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The extraordinary reactions of phenyldimethylsilyllithium with *N*,*N*-disubstituted amides†

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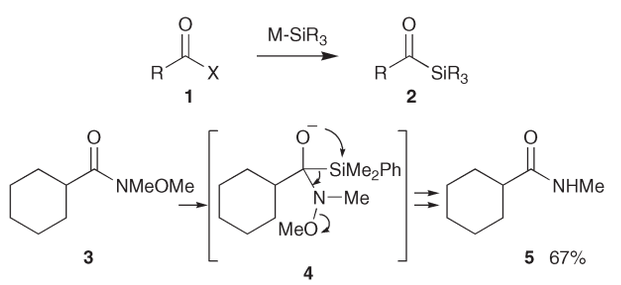
Phenyldimethylsilyllithium reacts with *N*,*N*-dimethylamides in a variety of ways, depending upon the stoichiometry, the temperature and, most subtly, on the structure of the amide, with quite small-seeming changes in structure leading to profound changes in the nature of the products. When equimolar amounts of the silyllithium reagent and *N*,*N*-dimethylamides **6** are combined in THF at −78 °C, and the mixture quenched at −78 °C, the product is the corresponding acylsilane **8**. If the same mixture is warmed to −20 °C before quenching, the product is a *cis* enediamine **11**. The enediamines are easily isomerised from *cis* to *trans*, easily oxidised to dienediamines **15**, and, with more difficulty, hydrolysed to α-aminoketones **13**. If two equivalents of the silyllithium reagent are used, the product is an α-silylamine **20**. The mechanism of formation of the enediamines appears to be by way of a Brook rearrangement of the tetrahedral intermediate **17** followed by loss of a silanoxide ion to give a carbene or carbene-like species. The 'carbene' combines with the Brook-rearranging nucleophile to give an intermediate **28**, which loses another silanoxide ion to give the enediamine. The same carbene can be attacked by a second equivalent of the silyllithium reagent to give the α-silylamine **20**. Other nucleophiles, like alkyllithiums, phenyllithium, and tributylstannyllithium also trap the carbene to give products **48**–**52**. The intermediate anions in these reactions, when benzylic, can be further trapped with alkylating agents to give the products **33**, **34** and **53**–**55**. In special cases, the anion formed by attack on the carbene can be trapped by intramolecular reactions displacing internal leaving groups, as in the formation of the enamine **37** and the cyclopentane **41**, or attacking a carbonyl group, as in the formation of the indanone **61**, or attacking a double or triple bond, as in the formation of the cyclopentanes **71** and **75**. In another special case, the carbene reacts with vinyllithium to give an allyllithium intermediate **56**, which selectively attacks another molecule of carbene to give eventually the γ-aminoketone **58**. Small changes in the structure of the amide lead to a variety of other pathways each of which is discussed in the text. Notably, each member of the homologous series of amides $Ph(CH_2)_nCONMe_2$ gives rise to a substantially different product: when $n = 0$, the reaction is normal, and the yield of the α-silylamine **20e** is high; when $n = 1$, proton transfer in the intermediate anion **64** and displacement of the phenyl group leads to the silaindane **66**; when $n = 2$, fragmentation of the intermediate anion **80**, and capture of the carbene by benzyllithium leads to the 1,4-diphenylbut-2-ylamine **83**; and when $n = 3$, proton transfer in the intermediate anion **67** and displacement of the phenyl group leads to the silacyclopentane **69**.

Introduction

We have described in detail the preparation[1] of Gilman's phen yldimethylsilyllithium reagent, and its reactions with a variety of compounds, including sulfonamides,[2] α-silyloxy ketones,[3] aluminium-coordinated aromatic carbonyl compounds,[4] β-*N*,*N*-dimethylaminoacrylic esters,[5] nitriles,[6] esters,[7,8] acid chlorides[8] and thioamides,[9] supplementing our earlier work on the cuprate reagents[10] derived from the lithium reagent. This paper is the full account of the reactions of the silyllithium reagent with tertiary amides, previously published as five preliminary communications.[11,12]

In our work with nitriles, esters, acid chlorides, thioamides and amides, we had in mind that one or more of them might furnish a simple synthesis of acylsilanes in the general sense **1** → **2**. We were successful using esters[7] and acid chlorides,[8] and Bonini[13] and others[14] were successful with the reaction of the silylcuprate and other silyl–metal reagents with acid chlorides. Weinreb amides **3** do not work in this type of reaction, because the tetrahedral intermediate **4** undergoes an elimination reaction (arrows) by way of a Brook rearrangement, and the net result **5** is the cleavage of the N–O single bond.[15]



Weinreb amides are normally used for the synthesis of ketones because the tetrahedral intermediate is stabilised, slowing down the expulsion of the nitrogen function. Fortunately, the high nucleophilicity of the silyllithium reagent allows it to react with *N*,*N*-dimethylamides **6** in a short time at low temperatures, typically within two hours in a dry-ice acetone bath, at a temperature at which the tetrahedral intermediate **7** does not expel the dimethylamino group. Provided that the tetrahedral intermediate is quenched at this low temperature, acylsilanes **8** are formed in reasonable yield.[7]

With all these methods for making acylsilanes, it is perhaps worth pointing out that the most simple is probably to use the reaction of two equivalents of the silyllithium reagent with an acid chloride **9**, quenching the 1,1-disilylmethanolate

† Electronic supplementary information (ESI) available: Experimental data. See http://www.rsc.org/suppdata/ob/b4/b412768d/

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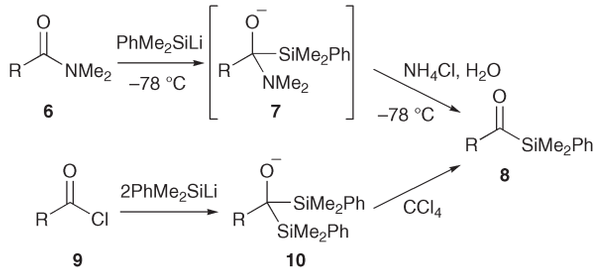
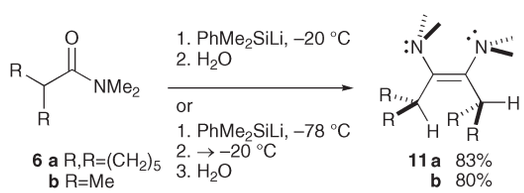


10 with carbon tetrachloride.[8] It avoids the need for copper, the oxidising agent is cheap and free of toxic metals, and, if carbon tetrachloride is deemed too hazardous, it is likely that other electrophilic chlorine agents will work equally well. Furthermore, if the tertiary amides are to be made from acid chlorides, the only advantage to using them would be to save one equivalent of silyllithium reagent. However, in the course of our work on the synthesis of acylsilanes from tertiary amides, we came across the first of the bizarre reactions that set off the work described in this paper.

Results and discussion

The first unexpected result came when we carried out the reaction shown as **6** → **7** → **8** (R = cyclohexyl) at −20 °C instead of using a dry-ice acetone bath in both steps. The product was the enediamine **11a**, easily isolated as a beautifully crystalline compound among the basic products, and in good yield (Scheme 1). This compound had survived dissolution in dilute hydrochloric acid for several hours, which was not typical for an enamine, leading us at first to doubt this structure, but an X-ray crystal structure confirmed that it was the enediamine, and that it was the *cis* isomer.[16] We repeated the reaction using the amide **6b** (R = Me), and obtained the corresponding *cis* enediamine **11b**. The best yields were obtained when the amides were treated with a small excess of the silyllithium reagent at −78 °C for an hour or two, and the mixture warmed to −20 °C or above before quenching with water.



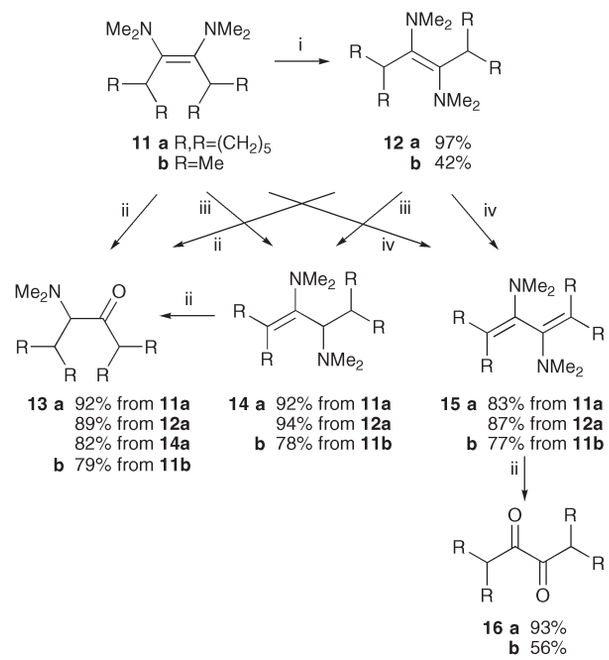
Scheme 1

We were presented, therefore, with two immediate tasks: to investigate the chemistry of these intriguing compounds, and to investigate the generality and especially the mechanism by which they had been formed.

