THE DEVELOPMENT OF ALDEHYDE SELECTIVE ORGANOALUMINUM REAGENTS FOR ORGANIC SYNTHESIS

BY
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Dedicated

to my

parents and sister
ACKNOWLEDGMENTS

At this time, I would like to thank my advisor and mentor professor Merle Battiste for his graciousness and generosity with time and knowledge on my behalf. I would also like to thank my parents and sister, without the love and support of whom this achievement would have been impossible. As for Velva, though there might not have been many words said, the gourmet meals, the friendship, and knowing she was there was appreciated. Many thanks to all the Perles, Curt, Jim, Johnny, Mapi and Radi for all the help and company they have provided throughout these years. And lastly, this acknowledgment will not be complete without thanking Sev for his unconditional companionship.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>ACKNOWLEDGEMENTS</th>
<th>iii</th>
</tr>
</thead>
<tbody>
<tr>
<td>LIST OF TABLES</td>
<td>vi</td>
</tr>
<tr>
<td>ABBREVIATIONS</td>
<td>vii</td>
</tr>
<tr>
<td>ABSTRACT</td>
<td>ix</td>
</tr>
<tr>
<td>CHAPTER I</td>
<td>1</td>
</tr>
<tr>
<td>INTRODUCTION</td>
<td></td>
</tr>
<tr>
<td>SELECTIVE OLEFINATION REACTIONS</td>
<td>4</td>
</tr>
<tr>
<td>THE PETERSON OLEFINATION REAGENT</td>
<td>6</td>
</tr>
<tr>
<td>ORGANOALUMINUM COMPOUNDS:</td>
<td>9</td>
</tr>
<tr>
<td>STRUCTURE AND REACTIVITY</td>
<td></td>
</tr>
<tr>
<td>THE APPROACH</td>
<td>15</td>
</tr>
<tr>
<td>CHAPTER II</td>
<td>17</td>
</tr>
<tr>
<td>THE RELATIVE REACTIVITY OF ALKYL</td>
<td></td>
</tr>
<tr>
<td>AND TRIMETHYLSILYL METHYL SUBSTITUENTS ON ALUMINUM</td>
<td></td>
</tr>
<tr>
<td>REACTIONS OF TMA, DMTA, DETA, AND MDTA.</td>
<td>27</td>
</tr>
<tr>
<td>WITH ALDEHYDES AND KETONES</td>
<td></td>
</tr>
<tr>
<td>REACTIONS OF TTMA WITH ALDEHYDES AND KETONES</td>
<td>33</td>
</tr>
<tr>
<td>RESULTS AND DISCUSSION</td>
<td>35</td>
</tr>
<tr>
<td>CHAPTER III</td>
<td>41</td>
</tr>
<tr>
<td>PREPARATION, AND REACTIONS OF.</td>
<td></td>
</tr>
<tr>
<td>ALDEHYDE-SELECTIVE ((\text{TMSCH}_2)_3\text{Al}) REAGENT WITH ALDEHYDES AND KETONES</td>
<td></td>
</tr>
<tr>
<td>PREPARATIONS OF ((\text{TMSCH}_2)_3\text{Al}).</td>
<td>41</td>
</tr>
<tr>
<td>REACTONS OF ((\text{TMSCH}_2)_3\text{Al}).</td>
<td>50</td>
</tr>
<tr>
<td>CHAPTER IV</td>
<td>62</td>
</tr>
<tr>
<td>A STUDY OF THE REACTIONS OF ORGANO-</td>
<td></td>
</tr>
<tr>
<td>ALUMINUM ALKOXIDES AND ARYLOXIDES</td>
<td></td>
</tr>
<tr>
<td>WITH AROMATIC ALDEHYDES</td>
<td></td>
</tr>
<tr>
<td>CHAPTER V</td>
<td>77</td>
</tr>
<tr>
<td>SUMMARY</td>
<td></td>
</tr>
<tr>
<td>CHAPTER VI</td>
<td>80</td>
</tr>
<tr>
<td>EXPERIMENTAL</td>
<td></td>
</tr>
<tr>
<td>GENERAL</td>
<td>80</td>
</tr>
<tr>
<td>EXPERIMENTAL PROCEDURES</td>
<td>82</td>
</tr>
</tbody>
</table>
LIST OF TABLES

<table>
<thead>
<tr>
<th>TABLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-1</td>
<td>7</td>
</tr>
<tr>
<td>pKa values of Me₃Si-substituted phenols.</td>
<td></td>
</tr>
<tr>
<td>2-1</td>
<td>29</td>
</tr>
<tr>
<td>Reactions of R&quot;R'₂Al (R&quot; = Me, TMSCH₂, R' = Me, Et) with selected carbonyl compounds.</td>
<td></td>
</tr>
<tr>
<td>2-2</td>
<td>31</td>
</tr>
<tr>
<td>Reactions of R&quot;₂R'Al (R' = Me, TMSCH₂) with selected carbonyl compounds.</td>
<td></td>
</tr>
<tr>
<td>2-3</td>
<td>39</td>
</tr>
<tr>
<td>Reactions of (TMSCH₂)₂Et₂Al⁻Li⁺ with selected carbonyl compounds.</td>
<td></td>
</tr>
<tr>
<td>3-1</td>
<td>54</td>
</tr>
<tr>
<td>Reactions of (TMSCH₂)₃Al (3-1a) with selected aldehydes.</td>
<td></td>
</tr>
<tr>
<td>3-2</td>
<td>56</td>
</tr>
<tr>
<td>Reactions of (TMSCH₂)₃Al (3-1a) with selected ketones.</td>
<td></td>
</tr>
<tr>
<td>4-1</td>
<td>70</td>
</tr>
<tr>
<td>Reaction of aromatic aldehydes with DMBA and DMBAE.</td>
<td></td>
</tr>
<tr>
<td>4-2</td>
<td>72</td>
</tr>
<tr>
<td>Reactions of B₃ and B₄ with aromatic aldehydes.</td>
<td></td>
</tr>
<tr>
<td>4-2a</td>
<td></td>
</tr>
<tr>
<td>Reactions with benzaldehyde.</td>
<td></td>
</tr>
<tr>
<td>4-2b</td>
<td></td>
</tr>
<tr>
<td>Reactions with 4-Tolualdehyde.</td>
<td></td>
</tr>
<tr>
<td>6-1</td>
<td>140</td>
</tr>
<tr>
<td>GC analysis of the MPV reduction of benzaldehyde via its reaction with the product of the reaction of Me₃Al with 1-phenylethanol.</td>
<td></td>
</tr>
<tr>
<td>6-2</td>
<td>141</td>
</tr>
<tr>
<td>GC analysis of the MPV reduction of benzaldehyde via its reaction with the product of the reaction of Me₃Al with 1-phenyl-2-trimethylsilylethanol.</td>
<td></td>
</tr>
<tr>
<td>6-3</td>
<td>143</td>
</tr>
<tr>
<td>GC analysis of the MPV reduction of benzaldehyde via its reaction with the product of the reaction of Me₂BHTAl.0Et₂ with 1-phenylethanol.</td>
<td></td>
</tr>
<tr>
<td>6-4</td>
<td>144</td>
</tr>
<tr>
<td>GC analysis of the MPV reduction of benzaldehyde via its reaction with the product of the reaction of Me₃Al with 1-phenylethanol.</td>
<td></td>
</tr>
</tbody>
</table>
ABBREVIATIONS

BHT-H 2,6-di-tert-butyl-4-methylphenol
BHT 2,6-di-tert-butyl-4-methylphenoxy
'Bu tert-butyl
t-BuO tert-butoxy
Cat catechol
cond. condensation
DEDTA diethylbis(trimethylsilylmethyl)aluminate
DETA diethyltrimethylsilylmethylaluminum
DMBAE 2,6-di-tert-butyl-4-methylphenoxydimethyl-aluminum-etherate
DMBA 2,6-di-tert-butyl-4-methylphenoxydimethyl-aluminum
DMTA dimethylbis(trimethylsilylmethyl)aluminum
equiv. equivalent
Et ethyl
hrs hours
M molarity
Me methyl
MDTA methylbis(trimethylsilylmethyl)aluminum
MPV Meerwein-Pondorff-Verley
PDC pyridinium dichromate
Pr propyl
'iPr iso-propyl
r.t. room temperature
RED reduction
s.m. starting material
THF tetrahydrofuran
TMA trimethylaluminum
TMEDA N, N, N', N'-tetramethylethylenediamine
TMSCH₂-TMSC trimethylsilylmethyl
TMS trimethylsilyl
TTMA tris(trimethylsilylmethyl)aluminum
TTMA₃ tris(trimethylsilylmethyl)aluminum, the LiBr salt, [(TMSCH₂)₃Al·3LiBr]
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DEVELOPMENT OF ALDEHYDE SELECTIVE ORGANOALUMINUM REAGENTS FOR ORGANIC SYNTHESIS

BY

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DECEMBER, 1991

Chairman: Merle A. Battiste
Major Department: Chemistry

In the present study aluminum has been used as the metal center in the modification of the Peterson reagent [(CH₃)₃SiCH₂M, M = Li, MgBr] for the selective methylenation of aldehydes. The modification was approached through variation of the substituents on the organoaluminum. The effect of alkyl, alkoxy, and halide groups as coligands on aluminum on the transfer of the (CH₃)₃SiCH₂ (TMSCH₂) group to the carbonyl carbon has been examined. Alkoxy and halide substituents deactivate the aluminum reagent to carbonyl addition, whereas alkyl groups (ethyl and methyl) compete with TMSCH₂ in addition reactions with carbonyls. The deactivation of the organoaluminums by the alkoxy and halide ligands is believed to be the result of the strong bridging capacity and aggregating capability of the...
the heteroatoms in addition to their inductive electron withdrawing effect. The competitive transferal of the methyl and ethyl substituents is contrary to the anion stability criteria established for the preferred delivery of carbanions on aluminum. The competitive addition of the simple alkyl nucleophiles can be rationalized by the exceptional bulk of the Me₃Si group which outweighs its anion stabilizing effect. The substitution of three TMSCH₂ groups on aluminum affords [(CH₃)₃SiCH₂]₃Al (TTMA) which has emerged as an aldehyde-selective TMSCH₂ transferal agent. The superior selectivity of this reagent is demonstrated by its relative ease of reaction with aldehyde vs. ketones and, more convincingly, with keto-aldehydes under moderate reaction conditions. In addition, the previously reported methylation and oxidation reactions of BHTMe₂Al:OEt₂ (BHT = 2,6-di-tert-butyl-4-methylphenoxy) with aromatic aldehydes has been reinvestigated. The results of this study support an alternative scheme wherein trimethylaluminum, liberated in low steady state concentration from the solution of BHTMe₂Al:OEt₂, is the major methylating agent in these reactions.
CHAPTER I

INTRODUCTION

The area of organoaluminum chemistry has been under a constant growth and development since discovery of the direct synthesis oftrialkylaluminums and the demonstration of their application to the polymerization of olefins by Ziegler and coworkers.\(^1\) As the result of the unique properties of the carbon-aluminum bond, such as the tendency to form bridged complexes with heteroatoms and other metals, and their various modes of reactions with olefins and other nucleophiles, organoaluminums have attracted considerable interest in both areas of industry and laboratory.

Additionally, organoaluminum compounds, due to their lower reactivity and high oxophilicity, have found a variety of applications in organic synthesis as selective nucleophilic reagents. These applications include diastereo-selective opening of epoxides,\(^2\) selective alkylation and reduction of aldehydes\(^3\) and ketones\(^4\) and selective reduction of alkenes, alkynes,\(^5\) and carboxylic acid derivatives.\(^6\)
The main subject of this dissertation, the development and modification of the novel organoaluminum reagents, is concentrated on the selective reactions of trialkyl- and mixed-trialkylaluminum with carbonyls. While many characteristic properties of trialkylaluminum have been explored, their employment in organic syntheses, as nucleophilic compounds has not been fully recognized.

The development of an aldehyde selective methylenating reagent by appropriate modification of the Peterson olefination reagent was a major goal of this investigation. These modifications involved incorporating the TMSCH₂ substrate on a less reactive metal center. While there are a variety of metals suitable for this purpose, the previous experience in this laboratory with selective aluminum reagents and the inherent selective properties of organoaluminum reagents, focused attention mainly on aluminum.

One of the more attractive properties of mixed-organoaluminum compounds is their ability to deliver one of their substituents, generally exclusively, to a variety of electrophiles. For example, Rathke alanes are among a variety of other examples where the more stable carbanion, the acetate group, is transferred preferentially over the alkyl substituents (figure 1-la). Other examples include dialkylalkynyl- (1-la), dialkylalkenyl-(1-1c), and dialkylindanylandaluminums. In all of these cases the more stable anion is transferred preferentially. An additional
characteristic of trialkylaluminums which makes them especially suitable for an aldehyde selective reagent is their inherent aldehyde and ketone selectivity in the presence of esters and other less reactive electrophiles.\textsuperscript{13} The selective alkylation of aldehydes in the presence of esters, by manipulation of the reaction conditions, has been successfully employed in several synthesis (1-1c).
Selective Olefination Reactions

The olefination reaction of carbonyl compounds is an important strategic transformation in organic synthesis. There are many reagents available for the olefination reaction of carbonyl compounds. The Wittig reaction\(^1\) and its modifications\(^2\) and the Peterson reagents\(^3,4\) are some of the better known and more popular reagents employed for this purpose (figure 1-2). These reagents are highly effective olefinating reagents and react readily with a variety of carbonyl compounds. However, there are numerous occasions in organic synthesis where there is a need for olefination of one carbonyl in presence of other reactive
electrophilic centers, which often introduce a laborious series of protection and deprotection steps. An alternate solution to this problem would be the use of, for example, a methylenating agent which would discriminate between two or more carbonyl centers to react selectively with only one.

The selective methylenating reagents known to this point have differing applications and properties in their reactions with carbonyl compounds (figure 1-3). Some reagents are selective towards aldehydes (1-3a), while

```
O
\[ \text{TMSCH}_2\text{TiCl}_3 \] \[ \text{hexanes} \]
\[ \text{CH}_2\text{TiCl}_3 \] \[ \text{Me}_3\text{SiCH}_2\text{Li/Cl}_2 \]

H
```

60%

```
CH_2\text{CHO}
\[ \text{CH}_2\text{(AlBr}_2\text{)}_2 \] \[ \text{THF, reflux} \]

H
```

75%

```
O
\[ \text{Me}_3\text{SiCH}_2\text{Li/Cl}_2 \] \[ \text{THF, -78°C} \]

H
```

65%

```
C\[\text{p}_2\text{TiCH}_2\text{ClAlMe}_2 \]
\[ \text{THF} \]

H
```

84%

Figure 1-3
others are only compatible with nonenolizable carbonyls \((1-3b)^{19}\) and a few are useful for readily enolizable carbonyls \((1-3c^{20},d^{21})\).

The selectivity of these reagents is the result of one or a combination of the following factors: a) higher reactivity of one carbonyl compared to the other, b) the variations in the steric requirements of the two, and c) the lower reactivity of the reagent. As is the case with most selective reagents, it is the lower reactivity of the reagent that leads to the distinguishing of the two differing carbonyl groups. Hence, a common practice in development of a selective methylenating reagent is the modification of the parent reagent by either altering or replacing the metal center.

**The Peterson Olefination Reagent**

The Peterson reagent\(^{22}\) \((\text{TMSCH}_2\text{M}, \ M = \text{Li, MgX})\) is a convenient and versatile olefinating agent that reacts readily with aldehydes, ketones and esters at \(-78^\circ\text{C}\). The Peterson reagent takes advantage of the silyl group in both addition and elimination steps of its reaction with carbonyls. The silyl group stabilizes the \(\alpha\)-anion in the organometallic reagent and it also facilitates the removal of the hydroxy group in the addition product, via its well known \(\beta\)-effect.\(^{23}\) The \(\beta\)-silyl group offers a strong stabilizing effect through electron donation to an adjacent
Figure 1-4. The β-effect of the silyl group

electron deficient center. The mechanism for this electron donation is believed to be through hyperconjugation\(^2\) (\(p-\sigma\) conjugation, figure 1-4); the high degree of polarization of the carbon-silicon bond, due to lower electronegativity of the silicon, ensures a high electron density on carbon, and enhances its ability to stabilize an adjacent electron-poor center. The α-anion stabilization by thetrialkylsilyl group is believed to be due to a weak electron accepting capability of the silyl group; this effect is detectable with \(p\)-trimethylsilyl substituted

Table 1-1. The \(pK_a\) values for para-trimethylsilyl substituted phenols and anilines.

<table>
<thead>
<tr>
<th>Arylsilane</th>
<th>(pK_a) at 25 °C</th>
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</thead>
<tbody>
<tr>
<td>(R-\text{OH})</td>
<td>(R = \text{H})</td>
</tr>
<tr>
<td></td>
<td>(= \text{SiMe}_3)</td>
</tr>
<tr>
<td></td>
<td>10.85</td>
</tr>
<tr>
<td></td>
<td>10.64</td>
</tr>
<tr>
<td>(R-\text{NH}_3)</td>
<td>(R = \text{H})</td>
</tr>
<tr>
<td></td>
<td>(= \text{SiMe}_3)</td>
</tr>
<tr>
<td></td>
<td>4.62</td>
</tr>
<tr>
<td></td>
<td>4.36</td>
</tr>
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</table>
phenols as they are more acidic than their unsubstituted analogues\textsuperscript{25} and 4-trimethylsilyl-substituted anilines are less basic (table 1-1).

The elimination of the trimethylsilyl and the hydroxy group is possible under both acidic and basic conditions. Under acidic condition the elimination occurs through an $E_2$ antiperiplanar transition state, whereas the base catalyzed elimination occurs in a syn manner\textsuperscript{20} (figure 1-7). These different modes of elimination offer a convenient route to the stereoselective synthesis of cis and trans double bonds.

\[ \text{Figure 1-5} \]
Trialkylaluminum compounds are almost all colorless pyrophoric liquids at room temperature that are generally dimeric in solution. The proton NMR of trimethylaluminum shows only one peak, due to the rapid exchange of the bridging methyl groups; however, at -75° C this process is sufficiently slow for separate resonances to be observed\(^27\) (figure 1-6). An increase in the size of the alkyl substituent, especially the branching at the β-position, hinders the formation of the dimers and leads to monomeric species, e.g. tris-2,4,4-trimethylpentylaluminum\(^28\) and tri(tert-butyl)aluminum.\(^29\)

The dimeric nature of the trialkylaluminums results in scrambling of the mixed trialkylaluminums. Studies on this subject have demonstrated the dimeric nature of the mixed trialkylaluminums, with the bridging positions occupied preferentially by the smaller alkyl groups. NMR studies\(^30\) of a 4:1 mole ratio mixture of monomeric tri-isobutylaluminum and dimeric trimethylaluminum show the exchange of methyl and isobutyl groups to form

\[
2 \text{Me}_3\text{Al} \rightarrow \text{Me}_6\text{Al}_2
\]

Figure 1-6

**Organoaluminum Compounds: Structure and Reactivity**
di-isobutylmethylaluminum, which exists as a methyl-bridged dimer (figure 1-7).

![Figure 1-7](image)

The reaction of trialkylaluminums with carbonyl compounds exhibits three possible reaction types: 1) alkyl addition, 2) β-hydride transfer (reduction), and 3) enolization of the carbonyl compound when α-hydrogens are present (figure 1-8). The β-hydride reduction and the alkyl addition reactions become competitive when a

![Figure 1-8](image)
β-hydrogen is present on the aluminumalkyl substituent. The yields of reduction are increased by branching at the β position of the alkyl substituent, or by employing low ratios of the organoaluminum to carbonyl compound\(^{31}\) (≤1:1). The enolization reaction is also affected by similar factors and can become a major side reaction with readily enolizable carbonyls. With the exception of Me\(_3\)Al and Ph\(_3\)Al, these characteristics limit the alkylation ability of most other trialkylaluminums.

The less common side reactions of trialkylaluminums with aldehydes are the Meerwein-Pondorff-Verley (MPV)

\[
\begin{align*}
\text{R} \quad \text{H} \\
\text{O} \\
\text{C} \\
\text{H} \\
\text{R} \\
\text{Al} \\
\text{OH} \\
\text{R} \quad \text{H}
\end{align*}
\]
reduction\textsuperscript{32} and the Oppenauer oxidation\textsuperscript{33} reactions (figure 1-9). These reactions usually arise from the presence of excess carbonyl compound, or the low reactivity of the trialkylaluminum. In situations where an excess of aldehyde is present, after the addition reaction is complete, the MPV reduction and the Oppenauer oxidation take over to yield the reduced aldehyde and the oxidized sec-alcohol. The slower oxidation and reduction processes also become competitive with the addition reaction when the trialkylalane is sluggish in transferal of the alkyl substituents.

Another limitation of the trialkylaluminums is the diminished reactivity of the alkylaluminum after the transferring of the first alkyl group to a carbonyl compound. Studies conducted by Mole and coworkers\textsuperscript{34} show the formation of stable hemialkoxides after the reaction of two moles of trimethylaluminum with one mole of ketone or aldehyde (figure 1-10). This observation then relates the single alkyl transferal ability of trialkylaluminums to the

\[
\text{RCHO} + \text{Me}_6\text{Al}_2 \rightarrow \text{Product}
\]

Figure 1-10
deactivating effect of oxygen and other heteroatoms on alkylaluminums.

The lack of nucleophilicity of dialkylaluminum alkoxides is explained by the inductive electron withdrawing effect of oxygen, and the formation of oxygen bridged aggregates. These aggregates inhibit the access of the carbonyl group to the aluminum thus hindering the formation of the carbonyl aluminum complex which leads to the transition state of the alkyl addition. Other heteroatom substituents have a similar effect on organo-aluminum compounds. Note that the bridging capability\textsuperscript{35} of heteroatoms with aluminum is stronger and more pronounced than that of alkyl substituents. An excellent example of the more favorable bridging ability of heteroatoms is the thermal redistribution of a equimolar mixture of tri-isopropoxyaluminum and trimethylaluminum. This method is employed in preparation of dimethylaluminum isopropoxide\textsuperscript{36} which exists as a dimer with bridging alkoxy groups (figure 1-11). This enhanced bridging capability arises from the

$$2 \text{i-PrO}_3\text{Al} + 4 \text{Me}_3\text{Al} \rightarrow 3$$

Figure 1-11
association of the Lewis acidic aluminum center with a lone pair of electrons from the more electronegative atom, and usually leads to the formation of higher aggregates of alkoxy, aryloxy and amine substituted organoaluminums.\textsuperscript{37}

Preparation of monomers of organoaluminum aryloxides is also possible when bulky phenoxides are employed.\textsuperscript{38} One of the more popular phenols employed is the 2,6-di-tert-butyl-4-methylphenol (BHT-H). Substitution of BHT for two of the methyls of trimethylaluminum leads to the formation of the monomeric BHT\textsubscript{2}AlMe, which has found a variety of applications in stereoselective alkylation of ketones and aldehydes.\textsuperscript{39}

The successful reaction of trialkylaluminum with carbonyl compounds often requires more than one equivalent of the aluminum reagent. Generally, in alkylations of carbonyls 1.5 to 2 equivalents of the organoaluminum are used; however, in cases where β-hydride reduction competes with the addition, up to four equivalents of the reagent have been employed.\textsuperscript{31} Based on these results and related kinetic studies,\textsuperscript{40} two moles of trialkylaluminums are believed to be involved in their addition reactions to carbonyls. Two mechanisms have been proposed\textsuperscript{41} based on this criteria (figure 1-12): 1) transfer of the alkyl substituent through a six membered cyclic transition state, where the dimeric trialkylaluminum is complexed to the carbonyl oxygen (1-12a); 2) delivery of the alkyl group
through a four membered transition state, by one of the two trialkylaluminums complexed to the carbonyl oxygen (1-12b).

\[
R_3\text{Al} + R_1R_2\text{CO} \rightarrow \text{products}
\]

Figure 1-12

The Approach

As previously stated, the main subject of the investigations reported in this dissertation involve the development of a selective aluminum-based Peterson reagent. The fulfillment of this task required the preparation of a variety of organoaluminum reagents containing the TMSCH\_2 substituent, together with the study of their reactions with carbonyl compounds. The lack of reactivity and competitive transferring of alkyl substituents (ethyl and
methyl) on aluminum led to a more detailed study of the relative reactivity of mixed trialkylaluminums (Chapter 2). From the investigations on mixed trialkylaluminums, (TMSCH$_2$)$_3$Al emerged as the aldehyde-selective modified Peterson reagent. The superior aldehyde-selectivity of (TMSCH$_2$)$_3$Al is demonstrated by its reactions with aldehydes, ketones, and keto-aldehydes (Chapter 3). A tangent to this project was the study of the methylation of aromatic aldehyde using BHT (2,6-di-tert-butyl-4-methyl-phenoxide) substituted alkylaluminums (Me$_2$BHTAl:OEt$_2$), which surfaced from the future outlook for development of stereoselective methylenating reagents (Chapter 4).
CHAPTER II

THE RELATIVE REACTIVITY OF ALKYL AND TRIMETHYL-SILYL METHYL SUBSTITUENTS ON ALUMINUM

The first step in developing a selective organometallic reagent involves defining a suitable metal center with its corresponding ligands. As our initial attempt in modification of the Peterson olefination reagent titanium was chosen as the selective metal center in consideration of its oxophilic character. In this area of selective organometallic chemistry, reagents of titanium have proven extremely effective. Various titanium reagents have been used in stereo- and enantio-selective alkylations of aldehydes\(^4_2\) (figure 2-1a) and chemoselective alkylation of tertiary halides\(^4_3\) (2-1b). In particular, \((i\text{-PrO})_3\text{TiCH}_3\) has shown excellent selectivity in methylating aldehydes in presence of ketones. Based on this information, an extrapolation from the highly selective methylating reagent \((i\text{-PrO})_3\text{TiCH}_3\), resulted in choosing \((i\text{-PrO})_3\text{TiCH}_2\text{TMS}\), which appeared to be a good starting point for a selective \text{TMSCH}_2 transferal agent.

