

SILYLATION COUPLED WITH DESILYLATION AS A ROUTE TO SYNTHESIS

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Acyldesilylation reactions and their usefulness in ketone synthesis will be discussed. The aromatic C-H bond is less reactive than aromatic C-M ($M = \text{Si, Ge, Sn \& Pb}$) bonds under identical electrophilic reaction conditions. Thus, various types of ketonic compounds have been prepared smoothly without complications due to unwanted isomer distribution in the products.

Trimethylsilylation of multidentate organic ligands and their subsequent reactions with metal and organometal halides leading to the synthesis of new and novel compounds will be discussed.

Synthesis of some new heterocyclic compounds involving B and P as hetero atoms is also presented.

Key Words : Silylation, Desilylation; Ketone Synthesis; Coordination and Organometallic Compounds; Homo- and Hetero-bymetallic Complexes

INTRODUCTION

THE use of organosilicon compounds in organic synthesis is extensively studied. It is now well established that silylsubstituted reagents and substrates activate the substrate to reaction, direct the course of reaction, and also protect the substrate from unwanted reaction. Practical application of silylation as derivatization to confer g.l.c. volatility or characterizable mass spectral fragmentation have been reviewed.

Successful applications of organosilicon compounds in organic synthesis are mainly based on the relative bond strengths between Si-E and C-E (where E stands for F, O, C or H) (Table I), available vacant *d*-orbitals and relative electronegativity values (Table I).

TABLE I
Relative bond energies/KJ mol⁻¹

Si-F	540-570	C-F	440-465
Si-O	370-450	C-O	350-360
Si-C	230-320	C-C	347
Si-H	290-320	C-H	414

Such characteristics may give rise to a wide range of thermodynamically favourable processes.

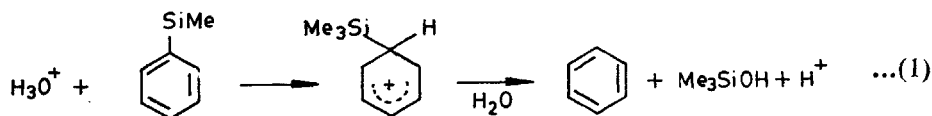
The vacant d-orbitals on silicon are of suitable energy for backbonding with a filled 2p orbital on an adjacent atom of a first-row elements, enabling silicon to stabilize, for example, an adjacent carbonion. They can also be involved in substitution reactions at silicon or at an adjacent atom.

Bonds between carbon and a group IVb metal are much less reactive to most reagents than say, C-Mg, C-Cd bonds. Nevertheless, the C-M bond breaks in the direction $C^{-\delta} - M^{+\delta}$ (Table II), either by electrophilic attack at carbon or nucleophilic attack at the metal, or a combination of both. Bond heterolysis is thus very easy, when the carbon fragment is a good leaving group.

TABLE II
Relative electronegativity (Allred-Rochow)

Si	1.74	C	2.50
Li	0.97	O	3.50
Na	1.01	F	4.10
Mg	1.23	Cl	2.83
Ti	1.32		

A trimethylsilyl group or any other triorganosilyl group can be very easily introduced into a specific ring position *via* a Grignard or Wurtz-Fittig reaction and subsequent desilylation reactions with suitable chemical compound may lead to new/novel synthesis. Here one should give due consideration on the groups attached to carbon and (or) silicon. Of the various desilylations, protodesilylations is the one which has been most fully investigated and has been the subject of intensive kinetic studies. The reaction is acid-catalysed, first order in silane substrate and the rate determining step involves the transfer of a proton from the solvent to that substrate.¹ It has been observed that most of the features of the reaction are consistent with the S_L2 mechanism, which is common to many other substitutions (e.g. nitration of aromatics.²)



In so far as the scope of the present talk is concerned, the most important factor associated with protodesilylation is that the aryl-silicon bond is cleaved by acid at a rate which is much faster than the rate at which a comparably situated aryl-hydrogen undergoes acid catalysed hydrogen exchange.