The chemistry of the enediamines

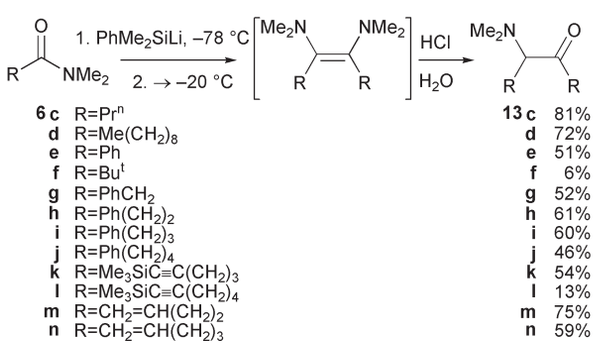
The X-ray structure for the enediamine **11a** showed that the nitrogen lone pairs were orthogonal to the π-bond, which explained why the enediamines were not hydrolysed in dilute aqueous acid, as typical enamines would have been. It also explained why there were two six-proton *N*-Me singlets in the low-temperature (−43 °C) ^{1}H-NMR spectrum—one of the NMe_2 groups was oriented so that the two methyl groups were *cis* to the double bond and the other two methyl groups were *trans*. At room temperature, the lines were broad, but at 77 °C, the lines were sharp again, with only one *N*-Me signal. In the ^{13}C-NMR spectrum at −43 °C, there were ten signals (there ought to have been twelve), but only six at room temperature and above, presumably as a result of rotations about the single bonds attached to the double bond.

The *cis* isomers **11** easily isomerised to the *trans* **12** when they were stirred with Adams' catalyst in an inert atmosphere (Scheme 2). The *cis* and *trans* enediamines **11** and **12** could be hydrolysed to the corresponding α-aminoketones **13** in dilute hydrochloric acid solution, but only after heating the solution for several hours. The *cis* and the *trans* enediamines isomerised to the enamines **14** when their oxalate salts were warmed (in an attempt to recrystallise them), presumably by a protonation–deprotonation pathway. Finally, the *cis* and *trans* enediamines were easily oxidised to the dienediamines **15**, using palladium on charcoal. This reaction was so easy that it even took place in a hydrogen atmosphere (during an attempt to hydrogenate the double bond), but the yields, naturally enough, were better when the reaction was conducted in the air. The dienediamines could be hydrolysed to the α-diketones **16**, in a remarkably simple way to make these compounds. All our attempts to reduce the double bond of the enediamines were fruitless.



Scheme 2 Reagents and conditions: i, PtO_2, MeOH, 50 °C, 15 min; ii, 3 N HCl, 70 °C, 18 h; iii, (a) $(CO_2H)_2$, (b) recrystallise from EtOAc, (c) NaOH; iv, Pd/C, MeOH, rt, 4 h.

Although the enediamines were formed from amides with an unbranched alkyl group **6c** and **6g**–**6n**, isolating them proved to be difficult, because they were much more easily hydrolysed. Accordingly, we simply hydrolysed the mixture of products from all the examples in Scheme 3 in warm dilute hydrochloric acid to give the α-aminoketones **13c**–**13n** (Scheme 3), most of them in reasonably good yield.

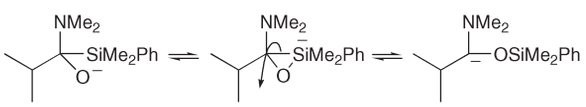


Scheme 3

The chemistry of the enediamines had proved to be rich in surprises, and there is much more that could be done. However, we turned our attention to the intriguing problem of how they had been formed.

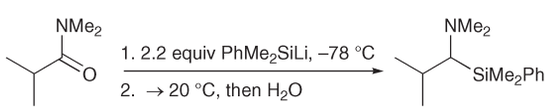
The pathway for the formation of the enediamines

The good yields of acylsilanes **8** when the reaction was conducted entirely with cooling in a dry ice-acetone bath showed that the tetrahedral intermediate was fully formed after an hour or two at this temperature. The formation of the enediamine when the solution of the tetrahedral intermediate was warmed to −20 °C showed that both halves of the enediamine came from this source. The nucleophilic component can be identified as the outcome of a Brook rearrangement, which can be formulated as an equilibrium between an α-silyl alkoxide **17** and an α-silyloxy anion **19**, with the latter as the umpolung species. Alternatively, it can be formulated as a single hypervalent silicon species **18**, which can react as an oxygen or as a carbon (**18**, arrow) nucleophile, depending upon the circumstances. The electrophilic component of the coupling was not so easily identified. It cannot have been the amide **6**, because it had already been consumed in the formation of the tetrahedral intermediate. Furthermore, this step is not reversible: when we added one equivalent of the silyllithium reagent to the amide **6b** at −78 °C, followed after an hour by one equivalent of the amide **6a**, and then warmed the mixture to −20 °C before quenching, the enediamine **11b** was the only product, with no sign of cross coupling. The tetrahedral intermediate must have provided both the nucleophilic and the electrophilic components of the coupling.



17 **18** **19**

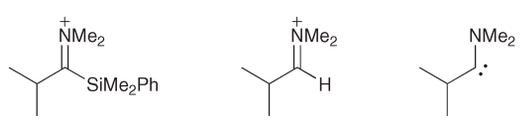
The most substantial clue to the structure of the electrophilic component came when we repeated the reaction with the amide **6b**, but used 2.2 equivalents of the silyllithium reagent, hoping that the second equivalent would trap the electrophilic component. The product this time was the α-silylamine **20b** in high yield (Scheme 4), with no trace of the enediamine **11b**, confirming that the silyllithium reagent was more nucleophilic than the Brook-rearranging species **17**–**19**. This ruled out the acylsilane **8** as the electrophilic species. In any case, it had been an unlikely candidate, since it was hard to believe that the dimethylamino group would reappear in the enediamine once it had been expelled.



6b **20b** 96%

Scheme 4

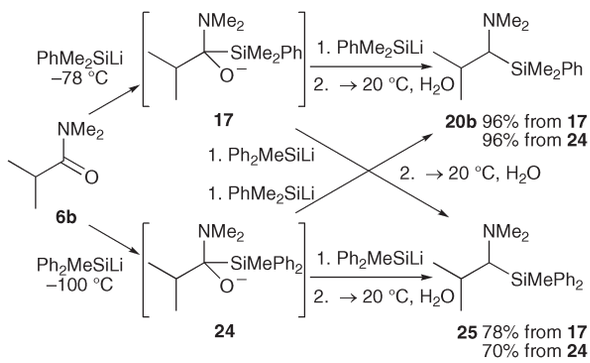
Having dismissed the amide **6** and the acylsilane **8** as plausible candidates for the electrophilic species, we were left with three possibilities: the silyliminium ion **21**, the iminium ion **22** and the carbene **23**, the first of which could be formed in a reasonable way if the oxyanion, presumably coordinated to lithium, were to be the leaving group from the tetrahedral intermediate instead of the dimethylamino group, just as it is, coordinated to aluminium, in the reduction of amides by lithium aluminium hydride.



21 **22** **23**

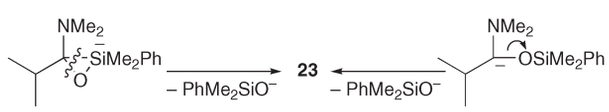
The problem with the silyliminium ion **21** was that trapping it with the silyllithium reagent ought to give an α,α-disilylamine, and it seemed unlikely from established organosilicon chemistry that a silyl group would have been cleaved off under the mild conditions of the acidic workup.