The requisite reagent [(i-PrO)_3TiCH_2TMS] was prepared by reaction of (i-PrO)_3TiCl (in hexanes) with TMSCH_2Li (in
pentane) and was employed (in situ) immediately after preparation (figure 2-2). Preliminary examination of the reactivity of this reagent with phenylacetaldehyde proved fruitless, as GC analysis showed unreacted aldehyde and aldol condensation as major products of these reactions. Subsequently, it was discovered that this modified Peterson reagent had also been studied by Maycock, yielding a similar outcome.44

\[ \text{(i-PrO)₃TiCl} + \text{TMSCH₂Li} \xrightarrow{-78^\circ C \text{ to r.t.}} (\text{i-PrO})₃\text{TiCH₂TMS} + \text{LiCl} \]

\[ \text{PhCH₂CHO} + (\text{i-PrO})₃\text{TiCH₂TMS} \xrightarrow{-78^\circ C \text{ to r.t.}} \text{s.m.} + \text{Condensation} \]

The next obvious choice of a metal center for our investigation of an aldehyde selective organometallic reagent was aluminum; this choice was mainly based on the
well known oxophilic behavior of aluminum and our laboratories familiarity with organoaluminum reagents. Rathke alane (R₂AlCH₂CO₂t-Bu, R = Me, Et) and its regioselective opening of allylic epoxides had been the subject of continuing interest and detailed studies in our group⁸ (Chapter 1).

As it was pointed out previously, dialkylalkynyl- and dialkylalkenyllaluminum reagents have also been employed as selective alkynyl and alkenyl transferring agents in addition to aldehydes,⁴⁵ and in stereo- and regio-selective opening of epoxides⁴⁶ (Chapter 1). The above reagents are typically prepared from the corresponding alkynyl or vinyllithium compounds and the diethyl- or the dimethylchloroalane. Exchange of lithium with aluminum reduces the reactivity of the organometallic reagent thereby increasing its selectivity. The high regio- and stereoselectivity of the aluminum reagents is thus explained by the lower nucleophilicity and higher oxophilicity of organoaluminum reagents, compared to lithium or magnesium reagents.

Considering the studies above, replacement of the acetate group in the Rathke alane by a TMSCH₂ group would appear to be a reasonable choice for development of a suitable TMSCH₂ group transferring agent (figure 2-3).

\[
\text{R}_2\text{AlCH}_2\text{CO}_2\text{Bu}^+ \rightarrow \text{R}_2\text{AlCH}_2\text{TMS}
\]

Figure 2-3
Based on the stability of the TMSCH$_2$ anion, the preferred transferal of this substituent over the ethyl or the methyl would also be expected. The higher stability order of the TMSCH$_2$ anion compared to the analogous hydrocarbon anions has been established by gas phase studies conducted by Brauman;$^{47}$ other evidence for this higher stability include the preparation of TMSCH$_2$Li by direct lithiation of tetramethyldisilane using n-BuLi and TMEDA.$^{48}$

In spite of these considerations, the reaction of Me$_2$AlCH$_2$TMS (DMTA) with phenylacetaldehyde offered very small amounts of the TMSCH$_2$ addition product and more of another which was later identified as the methyl addition product (figure 2-4). The use of Et$_2$AlCH$_2$TMS (DETA) adduct did not effect the outcome of the reaction, and yielded the ethyl addition as the major product.

![Chemical Reaction](image)

Figure 2-4

An alternate solution to the unexpected preferred transferal of the methyl and the ethyl group was the replacement of the alkyl groups on aluminum with other less nucleophilic substituents, which would have a stronger bonding to aluminum, e.g. halogens and phenoxy groups. The lowered nucleophilicity of the organoaluminum reagent, due
to exchange of the alkyl groups with the more electronegative substituents was expected; however, the extent of this effect was not predictable.

In investigating the reactivity of these reagents, both AlCl$_3$ and AlBr$_3$ were used to prepare $X_2$AlCH$_2$TMS and XAl(CH$_2$TMS)$_2$. The preparation was performed by adding one or two equivalents of TMSCH$_2$Li to the hexane solution of the corresponding aluminum halides (figure 2-5). The spontaneous reaction of the aluminum halide and the alkyl lithium was accompanied by precipitation of LiBr and slight warming of the reaction solution.

As in the cases above, reaction of these reagents with selected carbonyls (cyclohexanone, heptanal, benzaldehyde) proved unsatisfactory, yielding small amount (10% <) of the desired product and aldol condensation or unreacted starting material as the major products (figure 2-6).
The use of catechol (catechol = Cat) as a potential substituent on aluminum was also investigated. Catechol substrates of aluminum were prepared by reaction of equimolar solutions of catechol (THF or CH$_2$Cl$_2$ solution) and dimethyl chloroalane (hexanes solution), yielding the evolution of methane and the production of CatAlCl (figure 2-6). CatAlCl (2-6a) can be subsequently reacted with TMSCH$_2$Li producing CatAlCH$_2$TMS (2-6b) and LiCl. The reaction of this reagent with heptanal resulted in small amounts of reduced aldehyde (up to 25%) and mostly condensation products with no evidence of any TMSCH$_2$ addition products.

![Chemical Reaction Diagram](image)

The presence of the reduced aldehyde in this set of reactions in the absence of any addition or oxidized
addition products, rules out the MPV reduction and the Oppenauer oxidation processes. A closer inspection of the GC/MS analysis shows condensation products of heptyl heptanoate with heptanal, which is an evidence for the Tishchenko reaction\textsuperscript{49} (figure 2-7). While the Tishchenko reaction is similar to the Cannizzaro reaction in that the aldehyde is both oxidized and reduced, the two differ in the conditions and the outcome of their reactions. The trialkoxy aluminum catalyzed Tishchenko reaction is not limited to non-enolizable aldehydes and yields an ester as the major product.

\[
\begin{align*}
    &\text{RCHO} &\text{i-PrO}_3\text{Al} &\rightarrow &\text{RCOCH}_2\text{R} \\
    &\text{R = alkyl, aryl}
\end{align*}
\]

Figure 2-7

The exact structure of the catechol based aluminum reagent is not known, since the high oxophilicity of aluminum (Chapter 1) could cause the formation of dimers or higher aggregates with the alkoxide substituents. The formation of aggregates with both the catechol and halide substituted aluminum reagents together with the inductive electron withdrawing effect of the oxygen and the halogens on aluminum are the most likely reasons for their observed lack of reactivity.

The unsatisfactory results in these experiments with various substituents on aluminum, directed at modifying the
Peterson olefination reagent, led to a more detailed study of the mixed trialkylaluminums and their reactions with carbonyls. The purpose of this study was to obtain a better understanding of the reactivity of the mixed trialkylaluminums, and perhaps be able to determine the criteria and the factors which govern the preferred transferal of the substituents on aluminum. The factors to be considered are a) statistical factors, i.e., the ratio of ethyl and methyl to TMSCH₂, b) steric reasons, i.e., the bulk of TMSCH₂, c) electronic reasons related to the stability of the different alkyl anions or d) perhaps a combination of all or some of the factors above.

The reactions of five aluminum reagents with selected carbonyl compounds were used for this study. The carbonyl compounds included three aldehydes (heptanal, benzaldehyde, phenylacetaldehyde) and two ketones (cyclohexanone and fluorenone). The aluminum reagents employed were diethyltrimethylsilylmethylaluminum (Et₂AlCH₂TMS, DETA), diethylbis(trimethylsilylmethyl)aluminate [Li⁺(Et₂Al(CH₂TMS)₂⁻], DEDTA), dimethyltrimethylsilylmethylaluminum (Me₂AlCH₂TMS, DMTA), Lithium methylbis(trimethylsilylmethyl)aluminate [Li⁺(MeAl(CH₂TMS)₂⁻], MDTA), trimethylaluminum (Me₃Al, TMA), and tris(trimethylsilylmethyl)aluminum (Al(CH₂TMS)₃, TTMA). Each reagent was prepared (with the exception of Me₃Al) by adding the required amount of TMSCH₂Li (1.0 M in pentane) to the corresponding hexanes solution of the dialkyl chloroalane, alkyl dichloroalane or aluminum.
trihalide (figure 2-8). Once prepared the reagents were used immediately. The product distribution of these reactions was determined by GC analysis using an internal standard (tridecane), the yields were calculated as % conversions and are listed in tables 2-1, 2-2, and 2-3.

\[
\begin{align*}
R_2AlCl + TMSCH_2Li & \xrightarrow{-78^\circ \text{C to r.t.}} R_2AlCH_2TMS + LiCl \\
R_2AlCl + 2 TMSCH_2Li & \xrightarrow{\text{Hexanes}} [R_2Al(CH_2TMS)_2]^-Li^+ + LiCl \\
RA_1Cl_2 + 2 TMSCH_2Li & \xrightarrow{\text{Hexanes}} [RA_1(CH_2TMS)_2]^- + 2 LiCl \\
RA_1Cl_2 + 3 TMSCH_2Li & \xrightarrow{0^\circ \text{C to r.t.}} [RA_1(CH_2TMS)_3]^-Li^+ + 2 LiCl \\
AlCl_3 + 3 TMSCH_2Li & \xrightarrow{0^\circ \text{C to r.t.}} Al(CH_2TMS)_3 + 3 LiCl
\end{align*}
\]

R = Me, Et

Figure 2-8

Because of the facile alkyl exchange capability of mixed trialkyl aluminums, it is not possible to determine the exact structure of the alkylating agent. As was discussed in Chapter 1, mixed trialkyl aluminums exist predominantly in a dimer structure where the unbranched smaller alkyl groups occupy the bridging positions. Thus, in the cases of DMTA and DETA the most likely structures for the equilibrated mixed alanes are depicted in the following equations (figure 2-9).
Both DMTA and DETA can exist as dimers of the original monomers \((2-9a)\) or could equilibrate to produce a new dimer \(2-9c\) and \(R_3Al\) as illustrated in equations \(2-9b\) and \(2-9c\). If the equilibration \(2-9b\) dominates, then the majority of the ethyl and methyl addition products would be the result of \(R_3Al\) alkylation. It is possible for \(R_3Al\) to be the major alkylating agent even if its concentration is low in the solution. The facile reaction of \(R_3Al\) with carbonyls could lead to steady production of this aluminum reagent by shifting the equilibrium \(2-9b\) to the right. The slow production of \((TMSCH_2)_3Al\) and its inability for association into a more stable dimer\(^50\) however, is expected and was shown to disfavor the equilibrium suggested by equation \(2-9d\) (Chapter 4).

\[
2 R_2AlCH_2TMS \xrightleftharpoons[k_1, k_{-1}]{k_2, k_{-2}} RAl(CH_2TMS)_2 + R_3Al (2-9b)
\]

\[
2 RAl(CH_2TMS)_2 \xrightleftharpoons[k_2, k_{-2}]{(2-9d)} Al(CH_2TMS)_3 + R_2AlCH_2TMS
\]

\(R = \text{Me, Et}\)
The structure for MDTA can be compared to that of (i-Bu)₂MeAl where its NMR studies have concluded that this species exists in a dimeric form (2-9c) with the majority of the methyl groups occupying the bridge positions³⁰ (Chapter 1).

The role or effect of the lithium halide salts present in the reaction mixtures, due to in situ preparation of the aluminum reagents, is not well known, and will not be elaborated on in this chapter.

Reactions of TMA, DMTA, DETA, and MDTA with Aldehydes and Ketones

The simplest of alltrialkyl aluminums, Me₃Al, though an effective alkylating agent for aldehydes and ketones, has not found widespread use in organic synthesis (Chapter 1). The selectivity of TMA allows its use in presence of lactones and esters under controlled conditions.³ This carbonyl selectivity of TMA combined with its impressive yields of addition products(table 2-1), illustrate its potential for employment in organic synthesis. The best yields for reactions of Me₃Al with carbonyl compounds are obtained in hydrocarbon solvents at 0 °C, where the reactions are usually complete within ten minutes.

An overview of the reactions of DMTA, the nexttrialkylaluminum in table 2-1, with all of the carbonyls shows a larger than statistical (2:1) ratio of methyl to TMSCH₂ addition. These ratios hints to the presence of
other factors that are governing the preferential transferal of one group over the other.

The Me:TMSCH₂ ratio of addition is similar in all of the DMTA examples except for fluorenone. Fluorenone is both less reactive (conjugation of the carbonyl group with the two aromatic rings) and sterically more demanding towards nucleophilic additions. The steric limitations caused by the two ring hydrogens at 1 and 8 positions of fluorenone particularly reduce the access of large nucleophiles, such as the TMSCH₂ anion. This lower reactivity is clearly evident in all reactions of fluorenone with TMSCH₂ containing alanes, notably so in the reactions with DMTA and TTMA.

Cyclohexanone, the other ketone studied, is more reactive and sterically less demanding than fluorenone, however, because of the presence of its α-hydrogens, it can be enolized. The less reactive and highly Lewis acidic aluminum reagents in this study facilitate the enolization, which is responsible for significant amounts of unreacted starting material and aldol condensation products. The results from the reaction of cyclohexanone with DMTA show lower yields than that of the aldehydes; nevertheless, the Me:TMSCH₂ addition ratio (8.2) is comparable if not higher than that of the aldehydes. The same argument holds true for the reaction of cyclohexanone with DETA. Here once again, the overall yield is much lower than others, but the Et:TMSCH₂ addition ratio (3.2)
TABLE 2-1. Reaction of \( R^"R'_{2}Al \) (\( R^" = \text{Me, TMSCH}_2 \), \( R' = \text{Me, Et} \)) with selected carbonyl compounds.

\[
\text{CARBONYL} + R^"R'_{2}Al \rightarrow R_2R'_1R'' \quad + \quad R_2R'_1R''
\]

<table>
<thead>
<tr>
<th>CARBONYL</th>
<th>( R^&quot;R'_{2}Al )</th>
<th>( R^&quot; )</th>
<th>( R' )</th>
<th>( R_1 )</th>
<th>( R_2 )</th>
<th>( R'_1 )</th>
<th>( R'_2 )</th>
<th>( R'' )</th>
<th>( R'/R'' )</th>
<th>( \text{Red.} )</th>
<th>( \text{OTHER} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{CHO} )</td>
<td>Me</td>
<td>Me</td>
<td>99(^b)</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>TMSC</td>
<td>Me</td>
<td>71</td>
<td>9 (&lt;1)(^a)</td>
<td>7.9</td>
<td>&lt;1</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>TMSC</td>
<td>Et</td>
<td>85</td>
<td>&lt;1</td>
<td>142</td>
<td>--</td>
<td>7[12]</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>( \text{CHO} )</td>
<td>Me</td>
<td>Me</td>
<td>43</td>
<td>7.3</td>
<td>5.9</td>
<td>--</td>
<td>6SM, 2C</td>
<td>--</td>
<td>--</td>
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<td>9</td>
<td>6.7</td>
<td>--</td>
<td>2SM</td>
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<td>2</td>
<td>29</td>
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<td>6[10]</td>
<td>--</td>
<td>--</td>
<td>--</td>
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<tr>
<td>( \text{CHO} )</td>
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<td>Me</td>
<td>80(^b)</td>
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<td>--</td>
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<td>--</td>
<td>--</td>
<td>20SM</td>
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<td>6</td>
<td>8.2</td>
<td>--</td>
<td>13C</td>
<td>--</td>
<td>--</td>
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<tr>
<td>TMSC</td>
<td>Et</td>
<td>26</td>
<td>8</td>
<td>3.2</td>
<td>--</td>
<td>5C</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>( \text{CHO} )</td>
<td>Me</td>
<td>Me</td>
<td>97(^b)</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>4SM</td>
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</tr>
<tr>
<td>TMSC</td>
<td>Me</td>
<td>73</td>
<td>3</td>
<td>24</td>
<td>--</td>
<td>8SM</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
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<td>Et</td>
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<td>&lt;1</td>
<td>146</td>
<td>15[5]</td>
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<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

**Note:**
- TMSC = TMSCH\(_2\), S.M. = starting material, C = condensation products.
- \( a \): % methyl ketone, \( b \): uncorrected GC results.
- RED.: reduction
- [ ] = R / RED.. All yields calculated as percent conversion, based on GC analysis using tridecane as an internal standard.
is surprisingly smaller than that for the aldehydes. The reaction of cyclohexanone with MDTA, holds yet another surprise; the overall yield is low as usual, but the Me:TMSCH₂ addition ratio is identical to benzaldehyde (2.8). In all of the above cases the lower overall yields from cyclohexanone can be attributed to the enolization problem, and the similar Me:TMSCH₂ addition ratios of cyclohexanone and benzaldehyde indicate a similar steric environment. Since cyclohexanone is the only sterically less hindered ketone studied it would be difficult to arrive at or propose any other conclusions about its similar reactivity to that of benzaldehyde.

The lower reactivity of benzaldehyde compared to the other aldehydes observed in this set of reactions is probably due to the conjugation of the carbonyl to the aromatic ring which decrease the electrophilicity of the carbonyl group. The product ratios from the reaction of benzaldehyde with DMTA is similar to that of the other aldehydes, with a slightly larger Me:TMSCH₂ addition ratio (7.9). A slight difference in the outcome of the reaction of benzaldehyde with DMTA vs. other aldehydes is the result of small amounts of oxidation and reduction products which are undetectable in other cases. The oxidized and reduced side products are due to the Meerwein-Pondorff-Verley (MPV) reduction of the starting aldehyde and Oppenauer oxidation of the alcohol product.
TABLE 2-2. Reaction of \( R''_2R'Al \) (\( R'' = \text{TMSCH}_2 \), \( R' = \text{TMSCH}_2 \), Me) with selected carbonyl compounds.

\[
\text{CARBONYL} \xrightarrow{R''_2R'Al} \begin{align*}
\text{OH} \\
\text{R}'' \hspace{1em} \text{R}' \\
\text{R}'' \hspace{1em} \text{R}' \\
\end{align*}
\]

<table>
<thead>
<tr>
<th>CARBONYL</th>
<th>( R'' ) ( R' ) ( R''_2R'Al )</th>
<th>( R'' ) ( R' )</th>
<th>( R'' ) ( R' )</th>
<th>( R'' / R' )</th>
<th>( \text{Red.} )</th>
<th>( \text{OTHER} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzaldehyde</td>
<td>TMS</td>
<td>Me</td>
<td>54</td>
<td>19</td>
<td>2.8</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>TMS</td>
<td>TMS</td>
<td>--</td>
<td>45 (19) ( ^a )</td>
<td>--</td>
<td>33</td>
</tr>
<tr>
<td>Benzylaldehyde</td>
<td>TMS</td>
<td>Me</td>
<td>19</td>
<td>24</td>
<td>0.79</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>TMS</td>
<td>TMS</td>
<td>--</td>
<td>14</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>TMS</td>
<td>TMS</td>
<td>--</td>
<td>14</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>2-Methylpropanaldehyde</td>
<td>TMS</td>
<td>Me</td>
<td>18</td>
<td>29 (9) ( ^a )</td>
<td>0.62</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>TMS</td>
<td>TMS</td>
<td>--</td>
<td>77</td>
<td>--</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Cyclohexanone</td>
<td>TMS</td>
<td>Me</td>
<td>29</td>
<td>10</td>
<td>2.8</td>
<td>--</td>
</tr>
<tr>
<td></td>
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<td>TMS</td>
<td>--</td>
<td>12</td>
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<td></td>
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<td>8C</td>
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<td>--</td>
</tr>
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<td>TMS</td>
<td>--</td>
<td>4</td>
<td>--</td>
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</tr>
</tbody>
</table>

\( \text{TMS} = \text{TMSCH}_2 \), \( \text{SM} = \text{starting material} \), \( \text{C} = \text{condensation products} \).
\( \text{RED.} = \text{reduction} \).
\( ^a \) methyl ketone, also included in the total yield.
All yields were calculated as \% conversion, based on GC analysis, using tridecane as an internal standard.
Reaction of benzaldehyde with DETA (table 2-1) yields a majority of ethyl addition with very small amounts of TMSCH₂ addition; the ratio of the two products being noticeably larger (142) than the other carbonyl compounds, except for that of fluorenone. The significant amount of reduced aldehyde (benzyl alcohol, 7%) in this reaction which is greater than the TMSCH₂ addition product (1%<) results from β-hydride reduction. The reaction of MDTA with benzaldehyde (table 2-2) gives a Me:TMSCH₂ addition ratio of 2.8 which is unlike the product ratios of other aldehydes and is identical to cyclohexanone.

In general, reactions of phenylacetaldehyde with trialkylaluminums and even alkyllithiums give lower yields, with unreacted aldehyde and aldol condensation products as the majority of the side products. This problem arises from the acidic hydrogen of phenylacetaldehyde, which is alpha to both the aromatic ring and the carbonyl group, and facilitates the enolization of the aldehyde. The reaction of phenylacetaldehyde with DMTA and DETA (table 2-1) is typical of the reactions of the other aldehydes, with similar Me:TMSCH₂ and Et:TMSCH₂ addition ratios of 5.9 and 12 respectively. The Me:TMSCH₂ addition ratio from the reaction of phenylacetaldehyde with MDTA (table 2-2) (0.79) comes close to the statistical ratio of 0.5, a sign of higher reactivity of the aldehyde and thus, lower selectivity of the reagent with this carbonyl compound.
Heptanal is as reactive as phenylacetaldehyde with a lesser tendency for enolization, and its reactions with DMTA and DETA (table 2-1) result in outcomes similar to that of phenylacetaldehyde. Heptanal also affords a close to a statistical ratio of Me:TMSCH₂ addition ratio (0.69) in its reaction with MDTA (table (2-2), indicative of its higher reactivity, and thus lower selectivity.

Reactions of TTMA with Aldehydes and Ketones

The results listed in table 2-2 for the reaction of TTMA with carbonyl compounds are not an accurate measure of this reagent's reactivity or usefulness. However, these results expose some of the problems of the aluminum reagents, and give an insight into their reactivities. The basis for the above comments is the variety of ways that TTMA can be prepared and used. For this set of reactions the reagent was prepared (in situ) by adding three equivalents of TMSCH₂Li to one equivalent of anhydrous 99.99% AlCl₃ (methylene chloride solution) with stirring at room temperature for 2.5 hours. Since other similar preparations call for extended reflux times, it is not clear if in the preparation above, the formation of TTMA is complete before its use (details on other methods for preparation and use of this reagent will be discussed in Chapter 3).
Reaction of benzaldehyde with TTMA shows three major products, TMSCH₂ addition (26%), benzyl alcohol (33%) and acetophenone (19%). The benzyl alcohol is the product of the MPV reduction of the aldehyde, which is concurrent with the Oppenauer oxidation of the β-hydroxysilane, producing the β-ketosilane. Acetophenone is believed to be the result of the loss of TMS group from the β-ketosilane, which is sensitive to enolization and desilylation. The desilylation could occur either during the reaction through enolization of the ketone, or during initial steps of the work up from the direct desilylation of the β-ketosilane.

The extensive oxidation and reduction in these reactions seem to be partially due to the lower reactivity of the bulkier aluminum reagent. The slow addition of the reagent combined with unreacted aldehyde gives the ideal conditions for this oxidative and reductive processes (Chapter 1).

The low reactivity of TTMA seems to lead to a larger degree of enolization in its reaction with phenylacet-aldehyde, and hence to larger amounts of aldol condensation and recovered starting material.

Heptanal gave the best TMSCH₂ addition results, with a very small amount of reduction, in its reaction with TTMA. This higher yield of addition product is most likely due to the higher reactivity and lower enolization tendency of heptanal.
In reactions of TTMA with cyclohexanone, poor yields of addition and large amounts of aldol condensation products were noted together with recovered starting material. The results from this reaction were predictable considering the lower reactivity and ease of enolization of cyclohexanone compared to other carbonyls.

The effect of the bulk of the TTMA reagent on its reactivity becomes more apparent in its reaction with fluorenone, where after similar reaction time (4 hours) as other carbonyls, only 4% of addition product is obtained.

Results and Discussion

A better insight to the reactivity and nature of these reagents (DETA, DMTA, and MDTA) is obtained by an overall look at the experimental results. In comparing the product ratios from the reactions of DETA and DMTA one sees: first a larger ratio of simple alkyl addition than TMSCH₂ addition with DETA, and second, a comparable amounts of reduction with DETA vs. TMSCH₂ addition with DMTA. The difference in reactivity of these two reagents could be due to the bulk of the reagent and/or the variety of the pathways for their reactions. For DMTA there are two paths of reaction, either transferring of the methyl or the TMSCH₂ group. In the case of DETA there are three paths of reaction a) ethyl addition, b) TMSCH₂ addition, and c) β-Hydride reduction. The transferal of the methyl group
from DMTA seems to be much more facile than that of the TMSCH$_2$ group, which also holds true for DETA, however with DETA there is an additional reaction pathway, the $\beta$-hydride reduction, that could compete with the transferal of the TMSCH$_2$ group. The $\beta$-hydride reduction indeed competes with the TMSCH$_2$ transferal as is evident by the greater amount of reduction vs. addition observed in the reactions of DETA with carbonyls.