Various other electrophiles have been used to study the mechanisms of cleavage of carbon-silicon bonds.¹

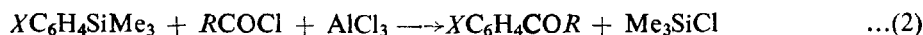
In the present work, the author has tried to demonstrate the utility of silylations and desilylations in developing new/novel synthetic strategies taking examples

mostly from our own work. For convenience, it will be divided into three synthesis, viz.,

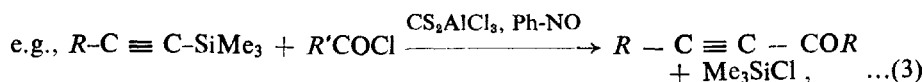
(i) Ketones (ii) Coordination/Organometallic compounds and (iii) Heterocyclic compounds.

(i) Ketones

The higher reactivity of the Ar-Si bond in comparison with the Ar-H bond towards electrophilic reagents allows the introduction of an acyl group at a specific ring position under mild reaction conditions. Contrary to several earlier reports, Ar-Si bonds are now known not to be cleaved by AlCl_3 under moderate conditions³ but if acyl halides are present aromatic acyl desilylation occurs.⁴

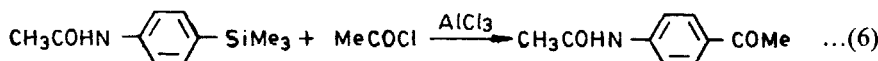
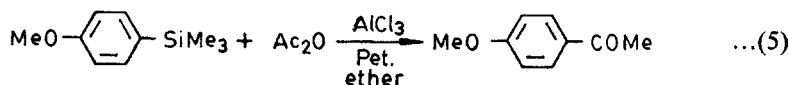
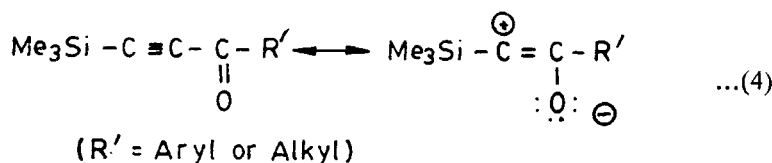


In fact, we have studied thoroughly the scope of this reaction as a method of preparing ketones.^{1,5} However, prior to our work some isolated results were published^{6,7}



where $R = \text{Me}_3\text{Si}, \text{C}_4\text{H}_9, \text{C}_6\text{H}_5$, etc., $R^1 = \text{Me}, \text{Et}, p\text{-O}_2\text{N C}_6\text{H}_4, \text{ClCH}_2$, etc.

The second Me_3Si group is not cleaved easily as the electron withdrawing effect of the RCO group introduced effectively deactivates the second $-\text{C} \equiv \text{C} - \text{Si} \equiv$ to electrophilic displacement :



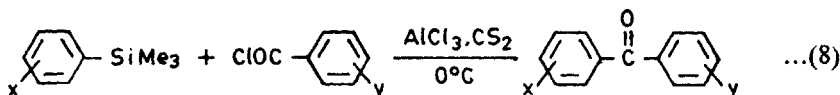
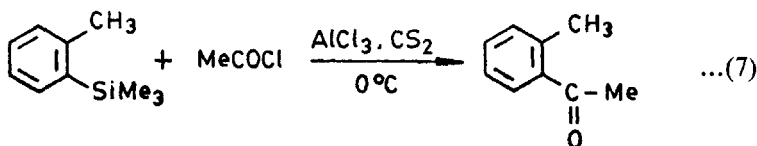
The reaction between equimolar amounts of an aryltrimethylsilane, $\text{XC}_6\text{H}_4\text{SiMe}_3$, CH_3COCl or a benzoyl chloride, $\text{YC}_6\text{H}_4\text{COCl}$, and AlCl_3 in CS_2 at 0°C gives the expected ketones, $\text{XC}_6\text{H}_4\text{COCH}_3$ or $\text{XC}_6\text{H}_4\text{COC}_6\text{H}_4\text{Y}$ in moderate to good yield.^{1,5,8} (Table III).