We were able to prove that this could not have been the pathway by treating the tetrahedral intermediate **17** with the diphenylmethylsilyllithium reagent, when we obtained only the α-silylamine **25**, in which the second silyllithium reagent was the one to find its way into the product (Scheme 5). In a complementary experiment, we made the tetrahedral intermediate **24** using diphenylmethylsilyllithium as the first reagent. It is known that the more phenyl groups there are on the silicon the faster the Brook rearrangement,[17] and therefore this reaction had to be performed at −100 °C, because at −78 °C the enediamine was formed directly, the whole process evidently being faster with this silyl group. We then treated the tetrahedral intermediate **24** with the phenyldimethylsilyllithium reagent, and warmed the mixture to −20 °C before quenching, and obtained the α-silylamine **20b**, in which it was again the second silyllithium reagent that appeared in the product. This proved that an α,α-disilylamine could not have been an intermediate, and that therefore the α-silyliminium ion **21**, however plausible it was, was not involved.



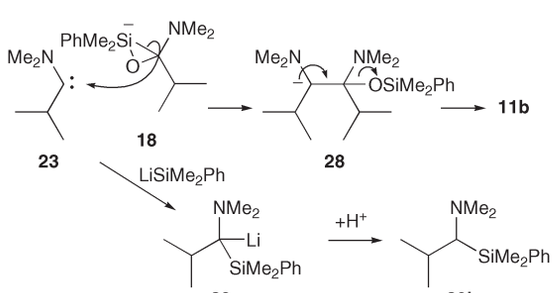
Scheme 5

The problem with the iminium ion **22** was that it was not a plausible intermediate: where had the proton come from? On the other hand the carbene **23** was a plausible intermediate,‡ simply from loss of silanoxide from the Brook-rearranging system **17**–**19** in a reaction as illustrated in the alternative drawings **26** or **27**. This step will be easier than it is in other Brook-rearranging systems because of the presence of the carbene-stabilising amino group.[18]



26 **27**

The reaction of the carbene **23** with the Brook-rearranging system would give an intermediate **28**, from which the enediamine **11b** can be formed by β-elimination of silanoxide. That the product is the *cis* isomer might be a consequence of the two amino groups' coordinating a lithium ion. Even more straightforwardly, the reaction of the carbene with excess silyllithium reagent would give the α-silyllithium intermediate **29**, and hence the α-silylamine **20b** after protonation.

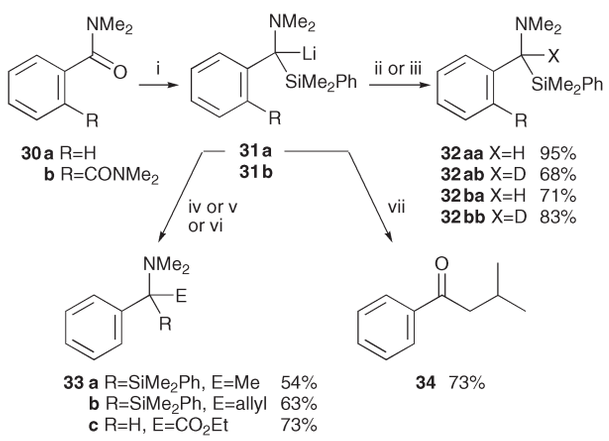


‡ We discuss possible structures for the 'carbene' in a later section, but use the term carbene here for simplicity.

Evidence for an α-silyllithium intermediate

Naturally, we assumed that the α-proton in the α-silylamine **20b** had arrived during the workup, but this was not the case. When the mixture produced by adding two equivalents of the silyllithium reagent to the amide **6b** at −78 °C, and warming to −20 °C, was quenched with deuterium oxide, the usual product **20b** was formed without deuterium incorporation at the α-carbon.

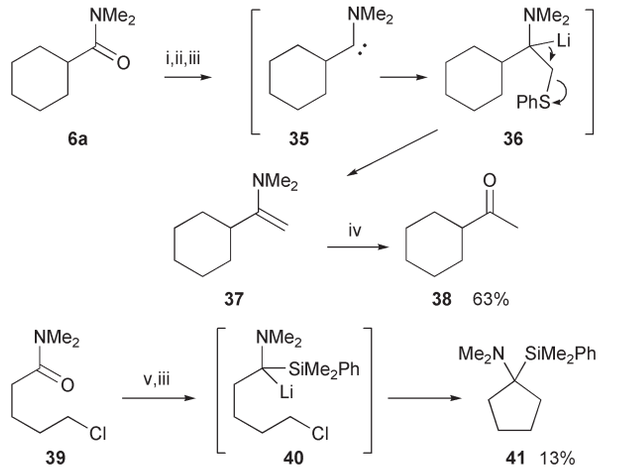
We thought that the lithium reagent **29** might have abstracted a proton from the phenyldimethylsilyl group, in which the methyl groups and the phenyl group have hydrogen atoms six atoms away from the α-carbon. This was not the case: integration of the SiMe and SiPh signals in the ^{1}H-NMR spectrum were at full strength, and so deuterium had not been incorporated there. In case the integration had not been reliable enough, we also synthesised a fully deuterated phenyldimethylsilyllithium reagent, and found that it too failed to lead to the incorporation of a deuterium atom at the α-carbon. Although we have not been able efficiently to trap the intermediate **29** itself, we obtained much evidence that an α-silyllithium intermediate is involved in the reactions between the silyllithium reagent and a large number of other tertiary amides, as discussed below. Three sets of reactions (Schemes 6–8) provided compelling evidence for an α-silyllithium intermediate, and these are discussed here.



Scheme 6 Reagents: i, 2.2 equiv. $PhMe_2SiLi$; ii, H_2O; iii, D_2O; iv, MeI; v, allylBr; vi, $ClCO_2Et$; vii, Me_2CHCHO.

The aromatic amides **30** reacted with two equivalents of the silyllithium reagent, and quenching the intermediates **31** with water gave the α-silylamines **32aa** and **32ba** (Scheme 6). In both cases, the benzyllithium intermediates survived long enough for quenching with deuterium oxide to give the α-silylamines **32ab** and **32bb** with high levels of deuterium incorporation (90% and 98%, respectively). The intermediate lithium reagent **31a** could also be trapped with methyl iodide, allyl bromide, ethyl chloroformate and isobutanal, giving the products **33a**–**c** and **34**, respectively. The amine **33c** has presumably lost the benzylic silyl group during the workup, and the ketone **34** was presumably formed by Peterson elimination followed by hydrolysis of the enamine.

We carried out two experiments (Scheme 7) in a deliberate attempt to intercept an α-silyllithium intermediate when it was too unstable to be picked up by deuteration. We treated the amide **6a** with one equivalent of the silyllithium reagent at −78 °C, followed by one equivalent of phenylthiomethyllithium, and then warmed the mixture to −20 °C before quenching with aqueous acid. Under these conditions, we expected that the intermediate carbene **35** would be trapped by the carbon nucleophile to give the intermediate lithium reagent **36**, which would undergo β-elimination to give the enamine **37** (Scheme 7). Gratifyingly, the product, after hydrolysis with aqueous acid, was cyclohexyl methyl ketone **38** in fairly good yield. We also treated the δ-chloroamide **39** with two equivalents of the silyllithium reagent, expecting the intermediate lithium reagent

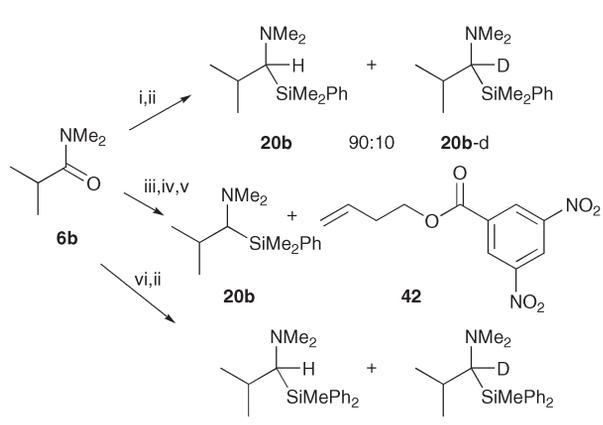


Scheme 7 Reagents: i, 1.1 equiv. $PhMe_2SiLi$, −78 °C; ii, $PhSCH_2$-Li, −78 °C; iii, warm to −20 °C; iv, HCl, H_2O; v, 2.2 equiv. $PhMe_2SiLi$, −78 °C.

40 to undergo cyclisation to give the cyclopentane **41**, which it did, although the yield was low.