Reactions of MDTA with carbonyls shows a significantly larger amount of TMSCH$_2$ addition than any of the previous reactions. However, only in cases of heptanal and phenyl-acetaldehyde does the Me:TMSCH$_2$ ratio (0.62 and 0.79) come close to the statistical one (0.5). There are also larger amounts of oxidation and reduction products that could be explained by the larger size and hence more sluggish reactivity of MDTA (as discussed for TTMA); the effect of the $\beta$-silyl group on the oxidation rate of the alcohol is also an important factor which will be discussed in Chapter 3. This MPV reduction of the starting material is possible only with aldehydes and is detected in all of the three examples. However, the Oppenauer oxidation product which should accompany the reduction is not detectable by GC analysis of all of the product mixtures. The absence of the oxidized products from GC chromatogram could be due to three factors; first, the retention time of the alcohol and its oxidized adduct, the ketone, are very close in most cases so the identification of the two is difficult,
second, the ketone adducts could readily undergo multiple aldol condensations and not be detected on GC, and lastly, the possibility of the Tishchenko reaction exists which could lead to esters and their subsequent crossed-Claisen condensations, all of which would also be undetectable by GC.

The explanation for the preferred or faster addition of the simple alkyl groups vs. TMSCH$_2$ group could be steric, electronic, or a combination of both. Electronically, according to the literature and the research done in our group; the more stable carbanion on aluminum is transferred more readily, and in most cases exclusively, to the electrophile. In these studies the TMSCH$_2$ anion is the more stable carbanion when compared to the methyl or ethyl anions, and thus should be the preferred transferal group.

Sterically, larger more bulkier substrates on aluminum would inhibit or slow down the complexation of the aluminum and the carbonyl oxygen. These types of complexes are believed to be the first intermediates in the formation of addition products and are assumed to be on the pathway leading to the transition state for successful transferring of the alkyl groups (Chapter 1).

Preferential addition of the methyl and ethyl groups in our studies of the mixed trialkylaluminums do not support the correlation between carbanion stability and preferential transferring of that group. This contra-
diction, nevertheless, can be explained by the size of the TMSCH$_2$ group. In this instance the steric factors seem to outweigh the electronic ones. Even though TMSCH$_2$ is the more stable anion, the bulk of the group and the steric requirements of the transition state inhibit its preferential delivery. Even when tris(trimethylsilyl-methyl)methylaluminate [(TMSCH$_2$)$_3$MeAl-Li$^+$], prepared from the reaction of 1:3 ratio of methylaluminum dichloride to TMSCH$_2$Li, was allowed to react with equimolar amounts of benzaldehyde, only 42% of TMSCH$_2$ addition compared to 46% of methyl addition was observed (figure 2-10). Even though

\[ \text{[(TMSCH$_2$)$_3$MeAl-Li$^+$]} + \text{PhCHO} \xrightarrow{\text{hexanes, } 0\, ^\circ\text{C} - \text{r.t.}} \text{PhCHCH$_3$OH} + \text{PhCHCH$_2$TMSOH} \]

Figure 2-10

the aluminum species in this example is an anionic one (the ate complex), and it does not possess the oxophilic character of the aluminum reagents discussed previously, nevertheless, it shows the greater facility of methyl addition vs. the TMSCH$_2$ addition.

In the reactions of [(TMSCH$_2$)$_2$Et$_2$Al-Li$^+$, (BTDEA)] with carbonyls, the preferential delivery of the two substituents can be compared without the interference of the statistical considerations (table 2-3). In all three examples of the reactions of BTDEA with carbonyls, ethyl addition was the major pathway observed, and due to the
TABLE 2-3. Reaction of (TMSCH₂)₂Et₂Al⁻Li⁺ with selected carbonyl compounds.

\[
RCHO + (TMSCH₂)₂Et₂Al⁻Li⁺ \rightarrow \text{ALDEHYDE} \quad \text{OH} \quad \text{OH} \quad \text{CH₃} + \quad \text{OH} \quad \text{TMS}
\]

<table>
<thead>
<tr>
<th>ALDEHYDE</th>
<th>OH R CH₃</th>
<th>OH R TMS</th>
<th>R/TMSC</th>
<th>S.M.</th>
</tr>
</thead>
<tbody>
<tr>
<td>benzaldehyde</td>
<td>96</td>
<td>&lt; 1</td>
<td>193</td>
<td>--</td>
</tr>
<tr>
<td>cyclohexanone</td>
<td>58</td>
<td>2</td>
<td>31</td>
<td>12</td>
</tr>
<tr>
<td>hexanal</td>
<td>63</td>
<td>9</td>
<td>7</td>
<td>--</td>
</tr>
</tbody>
</table>

TMS = TMSCH₂, S.M. = starting material, yields were calculated as % conversion, and based on GC analysis using tridecane as an internal standard.

lower oxophilicity of this aluminum species, no β-hydride reductions of the carbonyls were observed. Based on the reactions of tetraalkylaluminates discussed above, the alkylating species is most likely the tetracoordinated aluminum rather than the dissociated alkyl anion (figure 2-11). The most favorable dissociation of the aluminate should be due to the loss of the larger and more stable TMSCH₂ carbanion to give a less crowded aluminum center and a more stable dissociated carbanion. However, if this were true, then the major product should have resulted from the
TMSCH₂ addition, not ethyl addition as was observed in all of the examples. Information available in literature related to our investigations is the study on the stability of tetraalkylaluminates which demonstrates that lithium tetramethylaluminate undergoes exchange reactions less readily than trimethylaluminum. This study then, is also in support of the mechanism of alkyl addition to carbonyls via the associated tetraalkylaluminate.

The most important outcome of the reactions of BTDEA with carbonyl compounds, is its evidence for much faster addition of the ethyl group when statistically there is an equal probability of addition by both substituents. Furthermore, these results illustrate that, even with possibly two different mechanisms of addition (ate species vs. the uncharged alane), the smaller alkyl group transfers much more readily than the larger TMSCH₂ group.

A conclusion relevant to the development of a selective Peterson methylenating reagent is the relationship between the reactivity of the trialkylaluminum and its size. This correlation is especially noticeable in reactions of fluorenone, where as the bulk of the organoaluminum increases (TMA < DMTA ≈ DETA < MDTA < TTMA), the reactivity and the alkyl addition yield decreases.
CHAPTER III

PREPARATION, AND REACTIONS OF THE ALDEHYDE SELECTIVE
(TMSCH₂)₃Al REAGENT
WITH KETONES AND ALDEHYDES

Preparation of (TMSCH₂)₃Al

The most relevant ramification from the study of the mixed trialkylaluminum, for our pursuit of a selective Peterson reagent, was the emergence of (TMSCH₂)₃Al as an aldehyde-selective alkylating agent. Preliminary investigations of the reactivity of TTMA showed close to a three-fold selectivity in the alkylation of benzaldehyde in presence of cyclohexanone. This encouraging result led to further investigation of both the reactivity and various preparative methods of TTMA.

The synthesis and isolation of TTMA offered one of the more challenging tasks of this research project, where even the various methods of its preparation offered no help in carrying on this task. In order to obtain enough TTMA for a complete study of its reactions with carbonyl compounds, all but one of the preparation methods had to be
investigated. As mentioned in chapter 2, there were three known methods for preparing TTMA that employed different organometallic reagents, and a proposed new method which utilized trialkylborane and trialkylaluminum exchange process (figure 3-1).

The first reported synthesis required a tedious fourteen day reflux period of a mixture of Hg(CH₂TMS)₂, aluminum foil and toluene (3-1a). In this report (TMSCH₂)₃Al was characterized as a colorless pyrophoric liquid (b.p. 51 °C at 0.08 mm Hg), which appears to give a mixture of monomeric and dimeric species in benzene. The proton NMR of TTMA in toluene showed two single peaks at 0.34 ppm (Me₃Si⁻) and -0.22 ppm (-CH₂-) with a 4.5:1 ratio.

\[ 3(\text{Me}_3\text{SiCH}_2)_2\text{Hg} + 2 \text{Al/Hg} \xrightarrow{110 \, ^\circ\text{C}} \xrightarrow{14 \, \text{days}} 2 (\text{Me}_3\text{SiCH}_2)_3\text{Al} + 3 \text{Hg} \] (3-1a)

\[ 3 \text{TMSCH}_2\text{Li} + \text{AlBr}_3 \xrightarrow{\text{hexanes, reflux}} \xrightarrow{12 \, \text{hrs}} (\text{TMSCH}_2)_3\text{Al} + 3 \text{LiBr} \] (3-1b)

\[ 3 \text{TMSCH}_2\text{Li} + \text{AlCl}_3 \xrightarrow{\text{r.t., 45 min.}} \xrightarrow{\text{ClCH}_2\text{CH}_2\text{Cl}} (\text{TMSCH}_2)_3\text{Al} + 3 \text{LiCl} \] (3-1c)

figure 3-1

The newer and more convenient synthesis (3-1b) involved a 12 hour reflux of a 3:1 mixture of TMSCH₂Li (1.0 M, pentane solution) and aluminum bromide (suspended in hexane). Another similar reported method (3-1c) required only a thirty minute stirring of anhydrous AlCl₃ and TMSCH₂Li (three equivalents) in 1,2-dichloroethane at
room temperature. The TTMA reagent mixture was then used in situ for chemoselective synthesis of allyltrimethyl-silanes via the coupling of TTMA with vinyl triflates (figure 3-2).

\[
\begin{align*}
\text{Ph} & \quad \overset{\text{OSO}_2\text{CF}_3}{\text{ClCH}_2\text{CH}_2\text{Cl}, \text{PhH}} \\
1.4 \text{ eq. TTMA, Pd(0)} & \quad \rightarrow \\
\text{Ph} & \quad \overset{\text{SiMe}_3}{\text{ClCH}_2\text{CH}_2\text{Cl}, \text{PhH}} \\
& \quad \text{81%}
\end{align*}
\]

**figure 3-2**

In order to obtain the pure TTMA in any of these synthesis, separation of the resulting metal reagent from the metal salts by vacuum (<.01 mm of Hg) distillation was required.

For our preliminary studies, the synthesis of TTMA was carried out using the AlBr$_3$ synthesis which was simple and straightforward, however, the distillation and isolation of the TTMA proved to be extremely difficult and gave low yields. In the literature, the conditions for the preliminary distillation (separation of liquid TTMA from LiBr salt) did not include temperature of the heating bath, the exact pressure (ca. high vacuum), or the amount of time required for the complete distillation. During our distillation attempts, even after six to seven hours of heating at bath temperatures of 80-90°C and a pressure of 0.01 mm (at best), lower than 45% isolated yields were
obtained (85% reported yield). Heating the distillation flask over 140°C resulted in the extensive decomposition of the solid mixture, which was apparent by its yellow discoloration. Initially, the non availability of a high vacuum source was thought to be the major cause of the difficulties and the low yields encountered. Further attempts using this synthetic and distillation procedure, even at lower pressures, suggested that other factors such as the purity of the starting materials were also affecting the outcome of the reaction.

Unsatisfied with the above synthesis, we examined other possible routes for preparation of TTMA. A less important, but novel preparation oftrialkylaluminums involves the facile exchange of alkyl groups between boron and aluminum. The preparation depends upon the progressive displacement of exchange equilibrium by distillation of the most volatile trialkylborane (figure 3-3). The recent availability of (TMSCH$_2$)$_3$B from Aldrich

$$\text{Me}_3\text{Al} + (\text{TMSCH}_2)_3\text{B} \xrightleftharpoons{\Delta} (\text{TMSCH}_2)_3\text{Al} + \text{Me}_3\text{B} \uparrow$$

(3-3a)

Figure 3-3

chemical company made this procedure even a more attractive one. The exchange of the TMSCH$_2$ groups on boron [(TMSCH$_2$)$_3$B] with the methyl groups on aluminum (Me$_3$Al, b.p. 130°C) would produce Me$_3$B (b.p. -22°C), which should
easily distill from the reaction mixture, driving the equilibrium to the aluminum side. According to the available literature on the transalkylations between trialkyl borons and aluminums,\textsuperscript{28} high reflux temperatures which exceeded the b.p. of the solvent (140°C) were needed. This information translated to the need for the neat reagents, which posed the experimental problems of obtaining and handling the highly pyrophoric neat TMA. To avoid this difficulty, the 1.0 M hexane solution of Me\textsubscript{3}Al was employed, and after addition of the neat (TMSCH\textsubscript{2})\textsubscript{3}B to this solution, the solvent was distilled off leaving a neat mixture of the aluminum and the boron reagents. After the mixture was refluxed (ca. 110°C) for 12 hours, NMR analysis of the reaction mixture showed what appeared to be a mixture of (TMSCH\textsubscript{2})\textsubscript{3}B and Me(TMSCH\textsubscript{2})\textsubscript{2}Al. The attempts to separate the boron and the aluminum species through vacuum distillation, also proved unsuccessful. The difficulty in replacing the last methyl group on aluminum, verified by the outcome of this experiment, is one more bit of evidence for the kinetically slow conversion of MDTA to TTMA, as pointed out previously (Chapter 2).

The AlCl\textsubscript{3} version of TTMA’s synthesis was also investigated; the in situ synthesis required the addition of a 3:1 ratio of TMSCH\textsubscript{2}Li solution to AlCl\textsubscript{3} (anhydrous 99.9%, in CH\textsubscript{2}Cl\textsubscript{2}), and stirring of the mixture for 2.5 hours before addition of the carbonyl compounds. As mentioned previously, the TTMA used for the reactions
discussed in Chapter 2 was prepared using the above procedure. However, the results of these reactions did not seem to be the optimal outcomes expected from reactions of TTMA. Also, it was not clear if the formation of TTMA under these reaction conditions was complete or not. In hopes of obtaining pure TTMA using this procedure, the reaction was repeated on a larger scale, and was allowed to stir for 22 hours at room temperature. As before, the attempted distillations of this reaction mixture were most unsatisfactory. Also, the reaction of the distillate (the solid reaction mixture), after the distillation attempt, with benzaldehyde afforded no TMSCH$_2$ addition products.

At that time, the only hope for obtaining reasonable amounts of neat TTMA, was to improve the yields of the AlBr$_3$ procedure. The literature procedure for the preparation of TTMA required freshly sublimed AlBr$_3$ and TMSCH$_2$Li, which was not performed in our previous attempts. Aluminum bromide was originally purchased from Alpha (99.9%, white crystalline powder), and afforded reasonable yields of distilled TTMA (up to 45%). However, the subsequent purchase of AlBr$_3$ from Aldrich (98.8%, large yellow and brown crystals), and reactions from this sample gave very low or no yields of neat TTMA. One of the concerns in using the unpurified AlBr$_3$, was the presence of aluminum oxides that could cause the formation of large aluminum aggregates and hinder the successful distillation of the TTMA. Hence, the purification of the starting
materials seemed to be the best solution for improving the yields of neat liquid TTMA.

The sublimation of the AlBr₃ was performed in a large sublimation apparatus at low pressures (0.25 mm of Hg), in a 90°C oil bath using a cold finger cooled by a dry ice acetone bath. The sublimation yielded a fine white powder which produced a white smoke during its weighing in the dry box. However, we were unable to purify the TMSCH₂Li, since it required a vacuum of 10⁻⁵ mm that was not available to us. Thus, the 1.0 M pentane solutions of TMSCH₂Li, purchased from Aldrich, had to be employed.

The sublimation of the AlBr₃ immediately before use improved the outcome of the distillation dramatically. The distillation of the TTMA from the LiBr salt started smoothly at a bath temperature of 70°C and a pressure of 0.01 mm, resulting in 56% yield of neat TTMA; all of the neat TTMA was subsequently smoothly redistilled at 45-48 °C (0.02 mm of Hg). Even though this yield was higher than the previous distillation attempts had afforded, it was still well below the literature yield of 85%. The ¹H NMR spectra of TTMA in benzene-d₆ showed two singlets, one at 0.18 ppm (9 H) and other at -0.38 ppm (2 H), belonging to the nine methyl and the three methylene groups, respectively. The ¹³C NMR spectra also showed two singlets; the larger (Me₃Si-) at 2.89 ppm and the smaller (-CH₂-) at 5.15 ppm. This improvement in the reaction yield suggests that starting materials of high purity are
essential for acceptable conversion yields, and perhaps a better quality of TMSCH$_2$Li could improve the yields even further.

In the early stages of this research the difficulty in separation of the TTMA from the lithium salt through distillation led us to attempt the separation by filtration of the reaction mixture. The filtration was carried out using the cannula filtration method, and proved to be a slow and time consuming process.

The filtration of the liquid from the mixture removed the yellow coloration of the solid, but the $^1$H NMR of the concentrated filtrate, and also its reaction with benzaldehyde, verified that the filtrate contained only very small amounts of TTMA. This suggested that almost all of the reagent was tied up (complexed) with the lithium salt. The complete removal of the solvent from the solid under vacuum produced a white solid (TTMA$_x$) which could be powdered and stored in the dry box for an indefinite periods of time (figure 3-4). This powder also proved to be a potent TMSCH$_2$ transferal agent in its reactions with

\[
3 \text{ TMSCH}_2\text{Li} + \text{AlBr}_3 \xrightarrow{\text{1) reflux, 12 hrs}} (\text{TMSCH}_2)_3\text{Al} \cdot 3\text{LiBr} \\
\xrightarrow{\text{2) removal of solvent}} \text{White powder}
\]

Figure 3-4
carbonyl compounds, further consequences of which will be discussed in the reactions of TTMA.

The formation of such strong complexes of LiBr with trialkylaluminums is not documented in the literature. Furthermore, both lithium and bromide ions are believed to have a lesser tendency and ease of complex formation with trialkylaluminums.\textsuperscript{56} Thus, it is possible that three equivalents of LiBr are needed for the formation of the white powder we had isolated. Preliminary studies on this hypothesis was performed by successive addition and then reflux of 1, 2, and 3 equivalents of anhydrous LiBr to 1 equivalent of the neat liquid TTMA (solution in hexane) and analyses of the mixture after each addition. Evaporation of solvent after reflux with 1 and 2 equivalents of LiBr gave a mixture of oil and powder; however, after the third equivalent of LiBr was added a pasty mixture was obtained. While, the results from this preliminary study are not conclusive, it appears that three equivalents of LiBr are needed for the formation of the solid complex.

The LiBr complex of TTMA (TTMA\textsubscript{4}) is mostly soluble in THF and is accompanied by a slight warming of the resulting solution. However, the proton NMR of TTMA\textsubscript{4} in THF-d\textsubscript{4} shows a large multiplet in the vicinity of 0.0 ppm which is difficult to interpret. This broadening of peaks is presumed to be the result of the complexation of THF with aluminum. Attempts at determining the stoichiometry of TTMA\textsubscript{4} by utilizing its solubility in THF-d\textsubscript{4} and employing
anhydrous anisole as an standard also proved inconclusive. While the results of this experiment showed the presence of approximately 60% neat TTMA in the LiBr salt mixture, the reaction of TTMA₄ with aldehydes indicated a minimum of 77% TTMA. These anomalies are probably the result of the presence of adventitious water in both THF and anisole.

Additional investigations on this subject are clearly necessary for understanding and utilization of this property of the trialkylaluminums.

Reactions of (TMSCH₂)₃Al

In order to investigate the selectivity of the modified Peterson reagent (TTMA) in its reactions with carbonyl compounds, there was a choice of two different species of TTMA; the neat TTMA and its lithium bromide complex (TTMA₄). However, because of our desire to compare the reactivity of the two species, it was decided to explore the reactions of both reagents with carbonyl compounds. For the purpose of this study six more aromatic aldehydes and ketones were added to the previous list of carbonyls. The new aldehydes consisted of 4-tolualdehyde, 4-chloro-, 4-methoxy-, and 4-trifluoromethylbenzaldehydes; the new ketones included acetophenone and 1-indanone.

The reaction conditions and reagent ratios for these reactions were determined according to the reactions of other trialkylaluminums. The consideration of these
factors is necessary, since they do have a considerable effect on the course of the reactions of trialkylaluminums with carbonyl groups. The major factors include the solvent, the ratio of reagent to reactant, and the temperature. While the temperature plays a less important role in reactions of trialkylaluminums, large changes in temperature do effect their reactivity. For example, trimethylaluminum is unreactive with carbonyl groups at -78°C, but the best yields are obtained when reactions are carried out at 0°C. A better selectivity seems to be obtained when reactions of TTMA are performed at room temperature, nonetheless, TTMA remains reactive at 0°C. According to our experience, hydrocarbon solvents are best suited for the reactions of trialkylaluminums with carbonyls. Halogenated solvents are also compatible with trialkylaluminums, but the more polar oxygenated solvents (THF and ether) tend to lower both the reactivity of the reagent and the yield of the reaction.

The ratio of the trialkylaluminum to the carbonyl is one of the more important factors in the outcome of their reactions, where an excess of the reagent is generally required for a clean and a high yield reaction. Published reports on reactions of trialkylaluminums with carbonyls and mechanistic considerations show that for optimal results 1.3 to 2 fold excess of the organo-aluminum is usually required.57
The reaction of neat liquid TTMA with excess benzaldehyde in hexane shows the importance of the reagent to carbonyl ratio, where the presence of excess aldehyde causes a variety of major side reactions. The additional products were identified by GC/MS analysis of the reaction mixture as the MPV oxidation/reduction and crossed-aldol condensation products (figure 3-5). The mass spectrum confirms the structure of the condensation product as \(3-5e\) or \(3-5f\), which is the result of the crossed-aldol condensation of benzaldehyde with \(\beta\)-silylketone. The silyl group could be positioned either on the oxygen as the silyl enol ether \(3-5e\) or \(\beta\) to the carbonyl \(3-5f\); however,
distinguishing the two isomers is difficult from analysis of the mass spectra. The origin of the other side products have already been discussed in Chapter 2.

Considering the importance of the reaction conditions, all the reaction of TTMA and TTMA\textsubscript{s} were carried out in hexanes at room temperature. There were four exceptions with the reactions of TTMA\textsubscript{s}; 4-methoxy- and 4-trifluoro-methylbenzaldehydes, acetophenone, and 1-indanone; here the aldehydes were added to the cooled reagent mixture (immersed in ice bath) and were warmed to r.t. within 30 minutes of the addition. The neat TTMA and TTMA\textsubscript{s} were previously prepared and stored in the dry box. Prior to each reaction the reagents were weighed into the reaction flasks inside the dry box. Outside the dry box, they were diluted with dry hexanes under an argon atmosphere.

Approximately 1.3:1 ratio of reagent to carbonyl was used for each reaction. In the case of TTMA\textsubscript{s}, since the exact stoichiometry of the salt was unknown, the formula weight of \((\text{TMSCH}_2)_3\text{Al.3LiBr}\) (549.2 g/mole) was used in measuring 1.3 equivalent of this reagent. The products and their distributions, from the reactions of TTMA and TTMA\textsubscript{s} with the aldehydes and ketones have been listed in tables 3-1 and 3-5 respectively.

An overall look at the reaction of the aldehydes with the neat TTMA reveals the extent of oxidation and reduction involved. All aldehydes, except for phenylacetaldehyde, show at least a 10\% reduction of starting material
TABLE 3-1. Reaction of (TMSCH₂)₃Al (TTMA) with selected aldehydes.

(TMSCH₂)₃Al + RCHO

<table>
<thead>
<tr>
<th>ALDEHYDE</th>
<th>TTMA</th>
<th>% CONVERSION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>ADDITION PRODUCTS</td>
</tr>
<tr>
<td>phenylCHO</td>
<td>A</td>
<td>53 (21)</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>100</td>
</tr>
<tr>
<td>tolueneCHO</td>
<td>A</td>
<td>63 (21)</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>79</td>
</tr>
<tr>
<td>CF₃ phenylCHO</td>
<td></td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>61</td>
</tr>
<tr>
<td>chloro phenylCHO</td>
<td>A</td>
<td>38 (20)</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>100</td>
</tr>
<tr>
<td>methoxy phenylCHO</td>
<td>A</td>
<td>46 (26) [13]</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>35 [31]</td>
</tr>
<tr>
<td>benzylCHO</td>
<td>A</td>
<td>41</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>38</td>
</tr>
<tr>
<td>allylCHO</td>
<td>A</td>
<td>57 (17)</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>83 (3)</td>
</tr>
</tbody>
</table>

A : neat (TMSCH₂)₃Al, B (TMSCH₂)₃Al.3LiBr salt.
( ) : % of elimination product, also included in the total addition yield listed out side the paranthesis.
[ ]: % methyl ketone, also included in the total addition yield, RED. : reduction, COND. : condensation, S.M. : starting material.
All yields were calculated by GC analysis using tridecane as an internal standard.
accompanied by its corresponding oxidation product (the methyl ketone). Ideally the amounts of oxidation and reduction products should be the same, but, as was discussed in Chapter 2, the percentage of the Oppenauer oxidation products detected by GC are generally slightly less than the MPV reduction ones.