TABLE III

Diaryl ketones, $XC_6H_4COC_6H_4Y$, made from aryltrimethylsilanes, $XC_6H_4SiMe_3$, and acylhalides, YC_6H_4COCl , in carbon disulphide

X	Y	Reaction temp./time (h)	Yield (%)	M.p. (°C) or b.p. (°C/mm)	Lit. m.p. (°C) or b.p. (°C/mm)
<i>p</i> -Me	H	reflux/3	60	56-58	59-60 ^f
<i>o</i> -Me	H	0°/0.5, then reflux/1.5	62	158-160/2 ^a	168-12 ^f
<i>o</i> -OMe	H	0°/0.5, then reflux/3	73	163-165/5 ^b	210-27 ^{1a}
<i>m</i> -OMe	H	0°/0.5, then reflux/3	61	180-182/5 ^c	342-343/733 ^{1a}
<i>m</i> -Me	<i>m</i> -Me	0°/0.5, then reflux/2	69	45-46	45 ^f
<i>p</i> -Me	<i>p</i> -Me	0°/0.5, then reflux/2	80	92-94	95 ^f
<i>p</i> -Me	<i>m</i> -NO ₂	30-35°/2	76	110-111	111 ^f
<i>p</i> -Cl	H	reflux/3	58	80-80.5	77-78 ^f
<i>p</i> -Cl	<i>p</i> -Me	reflux/2	30	128-130	129
<i>o</i> -Me	<i>o</i> -Me	reflux/2	68	70-73	72 ^f
<i>m</i> -Me	<i>m</i> -SiMe ₃	25°/3	40	48-49 ^d	
<i>p</i> -SiMe ₃	<i>p</i> -SiMe ₃	30°/6	75	105-107 ^e	
<i>o</i> -OMe	<i>p</i> -SiMe ₃	30°/3	40	188-190/0.1 mm ^f	

^a n_D^{20} 1.6000 (lit.⁸ n_D^{20} 1.6065). ^bM.p. 45-47° (from ethanol). ^cM.p. 43-44° (from ethanol). ^d(nc) (Found : C, 75.8; H, 7.1; mol. wt., 324. C₁₇H₂₀O₂Si calcd. : C, 76.1; H, 7.4%; mol. wt., 326.) The 2,4-dinitrophenylhydrazone had m.p. 135-136° (dec.) (from EtOH). ^e(nc) Found : C, 70.1; H, 8.0. C₁₇H₂₀O₂Si calcd. : C, 69.9; H, 8.0%.) ^f(nc) (Found : C, 71.9; H, 7.0. C₁₇H₂₀O₂Si calcd. : C, 71.8; H, 7.0%.)



Especially noteworthy is the fact that (*m*-methoxy phenyl) trimethylsilane and benzoyl chloride at 0 °C give the expected *m*-methoxyphenyl phenyl ketone, *m*-MeOC₆H₄COC₆H₅, in 61 per cent yield, free from any *O*- and *p*-isomers, although when the reaction was carried out under reflux small amounts of these isomers were obtained.

The benzylacyl carbonium ion, ArCH₂⁺CO, once it is formed, is possibly more reactive than the benzyl carbonium ion, Ar⁺CO, since the positively charged carbon atom is separated from the ring-system by a methylene group, where as in Ar⁺CO, it is directly attached to the ring, and may be stabilized by π-electron

delocalization. Phenylacetyl chloride was, therefore, used by us in acetyldesilylations to synthesize benzylphenyl ketones^{1,5} (Table IV)