We concluded that the α-silyllithium intermediate **29** must have been formed, but that it was so reactive that it found a proton somewhere before we could trap it. We took all the obvious precautions, but the only direct evidence for its intermediacy came when we carried out the reaction with the amide **6b** in d_8-THF at −15 °C, in order to minimise the isotope effect. The product **20b** did have 10% of deuterium incorporation at the α-position (Scheme 8), showing that at least one of the places the α-silyllithium reagent had found a proton was in the solvent. Rather curiously, when we examined what the product from the THF might be, we were surprised to find that it was not the lithium enolate of acetaldehyde, but lithium but-3-enolate, as shown by trapping it with 3,5-dinitrobenzoyl chloride to give the ester **42**. The fragmentation of 2-lithiotetrahydrofuran into the enolate of acetaldehyde and ethylene has been known for a long time,[19] and we have twice seen this pathway giving us unexpected products.[20] The fragmentation to give a but-3-enolate has been seen in the gas phase,[21] and more recently it has been seen in solution in the presence either of HMPA[22] or of potassium *tert*-butoxide.[23]

Finally, we treated the amide **6b** with diphenylmethylsilyllithium at −78 °C, knowing that in this case the α-silyllithium can be formed at this temperature (see Scheme 5) and might survive at this temperature. Quenching this mixture with D_2O at −78 °C gave the α-silylamine **25**-d with high levels of deuterium incorporation, presumably because at this temperature the lithium reagent is slower to find a proton in THF or anywhere else.

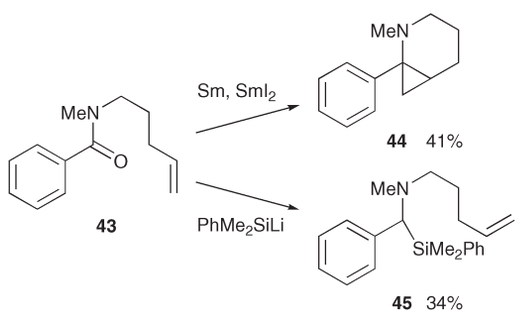


Scheme 8 Reagents: i, 2.2 equiv. $PhMe_2SiLi$, d_8-THF, −15 °C; ii, D_2O; iii, 2.2 equiv. $PhMe_2SiLi$, THF; iv, warm to −20 °C; v, 3,5-$(O_2N)_2C_6H_3COCl$; vi, 2.2 equiv. $Ph_2MeSiLi$, THF, −78 °C.

The nature of the 'carbene'

The formation of α-silylamines and of enediamines from the reaction of silyllithium reagents with amides was not without precedent. Both Gilman[24] and Vyazankin[25] and their co-workers had seen the formation of an α-silylamine, and the latter group had seen the formation of an enediamine, but only in mixtures and not in good yield. Kashimura and Shono found that reductive silylation of *N*,*N*-dimethylamides using trimethylsilyl chloride and magnesium leads to α-silylamines, and electrolytic silylation leads to α-aminoketones similar to **13**.[26] Ogawa and Sonoda and their co-workers were able to make enediamines by treating tertiary amides with samarium[27] or ytterbium[28] iodide, and by reducing selenoamides with copper(0).[29] Furthermore, they were able to trap the carbenoids as cyclopropanes, either by including a double bond in one of the alkyl chains **43** → **44**,[27] or intermolecularly with styrene.[30]

We attempted to trap the carbene by treating Ogawa and Sonoda's amide **43** with the silyllithium reagent, but the α-silylamine **45** was the only recognisable product (Scheme 9). α,α-Diaminocarbenes are stable in the presence of a pendant alkene,[31] indicating that α-aminocarbenes are not the easiest carbenes to trap, and nucleophilic carbenes in general—those carrying amino or alkoxy substituents—do not customarily insert into the double bonds of simple alkenes.[32] Nevertheless, the successful trapping of the α-aminocarbenoids in Ogawa and Sonoda's samarium work shows that it is not impossible. For whatever reason, our carbene was not intercepted.

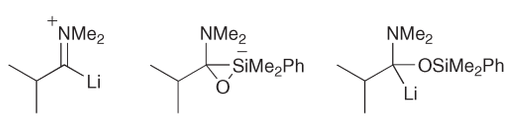


Scheme 9

We also attempted to trap the carbene with electrophiles, on the grounds that an α-aminocarbene ought to be nucleophilic in character. The problem with this idea is that our carbene is formed when the tetrahedral intermediate is warmed, and the tetrahedral intermediate is itself a good nucleophile for any electrophile we might think of adding. In the event, the only product we could recognise with benzoyl chloride, benzaldehyde, methyl benzoate or methyl acrylate was the acylsilane, presumably formed by *O*-acylation or alkylation of the tetrahedral intermediate before the carbene could be formed.

Thus in none of these experiments, nor in any of the others described below, were we able to obtain direct evidence for a carbene intermediate. Our only evidence is the nucleophilic attack upon the carbene, giving the various α-aminolithium reagents described above, together with several others described later in this paper. One feature in particular gave us pause—in none of our experiments did we find any products that could be ascribed to insertion by the carbene into a neighbouring C–H bond, which is normally an easy pathway. Along with our failure to trap a carbene by cyclopropane formation, this indicated that the intermediate is probably not a simple carbene. In the discussion above, and later, we have used the word carbene as a unifying idea rather than as a precise description of the intermediate.

Whatever its structure, the carbene in these reactions is not the usual kind of carbenoid. Carbenoids, more often than not, are complexes with a transition metal or a lanthanoid, and the only metal we have is lithium. What we have been calling a carbene could be a lithioiminium ion **46**, it could be the Brook-rearranging intermediate **18** itself, or it could be the lithio intermediate **47**, which is a redrawing of the conventional Brook rearrangement 'product' **19**. Whatever its structure, it principally behaves as an electrophile. It reacts with the Brook-rearranging nucleophile to give the enediamine, with the silyllithium reagent to give the α-silylamine, and similarly with the other organolithium reagents discussed below. The lithioiminium ion **46** would explain electrophilic behaviour straightforwardly. That the other formulations **18** and **47** for the 'carbene' would react as electrophiles is less obvious, but the presence of an α-lithium atom is known greatly to speed up nucleophilic substitution.[33] The hypervalent α-silyloxyanion in the species **18** can reasonably be expected to have a similar effect, and the product of nucleophilic attack opening the three-membered ring with C–O bond cleavage can be expected to lose silanoxide to give the α-silyllithium intermediate. Similarly, the α-lithium atom in the intermediate **47** can be expected to encourage the nucleophilic displacement of silanoxide. We cannot distinguish between these possibilities, but we can say that they are probably better than the bald description of the intermediate as a carbene. They all explain why the insertion into an α-C–H bond is not as easy as it is with a conventional carbene, and they account for our inability to trap the carbene as a cyclopropane. Nevertheless, because we do not know the structure of the intermediate, and because it is not like other carbenoids, we shall continue, for simplicity in the discussion, to *draw* it as a carbene and to use the word *carbene*.

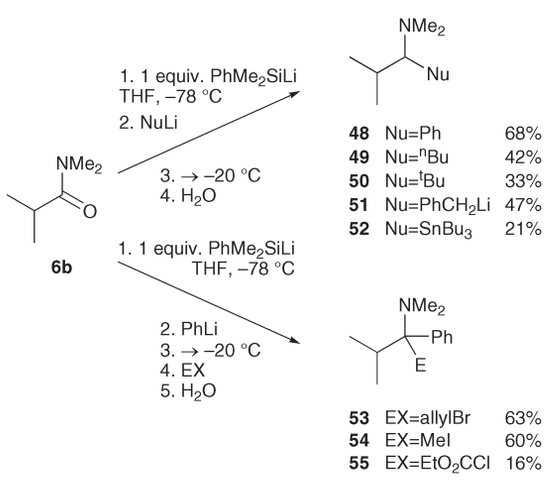


46 **18** **47**

Intercepting the 'carbene' with other nucleophiles

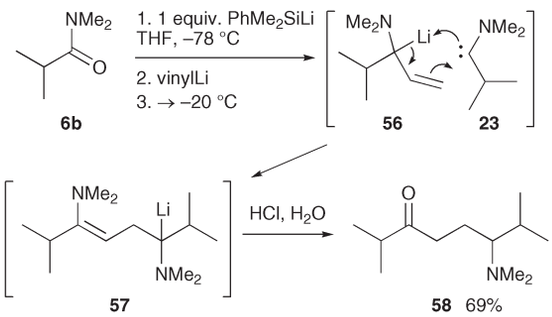
Having had success trapping the carbene with the phenylthiomethyllithium reagent (Scheme 7), we tried a number of other carbon nucleophiles, and one tin nucleophile, and obtained the products **48**–**52** (Scheme 10). In each case, we mixed the amide **6b** with slightly more than one equivalent of the silyllithium reagent at −78 °C, kept the mixture at this temperature for an hour or two, then added the second nucleophile, before warming to −20 °C and quenching with water. When the nucleophile was phenyllithium, the intermediate α-silyllithium reagent was stable enough to be trapped with allyl bromide, methyl iodide and ethyl chloroformate, giving the tertiary alkyl tertiary amines **53**–**55**. Only one example of each of the reactions in Scheme 10 was carried out, and so the yields are probably not the best that could be obtained.