The GC/MS analysis of the reactions of neat TTMA with 4-methoxybenzaldehyde show some products that are not detected with reactions of most other carbonyls. These include the elimination product (-TMSOH) and the trimethylsilyl protected 4-methoxybenzylalcohol. The silylated alcohol, also detected in reaction of 4-chlorobenzaldehyde with neat TTMA, could be either due to GC decomposition or an actual product of the reaction which survived the hydrolytic workup (unlikely). Elimination products are also detected in reactions of 4-chlorobenzaldehyde, acetophenone, and 1-indanone. The presence of elimination products with these carbonyls results from the effect of the substituents on the aromatic ring or α to the alcohol functionality. These substituents further enhance the stability of the benzylic cation produced upon loosing the hydroxy group, hence facilitating the elimination process. The polymerization of the reactive eliminated products (substituted styrenes) is probable, it would be undetectable on GC, and would lead to inaccurate addition yields.
TABLE 3-2. Reaction of \((\text{TMSCH}_2)_3\text{Al}\) (TTMA) elected ketones.

\[(\text{TMSCH}_2)_3\text{Al} + \text{KETONE} \quad \text{TTMA}\]

<table>
<thead>
<tr>
<th>KETONE</th>
<th>TTMA</th>
<th>% CONVERSION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>ADDITION PRODUCTS</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>26</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>39</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>7</td>
</tr>
<tr>
<td>CH₃</td>
<td>B</td>
<td>8 (5)</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>9 (6)</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>B</td>
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</tbody>
</table>

A: neat \((\text{TMSCH}_2)_3\text{Al}\).
B: \((\text{TMSCH}_2)_3\text{Al}.3\text{LiBr}\) salt.
c: % of elimination product included in this number.
S.M.: starting material, COND.: condensation products.
( ): % elimination, also included in the total yield.
Yields based on GC analysis using tridecane as an internal standard.
The impact of substituent effects on the addition reactions of aromatic aldehydes with TTMA and TTMA, is only pronounced with 4-methoxybenzaldehyde. Here, the yields of addition products are inferior to those of other aldehydes; however, the low yields may have resulted from the elimination of the TMSCH₂ addition product (-TMSOH) and its subsequent polymerization which is not detectable on GC.

The selectivity of TTMA and TTMA₂ becomes evident in its reactions with ketones. In all of these reactions starting material had been the major constituent of the product mixture, and the highest yield of addition product (43%) was obtained with fluorenone. The low reactivity of TTMA (or TTMA₂) with ketones is due to the bulk of the reagent which hinders the complexation of it with the sterically more demanding carbonyl groups. Once the complexation has been achieved, the transferal of the large TMSCH₂ substituent also seems to be slow, and it leads to the enolization of the ketone rather than addition of the bulky group. The enolization due to the high Lewis acidity of TTMA is also a problem with readily enolizable aldehydes such as phenylacetaldehyde.

A comparison of the reactions of TTMA₂ and the neat TTMA show that in general, the reactions of TTMA₂ are much cleaner and give higher yields than that of the neat TTMA. This difference could be attributed to a several speculated factors. One factor could be the observed higher stability of the TTMA₂. The neat liquid TTMA is spontaneously
flammable upon exposure to air, and produces a white smoke even on introducing deoxygenated and dried argon gas. The lithium salt (TTMA₄) however, is more stable when exposed to air; turning yellow and decomposing slowly (note that the salt is still flammable when exposed to moisture). Even in the dry box, the lower stability of the neat TTMA during its continuous usage seem to cause the formation of aluminum oxides. The presence of these oxides during reactions with carbonyls appear to increase the rate of the oxidation and reduction side reactions which are greater in reactions of the neat TTMA. Another factor is the complexation of the bromide anion with aluminum which could slightly decrease the oxophilicity of the alane (similar to the ate complex), hence decreasing the unwanted oxidation-reduction reactions after the addition of the TMSCH₂ group. And lastly, it is possible that the reactivity of the carbonyl group is enhanced by its complexation with the lithium cations present in the solution.

An indirect measure of the aldehyde selectivity of TTMA can be obtained by analysis of the tabulated results of its reactions with aldehydes vs. ketones. However, a direct measurement of this selectivity can only be achieved when both functional groups, ketone and aldehyde, are present on one substrate. This comparison, thus requires the synthesis of keto-aldehydes for a further demonstration of the TTMA’s high selectivity.
The synthesis of the first keto-aldehyde was accomplished by the lithium tri-tert-butoxyaluminohydride [LiAl(t-BuO)_3H] reduction of 4-carbonylchloride-9-fluorenone (figure 3-6). The reduction afforded 33% of the target 4-carboxaldehyde-9-fluorenone (3-6a), and 66% of the corresponding alcohol (3-6b). The aldehyde and the alcohol were separated by flash column chromatography, and subsequently the alcohol was oxidized, using PDC, to the corresponding aldehyde.

The second keto-aldehyde was synthesized by simple reductive ozonolysis of (1R)-(+)-%-pinene, to give the expected cyclobutane tethered keto-aldehyde (figure 3-7).

The reaction of 9-fluorenone-4-carboxaldehyde with neat TTMA gave a mixture of many products which were not
identified; however, reaction of the keto-aldehyde with TTMA, (r.t.) afforded the aldehyde addition product (3-8a) exclusively in less than 20 minutes (94% homogeneous by GC). The reaction of TTMA, with the 3-acetyl-2,2-dimethylcyclobutane acetaldehyde under the same conditions within 15 minutes produced 76% of the aldehyde addition product (3-8b) and less than 4% of what appeared to be the ketone addition product (uncorrected GC yields, figure 3-8).

It is important to note that none of the reactions reported in this chapter have been optimized. Thus, an optimization of the reaction conditions, such as larger ratios of TTMA, should increase the observed yields even further.

The high selectivity of TTMA, with 4-carboxaldehyde-9-fluorenone is somewhat expected, since the ketone moiety is sterically more crowded (fluorenone) than the aldehyde. Nevertheless, in 3-acetyl-2,2-dimethylcyclobutane acetaldehyde, even though the steric requirements of the two functionalities are not as varied, a 19 to 1 aldehyde selectivity is observed. The results from the reactions of
TTMA₄ with the two keto-aldehydes further demonstrate its high selectivity and potential use in organic synthesis.
CHAPTER IV

A STUDY OF THE REACTIONS OF ORGANOALUMINUM ALKOXIDES AND ARYLOXIDES WITH AROMATIC ALDEHYDES

In investigations pertaining to the mixed trialkylaluminums and their reactions with carbonyl compounds, it was noticed that the increase in the TMSCH₂ addition products was concurrent with an increase in the oxidation and reduction products. Oppenauer and Meerwein-Verley-Pondorff processes, which involve a hydride transfer through a six membered cyclic transition state, were probably responsible for these oxidation and reduction processes (figure 4-1). Additionally, the apparent increase in rates of these processes for the intermediate TMSCH₂ aluminum alcoholates (4-1a and 4-1b) was preemptively accounted for by a β-silyl effect of the trimethylsilyl substituent. Hydride transfer during the Oppenauer oxidation of the β-silylalcohol should reduce the electron density on the carbon β to the silyl group, and this deficiency is compensated for by hyperconjugative
electron release from the silyl group, which in turn facilitates the rate of the hydride transfer.

The validity of this hypothesis was examined by a comparative rate study of the Oppenauer oxidation of a β-silyl substituted alcohol vs. the unsubstituted analog. It is worth noting that this rate study was aimed at comparing the rates of the oxidations of the two alcohols under normal reaction conditions, and was not meant to be an exact determination of the oxidation rates.

\[
\begin{align*}
\text{PhCHO} & \rightarrow \text{PhCH\textsubscript{2}CH\textsubscript{2}TMS} \\
& \quad + \quad \text{PhCHCH\textsubscript{2}TMS} \\
& \quad + \quad \text{PhCHCH\textsubscript{3}}
\end{align*}
\]

\(R = \text{Me, TMSCH\textsubscript{2}}\)

Figure 4-1. The beta Silyl effect and its rate enhancement of the MPV reduction.

Trimethylaluminum was added to separate solutions (0.1 M in hexanes, 0°C) of 1-phenylethanol and 1-phenyl-2-trimethylsilylethanol. An equimolar amount of benzaldehyde was then added to each solution at room temperature (figure 4-2). The GC analysis of the reactions, monitored at periodic intervals, showed that half of the β-silylalcohol
was oxidized within the first 15 minutes of the addition, whereas 1-phenylethanol required close to 2.5 hours. This difference translates to a 10 fold rate enhancement in the oxidation of β-silylalcohol under normal reaction conditions. Even though the rate enhancement is not enormous, its effects on the reaction course is significant and apparent in tabulated reactions of TMSCH₂ substituted alanes (Chapters 2 and 3).

\[
\begin{align*}
\text{Me}_3\text{Al} + & \quad \text{PhCHCH}_3 \quad \text{PhCHCH}_3 \\
& \quad \text{PhCHCH}_3 \quad \text{PhCHO} \\
& \quad \text{PhCCH}_3 + \text{PhCH}_2\text{OH} \\
\end{align*}
\]

\[
k_2/k_1 \approx 10
\]

Figure 4-2

Shortly after completion of the above investigation, there appeared an interesting report by A. Barron that attracted our close attention.⁵⁸

This report, and a series of others by Barron,⁵⁹,⁶⁰ involved a study of the properties, structures, and reactions of BHT (2,6-di-tert-butyl-4-methylphenoxy) substituted alkylaluminums. The catalytic features of the di-BHT and analogous optically pure binaphthol substituted alkylaluminums have recently been examined by other
groups as Lewis acid activators of pericyclic reactions involving oxygen centers. Additionally, the exceptionally bulky di-BHT substituted alkylaluminums have shown excellent diastereofacial selectivity in carbonyl

\[
\text{BHT}_2\text{AlMe} = \text{MAD}
\]

alkylation with reactive organoalkyl reagents, e.g. methyl magnesium halide (figure 4-3).

However, contrary to expectations based on organoaluminum chemistry to that point, Barron had reported a novel methyl addition by \((\text{BHT})\text{Me}_2\text{Al:OEt}_2\) (DMBAE) to aromatic aldehydes to yield directly the corresponding methyl ketone (figure 4-4). In a subsequent report there was a suggestion of a rather intriguing but speculative mechanism for this, at first glance, extraordinary reaction (figure 4-4).
The methylation of an aldehyde by a dimethylaluminum alkoxide, to the best of our knowledge, was the first one of its kind reported; however, no attempts were made by the authors to explain the mode of this addition. Until this point, it was generally believed that the substitution of even one alkoxide on an alkylaluminum deactivates the aluminum in its alkyl additions to aldehydes or ketones. The addition of only one out of the three alkyl groups on trialkylaluminumums to carbonyls, further supported this belief.
The deaggregating effect of the BHT substituent on aluminum, a key factor in the unexpected methylation ability of DMBAE, is demonstrated by the low temperature (-80°C) $^1$H NMR study reported by Ittel et al. The study shows that, contrary to previous reports (eq. 4-5a), the species present in solutions of AlMe$_2$BHT (DMBA) undergo two concurrent disproportionations (eqs. 4-5b and 4-5c). This type of a dissociation is not known for similar dialkyl-aluminum alkoxides bearing smaller alkoxy substituents.

\[
2\text{AlMe}_2\text{BHT} \rightleftharpoons \frac{1}{2} \text{Al}_2\text{Me}_6 + \text{AlMeBHT}_2 \quad (4-5a)
\]

\[
\text{Al}_2\text{Me}_5\text{BHT} \rightleftharpoons \frac{1}{2} \text{Al}_2\text{Me}_6 + \text{AlMe}_2\text{BHT} \quad (4-5b)
\]

\[
3 \text{AlMe}_2\text{BHT} \rightleftharpoons \text{Al}_2\text{Me}_5\text{BHT} + \text{AlMeBHT}_2 \quad (4-5c)
\]

The larger bulk of the BHT substituent inhibits the formation of the stable and unreactive hemialkoxide, and leads to its disproportionation and higher reactivity.
From the information that is available in the literature, the identification of the actual methylating species is not possible. Trimethylaluminum is the best candidate for the possible methylating agent present in the solutions of DMBA or DMBAE; however, acetophenone reacts with AlMe₃ but it is not methylated in solutions of AlMe₂BHT or its etherate. The selection of any other methylating agent at this point would be speculative in nature. Nevertheless, with the information presented here, we will also try to shed some light on the identity of the methylating agent.

By far the most interesting and peculiar result reported by Barron and coworkers was the oxidation of an alcohol by the reduction of a dialkylaluminum aryloxide. In our investigations of the reactions of aldehydes with dialkyl alkoxy andtrialkylaluminums, discussed previously, we had also encountered reduction and oxidation products. However, the concurrent presence of the reduced aldehyde and the oxidized product was clearly suggestive of MPV and Oppenauer type of processes. In the light of our studies and the well known reduction ability of alkoxyalumino-hydrides, the quantitative conversion of the aromatic aldehydes to the methyl ketone using DMBAE through an irreversible hydride transfer to aluminum did not seem plausible. Thus, as a consequence of the anomalies discussed above, we were led to embark on our own investigation of the reactions of DMBAE with aromatic aldehydes.
The preparation of DMBAE is easily performed by mixing equimolar hexane solutions of trimethylaluminum and BHT-H (at r.t., under argon), and subsequently adding a slight excess of anhydrous ethyl ether. DMBAE can be prepared on large scale and stored in the dry box, or it can be prepared in situ and used fresh (figure 4-6).

\[
\text{BHT-H} + \text{Me}_3\text{Al} \xrightarrow{\text{Hexanes}} \text{BHTMe}_2\text{Al} + \text{CH}_4 \\
\text{BHTMe}_2\text{Al} + \text{xs Et}_2\text{O} \rightarrow \text{BHTMe}_2\text{Al:OEt}_2
\]

Figure 4-6

The reactions of DMBAE with benzaldehyde were carried out using a variety of reagent to aldehyde ratios (up to 3:1), using different solvents (hexane and toluene), and using different orders of addition (adding aldehyde to reagent and vice versa). However, all the reactions afforded only close to a 50/50 mixture of benzyl alcohol and acetophenone (table 4-1). Also, when BHTMe_2Al was reacted with benzaldehyde in the absence of ether, considerable amounts of 1-phenylethanol was also detected illustrating the important and unclear roll of the ether in the oxidation-reduction processes involved. In all of the reactions of benzaldehyde with DMBAE a small amount of 2-phenylisopropanol, a product of a possible subsequent methyl addition to acetophenone, was also detected.
Table 4-1. Reaction of aromatic aldehydes with DMBA and DMBAE

\[
\begin{array}{c}
\text{Me}_2\text{BHTAl} \\
\text{and} \\
\text{Me}_2\text{BHTAl:OEt}_2
\end{array}
\xrightarrow{\text{ArCHO} \text{ r.t.}}
\begin{array}{c}
\text{PhCH}_2\text{OH} \\
\text{PhCH}_3 \\
\text{PhC(CH}_3\text{)}_2 \\
\text{PhCHO} \\
\text{PhCHCH}_3
\end{array}
\]

<table>
<thead>
<tr>
<th>REAGENT</th>
<th>Ar</th>
<th>EQUIV.</th>
<th>SOLVENT</th>
<th>% CONVERSION</th>
</tr>
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<tr>
<td></td>
<td></td>
<td>REAGENT</td>
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<td>1</td>
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<tr>
<td>DMBAE^b</td>
<td>Ph</td>
<td>1.5</td>
<td>Hex.</td>
<td>26</td>
</tr>
<tr>
<td>DMBAE</td>
<td>Ph</td>
<td>2</td>
<td>Hex.</td>
<td>45</td>
</tr>
<tr>
<td>DMBAE</td>
<td>Ph</td>
<td>3</td>
<td>Hex.</td>
<td>34</td>
</tr>
<tr>
<td>DMBAE^a</td>
<td>4-Tol.</td>
<td>1.5</td>
<td>Hex.</td>
<td>29</td>
</tr>
<tr>
<td>DMBAE</td>
<td>Ph</td>
<td>1.5</td>
<td>Tol.</td>
<td>42</td>
</tr>
<tr>
<td>DMBAE^b</td>
<td>Ph</td>
<td>1.5</td>
<td>Tol.</td>
<td>40</td>
</tr>
<tr>
<td>DMAB^c</td>
<td>Ph</td>
<td>1.5</td>
<td>Hex.</td>
<td>19</td>
</tr>
</tbody>
</table>

**DMBA** = Me\(_2\text{BHTAl}\), **DMBAE** = [Me\(_2\text{BHTAL}\)]OEt\(_2\), Ph = phenyl, 4-Tol. = 4-Tolyl
Hex. = hexanes, Tol. = toluene, Equiv. = equivalent.

a = reaction time was only ten minutes, the rest for 3.5 to 4 hours.
b = reverse addition, added the reagent to the aldehyde. All yields based on GC analysis, using tridecane (c: BHT was used as standard) as an internal standard.
Our findings at this point were neither in accord with Barron’s results nor supportive of the reported oxidation mechanism. Thus further investigations were required to specifically examine the validity of the suggested mechanism. This task was accomplished by approaching the suggested reaction intermediates by an alternative route: addition of one or two equivalents of 1-phenylethanol to one equivalent of DMBAE should afford the correct stoichiometry and structural composition postulated as the reaction intermediate 4-4c by Barron (figure 4-7).

\[
\begin{align*}
(BHT\text{Me}_2\text{Al})\text{OEt}_2 & \, + \, \text{PhCHCH}_3 \\
(\text{B3}) & \, 1 \, \text{mmole} \, \quad 1 \, \text{mmole} \, \text{hexanes, r.t.} \, 1 - 3.5 \, \text{hrs} \\
\text{Stirring two mmoles of DMBAE with one mmole of 1-phenylethanol in hexane for three hours did not result in any detectable oxidation of the latter, as it was implicated for the proposed intermediate 4-4c. The subsequent addition of 0.5 mmole of benzaldehyde to this}
\end{align*}
\]
mixture resulted in the rapid (less than one hour) methylation and reduction of benzaldehyde (0.14 mmoles), along with a small amount of methylated acetophenone (0.03 mmoles), (table 4-2). Reaction of a 1:1 mixture of 1-phenylethanol and DMBAE (1 mmole) with benzaldehyde

Table 4-2. Reactions of B3 and B4 with aromatic aldehydes.

4-2a: Reactions with benzaldehyde
4-2b: Reactions with 4-tolualdehyde

<table>
<thead>
<tr>
<th></th>
<th>PhCH</th>
<th>PhCH₂</th>
<th>PhCH₃</th>
<th>PhCCH₃</th>
<th>PhC(CH₃)₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>B3</td>
<td>0.02</td>
<td>0.31</td>
<td>0.41</td>
<td>0.40</td>
<td>0</td>
</tr>
<tr>
<td>PhCHO +</td>
<td>0</td>
<td>0.14</td>
<td>1.1</td>
<td>0</td>
<td>0.03</td>
</tr>
<tr>
<td>0.5 mmole</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>ArCH₂</th>
<th>ArCH₃</th>
<th>ArCCH₃</th>
<th>PhCCH₃</th>
<th>PhCCH₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>B3</td>
<td>0.38</td>
<td>0</td>
<td>0</td>
<td>0.40</td>
<td>0.53</td>
</tr>
<tr>
<td>ArCHO +</td>
<td>0.18</td>
<td>0.03</td>
<td>0.13</td>
<td>0</td>
<td>0.88</td>
</tr>
<tr>
<td>0.5 mmole</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The values in tables (4-2a) and (4-2b), reported as millimoles. Reactions of B3 were run for 18-19 hours, and reactions of B4 for 5.5 hours. Ar = 4-Tolyl.
(0.50 mmoles) afforded, slowly, the reduction of the aldehyde (0.31 mmoles) and the oxidation of 1-phenylethanol to acetophenone (0.40 mmoles). Even though both experiments clearly disprove the proposed oxidation mechanism by showing the need of a hydride acceptor, the interpretation of the observed product distribution is not straightforward for two reasons: a) the methylation product of benzaldehyde, 1-phenylethanol, is also used as a starting material which obscures the origin of the alcohol in the final product ratios, b) 1-phenylethanol and acetophenone exhibit very close GC retention times (separated by only 0.03 minutes) which results in peak overlap at certain concentrations and perturbs the accuracy of the GC analysis. To alleviate these difficulties, the above reactions were repeated using 4-tolualdehyde for which the GC retention time of methylated adduct and its oxidized form are well separated.

The reaction of reagent B3 (figure 4-7) with 4-tolualdehyde is a slow process which takes more than 5 hours to complete and yields only the oxidation and the reduction products (similar to benzaldehyde, table 4-2). Since the above reaction is very slow, unlike the reaction of DMBAE with benzaldehyde, and there are no methylated 4-tolualdehyde products, then it is clear that the species of aluminum involved in this reaction are not responsible for the oxidation or the methylation processes of DMBAE.
The reaction of reagent B4 (figure 4-7) with 4-tolu-aldehyde is a much faster process (less than 1 hour) and is similar to the reaction with benzaldehyde with the same reagent B4. The products from this reaction include the methylation and reduction of 4-tolualdehyde along with the oxidation of the methylation product (table 4-2). The difference between this reaction and that of benzaldehyde is the apparent consumption of the acetophenone in the latter reaction by the condensation with benzaldehyde.

The most striking observation of the product distribution for the 4-tolualdehyde reaction with B4 is the exclusive reduction, oxidation, and methylation of the 4-tolualdehyde and almost complete recovery of the starting 1-phenylethanol. An important conclusion drawn from this observation is that the methylation and the oxidation occur so rapidly that there is no possibility of a substituent exchange. This conclusion also implies that no 1-phenylethoxides are present on the methylating and oxidizing aluminum species. In light of this outcome, our earlier hypothesis, of trimethylaluminum as the methylating reagent appears more certain. To further justify our hypothesis it was decided to do a comparative rate study of the Oppenauer oxidation of 1-phenylethanol using trimethylaluminum and DMBAE (figure 4-8).

This experiment was carried out by mixing 1-phenyl-ethanol (0.02 M solution) with separate equimolar solutions of TMA and DMBAE (1:1 ratio). Subsequently, a solution of
benzaldehyde (1 equivalent, r.t.) was added to each mixture. The monitoring of these reactions by GC showed that the oxidation of the alcohol with the TMA-1-phenyl-ethanol adduct was half complete within two hours, whereas, even after 5 hours, the oxidation of the DMBAE-1-phenyl-ethanol adduct did not reach one half-life of reaction.

\[
\begin{align*}
\text{PhCH}_2\text{OH} + \text{Me}_3\text{Al} &\rightarrow \text{PhCHCH}_3 + \text{OAlMe}_2 \\
\text{BHTMe}_2\text{Al:OET}_2 &\rightarrow \text{PhCHCH}_3
\end{align*}
\]

Figure 4-8

The faster oxidation of the dimethylaluminum alkoxide vs. the BHT substituted aluminum alkoxide, the rapid methylation and oxidation observed with reactions of DMBAE with aldehydes, and the reaction of A with 4-tolualdehyde all support the argument that trimethylaluminum is the methylating agent in reactions of DMBA and DMBAE. The non-reactivity of DMBAE with acetophenone discussed previously would not appear to be in accord with this hypothesis; however, it can be explained by the strong complexation of DMBA with acetophenone. Furthermore the addition of ether to DMBA should diminish the disproportionation process of DMBA (eq. 4-5b) and thus reduce the concentration of TMA in solution. The subsequent addition of
acetophenone to such a solution would result in only a small amount of methylation before the complexation of the remainder of the acetophenone with DMBA is complete. The latter complexation would further impede the production of TMA, and would explain the DMBAE’s lack of reactivity towards acetophenone.

From the above discussion ether appears to have a two fold effect on the methylation and oxidation reactions of DMBAE with aldehydes: a) it decreases the concentration of TMA in solution which decreases the methylation rate, and allowing sufficient time for the slower oxidation process to take place, b) it helps the break up of the hemialkoxides formed after transference of the methyl group, thereby facilitating the complexation of another molecule of aldehyde which leads to faster oxidation and reduction rates.
CHAPTER V

SUMMARY

The results presented in this dissertation, reveal that unlike the previously known mixed organoaluminum reagents, the preferred transferal of the more stable carbanion is not always possible. While the preferred delivery of the simple alkyl substituents (methyl and ethyl) over the TMSCH₂ group, can be rationalized by the exceptional bulk of the latter, the preferred addition of large substituents (1-indanyl) over smaller alkyl groups to sterically demanding ketones (fluorenone), has also been reported. It is possible though, that the steric requirements of the TMSCH₂ substituent outweigh the effect of its carbanion stability, which would lead to its lack of reactivity. There could also be an argument that the lower anion stability of the TMSCH₂ anion compared to ethyl and methyl anions would also lead to the observed preferred addition of the smaller alkyl groups; however, this possibility is highly unlikely. An interesting correlation is observed in comparing the size and the reactivity of
trialkylaluminums in their reactions with carbonyls. This correlation is especially noticeable in reactions of fluorenone where, as the bulk of the organoaluminum increases (TMA < DMTA ≈ DETA < MDTA < TTMA), the reactivity and the product yield of alkyl addition decreases.