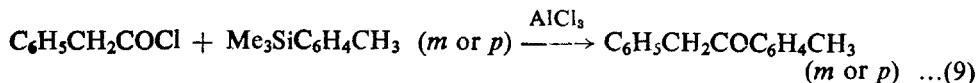


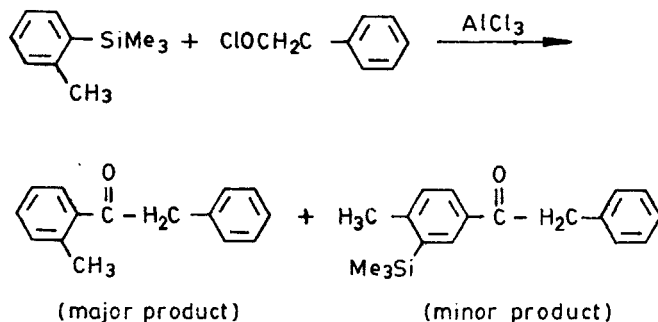
TABLE IV

Aryl benzyl ketones, XC₆H₄COCH₂Ph, made from XC₆H₄SiMe₃ compounds and PhCH₂COCl in carbon disulphide^a

X	Yield (%)	M.p. (°C) or b.p. (°C/mm)	Lit. m.p. (°C) or b.p. (°C/mm)
<i>p</i> -Me	77	108-110	110 ⁷
<i>m</i> -Me	70	43-45	42 ⁷
<i>o</i> -Me ^b	48	140-142/1	172-173/10 ⁷
<i>p</i> -SiMe ₃ ^c	88	73-75	75-77 ¹⁵

^aReaction conditions : 1 h at 0° followed by 3 h under reflux. ^bBenzyl 4-methyl-3-(trimethylsilyl)phenyl ketone (28%) (nc), m.p. 80-81° (from ethanol) (Found : C, 76.9; H, 7.6. C₁₈H₂₂OSi calcd. : C, 76.6; H, 7.8%), was also isolated. ^cUse of 2 molar equivalents of phenylacetyl chloride gave *p*-bis(phenylacetyl) benzene (32%), m.p. 165-166 (lit.⁵ m.p. 175°). Found : C, 83.7; H, 5.95. C₂₂H₁₈O₂ calcd. : C, 84.1; H, 5.7%.) The IR and NMR spectra were as expected.

However, the *ortho*tolyltrimethylsilane gave interesting results producing two ketones

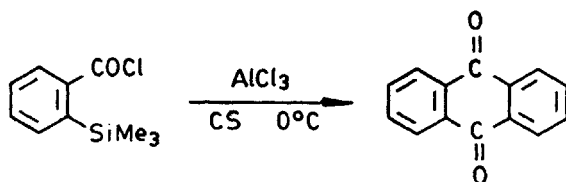


The combined activating effect of CH₃ group (*para*) and Me₃Si group (*meta*) apparently reduced the difference in reactivity between the Ar(C-H) and Ar(C-Si) bonds — so that acylation becomes a competitive process with acyl desilylation.⁸

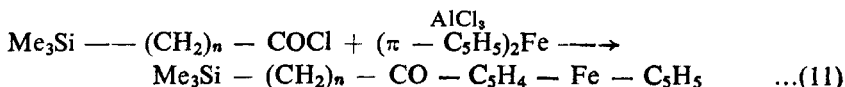
As expected, 2-thienyltrimethylsilane also gave ketones satisfactorily :