Two nucleophiles were not quite as simple. Vinyllithium trapped the carbene to give the intermediate **56**, which apparently attacked another molecule of the carbene **23** to give the enamine **57**, and hence the γ-aminoketone **58** (Scheme 11).

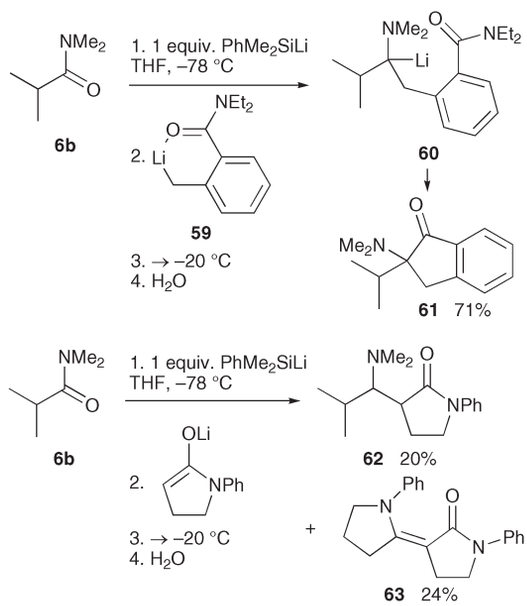


Scheme 10

A similar reaction on the amide **6a** gave the corresponding γ-aminoketone but in lower yield (28%). We deduce from these reactions that allyllithium reagents are exceptionally good at capturing a carbene, since the allyllithium reagent **56** evidently competed effectively with the vinyllithium reagent. Although we probably do not have an actual carbene, it is reasonable that allyllithium reagents should capture carbenes especially well, given that they can do so in a 5-membered cyclic transition structure **56** + **23** (arrows), and it is possible to reformulate this for whichever of our intermediates, **18**, **46** or **47**, it actually is.



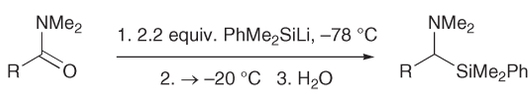
Scheme 11



Beak's reagent **59**,[34] which is a vinylogous enolate and a benzyllithium, and should therefore have similar allylic character, gave the intermediate **60**, which cyclised as expected to give the indanone **61** in reasonably good yield. We repeated two of the reactions described above with Grignard reagents (PhMgBr and CH_2=CHMgBr), working up with water, and obtained the same products **48** and **58** as we did with the corresponding organolithium reagents, but in lower yield (33% and 17%, respectively). In contrast, the lithium enolates of a ketone and of an ester, which also have allylic character, were not nucleophilic enough to trap the carbene—they were evidently unable to compete with the Brook-rearranging species, since the only product we isolated was the enediamine **11b**. On the other hand, the marginally more nucleophilic enolate of *N*-phenylpyrrolidone did trap the carbene, giving a low yield of the pyrrolidine **62**, along with some of the aldol condensation product **63**. This result was particularly significant with respect to the discussion in the last section of this paper on the reaction between the silyllithium reagent and *N*-phenylpyrrolidone.

Using two equivalents of the silyllithium reagent and varying the structure of the *N*,*N*-dimethylamide

In Schemes 1 and 3 and the attendant discussion, we saw the relatively straightforward results from treating a range of *N*,*N*-dimethylamides with *one equivalent* of the silyllithium reagent (if the formation of enediamines can be accepted at this stage of the discussion as straightforward). The straightforward result of treating them with *two equivalents* would be the formation of the α-silylamines analogous to the α-silylamine **20b**, which is what occurred with the otherwise unfunctionalised amides **6a**–**c** and with the benzamide **6e** (Scheme 12), and also with the *N*,*N*-diethyl and pyrrolidine amides of isobutyric acid, which gave the corresponding α-silylamines in 87% and 85% yield, respectively (not illustrated). In contrast, we obtained low yields of the α-silylamines when the amides included such minor functional groups as a benzene ring, a triple bond or a double bond two, three or four carbon atoms away from the amide group **6g**–**6o**. One of the reasons for the low yields was the formation of an extraordinary range of surprising products. We isolated most of them only in low yield, not all of them pure, but all of them identifiable and explicable if an α-silyllithium is an intermediate.



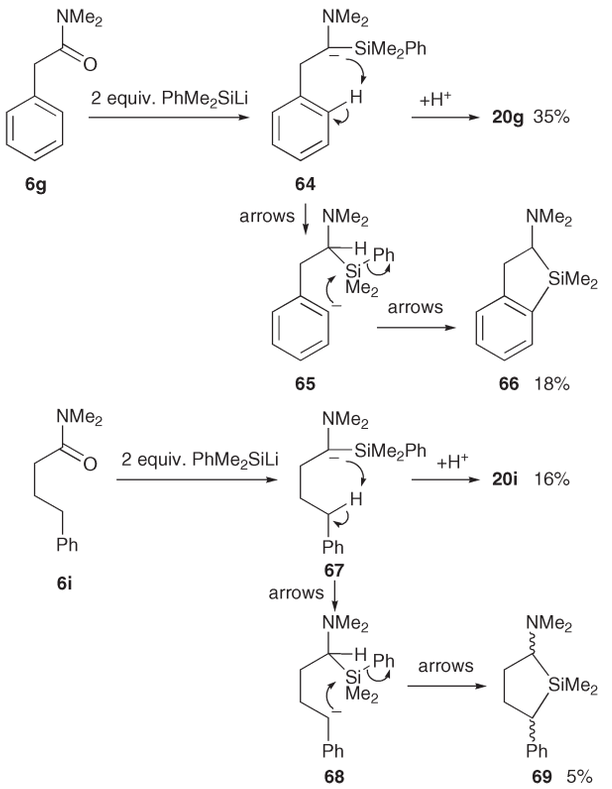
6 a	R=c-C_6H_{11}	**20a**	89%
b	R=Pr^i	**b**	96%
c	R=Pr^n	**c**	92%
e	R=Ph	**e**	95%
g	R=$PhCH_2$	**g**	35%
h	R=$Ph(CH_2)_2$	**h**	6%
i	R=$Ph(CH_2)_3$	**i**	16%
j	R=$Ph(CH_2)_4$	**j**	17%
k	R=$Me_3SiC{\equiv}C(CH_2)_3$	**k**	11%
l	R=$Me_3SiC{\equiv}C(CH_2)_4$	**l**	15%
m	R=CH_2=$CH(CH_2)_2$	**m**	10%
n	R=CH_2=$CH(CH_2)_3$	**n**	1%
o	R=CH_2=$CH(CH_2)_4$	**o**	low

Scheme 12

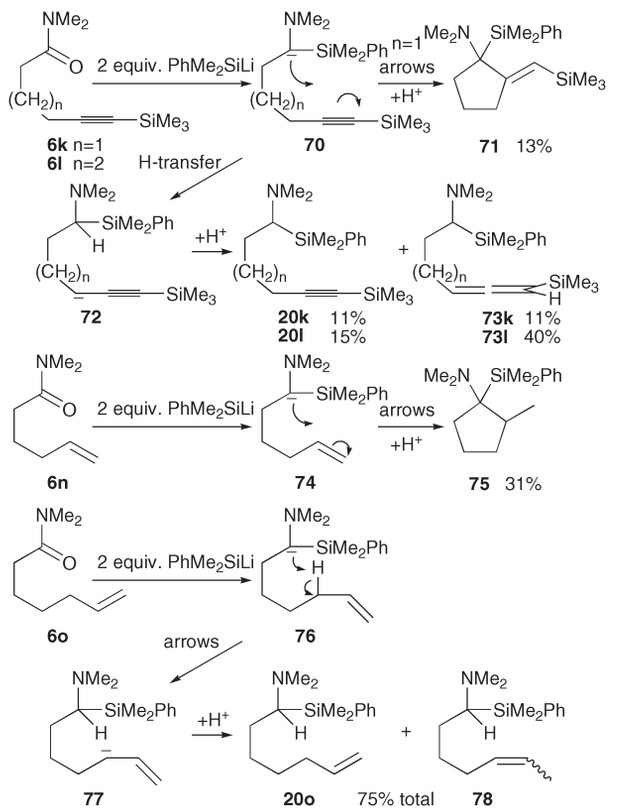
The amide **6g** gave, in addition to the α-silylamine **20g**, a cyclic α-silylamine **66** (Scheme 13). This can be explained by proton transfer **64** (arrows), followed by an intramolecular displacement of the phenyl group from the silicon **65** (arrows), for which there is precedent.[35] Similarly, with two more carbon atoms in the chain, a proton transfer **67** from the benzylic position and displacement of the phenyl group **68** explains the formation of the cyclic α-silylamine **69** from the amide **6j** (Scheme 13).