In contrast of the reactions of mixed trialkylaluminums with aldehydes and ketones, tris(trimethylsilylmethyl)aluminum (TTMA) is highly selective towards aldehydes. Two forms of TTMA can be employed in reaction with carbonyls; the neat liquid TTMA and TTMA₃[(TMSCH₂)₃Al.3LiBr]. Reactions of TTMA₃ with most aldehydes afford good to excellent yields of TMSCH₂ addition products, whereas with ketones the yields are low and mostly unreacted starting material is recovered. The selectivity also holds true for the neat TTMA; however, the yields are not as impressive as with TTMA₃. The physical characteristics (powder vs. liquid), higher air stability, and ease of preparation of TTMA₃ make its use and manipulation more convenient than the use of the neat liquid TTMA. In comparing neat TTMA to TTMA₃, it is clear then, that TTMA₃ is the preferred reagent for the selective methylenations of aldehydes.

In consideration of these results, the task of modifying the Peterson reagent for selective methylenation of aldehydes is accomplished by the development of the TTMA₃ reagent. The high selectivity of this reagent has been proven by its tabulated reactions with aldehydes vs.
ketones, and more convincingly, by its reactions with the keto-aldehydes.

And lastly, the results of the investigations on reactions of DMBAE and DMBA show that trimethylaluminum liberated from disproportionations of DMBAE or DMBA is the most likely methylating agent in the reactions of these aluminum reagents with aromatic aldehydes. This hypothesis is supported by the faster Me₃Al assisted MPV oxidation of 1-phenylethanol vs. the similar DMBAE assisted oxidation. Additionally, we have been unable to duplicate Barron’s reported high yields of methylation/oxidation reactions of DMBAE with aromatic aldehydes, and have no explanations for his published results.
CHAPTER VI

EXPERIMENTAL

General

Solvents

All solvents were freshly distilled before employing them in reactions, and were transferred using syringe techniques. Hexanes, THF, toluene, diethyl ether, and pentane were distilled from Na and benzophenone ketyl; methylene chloride was dried over CaH$_2$ and then distilled.

Reagents and Chemicals

All organometallic reagents were purchased from Aldrich in sure seal bottles (Trimethylsilylmethyllithium 1.0 M in pentane, trimethylaluminum 2.0 M in hexanes, dimethylaluminum chloride 1.0 M in Hexanes, methylaluminum dichloride 1.0 M in hexanes, diethylaluminum chloride 1.0 M in hexanes, MeMgBr 3.0 M in diethyl ether, MeLi 1.4 M in diethyl ether, LiAlH(OBu$_t$)$_3$ 1.0 M in THF). AlBr$_3$ was purchased from Aldrich (98%) and Alpha (better quality, 99.9% or 98%), and it was sublimed before using. Heptanal,
cyclohexanone, benzaldehyde, 4-tolualdehyde, anisaldehyde, acetophenone and phenylacetaldehyde were all distilled and stored over activated 3A molecular sieves, under nitrogen in septum fitted bottles. 1-indanone, fluorenone, and 4-chlorobenzaldehyde were recrystallized before use.

**Spectra and Instruments**

$^1$H and $^{13}$C NMR spectroscopy was carried out on either the General Electric QE-300 or Varian VXR-300 spectrometers. GC/MS and electron impact/low resolution mass spectra were obtained on a Finnigan MAT 4500 mass spectrometer. A Finnigan MAT 95 spectrometer was used for high resolution electron impact and chemical ionization exact mass determination. Infra-red spectra were run on a Perkin-Elmer Model 1600 FT-IR spectrophtometer. GC analysis was performed on HP5880A (crosslinked methyl-silicon [HP] high performance capillary column). Melting points were taken on a Thomas-Hoover capillary melting point apparatus.

**GC Standards**

For a quantitative analysis of the reaction products tridecane was used as an internal standard. Analytical solutions of authentic reaction products and tridecane were prepared and the relative response factors of the GC detector to tridecane and the products were calculated. A known amount of tridecane was added to the reaction
mixtures either during or after quenching of the reactions; using this amount, the areas from the GC chromatogram and the relative response factors, the corrected percentages and yields were determined. The % error in yields resulting from the use of the standards is assumed to be ± 4%. It was estimated by multiple runs of known standard and substrate mixtures.

Apparatus and Technique

All glassware used for air-sensitive reactions was flame dried under vacuum and filled with an inert atmosphere of argon by successive purging and charging using a dual manifold vacuum line; glassware was also dried in oven for over 24 hours (110 °C) and then purged with argon, as described previously, before use. Standard syringe techniques were used for the introduction of liquid reagents and solutions to reaction vessels; all syringes were dried in oven (above conditions) and before use were cooled in a desiccator or under a nitrogen atmosphere.

Experimental Procedures

Preparation of Authentic Samples of Trimethylsilylmethyl-alcohols

1-Phenyl-2-trimethylsilylethanol. In a dry round bottom flask, equipped with a magnetic stirring bar, rubber septum, and purged with argon was placed 2.50 ml of 1.0 M
pentane solution of trimethylsilylmethyllithium. To this solution was added 4.0 ml of dry THF (this prevents the crystallization of the reagent when cooled to -78 °C), and the flask was immersed in a dry ice-acetone bath. Benzaldehyde (0.24 g, 2.3 mmoles) dissolved in 4.0 ml of dry THF was then added to the cooled stirred solution (a slight yellow tint was observed upon addition of the aldehyde; and after 10 minutes GC examination showed 97% conversion to product). The reaction was allowed to stir with warming to 0 °C (ca. 20 minutes), and was quenched by adding 5.0 ml of 1.0 M HCl. The two layers were separated, the aqueous layer was extracted with 3 x 5 ml of ether, and the combined organic layers were washed with 5 ml of distilled water followed by 5 ml of brine. The organic layer was dried (MgSO₄) for two hours, filtered, and concentrated in vacuo to yield 0.25 g (1.3 mmoles, 58% yield, 97% homogeneous by GC) of a light yellow oil. ¹H NMR (CDCl₃), trimethylsilyl δ 0.00 [(ref.), (s, 9 H)], 1.35 (-CH₂α: ddd, JHz = 14.32, 7.37, 0.44, 1 H), 1.26 (-CH₂β: ddd, JHz = 14.32, 7.69, 0.47, 1 H), 2.0 (-OH: s, broad, 1 H), 4.92 (-CH: dd, JHz = 7.6, 7.5, 1 H), 7.40-7.65 (Ar: m, 5); ¹³C NMR: δ Me₃Si -1.1, -CH₂ 28.4, -CH 72.9, Ar 125.85, 127.6, 128.5, 145.3. GC/MS, m/e (70 ev): 191 (0.08), 179 (2), 107 (13), 104 (43), 77 (15), 75 (100), 73 (20), 45 (14).
1-(4-Chlorophenyl)-2-trimethylsilylethanol.\textsuperscript{64} Same procedure as above: 6.20 ml (6.20 mmole) of trimethylsilylmethyl lithium, 5 ml of THF, and 0.85 g (6.05 mmoles) of 4-chlorobenzaldehyde; solution changed from mirky to clear to orange yellow by the end of the addition. After concentration, 1.31 g (5.6 mmoles, 97% homogeneous by GC, 92% yield) of a light yellow oil was obtained. \textsuperscript{1}H NMR: (CDCl\textsubscript{3}), Trimethylsilyl \textsuperscript{6} 0.00 [(ref.) s, 9 H], 1.18 (-CH\textsubscript{2}\alpha: dd, J\textsubscript{Hz} = 14.26, 7.72, 1 H), 1.27 (-CH\textsubscript{2}\beta: dd, J\textsubscript{Hz} = 14.26, 7.34, 1 H), 2.57 (-OH: s, broad, 1 H), 4.83 (-CH: t, J\textsubscript{Hz} = 7.54), 7.29-7.39 (Ar: m, 4 H); \textsuperscript{13}C: \textsuperscript{6} Me\textsubscript{3}Si -1.2, -CH\textsubscript{2} 28.4, -CH 72.0, Ar (127.2, 128.4, 132.9, 144.9). GC/HR (Cl, methane): 228 (0.2), 219 (100), 211 (34), 131 (22), calculated for C\textsubscript{11}H\textsubscript{17}ClO\textsubscript{3}Si: found 228.074, calculated 228.074.

1-(4-Trifluoromethylphenyl)-2-trimethylsilylethanol. Same procedure as above: 6.20 ml (6.2 mmoles) of trimethylsilylmethyl lithium, 5 ml of THF, and 1.05 g (6.03 mmoles) of 4-triflouro methylbenzaldehyde; solution changed from colorless to greenish blue, almost black. After concentration, 1.78 g of a yellow oil (94% homogeneous by GC) was obtained. The oil was dissolved in methylene chloride, treated with activated charcoal, acid washed alumina, filtered, concentrated in vacuo, and was placed under higher vacuum (0.01 mm Hg, 30 minutes), to yield 1.10 g of light yellow oil (4.2 mmoles 99% homogeneous by GC,
69% final yield). ¹H NMR: (CDCl₃), Trimethylsilyl δ 0.00 [(ref.), s, 9 H], 0.89 (−CH₂α: dd, J_HZ = 14.40, 6.35, 1 H), 0.98 (−CH₂β: dd, J_HZ = 14.40, 8.04, 1 H), 2.20 (−OH: s, broad, 1 H), 4.93 (t, J_HZ = 7.45), 7.21 (Ar: d, J_HZ = 8.15, 2 H), 7.34 (Ar: d, J_HZ = 8.15 2 H); ¹³C: δ Me₃Si -1.1, −CH₂ 28.6, −CH 72.2, −CF₃ 124.2 (q, J_HZ = 272), Ar [C₃ 125.3, (q, J_HZ = 3.7), C₂ 126.0, C₄ 129.55 (q, J_HZ = 32.3), C₁ 150.6. HR/MS (Cl, methane); calculated for C₁₂H₁₆F₃OSi 261.0922 [(M − H)^+, (0.8)], measured 261.091, fragmentation: 263 (0.3), 262 (0.2), 243 (41), 153 (100).

1-(4-Tolyl)-2-trimethylsilylethanol.⁶⁴ Same procedure as above: 10.0 ml (10.0 mmoles) of trimethylsilylmethyl-lithium, 15 ml of THF, and 1.15 g (9.8 mmoles) of 4-tolualdehyde; color of solution changed to light yellow. Upon concentration, 2.00 g (9.59 mmoles, 97% homogeneous by GC, 95% yield) of a light yellow oil was obtained. ¹H NMR (CDCl₃), trimethylsilyl δ 0.00 [(ref.), (s, 9 H)], 1.22 (−CH₂α: ddd, J_HZ = 14.25, 7.94, 1.23, 1 H), 1.31 (−CH₂β: ddd, J_HZ = 14.13, 7.18, 1.15, 1 H), 2.42 (−CH₃: s, 3 H), 2.48 (−OH: s, broad, 1 H), 4.92 (−CH: t, J_HZ = 7.57, 1 H), 7.20 (Ar: d, J_HZ = 7.93, 2 H), 7.30 (Ar: d, 7.81, 2 H); ¹³C NMR: δ Me₃Si -1.2, −CH₃ 21.0, −CH₂ 28.1, −CH 72.4, Ar (125.73, 128.91, 136.9, 143.5). GC/HR (Cl, methane); calculated for C₁₂H₂₀OSi 208.1283 measured 208.128 (2), fragmentation: 207 (4), 191 (100).
2-Phenyl-1-trimethylsilyl-2-propanol. Same procedure as above: 6.40 ml (6.40 mmole) of trimethylsilylmethyllithium, 5 ml of THF, and 0.72 g (6.0 mmoles) of acetophenone; color of solution changed from clear colorless to light yellow by the end of the addition. Upon concentration, 1.14 g (74% conversion to product, and unreacted starting material) of a yellow oil was obtained. The product mixture was purified by flash chromatography (80:20, hexane:ethyl acetate mixture) to give 0.81 g of a colorless oil (3.9 mmoles, 95% homogeneous by GC, 65% final yield). ¹H NMR: (CDCl₃), Trimethylsilyl 0.00 [(ref.), s, 9 H), 1.52 (−CH₂: s, 2 H), 1.76 (−CH₃: s, 3 H), 1.99 (−OH: s, 1 H), 7.34 [(Ar (ortho): ddm, JHz = 7.08, 5.07 2 H]), 7.45 [(Ar (meta): ddm, JHz = 7.75, 7.15, 2 H)], 7.60 [(Ar (para): dm, JHz = 7.08, 1 H)]; ¹³C: 8 Me₃Si: -0.12, -CH₃ 33.5, -CH₂ 35.0, CH 75.0, Ar (124.5, 126.4, 128.0, 149.7). GC/MS, m/e (70 ev): 207 (1<), 193 (22), 121 (33), 103 (43), 75 (100), 43 (43).

9-Trimethylsilylmethyl-9-fluorenol. Same procedure as above: 6.40 ml (6.40 mmole) of trimethylsilylmethylolithium, 10 ml of THF, 1.08 g (6.00 mmoles) of fluorenone; the color of solution changed from clear colorless to a dark red wine color by the end of the addition. Upon quenching of the reaction mixture with 7 ml of saturated ammonium chloride, the color of the mixture changed to a bright cherry red color. After concentration, 1.77 g (75%
conversion to product) of a yellow powder was obtained. The product mixture was purified by washing the yellow solid with small amounts of hexane to remove the yellow coloring, and then it was recrystallized from hexane. The recrystallization resulted in isolation of 1.11 g (4.14 mmoles, 69% yield, 88% homogeneous by GC) of white crystals. Even though GC showed the presence of impurities with higher retention times than that of the product, proton NMR, carbon NMR, and CHN analysis were indicative of a single product. It was concluded then that the impurities present in the GC chromatogram were due to the decomposition of the product, either at the injection port or in the column of the GC. \( ^1\text{H NMR: (CDCl}_3\text{), Trimethylsilyl} \delta 0.00 [(\text{ref.}), S, 9 H], 2.37 (-\text{CH}_2: S, 2 H), 3.03 (-\text{OH}: S, 1 H), 7.92 (\text{Ar}: H_2, 7, ddd, J_HZ = 7.32, 7.32, 1.26, 2 H), 7.99 (\text{Ar}: H_3, 6, ddd, J_HZ = 7.38, 7.46, 1.38, 2 H), 8.10 (\text{Ar}: H_8 dm, J_HZ = 7.20, 2 H), 8.24 (\text{Ar}: H_4, 5 dm, J_HZ = 7.95, 2 H); \(^{13}\text{C:} \delta \text{Me}_3\text{Si: -1.5, -CH}_2 29.3, -\text{CH} 81.6, \text{Ar (119.9, 123.8, 127.9, 128.8, 138.9, 149.6); HR/MS m/e (70 ev) 268.13 (13), 250.99 (4), 181.07 (100), 178.08, (46), 152.06, (18), 75.02 (38), calculated for C}_{17}\text{H}_{20}\text{OSi 268.1284, measured 268.1286.}

\textit{1-Trimethylsilyl-2-octanol.}^{66} \text{ Same procedure as above: 17.5 ml (17.5 mmole) of trimethylsilylmethyl-lithium, 10 ml of THF, 1.94 g (17.0 mmoles) of heptanal. After concentration, 2.75 g (61% conversion to product, and}
condensation products) of a yellow oil was obtained. The product mixture was purified by vacuum distillation using a small fractional distillation column (14/20 joint, and vigreux column) at a pressure of 0.5 mm Hg with the receiving flask cooled in a dry ice-acetone bath. The product distilled at close to room temperature (ca 20-23°C). ¹H NMR: (CDCl₃), trimethylsilyl δ 0.00 [(ref.), 9 H, s], 0.84 (overlapping -CH₃ and R₃SiCH₂−: m, 5 H), 1.16-1.48 (-CH₂(chain): m, 10 H), 1.56 (-OH, v. broad s, 1 H), 3.69-3.81 (-CH: m, 1 H); ¹³C NMR: Me₃Si -0.76, 14.0, 22.6, 25.7, 26.6, 29.3, 31.8, 40.8, -CH 70.0. GC/HR (CI, methane); calculated for [(M - H)+, (1)] C₁₁H₂₅OSi 201.1675, measured 201.168, fragmentation: 186 (20), 185 (100), 131 (25), 117 (36), 75 (28), 73 (51).

3-Phenyl-1-trimethylsilyl-2-propanol.⁶⁶ Same procedure as above: 10.5 ml (10.5 mmole) of trimethylsilyl methyl-lithium, 25 ml of THF, and 1.20 g (10.0 mmoles) of phenylacetaldehyde; color of the solution changed from clear colorless to yellow by the end of the addition. Upon concentration, 1.67 g of a yellow oil was obtained. GC analysis of the final product showed only 23% of addition product along with 45% unreacted aldehyde and 20% of aldol condensation. The attempts of purification through distillation were unsuccessful, thus GC/MS was employed in identification and characterization of the product. GC/MS:
m/e (70 ev), 207 (<0.1), 191 (0.6), 117 (46), 101 (3), 92 (15), 91 (19), 75 (56), 73 (100), 45 (18).

1-Trimethylsilylmethyl-1-indanol. Same procedure as above: 6.4 ml (6.4 mmole) of trimethylsilylmethyl lithium, 10 ml of THF, and 0.76 g (5.8 mmoles) of 1-Indanone; color of the solution changed to yellow by the end of the addition. Upon concentration, 1.00 g of a yellow oil was obtained. GC analysis of the final product showed only 45% of addition product along with 46% of unreacted ketone. The purification of the mixture by flash chromatography caused the elimination of TMSOH and H₂O yielding a mixture of products. Due to the inability to isolate of the TMSCH₂ addition product, GC/MS was employed for identification and characterization of the alcohol product. GC/MS: m/e (70 ev), 203 (39), 202 [-18, (100)], 188 (29), 187 (94), 129 (26), 128 (72), 74 (51), 73 (91), 59 (42), 45 (36).

1-(4-Methoxyphenyl)-2-trimethylsilylethanol. Same procedure as above: 6.2 ml (6.2 mmole) of trimethylsilylmethyl lithium, 5 ml of THF, and 0.82 g (6.02 mmoles) of 4-methoxybenzaldehyde; solution changed from mirky to clear with a yellow tint by the end of the addition. Upon concentration, 1.14 g of a yellow oil was obtained. GC analysis of the final product showed only 14% of addition product along with 53% of the 4-methoxy styrene (elimination of TMSOH). The ease of the elimination
reaction prevented the isolation of the alcohol product, hence, GC/MS was employed for identification and characterization of the TMSCH₂ addition product. GC/MS: m/e (70 ev), 224 (15), 209 (22), 207 (14), 191 (8), 137 (100), 134 (27), 115 (16), 109 (21), 91 (12), 75 (83), 73 (39), 45 (16).

1-Trimethylsilylmethylcyclohexanol.⁶⁶ Same procedure as above: 15.0 ml (15.0 mmole) of trimethylsilylmethyl-lithium, 25 ml of THF, and 1.47 g (15.0 mmoles) of cyclohexanone; color of the solution changed from clear colorless to light yellow by the end of the addition. Upon concentration, 2.25 g (81% conversion to product, and unreacted starting material) of a yellow oil was obtained. The product mixture was purified by vacuum distillation using a short path distillation column at pressure of 0.05 mm Hg. The first fraction was collected in the receiving flask cooled in a dry ice-acetone bath (starting material and some product), with the product distilling at 33.5-34°C. Crystallization began in the receiver, but after a few minutes the distillate started crystallizing in the condenser. At this point the condenser was heated using a heat gun to prevent the clogging of the tube. A total of 1.45 g of white crystals was obtained (m.p. 35-36°C, 7.72 mmoles, 99% homogeneous by GC, final yield of 52%). ¹H NMR: (CDCl₃), trimethylsilyl δ 0.00 [(ref.), 9 H, s], 0.90 (s, 2 H), 1.19 (v. broad, 1 H), 1.33-1.87 (m, 10
H); $^{13}$C NMR: Me$_3$Si- 0.58, 22.7, 25.6, 32.8, 40.72, -C$_{quaternary}$ 72.6. HR/MS (CI, methane); calculated for C$_{10}$H$_{20}$OSi 186.144, measured 186.145, fragmentation: 186 (3), 185 (2), 171 (17), 170 (17), 169 (100).

Preparation of Diethyl(trimethylsilyl)methyl)aluminum (A3)

Under an argon atmosphere, to a dry, one neck, 25 ml round bottom flask equipped with a magnetic stirring bar and a rubber septum was added 4.0 ml of a 1.0 M pentane solution of diethylaluminum chloride in hexane. This solution was cooled in an dry-ice acetone bath and trimethylsilylmethyllithium (1.0 M solution in pentane) was added dropwise to the cooled solution. An exothermic reaction took place immediately precipitating a white powder (LiCl). After stirring the suspension for ten minutes in a dry-ice bath, the bath was removed, and the reaction flask was allowed to warm to room temperature with stirring for two hours. At this point the reagent was allowed to reacted with a variety of aldehydes and ketones as described below.

Reaction of Diethyl(trimethylsilyl)methyl)aluminum (A3) with Carbonyls

Benzaldehyde (sample procedure). To a 5 ml, oven-dried pear shaped flask fitted with a rubber septum was introduced 0.42 g (4.0 mmoles) of benzaldehyde under an
argon atmosphere followed by 4 ml of dry hexane. The benzaldehyde solution was then added dropwise via a syringe to the cooled, stirred aluminum reagent A3 (prepared as described above and immersed in an ice bath). A yellow color was observed upon addition of the first few drops of the aldehyde solution to A3 that persisted until well after half of the reactant solution was added. The ice bath was removed after the addition was complete, and the mixture was stirred at room temperature for 5.5 hours. At this point the reaction mixture was again immersed in an ice bath, and after 10 minutes was quenched by addition of 5 ml of 1.0 M HCl solution. The contents of the flask were transferred to a separatory funnel, and the aqueous layer was extracted with 4 x 6 ml of ether. The combined organic layer was washed with 2 x 5 ml of brine and 5 ml of deionized water. The organic layer was dried (MgSO₄), and the solvent was removed in vacuo to afford 0.49 g of yellow oil. GC analysis showed: 85% (3.4 mmoles) of ethyl addition (1-phenyl-1-propanol), less than 1% (0.024 mmoles) of TMSCH₂ addition, and 7% (0.030 mmoles) of reduced starting material. The products from this and the following reactions were identified by GC and spectral comparison with previously prepared (or available) authentic materials, or by comparison with the reported spectra of the known material.
**Phenylacetaldehyde.** Same as the above sample procedure: 0.47 g (3.9 mmoles) of the aldehyde; color of the reaction mixture changed to light yellow. After concentration, 0.41 g of a yellow oil was obtained. GC analysis showed: 38% (1.5 mmoles) of ethyl addition (1-phenyl-2-butanol), 1% (0.12 mmoles) of TMSCH₂ addition, 3% (0.10 mmoles) of unreacted starting material, and 13% (0.50 mmoles) of reduced starting material.

**Heptanal.** Same as the above sample procedure: 0.46 g (3.9 mmoles) of the aldehyde; color of the reaction mixture changed to light yellow. After concentration, 0.45 g of a yellow oil was obtained. GC analysis showed: 58% (2.32 mmoles) of ethyl addition (3-nonanol), 2% (0.12 mmoles) of TMSCH₂ addition, and 6% (0.24 mmoles) of reduced starting material.

**Cyclohexanone.** Same as the above sample procedure: 0.39 g (4.0 mmoles) of the ketone; color of the reaction mixture changed to a very light yellow. After concentration, 0.28 g of a yellow oil was obtained. GC analysis showed: 26% (1.0 mmoles) of ethyl addition (1-ethylcyclohexanol), 8% (0.32 mmoles) of TMSCH₂ addition, and 14% (0.55 mmoles) of unreacted starting material.

**Fluorenone.** Same as the above sample procedure: 0.72 g (4.0 mmoles) of the ketone; color of the reaction mixture
changed to red-brown (red wine color). After concentration, 0.69 g of yellow colored crystals were obtained. GC analysis showed: 73% (2.9 mmoles) of ethyl addition (9-ethyl-9-fluorenol), less than 1% (0.02 mmoles) of TMSCH₂ addition, 3% (0.10 mmoles) of unreacted starting material, and 15% (0.38 mmoles) of reduced starting material.

**Preparation of Dimethyl(trimethylsilylmethyl)aluminum (A4)**

The procedure for preparing diethyl(trimethylsilylmethyl)aluminum was followed here for preparing the title reagent. Dimethylaluminum chloride (4.0 ml, 4.0 mmoles, 1.0 M in hexanes) was used in place of diethylaluminum chloride. After addition of the trimethylsilylmethyl-lithium, the reaction mixture was stirred at room temperature for 4 hours. Then the carbonyl solutions were added to it at 0°C.

**Reaction of Dimethyl(trimethylsilylmethyl)aluminum (A4) with Carbonyls**

The procedure for reaction of carbonyls with diethyl-(trimethylsilylmethyl)aluminum was followed for the reactions of A4 with the listed aldehydes and ketones. The reaction times for the following reactions were between 4.5 to 5 hours. The products of the following reactions were identified by GC and spectral comparison with previously prepared (or available) authentic materials, or by
comparison with the reported spectra of the known materials.

**Benzaldehyde.** 0.43 g (4.0 mmoles) of the aldehyde; color of the reaction mixture changed to yellow. After concentration, 0.49 g of a yellow oil was obtained. GC analysis showed: 71% (2.84 mmoles) of methyl addition (1-phenylethanol), 9% (0.36 mmoles) of TMSCH₂ addition, less than 1% (0.01 mmoles) of the acetophenone, and less than 1% (0.02 mmoles) of reduced starting material.