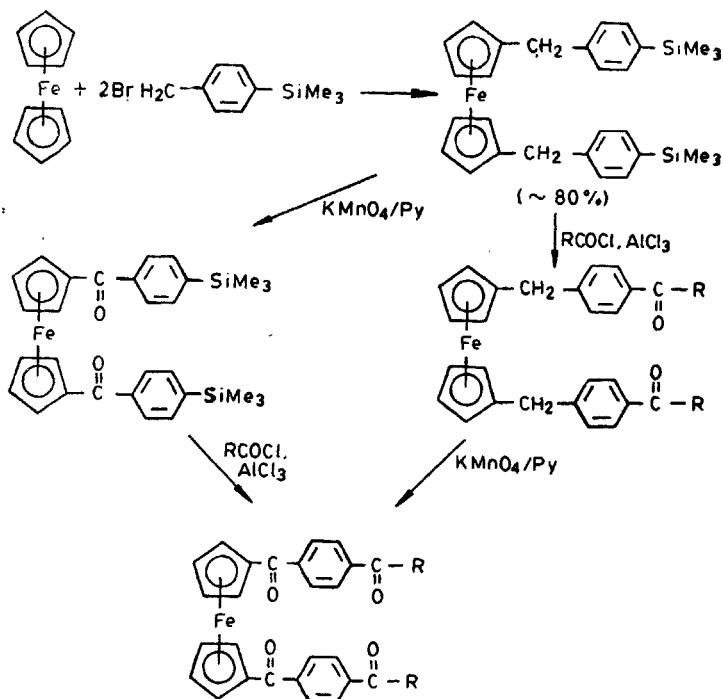
Interestingly, *o* (trimethylsilyl) benzoyl chloride gave anthraquinone on treatment with AlCl₃ :



The use of acid chlorides in Friedel-Crafts reactions may be extended to aromatics with reactivities in the toluene-benzene range, thus opening up a generally useful synthetic route for silyl aryl ketone intermediates,⁹ e.g.



As an extension of this reaction, we have done the following reactions on cyclopentadienyl ring(s) in ferrocene leading to the synthesis of some new/novel ketones :¹⁰



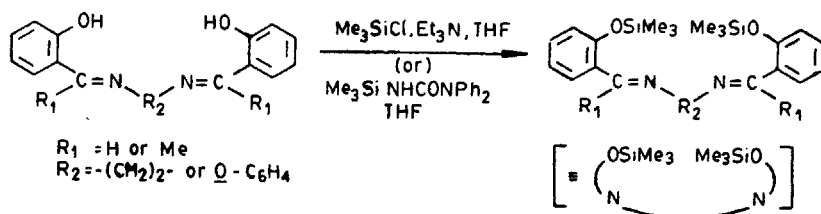
The above discussion reveals that the acyldesilylations under the the Friedel-Crafts reactions conditions occur more readily and are more selective than the conventional Friedel-Crafts acylations, and thus permit the synthesis of ketones with little trouble ensuing from unwanted isomer distribution in the products. As such, they serve as a complement to process like the organocadmium method,

and especially useful where reactive functional groups (such as acyl, nitro, etc) rule out the use of the more reactive organometallic systems.

(ii) *Synthesis of Coordination/Organometallic Compounds*

Although Schiff base complexes of most transition metals have been thoroughly studied, there are few known organo- and organo-oxo-titanium (IV) Schiff base complexes.¹¹ In fact, there are no reports of the reactions of silylated Schiff bases with organo- and organo-oxo-titanium (IV) halides, organo-tin (IV) halides, etc. other than the study by us.¹¹⁻¹⁶ However, a brief report is available¹⁷ on the reaction of silylated Schiff bases with $[\text{MoCl}_3\text{O}(\text{thf})_2]$ (thf = tetrahydrofuran) producing $[\text{MoCl}(\text{O})L]$ (H_2L = quadridentate Schiff base), the same results we also independently achieved (unpublished).

The author successfully silylated several Schiff bases and characterized them fully. These silylated Schiff