Some of the amides **6k**–**6o** with strategically placed triple and double bonds also gave, in addition to the low yields of α-silylamines (Scheme 12), products which can be accounted for either by nucleophilic additions to the triple and double bonds, or by intramolecular proton transfers giving propargyl- **72** or allyllithium intermediates **77**, as summarised in Scheme 14, although not all of these mixtures were separable into their individual components. These experiments provided further evidence for the intermediacy of an α-silyllithium reagent, since the intramolecular attack of an organolithium reagent on a terminal double bond **74** (arrows) forming a 5-membered ring **75** has several precedents,[36] and there is precedent for the addition to a triple bond too.[37] The product **75** appeared to be a single diastereoisomer, but we did not discover which one.

Of course, addition to double and triple bonds like this might also be radical reactions. Reactions of this type have been used as probes for radical intermediates, as in the formation of Grignard reagents from bromides.[38] We do not think that radical intermediates offer the best explanation for all our products, except perhaps in the sense that all two-electron mechanisms might be rapidly succeeding steps following a single electron transfer.[39] Single electron transfer from the silyllithium reagent remains an attractive and plausible possibility, especially in view of the similarities of some of our reactions with those observed with samarium iodide, but the sum total of all our results is more easily encompassed by the ionic mechanisms we have used, and which we prefer for the time being in the absence of any evidence demanding reappraisal.

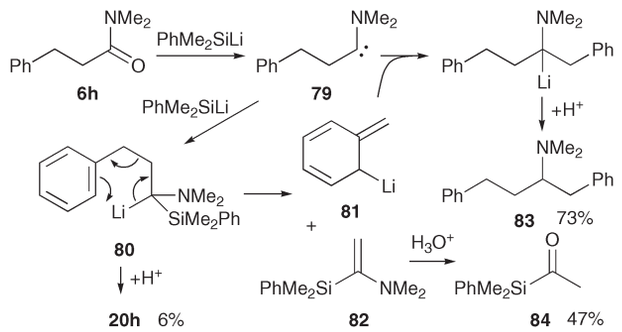


Scheme 13



Scheme 14

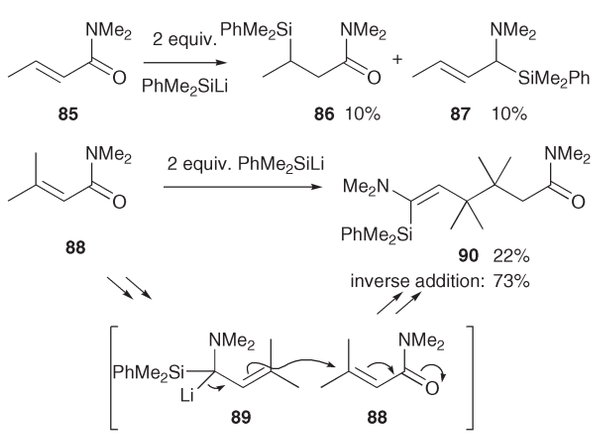
The most surprising result of all was the good yield of the amine **83** from the phenylpropionamide **6h** (Scheme 15). This result can be explained by an unprecedented fragmentation, in which the α-silyllithium intermediate **80** gives benzyllithium **81** and the enamine **82**. We draw the benzyllithium as its 'allylic' isomer to emphasise that the fragmentation might be a retro metalla-ene reaction, and to make the connection that this intermediate, like the allyllithium **56**, is evidently an exceptionally good trap for the carbene **79**, since it accounts for the formation of the amine **83**, even though it has to compete with the excess of silyllithium reagent. We isolated the acylsilane **84** among the basic products. Evidently the enamine **82** was extracted by the acid used to separate the basic products, and hydrolysed there. It is remarkable that, in spite of the excess of the silyllithium reagent, no silyl group appears in the major product **83**.



Scheme 15

The variety of pathways followed in the homologous series **6e** and **6g**–**6i**, illustrates how difficult it is to predict what will happen in these reactions. No matter how small a change one makes in the structure of the starting material, such as inserting a methylene group into the chain, something substantially different can occur. This is fascinating, but unfortunately it means that few of the reactions can be called general.

This unpredictability is even more decisively illustrated by the two reactions we saw with α,β-unsaturated amides. The crotonamide **85** and the silyllithium reagent gave a mixture of products, from which we could identify only the product of conjugate addition **86** and the normal product, the α-silylamine **87**. In an attempt at least to stop the conjugate addition, we added the silyllithium reagent to the β,β-disubstituted unsaturated amide **88**, and isolated, in addition to the α-amino ketone analogous to the products **13**, a most unexpected product, namely the amide **90** in 22% yield, clearly the result of some kind of β,β-coupling (Scheme 16). We speculated that this might be the result of a conjugate addition by the anion **89** to the unsaturated amide, and so attempted to optimise this pathway by inverse addition: adding the amide **88** to the silyllithium reagent. The yield rose to 73%, indicating that in outline the reaction may take this course, although β,β-coupling creating two adjacent quaternary centres might indicate that a modification to the mechanism, with electron transfer at some stage, might be an improvement.

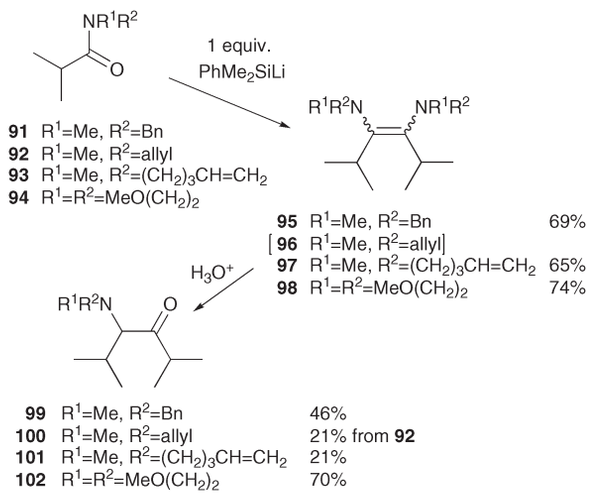


Scheme 16

Varying the structure of the groups on the nitrogen atom

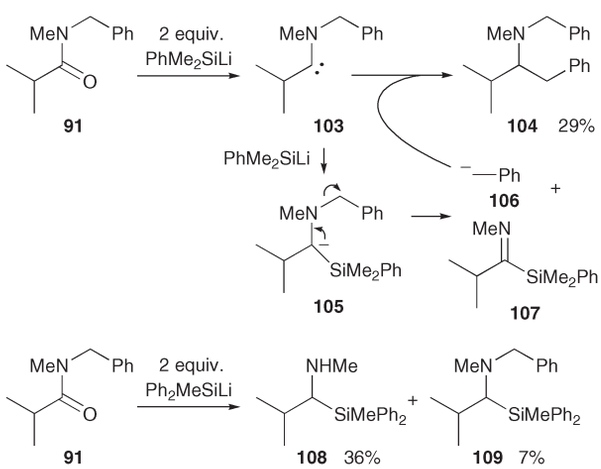
Two of the more reliable products of our reactions, the α-aminoketones **13** and the α-silylamines **20**, would be more useful in synthesis if they could be prepared shorn of their *N*-methyl groups. Accordingly, we examined the effect of having functionalised groups on the nitrogen which might have made it easier to remove them. The formation of enediamines **95**–**98**

when we used one equivalent of the silyllithium reagent was usually uneventful, except that the enediamines were not always cleanly the *Z*-isomer. Similarly we could hydrolyse them to the α-aminoketones **99**–**102** (Scheme 17). In contrast, we had little success with the recipe using two equivalents of the silyllithium reagent, suffering again from a bewildering variety of pathways.