**Phenylacetaldehyde.** 0.48 g (4.0 mmoles) of the aldehyde; color of the reaction mixture changed to light yellow. After concentration, 0.54 g of a yellow oil was obtained. GC analysis showed: 43% (1.7 mmoles) of methyl addition (1-phenyl-2-propanol), 7% (0.29 mmoles) of TMSCH₂ addition, 6% (0.10 mmoles) of unreacted starting material, and 2% (0.08 mmoles) of condensation products.

**Heptanal.** 0.46 g (3.9 mmoles) of the aldehyde; color of the reaction mixture changed to light yellow. After concentration, 0.57 g of a yellow oil was obtained. GC analysis showed: 59% (2.4 mmoles) of methyl addition (2-octanol), 9% (0.35 mmoles) of TMSCH₂ addition, and 2% (0.08 mmoles) of unreacted starting material.
Cyclohexanone. 0.39 g (4.0 mmol) of the ketone; color of the reaction mixture changed to a very light yellow. After concentration, 0.33 g of a yellow oil was obtained. GC analysis showed: 45% (1.8 mmol) of methyl addition (1-methylcyclohexanol), and 13% (0.53 mmol) of condensation products.

Fluorenone. 0.72 g (4.0 mmol) of the ketone dissolved in 5 ml of 1:1 mixture of dry toluene and hexane (the ketone containing flask was rinsed with 1 ml of toluene to insure complete transfer). The color of the reaction mixture changed to red-brown (red wine color). After concentration, 0.76 g of a yellow solid was obtained. GC analysis showed: 73% (2.9 mmol) of methyl addition (9-methyl-9-fluorenol), 3% (0.12 mmol) of TMSCH₂ addition, and 8% (0.3 mmol) of unreacted starting material.

Preparation of Methylbis(trimethylsilylmethyl)aluminum (A5)

The procedure for preparing diethyl(trimethylsilylmethyl)aluminum was followed here for preparing the title reagent. Methylaluminum dichloride (4.0 ml, 4.0 mmol, 1.0 M in hexanes) was used in place of diethylaluminum chloride. After addition of 8.0 ml of 1.0 M trimethylsilylmethylolithium (8.0 mmol), the reaction mixture was
stirred at room temperature for 3.5 hours, and then the carbonyl solutions were added to it at 0°C.

Reaction of Methylbis(trimethylsilylmethyl)aluminum (A5) with Carbonyls

The procedure for reaction of carbonyls with diethyl-(trimethylsilylmethyl)aluminum was followed for the reactions of A5 with the listed aldehydes and ketones. The reaction times for the following reactions were between 4.0 to 4.5 hours. The products of the following reactions were identified by GC and spectral comparison with previously prepared (or available) authentic materials, or by comparison with the reported spectra of the known material.

**Benzaldehyde.** 0.43 g (4.0 mmoles) of the aldehyde; color of the reaction mixture changed to yellow. Concentration afforded 0.45 g of a yellow oil. GC analysis showed: 54% (2.15 mmoles) of methyl addition (1-phenylethanol), 19% (0.76 mmoles) of TMSCH₂ addition, and 5% (0.20 mmoles) of reduced starting material.

**Phenylacetaldehyde.** 0.48 g (4.0 mmoles) of the aldehyde; color of the reaction mixture changed to light yellow. Concentration afforded 0.64 g of a yellow oil, GC analysis showed: 19% (0.76 mmoles) of methyl addition, 24% (0.96 mmoles) of TMSCH₂ addition (1-phenyl-2-propanol), 9% (0.35 mmoles) of unreacted starting material, 2% (0.08
mmoles) of reduced starting material, and 1% (0.04 mmoles) of condensation products.

Heptanal. 0.46 g (3.9 mmoles) of the aldehyde; color of the reaction mixture changed to light yellow. Concentration afforded 0.68 g of a yellow oil. GC analysis showed: 9% (0.34 mmoles) of methyl addition (2-octanol), 18% (0.72 mmoles) of 2-ocatanone, 20% (0.81 mmoles) of TMSCH$_2$ addition, 13% (0.50 mmoles) of reduced starting material, and 6% (0.24 mmoles) of condensation products.

Cyclohexanone. 0.39 g (4.0 mmoles) of the ketone; color of the reaction mixture changed to a very light yellow. Concentration afforded 0.47 g of a yellow oil, GC analysis showed: 29% (1.15 mmoles) of methyl addition (1-cyclohexanol), 10% (0.41 mmoles) of TMSCH$_2$ addition, and 15% (0.60 mmoles) of condensation products.

Fluorenone. 0.72 g (4.0 mmoles) of the ketone dissolved in 5 ml of 1:1 mixture of dry toluene and hexane (the ketone containing flask was rinsed with 1 ml of toluene to insure complete transfer). Color of the reaction mixture changed to red-brown (red wine color). Concentration afforded 0.76 g of a yellow solid. GC analysis showed: 42% (1.69 mmoles) of methyl addition (9-methyl-9-fluorenol), 3% (0.13 mmoles) of TMSCH$_2$ addition, and 56% (2.24 mmoles) of unreacted fluorenone.
Preparation of Diethylbis(trimethylsilylmethyl)aluminate (A6)

The procedure for preparing diethyl(trimethylsilylmethyl)aluminum was followed here for preparing the title reagent. TMSCH$_2$Li 8.0 ml (8.0 mmoles, 1.0 M in pentane) was added to the diethylaluminum chloride (4.0 ml, 4.0 mmoles, 1.0 M in hexane) solution at -78 °C. The reaction mixture was warmed to room temperature, and 10 ml of dry hexane was added to the flask in order to dilute the heterogeneous mixture (LiCl precipitate) and to sustain the proper stirring of the solution. After 4 hours, the carbonyl solutions were added to this mixture at 0 °C.

Reaction of Diethylbis(trimethylsilylmethyl)aluminate (A6) with Carbonyls

The procedure for the reaction of carbonyls with diethyl(trimethylsilylmethyl)aluminum was followed for the reactions of A6 with the listed aldehydes and ketones. The reaction times for the following reactions were between 4.5 to 5 hours.

Benzaldehyde. 0.43 g (4.0 mmoles) of the aldehyde; color of the reaction mixture changed to yellow. GC analysis of the final product mixture showed: 96% (3.84 mmoles) of the ethyl addition (1-phenyl-1-propanol), and less than 1% (0.02 mmoles) of TMSCH$_2$ addition.
Heptanal. 0.46 g (3.9 mmoles) of the aldehyde; no color change was observed. GC analysis of the final product mixture showed: 63% (2.52 mmoles) of ethyl addition (3-nonanol), and 9% (0.36 mmoles) of TMSCH$_2$ addition.

Cyclohexanone. 0.39 g (4.0 mmoles) of the ketone; color of the reaction mixture changed to a very light yellow. GC analysis of the final product mixture showed: 58% (2.32 mmoles) of ethyl addition (1-ethylcyclohexanol), 2% (0.08 mmoles) of TMSCH$_2$ addition, and 12% (0.48 mmoles) of unreacted starting material.

Preparation and Reaction of Methyltris(trimethylsilyl-methyl)aluminate with Benzaldehyde

The procedure for preparing diethyl(trimethylsilyl-methyl)aluminum was followed here for preparing the title reagent. Trimethylsilylmethyllithium 6.0 ml (1.0 M, 6.0 mmoles) was added to the methylaluminum dichloride (2.0 ml, 2.0 mmoles, 1.0 M in hexanes) solution at -78 °C. Subsequently, the reaction mixture was warmed to room temperature and 10 ml of dry hexane was added to the flask in order to dilute the heterogeneous mixture (LiCl precipitate) and sustain its proper mixing. After 3.5 hours, benzaldehyde (0.21 g, 2.0 mmoles, in an oven dried pear shaped flask dissolved in 5 ml of dry hexane under argon) was added dropwise to the cooled (immersed in an ice bath) reagent mixture. GC monitoring showed complete
reaction within the first 15 minutes of the reaction at 0 °C. The reaction was quenched after 3 hours by adding 5 ml of 1.0 M HCl to the cooled reaction mixture (immersed in an ice bath for 10 minutes). The aqueous layer was extracted with 3 x 7 ml of ether and the combined organic layers were washed with 3 ml of deionized water, 2 ml of 1.0 M HCl, and 5 ml of brine. The organic layer was dried (MgSO₄), filtered, and concentrated to give 0.35 g of a yellow oil. The GC analysis showed 42% (0.84 mmoles) of TMSCH₂ addition, and 46% (0.92 mmoles) of methyl addition.

**Trimethyloxylmethylaluminum Dichloride, Preparation and Reaction with Cyclohexanone**

In the dry box, 0.52 g of AlCl₃ (3.9 mmoles, anhydrous) was weighed into a flame dried, 100 ml, 3 neck, round bottom flask. The flask was equipped with magnetic stirring bar, two glass stoppers and a rubber septum. Outside the dry box 15 ml of freshly distilled hexane was added to the flask under an argon atmosphere and to the stirred suspension was added 6.0 ml of trimethyloxylmethyllithium (6.0 mmoles, 1.0 M in pentane). An exothermic reaction started slowly with the precipitation of LiCl and slight warming of the reaction mixture, and within 45 minutes most of the AlCl₃ had disappeared. At this point, 0.186 g (1.90 mmoles) of cyclohexanone dissolved in 10 ml of dry hexane was added to the reaction mixture. No sign of reaction was observed upon addition of the ketone and
even after 6 hours only condensation products and unreacted starting materials were observed.

Trimethylsilylmethylluminum Dibromide, Preparation and Reaction with Heptanal

The above reaction was repeated using 1.6 g (6.0 mmoles, 99.9%) of AlBr₃ suspended in 16 ml of dry hexanes, and 6.0 ml of TMSCH₂Li (6.0 mmoles) cooled in an ice bath. After 2 hours, 0.27 g (2.4 mmoles) of heptanal dissolved in 6 ml of THF and was added to the cooled reaction mixture (immersed in a dry-ice acetone bath). Then the stirred mixture was allowed to warm to room temperature. Monitoring the reaction by GC showed 5% of TMSCH₂ addition product after the first 15 minutes of the reaction. Subsequently, the amount of the desired product remained constant and only the amount of condensation products increased.

This reaction was repeated using a 2:1 ratio of TMSCH₂Li (8 mmoles) and AlBr₃ (1.1 g, 4.0 mmoles), and 0.34 g (2.9 mmoles) of heptanal dissolved in 4 ml of dry THF. Monitoring the reaction by GC showed 20% of TMSCH₂ addition product after the first ten minutes. After two hours, 25% of desired product along with 24% of reduced aldehyde, 11% of starting material, and 20% of condensation products were detected (uncorrected GC percentages).
Preparation, and Reaction of TMSCH$_2$Ti(O$^i$Pr)$_3$, with Phenylacetalddehyde

A dry, two neck, 25 ml, round bottom flask equipped with a magnetic stirring bar and a rubber septum, (under an argon atmosphere) was charged with 2 ml (2.0 mmoles) of chlorotitaniumtriisopropoxide (1.0 M in hexanes). TMSCH$_2$Li 2.0 ml (2.0 mmoles, 1.0 M in pentane) was added slowly to the stirred, cooled (immersed in an dry-ice acetone bath) solution. Upon addition of the lithium reagent the color of the solution changed from colorless to yellow and then to a dark green. The reaction flask was removed from the dry-ice bath after 45 minutes. Upon slight warming of the flask the color of the solution turned lighter green, and by 4 °C the color of the solution was gray. The reaction mixture was stirred for an additional hour in an ice-bath and was then cooled back to −78 °C. Phenylacetalddehyde (0.24 ml, 2.1 mmoles) was added to the cooled reaction mixture followed by (after 15 minutes) 0.1 ml of TiCl$_4$ (1.0 M, in hexane). The reaction was monitored by GC which, even after 2 hours, showed only condensation products and no TMSCH$_2$ addition products; after 24 hours, only the condensation products had increased.

Preparation of Trimethylsilylmethylaluminum Catechol and Its Reaction with Heptanal

Under an argon atmosphere, to a dry, 100 ml, 3 neck, round bottom flask equipped with two glass stoppers a
magnetic stirring bar and fitted with a rubber septum, was added 8.8 ml of Et$_2$AlCl (1.0 M solution in hexane). The flask was immersed in a dry-ice acetone bath (15 minutes). Then 0.84 g (7.7 mmoles) of catechol dissolved in 50 ml of dry methylene chloride was added to the cooled, stirred solution. Upon addition of the catechol, the reaction mixture became cloudy as the result of the crystallization of catechol in the cooled solution. The mixture was stirred at -78 °C for 30 minutes and was then allowed to warm to room temperature and stir for an additional 45 minutes. At this point the reaction flask was immersed in a dry-ice acetone bath (15 minutes) and 5.4 ml of TMSCH$_2$Li (1.0 M in pentane) was added to the reaction mixture. The reaction was allowed to warm slowly to room temperature. It was allowed to stir for an additional hour at this temperature, and was then immersed in a dry-ice acetone bath. Heptanal (0.51 g, 4.4 mmoles, in 5 ml of dry hexane) was added to the cooled reaction mixture and the reaction was monitored by GC. The only products observed by GC after 20 hours consisted of heptanal 6%, reduced heptanal 11%, heptyl heptanoate 8% (was compared with mass spectrum of authentic sample), and condensation products (uncorrected GC yields). Employment of GC/MS identified the condensation products as the product of the aldol condensation of heptanal with heptyl heptanoate ester, or the crossed Claisen condensation of heptyl heptanoate with the product of the aldol condensation of two heptanals.
Mass spectrum for crossed Claisen condensation product: m/e (70 ev), 325 [(M + 1), 0.34%], 227 (3.5), 131 (92), 113 (100), 98 (50), 85 (14), 70 (20), 69 (22).

Reactions of Trimethylaluminum with Carbonyl Compounds

Benzaldehyde (sample procedure). An oven dried, 25 ml, one neck, round bottom flask equipped with a magnetic stirring bar and a rubber septum was charged with (0.297 g, 2.80 mmoles) of benzaldehyde. Under an argon atmosphere, the aldehyde was dissolved in 10 ml of freshly distilled hexane. Trimethylaluminum (2.0 ml, 4 mmoles, 2.0 M in Hexane) was then added dropwise, with a syringe, to the stirred, cooled (immersed in an ice-bath, and was removed 10 minutes after addition was complete) solution of the aldehyde. Upon addition of the Me₃Al, the color of the reaction mixture turned to a peach-yellow color and within thirty minutes to yellow-orange. Three hours after the addition, the cooled reaction mixture (immersed in an ice bath for 10 minutes) was quenched by adding 5 ml of 1.0 M HCl solution. The contents of the flask were transferred to a separatory funnel and the aqueous layer was extracted with 3 x 10 ml of ether. The combined organic layers were washed 2 x 6 ml deionized water and 1 x 7 ml brine, dried (MgSO₄), and filtered. After concentration, 0.27 g of yellow oil was obtained. Uncorrected GC analysis showed: 99% of methyl addition (78% yield).
Heptanal. Same as the above sample procedure: 0.58 g (5.0 mmols) of the aldehyde, color of the reaction mixture changed to light yellow. Monitoring the reaction by GC analysis after the addition of the trimethylaluminum showed that methyl addition was complete within ten minutes, and that longer reaction time only increased the condensation products. After concentration, 0.49 g of a yellow oil was obtained. GC analysis of the final product mixture showed: 89% of methyl addition (67% yield), 4% of unreacted starting material, and 4% of aldol condensation products (uncorrected GC percentages).

Cyclohexanone. Same as the above sample procedure: 0.49 g (5.0 mmols) of the ketone, color of the reaction mixture changed to a very light yellow. After concentration, 0.46 g of yellow oil was obtained which showed: 80% of methyl addition (64% yield), and 20% of unreacted starting material (uncorrected GC percentages).

Fluorenone. Same as the above sample procedure: 0.537 g (2.98 mmols) of the ketone, color of the reaction mixture changed to yellow and faded within a few minutes after the addition was complete. Monitoring the reaction by GC showed that after 45 minutes the reaction was not complete and only 83% addition had occurred. The reaction was quenched after 2 hours, as described above, and after concentration, 0.47 g of yellow crystals was obtained. GC
analysis of product mixture showed: 96% of methyl addition (46% yield), and 4% of unreacted starting material (uncorrected GC percentages).

In Situ Preparation (\(\text{AlCl}_3\)) and Reaction of Tris(trimethylsilylmethyl)aluminum with Carbonyls

Preparation of tris(trimethylsilylmethyl)aluminum. In the dry box, an oven dried, 100 ml, one neck, round bottom flask equipped with a magnetic stirring bar and a rubber septum was charged with 0.53 g of \(\text{AlCl}_3\) (4.0 mmoles, 99.99%). Outside the dry box under an argon atmosphere, 40.0 ml of freshly distilled dry methylene chloride was added to the flask dissolving the \(\text{AlCl}_3\). TMSCH\(_2\)Li (12.0 ml of 1.0 M solution in pentane) was added to the \(\text{AlCl}_3\) solution. An exothermic reaction took place immediately precipitating a white powder (LiCl). The reaction mixture was stirred at room temperature for 2.5 hours and then the solutions of different carbonyls was added to the reaction mixture as described below.

Benzaldehyde (sample procedure). To an oven dried, 5 ml, pear shaped flask was weighed 0.43 g (4.0 mmoles) of benzaldehyde. The flask was then fitted with a rubber septum and under an argon atmosphere the aldehyde was dissolved in 4 ml of freshly distilled methylene chloride. Using a syringe the aldehyde solution was added dropwise to the reagent mixture (prepared as above). Upon addition of
the benzaldehyde, the color of the reaction of mixture turned to a bright yellow color with white precipitate present. After stirring for 4 hours at room temperature, the reaction was quenched by adding 5.0 ml of 1.0 M HCl solution to the cooled (in ice bath for 10 minutes) reaction mixture. The contents of the flask were transferred to a separatory funnel and the aqueous layer was extracted with 3 x 9 ml of methylene chloride. The combined organic layers were washed [2 x 7 ml (1 1.0 M HCl + 6 ml deionized water) and 7 ml of brine], dried (MgSO₄), and filtered. The GC analysis of the reaction mixture showed 26% (1.04 mmoles) of TMSCH₂ addition, 19% (0.76 mmoles) of acetophenone, 33% (1.32 mmoles) of reduced aldehyde, and 6% (0.24 mmoles) of aldol type condensation products.

**Cyclohexanone.** Same procedure as described above: 0.39 g (4.0 mmoles) of the ketone dissolved in 4 ml of dry hexane. A yellow tint was observed upon addition of the ketone. GC analysis of the product mixture showed 12% (0.48 mmoles) of the TMSCH₂ addition product, 13% (0.52 mmoles) of the unreacted ketone, and 8% (0.32 mmoles) of aldol type condensation products.

**Heptanal.** Same procedure as described above: 0.46 g (4.0 mmoles) of the aldehyde dissolved in 5 ml of dry hexane. Color of the solution changed to light yellow upon addition of the aldehyde. The GC analysis of the product
mixture showed 77% (3.06 mmoles) of the TMSCH₂ addition product, and 8% (0.32 mmoles) of condensation products.

**Phenylacetaldehyde.** Same procedure as described above: 0.48 g (4.0 mmoles) of the aldehyde dissolved in 4 ml of dry methylene chloride. Color of the reaction mixture changed to a light yellow upon addition of the aldehyde solution. The GC analysis showed 14% (0.56 mmoles) of the TMSCH₂ addition product, 22% (0.88 mmoles) of unreacted aldehyde, and 17% (0.68 mmoles) of aldol condensation products.

**Fluorenone.** Same procedure as described above: 0.72 g (4.0 mmoles) of the ketone dissolved in 5 ml of dry CH₂Cl₂ and 2 ml of hexane. Color of solution turned dark orange upon addition of the ketone, with time it turned to brick dark red color, and changed to yellow on quenching. The GC analysis showed 4% (0.15 mmoles) of the TMSCH₂ addition product, and 86% (3.5 mmoles) of unreacted ketone.

**Attempted Synthesis of Tris(trimethylsilylmethyl)aluminum by the Exchange Reaction of Trimethylaluminum and Tris-(trimethylsilylmethyl)borane**

A dry, 3 neck, round bottom flask equipped with a magnetic stirring bar, a rubber septum, a glass stopper, and a one piece reflux-distilling apparatus (equipped with grease stopcocks for vacuum and gas inlets, and for discon-
nection of the distilling column) was flame dried and purged with argon. One inlet on the distilling apparatus was connected to an oil bubbler and the other was connected to argon. Me₃Al (9.0 ml, 2.0 M in hexane, 18.0 mmoles) was added by syringe to the reaction flask and 6.4 ml (18.7 mmoles) of (TMSCH₂)₃B was then added to it; slight evolution of gas was observed upon addition of the boron reagent. The mixture was heated using an oil bath at 96 °C (with the argon flow closed) collecting approximately 4 ml of hexane in the receiving flask. After 12 hours of reflux, the apparatus was connected to vacuum (0.02 mm of Hg) and two fractions were collected (boiling range of 42-56 °C). The ¹H NMR spectra of residue from the distillation and the fractions collected showed singlet peaks at -0.83, -0.22 and a multiplet at 0.0 ppm which appeared to correspond to Me(TMSCH₂)₂Al, and a singlet at 0.8 ppm which combined with the narrow multiplet at 0.0 ppm corresponded to (TMSCH₂)₃B. The combination of these peaks suggests the presence of a mixture of (TMSCH₂)₃B and Me-(TMSCH₂)₂Al (the multiplet at 0.0 ppm, corresponding to the Me₃Si peak, was employed as the reference in the ¹H NMR).

Preparation of Keto-aldehydes

9-Fluorenone-4-methanol.⁶⁷ In a dry, 250 ml, 3 neck, round bottom flask equipped with a thermometer, a magnetic stirrer, an addition funnel, and a rubber septum, was
weighed 4.93 g (20.3 mmole, yellow colored powder, weighed under a flow of nitrogen) of 9-fluorenone-4-carbonyl chloride. The flask was then purged with argon and 50 ml of freshly distilled THF was added to the acid chloride, which did not dissolve completely so that a yellow colored mixture was formed. The flask was immersed in an ice bath, and 21.0 ml of 1.0 M LiAlH(OBu₃)₃ in THF was added dropwise to the stirring mixture through the addition funnel. The temperature of the reaction mixture was maintained between 5 and 10 °C throughout the addition, and the addition was complete within twenty minutes. After half of the aluminum reagent was added, most of the powder was dissolved but yellow pieces of solids were still floating in the orange brown solution. The yellow particles seem to have dissolved with time and the GC analysis after 10 minutes showed two products, the ratios of which stayed constant in the first two hours of the reaction. After 3.5 hours of stirring at 5-15 °C, the reaction was quenched by adding 10.0 ml of 1.0 M HCl solution to the cooled reaction mixture (5 °C). The temperature in the flask rose to 30 °C and the mixture turned gelatinous. The contents of the flask were then transferred into a 250 ml separatory funnel and the aqueous layer was extracted with 3 x 30 ml of ether (the mustard colored mixture was difficult to separate due to some yellow colored insoluble solids floating in between the two layers). The combined organic layers were washed with 15
ml of 1.0 M HCl, 2 x 15 ml of brine, dried (MgSO₄), filtered, and concentrated using the rotary evaporator to yield 3.15 g of yellow solid. GC analysis showed two major products; 33% of the keto-aldehyde and 66% of the keto-alcohol. The reaction mixture was separated by flash chromatography, using a 40/60 mixture of ethyl acetate and hexanes; 0.42 g (1.8 mmoles, 90% homogeneous by GC) of the keto-aldehyde was separated, the rest of the fractions containing the keto-alcohol were combined and concentrated to give 1.55 g (7.0 mmoles, 95% homogeneous by GC) of a yellow solid. ¹H NMR: (CDCl₃) 2.34 (-OH: broad s, 1 H), 4.97 (-CH₂: s, 2 H), 7.24 (ArH₂: t, J_H₂ = 7.4, 1 H), 7.26 (ArH₇: td, J_H₂ = 7.2, 1.2, 1 H), 7.46 (ArH₆: td, J_H₂ = 7.4, 1.2, 1 H), overlapping peaks [7.47 (ArH₅: d, J_H₂ = 7.0, 1 H), (ArH₃: d, J_H₂ = 7.0, 1 H)], 7.61 (ArH₁: d, J_H₂ = 7.4, 1 H), 7.61 (ArH₈: d, J_H₂ = 7.0, 1 H), ¹³C NMR: -CH₂ 63.0, Ar (123.6, 124.3, 124.7, 129.2, 129.4, 134.6, 134.7, 135.1, 135.3, 136.8, 142.3, 144.5), C=O 194.1; MS: m/e (70 ev), 210 (82.3), 193 (2.5), 181 (100), 165 (13.2), 152 (51.7), 76 (26.6). IR (KBr): 3324 (OH), 1718 (C=O), 1607, 1577, 1421, 1299, 1237, 1156, 1408, and 732 cm⁻¹.