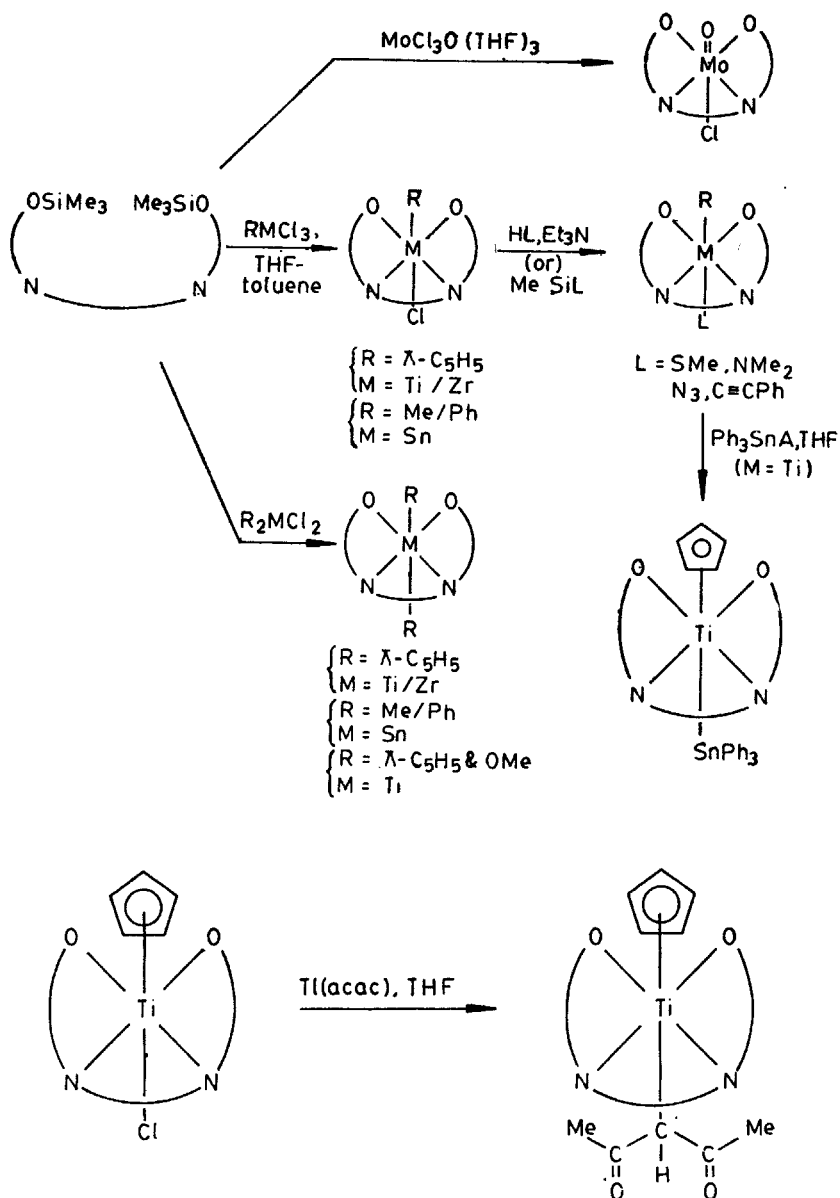
bases are then allowed to react with metal halides and organometal halides leading to the synthesis of many new/novel syntheses. Some of the newly synthesized compounds are allowed to react further with suitable substrates affording interesting compounds. A few complexes are shown below :

The complex $(\pi-\text{C}_5\text{H}_5)\text{Ti}(L)\text{Cl}$ (where L = dianion of quadridentate Schiff base) smoothly reacted with $\text{Tl}(\text{acac})$ to yield carbon-bonded acetylacetonato-complex of titanium (IV) as shown below :

The advantages of the silylation coupled with desilylation route for the synthesis of coordination/organometallic compounds may be summarised as follows (compare with the use of sodium/lithium salts of the ligands) :

- (i) silylated Schiff bases are soluble in organic solvents;
- (ii) this procedure gives much higher yield of the desired product;
- (iii) the reaction can be carried out at very mild conditions;
- (iv) less reaction time is necessary;
- (v) it gives much cleaner products; and
- (vi) by products is only Me_3SiCl which can be very easily removed.

