$_3$
Chapter 5

$^1$H-NMR of compound 63 in CDCl$_3$

$^{13}$C-NMR of compound 63 in CDCl$_3$
Chapter 5

$^1$H-NMR of compound 64 in CDCl$_3$

$^{13}$C-NMR of compound 64 in CDCl$_3$
Chapter 5

$^1$H-NMR of compound 65 in CDCl$_3$

$^{13}$C-NMR of compound 65 in CDCl$_3$
Chapter 5

$^1$H-NMR of compound 66 in CDCl$_3$

$^{13}$C-NMR of compound 66 in CDCl$_3$
Chapter 5

$^1$H-NMR of compound 68 in CDCl$_3$

$^{13}$C-NMR of compound 68 in CDCl$_3$
Chapter 5

$^1$H-NMR of compound 69 in CDCl$_3$

$^{13}$C-NMR of compound 69 in CDCl$_3$
5.8. References