9-Fluorenone-4-carboxaldehyde. In a dry, 100 ml, 3 neck, round bottom flask equipped with a thermometer, a magnetic stirring bar, and rubber septum, was added 1.53 g of 3A powdered molecular sieves. The sieves were activated by flame heating the flask under vacuum, and simultaneous
purging with nitrogen. To this flask was added 10.74 g of
PDC in 25 ml of dry methylene chloride. The flask was then
immersed in an ice bath. 9-Fluorenone-4-methanol (1.69 g,
7.6 mmoles; 1.55 g from previous reaction and 0.14 g from a
smaller scale reaction) was dissolved in 40 ml of methylene
chloride and was added rapidly to the stirred and cooled
PDC mixture. After 4 hours, TLC analysis showed the
presence of a small amount of the starting alcohol, but
after 6 hours no alcohol was detectable. The reaction
mixture at this point was passed through a 5.5 cm buchner
funnel filled with celite to remove the unreacted PDC and
other solids. The dark brown filtrate was then passed
through a column of 10% MgSO₄ and 90% silica gel (0.5
inches MgSO₄ and 4.5 inches of silica in 1 inch diameter
column), leaving the colored impurity at the top 0.5 inches
of the column and collecting the yellow solution. This
solution was concentrated in vacuo to afford 1.25 g (5.96
mmoles, 99.2% homogeneous by GC, 78% yield) of a yellow
solid, m.p. 165-172 °C. Recrystallization from
ethanol/water (mixed solvent method), followed by drying
under vacuum for 16 hours in a 40 °C oil bath gave 0.95 g
(4.5 mmoles, 76% yield) of yellow voluminous crystals,
(99.2% homogeneous by GC), m.p. of 173-175 °C. ¹H NMR:
(CDCl₃) 7.41 (Ar₇: td, JHz = 7.2, 1, 1 H), 7.48 (Ar₂: t,
JHz = 7.3, 1 H), 7.56 (Ar₆: td, JHz = 7.5, 1.5, 1 H), 7.73
(Ar₅: dm, 7.27, 1 H), 7.89 (Ar₈: dd, JHz = 7.2, 1.5, 1
H), 7.98 (Ar₁: dd, JHz = 7.4, 1.5, 1 H), 8.33 (Ar₃: dt,
\[ J_{Hz} = 7.4, \ 0.5<, \ 1 \text{H}, \ 10.43 \text{ (CHO: s, 1 H)}; \ ^{13}\text{C NMR: Ar} \]

(124.4, 126.7, 128.8, 129.1, 130.4, 132.5, 134.4, 135.4, 135.6, 137.5, 142.9, 144.8, 190.8, 192.3), HR/MS: \text{m/e (70 ev)}, 208 (100), 180 (88), 152 (40), 151 (46.0), 150 (32.5), 75 (21.0), calculated for \( \text{C}_{14}\text{H}_{8}\text{O}_{2} \) 208.5343, measured 208.05060. IR (KBr): 2750, 2362, 1718 (C=O), 1688 (C=O), 1606, 1566, 1404, 1308, 987, and 734.

3-Acetyl-2,2-dimethyl-cyclobutaneacetaldehyde (Pinonic aldehyde). To an oven dried, 300 ml, 3 neck, round bottom flask equipped with a magnetic stirring bar, a large bubbler (the end of which was extended close to the bottom of the flask), a glass stopper, and a gas outlet, was introduced 2.77 g (20.0 mmoles) of \( \alpha \)-pinene. The flask was immersed in a dry-ice acetone bath after addition of 190 ml of methylene chloride and argon purging. The ozone generator was started as described in the WELSCH INSTRUCTION MANUAL (model T-403). The power was set at 90 volts, pressure at 6.2 psi, and the flow rate of \( \text{O}_{2} \) at 2.0 SPLG. Ozone was bubbled through the stirred, cooled solution of the \( \alpha \)-pinene (-78 °C), and the outlet from the flask was directed towards the end of the hood using tygon tubing. After 20 minutes the color of the solution had turned to purple-blue (saturated with ozone). At this point the ozone generator was turned off and oxygen was bubbled through the solution for ten minutes (after this the blue color faded). Oxygen was replaced by argon, and
argon was bubbled through for an additional 10 minutes (the reaction mixture was kept at -78 °C throughout these changes). Methylsulfide (8.80 ml, 120 mmoles) was added rapidly to the reaction mixture at -78 °C, and the reaction was allowed to stir and warm slowly to room temperature (3 hours). In a separatory funnel, the mixture was poured over 25 ml of brine. The organic layer was separated, and the aqueous layer was extracted with 3 x 25 ml of methylene chloride. The combined organic layers were washed with 15 ml of brine and 15 ml of deionized water. The organic layer was then dried (MgSO₄) and concentrated under vacuo to yield 2.79 g of a yellow oil. The product was purified by flash chromatography (70/30 hexane/ethyl acetate) to yield 0.79 g (4.5 mmoles, 95% homogeneous by GC, 22% total yield) of a colorless oil. The proton NMR of this oil showed the presence of trans and cis isomers in a 9:1 ratio, determined using the aldehyde peaks of the two isomers. \(^1\)H NMR: (CDCl₃) 0.85 (−CH₃\(_{\text{gem}}\)): s, 3 H, 1.34 (−CH₃\(_{\text{gem}}\)): s, 3 H), 1.98 (−CH₂\(_{\text{ring}}\)): q, \(J_{\text{Hz}} = 7.64\), 2 H), 2.06 (−COCH₃: s, 3 H), overlapping peaks 2.25-2.54 [−CH₂: m], (−CH\(_{\text{ring}}\): m), total 3 H], 2.93 (CH\(_{\text{ring}}\): dd, \(J_{\text{Hz}} = 9.76\), 7.81, 1 H), 9.75 (−CHO: t, \(J_{\text{Hz}} = 1.45\), 1 H); \(^{13}\)C NMR: 17.5 (−CH₃\(_{\text{gem}}\)), 17.55 (−CH₃\(_{\text{gem}}\)), 22.7 −CH₂\(_{\text{ring}}\), 30.0 −COCH₃, 35.6 −CH\(_{\text{ring}}\), 43.2 −C\(_{\text{quaternary}}\), 44.9 −CH₂, 54.2 −CH\(_{\text{ring}}\), 201.4 −CHO, 207.4 −CO. IR (neat): 2956 (OH), 2724, 1724, (C=O), 1705 (C=O), 1464, 1371, 1227, 1183, and 950.
GC/MS (CI, methane); 169 (14), 151 (72), 127 (14), 107 (39), 99 (58), 71 (100).

Purification of AlBr₃

In the dry box, AlBr₃ (obtained from Aldrich or Alpha, 98%-99.9%) was placed into a large subliming apparatus. Outside the dry box the subliming apparatus was attached to the vacuum line at a pressure of 0.1 mm of Hg, the apparatus was then heated using an oil bath maintained at 100 °C, while the cold finger was cooled using a dry-ice acetone bath. After completion of the sublimation (3 hours) the apparatus was filled with argon and transferred to the dry box. In the dry box the AlBr₃ was measured into the reaction flask and was used immediately.

Preparation of Tris(trimethylsilylmethyl)aluminum

General procedure. In the dry box, 6.66 g (25 mmoles) of AlBr₃ was weighed into a dry, 250 ml, round bottom flask equipped with a sidearm stopcock, a magnetic stirring bar, and fitted with a rubber septum. Outside the dry box, under an argon atmosphere, 100 ml of dry hexane was added to the reaction flask through a rubber septum. The flask was then cooled in an ice bath, and 73.0 ml of a 1.03 M pentane solution of trimethylsilylmethylolithium (75.2 mmoles) was added slowly to the suspension of AlBr₃ in hexane. An exothermic reaction took place immediately,
precipitating LiBr. By the end of the addition the white precipitate had formed a pasty mixture in the flask. At this point, the septum was replaced by an oven dried reflux column under a flow of argon, and the flask was heated using a heating mantle until a gentle reflux was established. After 12 hours of reflux, the reaction flask was cooled to room temperature and the procedures A or B were followed for obtaining either pure of the tris-(trimethylsilylmethyl)aluminum or its LiBr salt, respectively.

A: Isolation of pure tris(trimethylsilylmethyl)-aluminum (Al). After cooling the flask to room temperature, the reflux column was replaced by a greased glass stopper. Under vacuum using the sidearm stopcock, the solvent was distilled into a 250 ml round bottom flask immersed in an dry ice-acetone bath (note: this distillation was accompanied with occasional bumping which spread the white paste on the walls of the distillation flask). Once all of the solvent was removed, under a flow of argon, the glass stopper was replaced by a 90 degree tube (the tube resembles a short path distillation column without the thermometer or the vacuum inlet), the receiving end of which was attached to a 50 ml flask with a sidearm stopcock. A vacuum of 0.01- 0.025 mm Hg was applied through the sidearm of the receiving flask, then the reaction flask was heated in an oil bath that covered the
entire flask; the receiving flask was cooled in an dry-ice acetone bath. Upon reaching 70 °C in the oil bath, the first drops of the product started appearing in the condenser. The distillation was maintained at a constant dropwise rate for close to two hours, but later slowed to a few drops per minute (the distillate solidified upon reaching the cooled receiver, forming a white solid). After four additional hours, distillation had stopped. At this point heating was discontinued, and the apparatus was filled with argon (introducing argon or nitrogen into the flask containing the pure alane causes the formation of a white smoke that fills the flask, and then slowly dissipates). Under a flow of argon, the receiving flask was removed, stoppered, and immediately transferred to the dry box and weighed. The 3.27 g (11.3 mmoles, 45% yield) of colorless liquid product obtained was redistilled using a short path distillation column under a vacuum of 0.02 mm Hg in an oil bath maintained at 70 °C. The distillation started at 45 °C and increased up to 54 °C. The fluctuations in the temperature were due to the slight changes in the pressure. Further heating of the reaction flask to 140 °C under vacuum yielded 0.80 g more of the product, which increased the yield to 4.07 g (total of 14.1 mmoles, 56.4% yield). $^1$H: (C$_6$D$_6$, 7.26 ppm), -0.38 (-CH$_2$-; s, 6 H), 0.17 (Me$_3$Si-: s, 27 H); $^{13}$C NMR: 2.41 (Me$_3$Si-), 4.74 (-CH$_2$-).
B: Isolation of the [tris(trimethylsilylmethyl)aluminum].3LiBr salt (A2). The previous general procedure was followed using 5.33 g (20.0 mmoles) of freshly sublimed AlBr$_3$ in 110 ml of dry hexane, and 59.0 ml of 1.03 M trimethylsilylmethylolithium (60.8 mmoles). After 12 hours of reflux, then cooling the flask to room temperature, the reflux column was replaced by a septum with a cannula filter (coarse filter paper wrapped by teflon tape at the base of an 18 gauge, 2 feet needle) inserted through it. The solvent was then filtered away from the white and light yellow pasty mixture into a dry 500 ml round bottom flask with two 35 ml rinses of freshly distilled dry hexane; the filtration removed the yellow color of the mixture. The complete filtration of the solvent was not possible, and the last 20-30 ml of the solvent was removed under vacuum. After complete removal of the solvent under vacuum (ca. 0.025 mm Hg), the flask was transferred to the dry box and the white solid covering the walls of the flask was scraped off, powdered, and stored in the dry box in a dry brown glass jar (10.85 g, 19.8 mmoles, 98.8% yield).

Reaction of [Tris(trimethylsilylmethyl)aluminum].3LiBr (A2) Salt with Carbonyls

Benzaldehyde (sample procedure). In the dry box, 1.37 g (2.50 mmoles) of A2 was placed into a dry, 50 ml, one neck, round bottom flask equipped with a magnetic stirring bar. Under an argon atmosphere, 25 ml of dry freshly
distilled hexane was added to the reaction flask, and the suspension was stirred until all larger pieces of the reagent were broken into a fine powder (15 minutes). Benzaldehyde (0.213 g, 2.01 mmoles) was weighed into a 5 ml pear shaped flask fitted with a rubber septum under argon. The aldehyde was then dissolved in 4 ml of dry hexanes. The aldehyde solution was added drop-wise to the reaction flask through a short cannula (6 inches). A lemon yellow color was detected on the contact of the first drops of the aldehyde solution with the reaction mixture (3 ml extra of solvent was used for rinsing the aldehyde flask into the reaction mixture). The color spread throughout the solution, then dissipated within thirty minutes. After being stirred for four hours at room temperature (24-25 °C) the reaction flask was immersed in an ice bath for ten minutes, and was quenched by adding 3 ml of 1.0 M HCl solution. The mixture was then stirred for a few minutes and the contents transferred into separatory funnel. The aqueous layer was extracted with 3 x 10 ml of ether, and the combined organic layers were washed with 2 x 3 ml of brine (more 1 M HCl solution was some times needed for breaking up emulsions or dissolving the aluminum salts). The organic layer was dried (Na₂SO₄) for 2 hours, filtered then concentrated in vacuo to yield 0.38 g (2.0 mmoles, 100% yield) of a yellow oil, which was 98% (homogeneous by GC) of the TMSCH₂ addition product by GC and spectral comparison to previously prepared authentic materials.
4-Chlorobenzaldehyde. Same procedure as described above: 0.278 g (1.98 mmoles) of the aldehyde dissolved in 5 ml of dry methylene chloride. Color of the solution changed to yellow upon addition of the aldehyde, then faded within one hour. After concentration, 0.46 g (2.0 mmoles, 98% yield) of a yellow oil of the TMSCH₂ addition product was obtained (100% homogeneous by GC).

Phenylacetaldehyde. Same procedure as described above: 0.236 g (1.96 mmoles) of the aldehyde dissolved in 3 ml of dry methylene chloride and 2 ml of dry hexane. No change of color was observed upon addition of the aldehyde. After concentration, 0.30 g of a yellow oil was obtained which contained 38% (0.74 mmoles) of the TMSCH₂ addition product, 27% (0.52 mmoles) of unreacted aldehyde, and aldol type condensation products 15% (0.20 mmoles).

Heptanal. Same procedure as described above: 0.220 g (1.93 mmoles) of the aldehyde dissolved in 5 ml of dry hexanes. No change of color was observed upon addition of the aldehyde. After concentration, 0.36 g of a yellow oil was obtained which contained 80% (1.55 mmoles) of the TMSCH₂ addition product, 2% (0.043 mmoles) of unreacted aldehyde, 3% (0.056 mmoles) of 2-octanone, 4% (0.082 mmoles) of reduced aldehyde (heptanol), and 3% (0.05 mmoles) of aldol type condensation products.
Cyclohexanone. Same procedure as described above:
0.69 g (1.3 mmoles) of the aluminum reagent (A2), and
0.0979 g (1.00 mmoles) of the ketone dissolved in 4 ml of
dry hexane. No change of color was observed upon addition
of the aldehyde. After concentration, 0.16 g of a yellow
oil was obtained which contained 39% (0.39 mmoles) of the
TMSCH$_2$ addition product, 38% (0.038 mmoles) of unreacted
aldehyde, and condensation products 3% (0.03 mmoles).

Fluorenone. Same procedure as described above: 0.69 g
(1.3 mmoles) of the aluminum reagent (A2), and 0.1776 g
(0.987 mmoles) of the ketone dissolved in a mixture of 3 ml
of dry CH$_2$Cl$_2$ and 2 ml of hexane (2 ml extra of CH$_2$Cl$_2$ was
used for rinsing the flask). Color of solution changed to
yellow orange upon addition of the ketone and became darker
orange throughout the progress of the reaction. After
concentration, 0.21 g of a yellow solid was obtained which
contained 43% (0.42 mmoles) of the TMSCH$_2$ addition product,
and 51% (0.51 mmoles) of unreacted ketone.

4-Tolualdehyde. Same procedure as described above:
0.69 g (1.3 mmoles) of the aluminum reagent A2 and 0.119 g
(0.991 mmoles) of the aldehyde dissolved in 4 ml of dry
hexane. Color of the solution changed to lemon-yellow upon
addition of the aldehyde, and faded within one hour. After
concentration, 0.20 g of a yellow oil was obtained which
contained 79% (0.78 mmoles) of the TMSCH$_2$ addition product, and 19% (0.19 mmoles) of unreacted starting material.

4-Trifluoromethylbenzaldehyde. Same procedure as described above: 1.45 g (2.64 mmoles) of the aluminum reagent (A2) suspended in 30 ml of dry hexane, and then added 0.35 g (2.01 mmoles) of the aldehyde dissolved in 3 ml of dry methylene chloride to the cooled reaction mixture (in ice bath). Color of the solution turned yellow after addition of the aldehyde. After four hours of reaction time the reaction was quenched by adding 3 ml of saturated ammonium chloride solution to the cooled (immersed in ice bath for 15 minutes) reaction mixture. After concentration 0.54 g of a yellow oil was obtain which was primarily (90% homogeneous by GC) the TMSCH$_2$ addition product. The calculated yield using GC standards was 60% (1.22 mmoles).

4-Methoxybenzaldehyde. Same procedure as described above: 1.45 g (2.64 mmoles) of the aluminum reagent (A2) suspended in 30 ml of dry hexane, then added 0.27 g (2.0 mmoles) of the aldehyde dissolved in 4 ml of dry methylene chloride to the cooled reaction mixture (immersed in ice bath). Color of the solution turned lemon yellow after addition of the aldehyde. After four hours of reaction, the mixture was quenched by adding 3 ml of saturated ammonium chloride solution to the cooled reaction mixture. Upon concentration, 0.37 g of yellow oil was obtained which
contained 4% (0.084 mmoles) of the TMSCH$_2$ addition product, 31% (0.61 mmoles) of elimination product, 2% (0.03 mmoles) of reduced aldehyde, and 6% (0.11 mmoles) condensation products.

1-Indanone. Same procedure as described above: 1.45 g (2.64 mmoles) of the aluminum reagent (A2) suspended in 30 ml of dry hexane, and then added 0.26 g (2.0 mmoles) of the ketone dissolved in 3 ml of dry methylene chloride to the cooled reaction mixture (in ice bath). No apparent color change was observed after addition of the aldehyde. After concentration, 0.33 g of an orange oil was obtained which consisted of 3% (0.058 mmoles) of the TMSCH$_2$ addition product, 35.5% (0.71 mmoles) of starting material, and 7% (0.13 mmoles) of elimination product.

Acetophenone. Same procedure as described above: 1.45 g (2.64 mmoles) of the aluminum reagent (A2) suspended in 30 ml of dry hexane, and then added 0.24 g (2.0 mmoles) of the aldehyde dissolved in 3 ml of dry methylene chloride to the cooled reaction mixture (ice bath). No apparent color change was observed upon addition of the ketone; however, after one hour the color of the solution had changed to orange. After concentration, 0.34 g of a yellow oil was obtained which contained 3% (0.06 mmoles) of the TMSCH$_2$ addition product, 59% (1.19 mmoles) of starting material,
2% (0.04 mmoles) of condensation products, and 5% (0.10 mmoles) of the elimination product (α-methylstyrene).

9-Fluorenone-4-carboxaldehyde. Same procedure as described above: 1.38 g (2.5 mmoles) of the aluminum reagent (A2) and 0.406 g (1.95 mmoles) of the keto-aldehyde dissolved in 4 ml of dry methylene chloride (an additional 2 ml of solvent was used for rinsing the flask). Color of the solution turned yellow upon addition of the keto-aldehyde and became darker yellow with continued addition. Eventually the color of the mixture was a mustard tint. The reaction was quenched by adding 4 ml of saturated ammonium chloride solution to the cooled (immersed in an ice bath for ten minutes) reaction mixture after two hours and forty minutes of reaction. Upon concentration, 0.55 g (1.8 mmoles) of yellow solid was obtained (94% homogeneous by GC) which was identified as the product of TMSCH₂ addition to the aldehyde functional group. The product was further purified by flash chromatography using a 60/40 mixture of hexanes and ethyl acetate; after purification m.p. was 121-123 °C. ¹H NMR (CDCl₃), trimethylsilyl δ 0.00 [(ref.), (s, 9 H)], overlapping peaks [1.18: (–CH₂α: d, J_Hz = 8.35, 1 H), (CH₂β: d, J_Hz = 6.29, 1 H)], 2.01 (–OH: d, J_Hz = 3.61, 1 H), 5.34 (–CH: td, J_Hz = 7.26, 3.54, 1 H), 7.16 (Ar_H₂: t, J_Hz = 7.62, 1 H), 7.18 (Ar_H₂: t, J_Hz = 7.84, 1 H), 7.38 (Ar_H₆: td, J_Hz = 7.59, 1.30, 1 H), 7.44 (Ar_H₃: broad d, J_Hz
= 7.18, 1 H), 7.56 (Ar_H1: broad d, J_Hz = 7.87, 1 H), 7.61 (Ar_H8: broad d, J_Hz = 7.76); 1^3C NMR: δ Me_3Si -0.76, -CH_2
26.2, -CH 69.1, Ar: (123.1, 124.3, 124.8, 128.5, 129.1, 132.1, 134.7), Ar_(quaternary) (134.5, 134.7, 134.0, 143.3, 144.2), C=O 194.2. HR/MS (GC-EI, m/e, 70 ev) calculated for C_18H_20O_2Si 296.1233, measured 296.123; fragmentation:
296 (36), 281 (100), 267 (18), 209 (65), 206 (36), 178 (82), 162 (40), 75 (99), 73 (48). IR (KBr) 3509 (OH),
2953, 2896, 1698 (C=O) 1608, 1577, 1388, 1299, 1246, 1048,
858.

3-acetyl-2,2-dimethyl-cyclobutaneacetaldehyde. Same
procedure as described above: 1.37 g (2.5 mmoles) of the
aluminum reagent (A2) and 0.334 g (1.99 mmoles) of the
keto-aldehyde dissolved in a mixture of 2 ml of dry CH_2Cl_2
and 3 ml of dry hexanes (this solution was dried over
activated 3A molecular sieves before addition to the
reaction mixture; an additional 2 ml of solvent was used
for rinsing the flask; no color change). The reaction was
quenched by adding 4 ml of saturated NH_4Cl solution to the
cooled (in an ice bath for ten minutes) reaction mixture
after 2.7 hours of reaction. Upon concentration, 0.42 g of
a yellow oil was obtained which consisted of 75% of the
TMSCH_2 addition to the aldehyde, 3% starting material, and
approximately 9% condensation products. The product keto-
alcohol was purified by flash chromatography using a 65/35
hexane/ethyl acetate mixture. ^1H NMR (CDCl_3), Me_3Si δ 0.00
[(ref.), (s, 9 H)], overlapping peaks [0.78 (Me$_3$SiCH$_2$α: d, J$_{Hz}$ = 6.9), 0.81 (CH$_3$($gem$): s), 0.82 (Me$_3$SiCH$_2$β: d, J$_{Hz}$ = 6.2), total 5 H], 1.25 (-CH$_3$($gem$): s), overlapping peaks [1.30-1.56 (-CH$_2$(β to OH): m), -OH, total 3 H], 1.75-1.98 (-CH$_2$(ring): m, 2 H), 2.00 (-COCH$_3$: s, 3 H), 2.02-2.14 (-CH$_3$(ring): m, 1 H), 2.79 (-CH$_2$(ring): dd, J$_{Hz}$ = 8.88, 8.62, 1 H), 3.70 (-CH: m, 1 H); $^{13}$C NMR shows mixture of two isomers: δ 0.00 Me$_3$Si-, 18.09 (18.05) Si-CH$_2$-, 23.93 -CH$_3$(gem), 24.74 -CH$_3$(gem), 27.86 (29.16) -CH$_2$(ring), 30.78 (31.16) CH$_2$(ring), 39.70 (39.37) -CH$_3$, 41.91 (41.48) CH$_2$, 44.23 (43.91) >C<, 55.34 (55.08) -CH$_2$(ring), 68.63 (70.02) -CHOH, 208.70 (208.65) C=O. IR (neat): 3439 (OH), 2952, 2895, 1710 (C=O), 1462, 1369, 1248, 863, 839, and 691. HR/MS (GC/CI), calculated for C$_{14}$H$_{28}$O$_2$Si 256.1859, measured 256.1885; M$^{+}$TMS (TMS = Me$_3$Si): calculated for C$_{17}$H$_{37}$Si$_2$O$_2$ 329.2333 measured 329.2260 (M$^{+}$TMS is the base peak which is due to silylation of the keto-alcohol in the new GC column). GC/EI (m/e, 70ev) fragmentation, 241 (0.3), 223 (1), 199 (2), 171 (2), 117 (21), 99 (38), 75 (48), 73 (100).

**Reaction of Pure Tris(trimethylsilylmethyl)aluminum (Al) with Carbonyls**

Benzaldehyde (sample procedure). In the dry box, 0.38 g (1.3 mmoles) of Al was placed in a dry, 50 ml, one neck, round bottom flask equipped with a magnetic stirring bar. Under an argon atmosphere, 20 ml of dry freshly distilled hexane was added to the reaction flask. Benzaldehyde
(0.115 g, 1.08 mmoles) was measured into a 5 ml pear shaped flask fitted with a rubber septum and dissolved in 4 ml of dry hexane under argon. The aldehyde solution was then added dropwise to the stirred reaction mixture through a short cannula (6 inches). An orange-yellow color was detected on contact of the first drops of the aldehyde solution with the reaction mixture (an additional 3 ml of solvent was used for rinsing the flask into the reaction mixture). After being stirred for 3.5 hours at room temperature (24-25 °C), the reaction flask was immersed in an ice bath for ten minutes, and was quenched by adding 3 ml of 1.0 M HCl solution. The mixture was then stirred for a few minutes and the contents transferred into a separatory funnel. The aqueous layer was extracted with 3 x 10 ml of ether, and the combined organic layers were washed with 2 x 3 ml of brine (more 1 M HCl solution was some times needed for breaking up emulsions or dissolving the aluminum salts). The organic layer was dried (Na₂SO₄) for two hours, and the filtered solution was then concentrated in vacuo to yield 0.13 g of a yellow oil consisting of 32% (0.34 mmoles) of the TMSCH₂ addition product, 21% (0.22 mmoles) of the oxidized TMSCH₂ addition product, and 27% (0.29 mmoles) of reduced starting material.