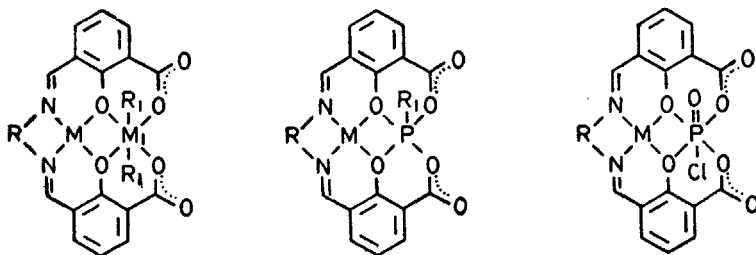
The synthetic strategy has been further extended to synthesize dinuclear complexes of the types shown below : ¹⁰⁻¹⁶



Several other uses of this versatile synthetic method will be presented to demonstrate the preparation of novel compounds of phosphorus.¹⁰

(iii) Synthesis of Heterocyclic Compounds

Progressing further in our journey with silylation desilylation reactions, we have achieved successful synthesis of some novel heterocyclic compounds involving B, P, As, etc as hetero atoms. Thus, N,N-dimethylethylenediamine is silylated,



$M = \text{Ni}^{\text{II}}, \text{Pd}^{\text{II}}, \text{etc.}$

$\begin{cases} M_1 = \text{Ti, Zr,} \\ R_1 = \pi\text{-C}_6\text{H}_5 \end{cases}$

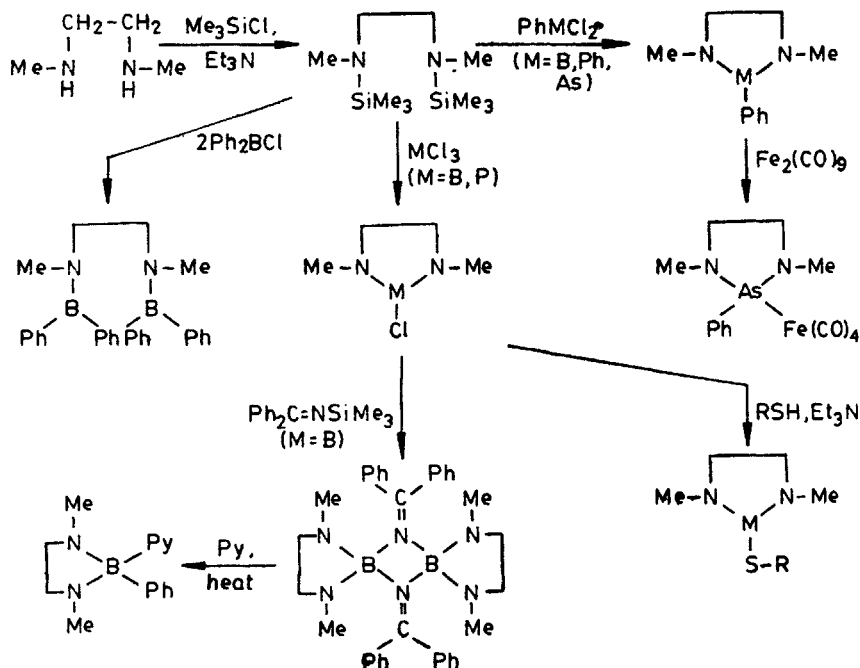
$\begin{cases} M_1 = \text{Sn} \\ R_1 = \text{Me, Ph} \end{cases}$

$R_1 = \text{Ph, Me}$
 $M = \text{Ni}^{\text{II}}, \text{Pd}^{\text{II}}$

$M_1 = \text{bivalent/trivalent transition metals}$

$R_1 = \text{solvents/anions}$

which on further reaction with suitable substrates afforded heterocyclic compounds : ¹⁰



CONCLUSION AND PROSPECTS

From the above excursion mainly through our own work on the silylations coupled with desilylation as a route to synthesis it is evident that this synthetic

strategy has opened multifaceted preparative possibilities. Although C-silylation and its use in organic and related syntheses has been extensively documented in literature, silylations of other elements and their use in syntheses is not so well-studied. Besides, silylations of chelate ligands and their utility in synthesising coordination and organometallic compounds have not been studied in detail. The knowledge gained from the present study and also from literature on silylations and related reactions, should further be employed and extended in developing newer synthetic strategies.

ACKNOWLEDGEMENT

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