Scheme 17

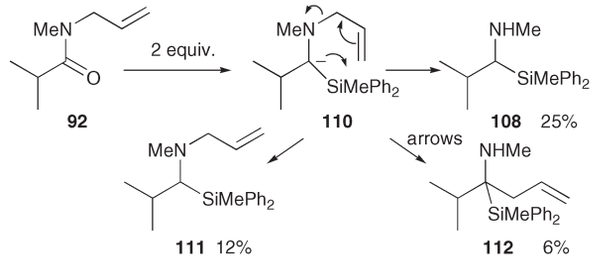
Thus the only basic product that we were able to identify from the reaction of the amide **91** with two equivalents of phenyldimethylsilyllithium, was the *C*-benzylated amine **104** (Scheme 18). This can be accounted for by another elimination releasing a benzyl anion **105** → **106** + **107**, followed by the attack of the benzyl anion **106** on the carbene intermediate **103** and subsequent protonation. When instead we used diphenylmethyl silyllithium, we did not find the corresponding product, but did isolate some of the debenzylated α-silylamine **108**, along with the normal product, the α-silylamine **109**.



Scheme 18

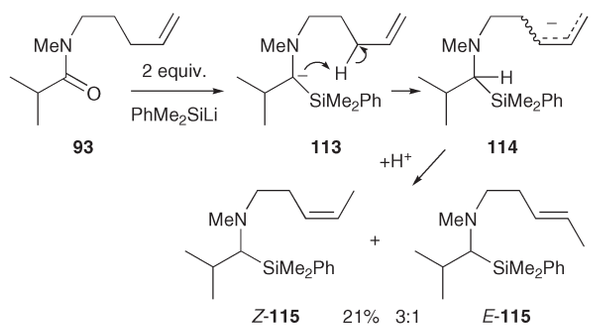
The *N*-allyl-*N*-methylamide **92** also reacted anomalously with two equivalents of diphenylmethylsilyllithium to give the same secondary amine **108** as that in Scheme 18, together with minor amounts of two other products, the normal product **111** and a little of the *C*-allyl product **112**, which might have been formed by a [2,3]-sigmatropic rearrangement (**110**, arrows) in the intermediate anion (Scheme 19).

The *N*-pent-4-enyl-*N*-methylamide **93** reacted with two equivalents of the silyllithium reagent, and proton transfer within a five-membered ring took place from the pentenyl substituent. The minor, but the only recognisable, basic products were the pent-3-enylamines *Z*-**115** and *E*-**115**, similar to the normal product, except that the double bond had moved (Scheme 20). Proton transfer **113** (arrows), with the formation of the allylic anion **114**, accounts for the formation of these



Scheme 19

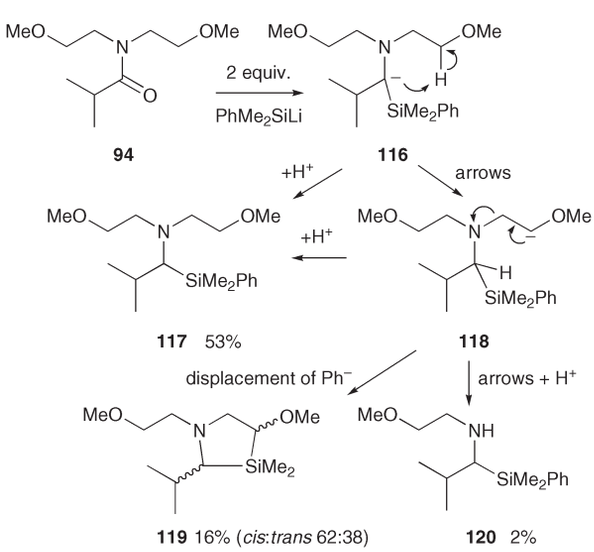
products. The formation of more of the *cis* alkene **115** than of the *trans* is a consequence of the lower energy of the sickle-shaped allyllithium intermediate **114** than of the W-shaped anion.[40] In contrast, the relatively stabilised anion derived from the benzamide **43** showed no sign of proton transfer analogous to that shown as **113** (arrows), and gave simply the normal product **45** (Scheme 9). We saw no products of carbene insertion into the double bond of the amide **93**, any more than we had for Ogawa and Sonoda's amide **43**.



Scheme 20

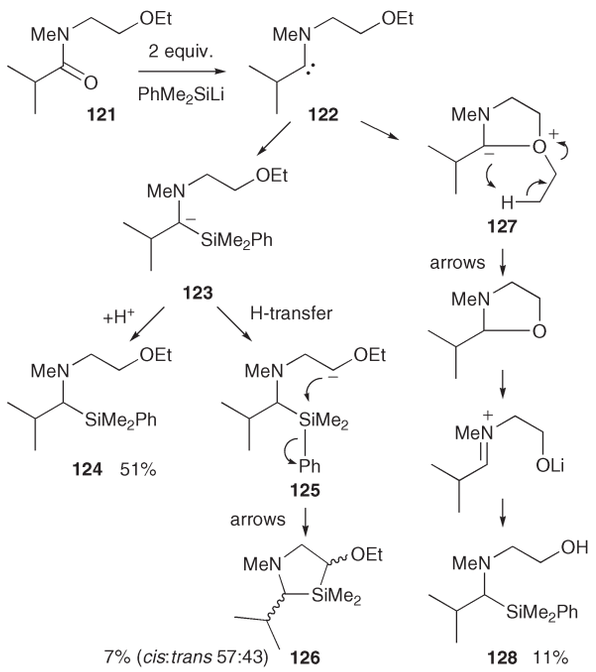
When we incorporated ether functionality into the *N*-substituents, we again saw proton transfer. The *N*,*N*-bis(methoxyethyl)amide **94** gave the normal product **117**, small amounts of the diastereoisomeric pyrrolidines **119** and the elimination product **120**. These products can be accounted for by proton transfer **117** (arrows), presumably intramolecular, followed either by displacement of the phenyl group **118** → **119** or β-elimination **118** (arrows) → **120** (Scheme 21).

When we carried out a similar reaction to that illustrated in Scheme 21, but using the *N*-(ethoxyethyl)amide **121** in place of the bis(methoxyethyl) amide **94**, we isolated, in addition to the products **124** and **126** analogous to those described before, the alcohol **128**, in which the ethyl group was absent (Scheme 22). There had been no sign of the corresponding product in the earlier work. The removal of the ethyl group is unlikely to be



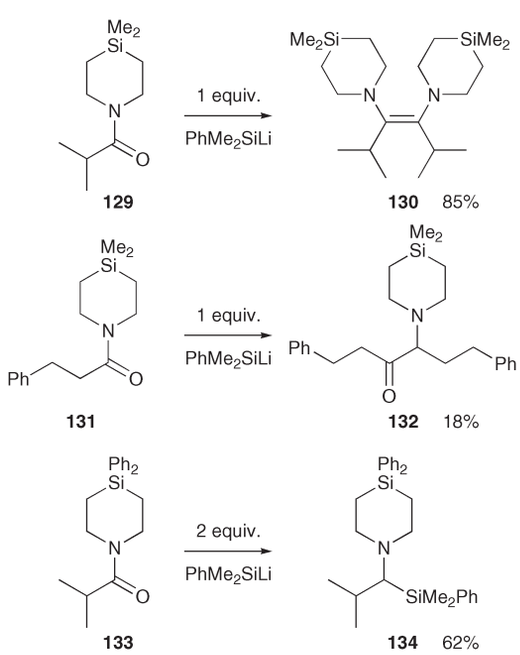
Scheme 21

a simple β-elimination from the intermediate **123** (it would have an eight-membered ring transition structure if it were to be intramolecular), but it is elegantly explained as a reaction **127** (arrows) with a five-membered ring transition structure following the formation of an ylid **127** from the carbene **122**.