4-Tolualdehyde. Same procedure as described above: 0.12 g (1.0 mmoles) of the aldehyde dissolved in 4 ml of
dry hexane. Color of the solution changed to light orange upon addition of the aldehyde. After concentration, 0.21 g of a yellow oil was obtained which contained 30% (0.30 mmoles) of the TMSCH$_2$ addition product, 12% (0.12 mmoles) of the oxidized TMSCH$_2$ addition product, 1% (0.01 mmoles) of the α-methyl alcohol, 21% (0.21 mmoles) of the methyl ketone, and 35% (0.35 mmoles) of reduced starting material.

**Heptanal.** Same procedure as described above: 0.108 g (0.947 mmoles) of the aldehyde dissolved in 5 ml of dry hexane. No change of color was observed upon addition of the aldehyde. After concentration, 0.17 g of a yellow oil was obtained which consisted of 40% (0.38 mmoles) of the TMSCH$_2$ addition product, 17% (0.16 mmoles) of the methyl ketone, and 24% (0.23 mmoles) of reduced starting material.

**1-Indanone.** Same procedure as described above: 0.129 g (0.977 mmoles) of the ketone dissolved in 3 ml of dry methylene chloride. Upon addition of the ketone, the color of the reaction mixture changed to lemon-yellow, after one hour to an orange-yellow, and to reddish-pink upon quenching. After 3.5 hours of reaction, the cooled mixture (immersed in an ice bath for ten minutes) was quenched by adding 3 ml of saturated ammonium chloride solution. Concentration of the organic layer afforded 0.16 g of an orange oil which was 93% (0.90 mmoles) of unreacted starting material.
**Acetophenone.** Same procedure as described above: 0.12 g (1.0 mmoles) of the ketone dissolved in 4 ml of dry methylene chloride. No apparent color change was observed after addition of the ketone. After 3.5 hours of reaction the cooled (immersed in an ice bath for ten minutes) mixture was quenched by adding 3 ml of saturated ammonium chloride solution. After concentration of the organic layer 0.10 g of yellow oil was obtained which consisted of 7% (0.07 mmoles) of the TMSCH$_2$ addition product, 4% (0.04 mmoles) of condensation products, and 71% (0.71 mmoles) of unreacted starting material.

**Cyclohexanone.** Same procedure as described above: 0.0933 g (0.95 mmoles) of the ketone dissolved in 4 ml of dry hexane. No change of color was observed upon addition of the ketone. Concentration afforded, 0.10 g of a yellow oil which contained 26% (0.25 mmoles) of the TMSCH$_2$ addition product, and 56% (0.53 mmoles) of the unreacted ketone.

**4-Chlorobenzaldehyde.** Same procedure as described above: 0.134 g (0.95 mmoles) of the aldehyde dissolved in 5 ml of dry hexane (the aldehyde was not completely soluble in hexanes and a few additional rinses with solvent were necessary for complete transfer). Color of the solution changed to yellow orange upon addition of the aldehyde. After concentration, 0.16 g of a light yellow oil was
obtained which contained 18% (0.17 mmoles) of the TMSCH₂ addition product, 31% (0.12 mmoles) of the α-methyl alcohol, 20% (0.19 mmoles) of the methyl ketone, and 10% (0.09 mmoles) of silylated (Me₃Si) alcohol.

**Phenylacetaldehyde.** Same procedure as described above: 0.118 g (0.98 mmoles) of the aldehyde dissolved in 3 ml of dry methylene chloride and 2 ml of dry hexane. Color of the reaction mixture changed to yellow upon addition of the aldehyde solution, which after an hour faded to a lighter yellow. After concentration, 0.16 g of a yellow oil was obtained which consisted of 41% (0.40 mmoles) of the TMSCH₂ addition product, 5% (0.01 mmoles) of unreacted aldehyde, and 1% (0.01 mmoles) condensation products.

**Fluorenone.** Same procedure as described above: 0.178 g (1.00 mmoles) of the ketone dissolved in a mixture of 3 ml of dry CH₂Cl₂ and 2 ml of hexane. Color of solution changed to a dark red-wine color upon addition of the ketone, became wine red after an hour, and turned yellow on quenching. After concentration, 0.19 g of a yellow oil was obtained which consisted of 17% (0.17 mmoles) of the TMSCH₂ addition product, and 55% (0.55 mmoles) of unreacted ketone.

**4-Methoxybenzaldehyde.** Same procedure as described above: 0.131 g (0.97 mmoles) of the aldehyde dissolved in 4 ml of dry methylene chloride. Color of the solution turned
yellow after addition of the aldehyde. After 3.5 hours of reaction the cooled (immersed in an ice bath for ten minutes) mixture was quenched by adding 3 ml of saturated ammonium chloride solution. After concentration of the organic layer 0.15 g of a yellow oil was obtained which contained 2% (0.02 mmoles) of the TMSCH₂ addition product, 26% (0.25 mmoles) of the methyl ketone, 13% (0.13 mmoles) of the Peterson elimination product, 22% (0.21 mmoles) of reduced aldehyde, 10% (0.09 mmoles) of unreacted aldehyde, 4% (0.04 mmoles) of the water eliminated product, 4% (0.04 mmoles) of condensation products, and 7% (0.07 mmoles) of the silylated (Me₃Si) alcohol.

Preparation of Dimethylaluminum-2,6-tert-butyl-4-methylphenoxide Etherate (BHTMe₇Al:OEt₇), (B1)

In the dry box, 2.65 g (12.0 mmole) of 2,6-tert-butyl-4-methylphenol (BHT-H) was weighed into a 250 ml 3 neck round bottom flask equipped with a magnetic stirring bar, 2 glass stoppers, and a rubber septum. Outside the dry box, under an argon atmosphere the BHT-H was dissolved in 70 ml of freshly distilled hexane. To this stirred solution (at room temperature) was then added drop-wise 6.0 ml of 2.0 M trimethylaluminum solution (in hexanes). Upon addition of the aluminum reagent, an exothermic reaction took place accompanied by evolution of gas (methane; the solution became warm with some solvent condensing on the walls of the flask). This solution was stirred for 2.5 hours and
then 2.1 ml (20 mmole) of freshly distilled diethyl ether was added to the solution which was stirred for an additional forty-five minutes. At this point the flask was immersed in a dry-ice acetone bath and the solvent was removed under vacuum (flash distillation); after approximately half of the solvent was removed a white precipitate began forming. Complete removal of the solvent was insured by leaving the flask under vacuum (0.05 mm Hg, at room temperature) for an additional thirty minutes after all solvent had visibly been removed. The flask was then filled with argon and transferred to the dry box where the product was weighed and stored in a dry dark glass jar; 4.3 g (12 mmoles, 100% yield) of a dry white powder. $^1$H NMR (C$_6$D$_6$) $\delta$ -0.22 (H$_3$C-: s, 6 H), 0.62 (H$_3$C-: t, $J_{H_2}$ = 7.0, 6 H), 1.62 (t-Bu: s, 18 H), 2.38 (H$_3$C-: s, 1H), 3.44 (CH$_2$: q, $J_{H_2}$ = 8.3, 4 H), 7.29 (Ar: s, 2 H); $^{13}$C NMR: $\delta$ 12.8, 21.4, 31.2, 31.8, 35.2, 65.9, Ar: 125.8, 126.1, 126.3, 138.8.

Reaction of Dimethylaluminum-2,6-tert-butyl-4-methyl phenoxide Etherate (B1) with Benzaldehyde and 4-Tolu-aldehyde

Sample procedure (2:1 ratio of B1 to benzaldehyde in hexane). In the dry box, 0.35 g (1 mmole) of the reagent (B1) was measured into a oven dried, 50 ml, round bottom flask equipped with a magnetic stirring bar and a rubber septum. Hexane (15 ml, freshly distilled) was added to the flask to completely dissolve the reagent. Into an oven
dried, 5 ml, pear shaped flask, 0.05 g (0.5 mmole) of benzaldehyde was weighed, and the flask was then purged with argon after the addition of 4 ml of dry hexane. The aldehyde solution was added to the stirred reagent solution at room temperature using a short cannula (the aldehyde flask was rinsed with an additional 2 ml of solvent). With the addition of the first few drops of the aldehyde solution the color of the reagent solution turned wine red and later to an even darker red color. The reaction was quenched after 2.5 hours by adding 2 ml of saturated ammonium chloride solution to the cooled (immersed in an ice bath for 10 minutes) reaction mixture. The contents of the flask were transferred to a separatory funnel and the aqueous layer was extracted with 3 x 8 ml of ether. The combined organic layers were washed with 3 x 3 ml of brine. The organic layer was then dried (Na₂SO₄) and concentrated in vacuo to afford 0.23 g of a yellow oil. GC analysis showed 2% (0.01 mmole) of unreacted benzaldehyde, 45% (0.22 mmole) reduced aldehyde (benzyl alcohol), 32% (0.15 mmoles) of acetophenone, and 9% (0.04 mmoles) of methyl addition to acetophenone.

1.5:1 Ratio of B1 to benzaldehyde in hexane (reverse addition). Same procedure as above; 0.53 g (1.5 mmole) of the reagent (B1), and 0.11 g (1.0 mmole) of the benzaldehyde. After work-up and concentration, 0.52 g of a yellow oil was obtained which on GC analysis showed 3%
(0.03 mmole) of unreacted starting material, 26% (0.27 mmole) of reduced aldehyde, 20% (0.21 mmoles) of acetophenone, and 2% (0.02 mmoles) of methyl addition to acetophenone.

1.5:1 Ratio of B1 to 4-tolualdehyde in hexane. Same procedure as above; 0.52 g (1.5 mmole) of the reagent (B1), 0.12 g (0.99 mmoles, in 4 ml of hexane) of 4-tolualdehyde, and 15 ml of freshly distilled hexane to dissolve the reagent. After work up and concentration 0.48 g of a yellow oil was obtained. GC analysis showed 37% (0.37 mmoles) of unreacted 4-tolualdehyde, 29% (0.29 mmoles) reduced aldehyde (4-tolylalcohol), 28% (0.28 mmoles) of 4-methylacetophenone, and 2% (0.02 mmoles) of 1-(4-methyl)-phenylethanol.

3:1 Ratio of B1 to benzaldehyde in hexane. The reagent was prepared in situ as described above, employing 0.44 g (2.0 mmole) of BHT-H, 1 ml of 2.0 M solution of Me₃Al in hexane, and 0.5 ml (5 mmoles) of freshly distilled diethyl ether. A hexane (5 ml) solution of benzaldehyde 0.070 g (0.67 mmole) was prepared and added to the reagent as described in the sample procedure. After concentration, 0.70 g of a yellow oil was obtained which on GC analysis showed 2% (0.01 mmole) of unreacted benzaldehyde, 34% (0.23 mmole) benzylalcohol, 9% (0.06 mmoles) of 1-phenylethanol,
34% (0.23 mmol) of acetophenone, and 6% (0.04 mmol) of methyl addition to acetophenone.

1.5:1 Ratio of B1 to benzaldehyde in toluene. Same procedure as above; 0.53 g (1.5 mmole) of the reagent (B1), 0.11 g (1.0 mmole, in 4 ml of toluene) of benzaldehyde, and 15 ml of freshly distilled toluene to dissolve the reagent. After concentration, 0.34 g of yellow oil was obtained. GC analysis showed 3% (0.03 mmole) of unreacted benzaldehyde, 42% (0.43 mmole) reduced aldehyde (benzylalcohol), 33% (0.34 mmoles) of acetophenone, and 4% (0.04 mmoles) of methyl addition to acetophenone.

1.5:1 Ratio of B1 to benzaldehyde in toluene; reverse addition. Same procedure as above; 0.53 g (1.5 mmole) of the reagent (B1), 0.11 g (1.0 mmole, dissolved in 7 ml of toluene in a 50 ml round bottom flask) of benzaldehyde, and 15 ml of freshly distilled toluene to dissolve the reagent. In this experiment the reagent solution was transferred by cannula into the aldehyde solution; the reaction mixture turned red wine color as before. Reaction time 3.5 hours. After work-up and concentration, 0.48 g of a yellow oil was obtained which on GC analysis showed: 3% (0.03 mmole) of unreacted benzaldehyde, 40% (0.41 mmole) reduced aldehyde (benzylalcohol), 33% (0.34 mmoles) of acetophenone, and 5% (0.05 mmoles) of methyl addition to acetophenone.
Preparation and Reaction of Dimethylaluminum-2,6-di-tert-butyl-4-methylphenoxide (B2) with Benzaldehyde

The procedure for preparation of B1 was followed employing 0.44 g (2.0 mmole) of BHT-H and 1.0 ml of 2.0 M Me₃Al in hexanes. After stirring the reagent for 2 hours at room temperature, 0.14 g (1.3 mmole) of benzaldehyde (dissolved in 4 ml of dry hexane in a 5 ml pear shaped flask) was added to the reagent flask changing the color of the reaction mixture to a dark red wine color. After quenching (after 1 hour) and work up (as described for the reactions above) GC analysis showed 26% of reduced aldehyde (benzylalcohol), 37% of acetophenone, and 38% of 1-phenylethanol.

Reaction of the Product of [Me₂BHTAl.OEt₂] (B1) with PHCHOHCH₃, (1:1) (B3) with Aromatic Aldehydes

Benzaldehyde (sample procedure). In the dry box, 0.35 g (1.0 mmoles) of B1 was weighed into a 50 ml, oven dried, one neck, round bottom flask equipped with a magnetic stirring bar and a rubber septum. The reagent (B1) was dissolved in 20 ml of dry hexane and 2.0 ml of a 0.502 M solution of 1-phenylethanol in hexane was then added to the reagent solution drop-wise under an argon atmosphere. No obvious signs of reaction (no evolution of gas, only a slight color change to a pale yellow tint) were observed upon addition of the alcohol, so the reaction was allowed to stir at room temperature for three hours. After the
three hours, GC analysis showed complete recovery of 1-phenylethanol. At this point 0.053 g (0.50 mmole) of benzaldehyde (dissolved in 4 ml of dry hexanes in an oven dried 5 ml pear shaped flask) was added drop-wise to the reaction mixture which changed the pale yellow color of the mixture to colorless. The reaction was quenched after 3 hours by adding 2 ml of saturated ammonium chloride solution. The contents of the flask were transferred to a separatory funnel. The aqueous layer was extracted with 3 x 8 ml of ether, and the combined organic layer was washed with 1 x 2 ml of 1.0 M HCl and 2 x 3 ml of brine. The organic layer was dried (Na₂SO₄), filtered and concentrated to afford 0.30 g of a yellow oil. GC analysis showed 0.02 mmoles of unreacted benzaldehyde, 0.31 mmoles of reduced aldehyde (benzylalcohol), 0.41 mmoles of acetophenone, 0.41 mmoles of 1-phenylethanol; a material balance of 76%.

4-Tolualdehyde. Same procedure as above; 0.35 g of B1 and 1.00 ml of 1.01 M solution of 1-phenylethanol in hexane; after 3 hours 0.0606 g (0.504 mmoles) of a 4-tolualdehyde solution in hexane (prepared as described above) was added. After concentration, there was obtained 0.40 g of a yellow oil which on GC analysis showed 0.38 mmoles of reduced aldehyde (4-methylbenzylalcohol), 0.40 mmoles of oxidized starting 1-phenylethanol (acetophenone), 0.53 mmoles of unreacted starting 1-phenylethanol; a material balance of 80%. 
Reaction of the Product of the [Me₃AlBHT·OEt₂ (B1) with PHCHOHCH₃, (2:1)] (B4) with Aromatic Aldehydes

Benzaldehyde. Same procedure as above; used 0.70 g of B1 and 2.00 ml of 0.502 M solution of 1-phenylethanol in hexane; after 3 hours added 0.056 g (0.53 mmole) of benzaldehyde (prepared as described above). Concentration afforded 0.19 g of a yellow oil which on GC analysis showed: 0.14 mmoles of reduced aldehyde (benzylalcohol), 1.10 mmoles of 1-phenylethanol, 0.03 mmoles of methyl addition to acetophenone; a material balance of 83%.

4-Tolualdehyde. Same procedure as above; 0.70 g of B1 and 0.117 g (0.98 mmole) of 1-phenylethanol (dissolved in 2 ml of dry hexane in a dry 5 ml pear shaped flask); after 3 hours added 0.062 g (0.52 mmole) of a hexane solution of 4-tolualdehyde (prepared as described above). After concentration, 0.61 g of a yellow oil was obtained. GC analysis showed 0.18 mmoles of reduced aldehyde (4-methylbenzylalcohol), 0.03 mmoles of methyl addition product [1-(4-methylphenyl)ethanol], 0.13 mmoles of 4-methylacetophenone, 0.88 mmoles of starting 1-phenylethanol; a material balance of 81%.

Comparison of the Rate of Me₃Al Promoted MPV Reduction of Benzaldehyde via the Oxidation of 1-Phenylethanol vs. 1-Phenyl-2-trimethylsilylethanol

Reduction of benzaldehyde via its reaction with the product of the reaction of Me₃Al with PHCHOHCH₃. Under an
argon atmosphere, into an oven dried, 25 ml, one neck, round bottom flask equipped with a rubber septum and a magnetic stirring bar. 0.12 g (1.0 mmoles) of 1-phenyl-ethanol was weighed. The alcohol was dissolved in 10 ml of freshly distilled hexane and the reaction flask was immersed in an ice bath (15 minutes). Me₃Al (0.5 ml of 2.0 M solution in hexane) was added to the cooled solution and the mixture was stirred for 45 minutes. To this solution, 0.11 g of benzaldehyde (1.0 mmoles, in 2 ml of hexane) was added at room temperature. The reaction was followed by GC analysis. The areas and ratios of benzaldehyde and benzyl alcohol (table 6-1) were used in monitoring the reaction.

Table 6-1. GC analysis of the MPV reduction of benzaldehyde via its reaction with the product of the reaction of Me₃Al with 1-phenylethanol.

<table>
<thead>
<tr>
<th>minutes</th>
<th>PhCHO</th>
<th>PhCH₂OH</th>
<th>PhCH₂OH/PhCHO</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>713</td>
<td>163</td>
<td>0.23</td>
</tr>
<tr>
<td>20</td>
<td>172</td>
<td>33.0</td>
<td>0.19</td>
</tr>
<tr>
<td>30</td>
<td>715</td>
<td>292</td>
<td>0.41</td>
</tr>
<tr>
<td>40</td>
<td>713</td>
<td>300</td>
<td>0.42</td>
</tr>
<tr>
<td>60</td>
<td>730</td>
<td>339</td>
<td>0.47</td>
</tr>
<tr>
<td>150*</td>
<td>80.4</td>
<td>82.0</td>
<td>1.0</td>
</tr>
<tr>
<td>960 (16 hrs)</td>
<td>71.0</td>
<td>447</td>
<td>6.3</td>
</tr>
</tbody>
</table>

* Half life
The reaction was quenched after 18 hours by adding 1 ml of 1.0 M HCl to the cooled solution. The aqueous layer was extracted with 3 x 5 ml of ether. The combined organic layers were washed with 3 ml of 1.0 M HCl and 2 x 3 of brine, dried (MgSO₄), filtered, and concentrated in vacuo to afford 0.14 g of light yellow oil.

**Reduction of benzaldehyde via its reaction with the product of the reaction of Me₃Al with PhCHOHCH₂TMS.** The above procedure was repeated simultaneously using 0.20 g of 1-phenyl-2-trimethylsilyl ethanol (1.0 mmole, 95% homogeneous by GC) in place of 1-phenylethanol. The areas and ratios of benzaldehyde and benzyl alcohol tabulated below

<table>
<thead>
<tr>
<th>Corrected areas from GC</th>
<th>minutes</th>
<th>PhCHO</th>
<th>PhCH₂OH</th>
<th>PhCH₂OH/PhCHO</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10</td>
<td>301</td>
<td>279</td>
<td>0.93</td>
</tr>
<tr>
<td></td>
<td>20*</td>
<td>163</td>
<td>171</td>
<td>1.1</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>234</td>
<td>355</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>71.1</td>
<td>91.1</td>
<td>1.3</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>134</td>
<td>261</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td>150</td>
<td>140</td>
<td>553</td>
<td>4.0</td>
</tr>
<tr>
<td></td>
<td>960</td>
<td>14.3</td>
<td>607</td>
<td>42</td>
</tr>
<tr>
<td></td>
<td>(16 hrs)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Half life
(table 6-2) were used in monitoring the reaction. After concentration in vacuo, 0.15 g of a light yellow oil was obtained.

Comparison of the Rate of Me₃Al and Me₂BHTAl.OEt₂ Promoted MPV Reduction of Benzaldehyde via the Oxidation of 1-Phenylethanol

Reduction of benzaldehyde via its reaction with the product of the reaction of Me₂BHTAl.OEt₂ (B1) with PHCHOHCH₃. The procedure for preparing (B3) was followed employing 0.70 g (2.0 mmoles) of Me₂BHTAl.OEt₂ (B1), 0.24 g (2.0 mmoles) of 1-phenylethanol, and 100 ml of freshly distilled hexane. This mixture was allowed to stir for 1.5 hours, then 0.21 g (2.0 mmoles, in 5 ml of hexane) of benzaldehyde was added to the reaction mixture. Tridecane 0.186 g (1.01 mmoles) was also added to the reaction mixture as an internal standard for GC monitoring of the reaction. The mmoles and ratios of benzaldehyde and benzyl alcohol listed in table 6-3 were used in monitoring the

<table>
<thead>
<tr>
<th>minutes</th>
<th>PhCHO</th>
<th>PhCH₂OH</th>
<th>PhCH₂OH/PhCHO</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>1.6</td>
<td>0.11</td>
<td>0.069</td>
</tr>
<tr>
<td>25</td>
<td>1.4</td>
<td>0.14</td>
<td>0.10</td>
</tr>
<tr>
<td>45</td>
<td>1.6</td>
<td>0.21</td>
<td>0.13</td>
</tr>
<tr>
<td>120</td>
<td>1.1</td>
<td>0.40</td>
<td>0.36</td>
</tr>
<tr>
<td>300</td>
<td>1.1</td>
<td>0.74</td>
<td>0.69</td>
</tr>
</tbody>
</table>
reaction. The reaction was quenched after 5 hours by adding 5 ml of 1.0 M HCl to the cooled solution. The aqueous layer was extracted with 3 x 7 ml of ether. The combined organic layers were washed with 3 x 3 ml of brine, dried (Na₂SO₄), filtered, and concentrated in vacuo to afford 0.76 g of a light yellow oil.

Reduction of benzaldehyde via its reaction with the product of the reaction of Me₃Al with PhCHOHCH₃. The above procedure was repeated simultaneously, employing 1.0 ml of Me₃Al (2.0 mmoles, 2.0 M solution in hexane) in place of Me₂BHTAl.ΟEt₂ (Bl), 0.24 g (2.0 mmoles) of 1-phenylethanol, and 100 ml of freshly distilled hexane. This mixture was allowed to stir for 1.5 hours, then 0.21 g (2.0 mmoles, in 5 ml of hexane) of benzaldehyde was added to the reaction.

Table 6-4. GC analysis of the MPV reduction of benzaldehyde via its reaction with the product of the reaction of Me₃Al with 1-phenylethanol.

<table>
<thead>
<tr>
<th>minutes</th>
<th>PhCHO (mmoles)</th>
<th>PhCH₂OH (mmoles)</th>
<th>PhCH₂OH/PhCHO</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>1.3</td>
<td>0.40</td>
<td>0.32</td>
</tr>
<tr>
<td>25</td>
<td>1.0</td>
<td>0.52</td>
<td>0.50</td>
</tr>
<tr>
<td>45</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>120*</td>
<td>0.78</td>
<td>0.80</td>
<td>1.0</td>
</tr>
<tr>
<td>300</td>
<td>0.61</td>
<td>1.0</td>
<td>1.7</td>
</tr>
</tbody>
</table>

* Half life
mixture. Tridecane 0.186 g (1.01 mmoles) was also added to the reaction mixture for GC monitoring of the reaction. The areas and ratios of benzaldehyde and benzyl alcohol (table 6-4) were used in monitoring the reaction. After concentration in vacuo, 0.23 g of a light yellow oil was obtained.


146


BIOGRAPHICAL SKETCH

Vahak Abedi was born, of Armenian descent, on December 12, 1961 in Tehran, Iran. In Tehran he attended the Goolbengian primary and Mary Manookian secondary schools. In the February of 1979, due to the political revolution in Iran, he relocated to Miami, Florida, where he completed his last year of high school. Mr. Abedi received his Associate of Arts degree from the Miami Dade Community College and his A.C.S. accredited Bachelor of Science degree from the Florida International University in December of 1985. He began his graduate studies in the Department of Chemistry at the University of Florida in August of 1986.
I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Merle A. Battiste
Chairman
Professor of Chemistry

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

William R. Dolbier
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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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This dissertation was submitted to the Graduate Faculty of the Department of Chemistry in the College of Liberal Arts and Sciences and to the Graduate School and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

December 1991

Dean, Graduate School