Scheme 22

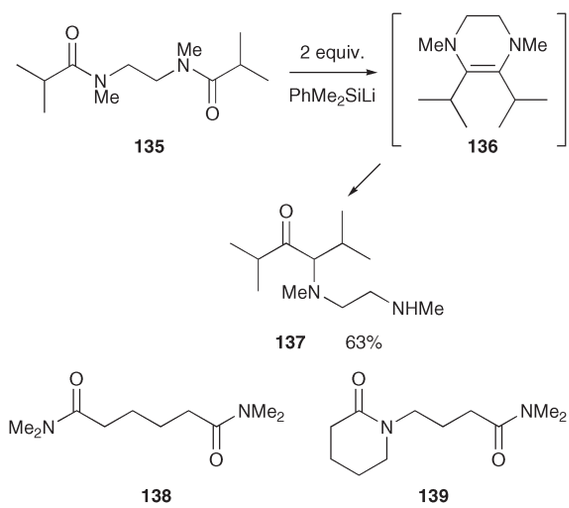
The nearest we came to finding an effective protecting group for the nitrogen atom was with the silapiperidine ring first reported by Jutzi.[41] We prepared the 4-dimethylsila- and the known 4-diphenylsilapiperidines as their hydrochlorides by modification of the literature routes,[41,42] and, amongst other compounds, made the amides **129**, **131** and **133** from them. These amides gave the enediamine **130**, the α-aminoketone **132** and the α-silylamine **134**, using the appropriate one-equivalent and two-equivalent recipes, without surprising us with unexpected products (Scheme 23), but we were unable to remove the silyl-based protection from any of them, in spite of an encouraging report in the literature with other amines protected in this way.[43] This work is incomplete, and we are not convinced that it cannot be made to work.



Scheme 23

Attempts to achieve intramolecular coupling with bisamides

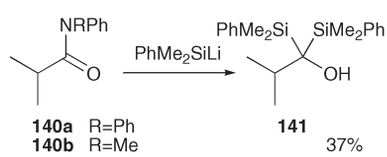
We tried a number of tertiary diamides in the hope of achieving intramolecular coupling. The diamide **135**, in which the two amide groups are joined through the nitrogen atoms, did give the α-aminoketone **137**, and gave it directly without the need for vigorous hydrolysis with acid (Scheme 24). Presumably the enediamine **136** is constrained to allow overlap of the nitrogen lone pairs with the C=C double bond, and it behaves in consequence like a normal enamine. It would have been more interesting to achieve intramolecular coupling with amides joined by one or both of the carbon atoms, but neither of the bisamides **138** or **139** gave us recognisable products.



Scheme 24

The special case with a phenyl group on the nitrogen atom

Unsurprisingly, the *N*,*N*-diphenylamide **140a** and the *N*-methyl-*N*-phenylamide **140b** reacted with the silyllithium reagent to give the disilylcarbinol **141** (Scheme 25), presumably by way of the acylsilane. Evidently the *N*-phenylamino groups are too effective as nucleofugal groups for the tetrahedral intermediate to live long enough to enter into the Brook-rearranging pathways.

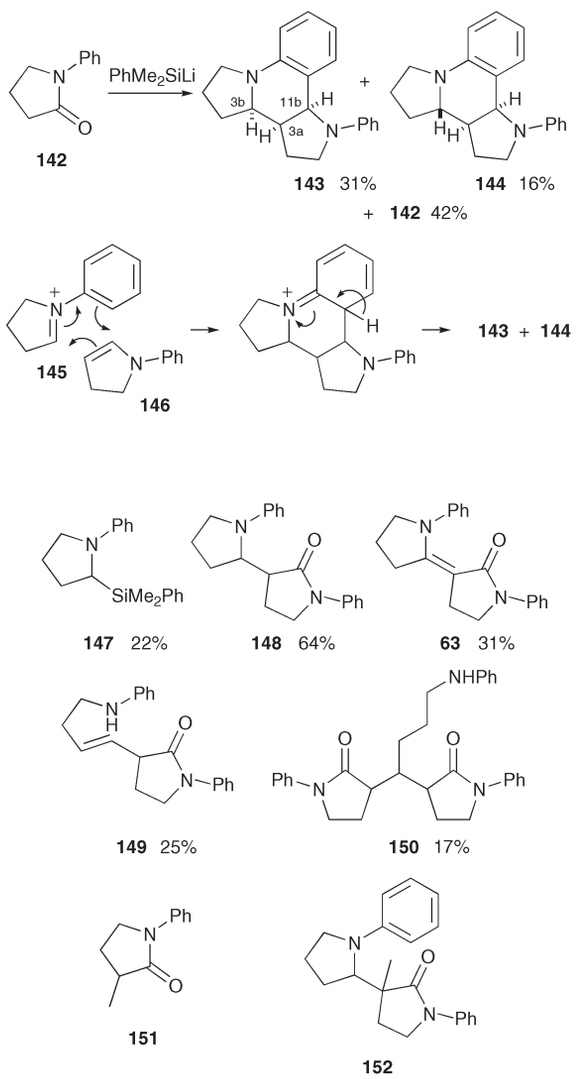


Scheme 25

In the hope that we might make the breakdown of the tetrahedral intermediate reversible, giving the Brook rearrangement a second chance, we tried the same reaction, using two equivalents of the silyllithium reagent, on *N*-phenylpyrrolidone **142**, and obtained a pair of tetracyclic amines **143** and **144**, together with a substantial amount of unchanged starting material, with 89% of the mass balance accounted for by these three compounds (Scheme 25). Initially, we assigned structures to the tetracyclic amines from their ^{1}H- and ^{13}C-NMR spectra, but in fact both compounds were already known. They were probably first produced by Wittig and Sommer in 1955, but given incorrect structures.[44] More recently they have been produced either by reduction of the pyrrolidone **142** with lithium aluminium hydride[45] or by oxidation of *N*-phenylpyrrolidine with such reagents as diethyl azodicarboxylate, ozone,[46] gamma rays or the *tert*-butoxy radical.[47] The mechanism suggested for their formation is a Diels–Alder reaction, or a stepwise equivalent, between the iminium ion **145** and the enamine **146**, and the relative stereochemistry was assigned on the basis that the major, and higher-melting, product **143** followed from the endo rule. This proved to be a lucky guess which we confirmed with X-ray crystallographic analyses on them both,[48] but we

were unconvinced that this mechanism was likely in our case, where we had the problem of working out why there was no silyl group in either product.

By carrying out the same reaction in a variety of conditions and with various stoichiometries, we obtained more or less of several byproducts **147**–**150** and **63** (Scheme 26, where the yields are the highest obtained for each).



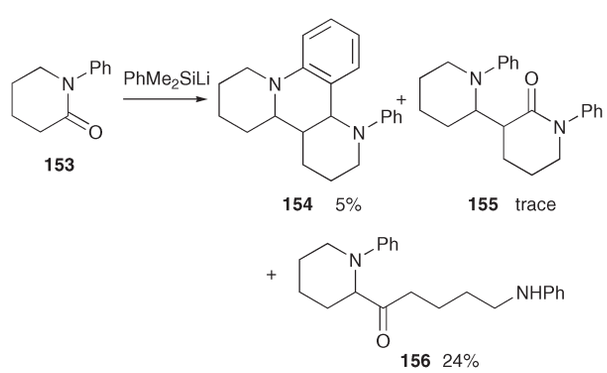
Scheme 26

The lactam **148**, obtainable in relatively high yield, was a mixture of diastereoisomers, which are known,[49] as also is the aldol product **63**.[50] The mixture of lactams **148** reacted with the silyllithium reagent to give the same mixture of products **143** and **144**, showing that the lactams **148**, or their anionic precursors, were plausible intermediates.

In all of these reactions, we always obtained a large amount, up to 42%, of unchanged pyrrolidone **142**. This was clearly present in the reaction mixture as its enolate, since it gave the *C*-methylated product **151** when we quenched with methyl iodide. Although the silyllithium reagent is usually a better nucleophile than a base, it is hardly surprising that it deprotonated some of the starting material, and that some of the resultant enolate survived until the workup. The α-silylamine **147** is what we have been calling the normal product for a reaction taking place between a tertiary amide and two or more equivalents of the silyllithium reagent. Its formation suggests that, at least in part, the reaction is taking the pathway involving Brook rearrangement, and the formation of the carbene. The formation of the lactam **148** can be explained if the carbene reacts with the enolate of the pyrrolidone. This pathway is rendered more plausible by the reaction in Scheme 11 giving the pyrrolidone **62**.

β-Elimination of the anilide group, and other straightforward steps, can account for the formation of the products **149** and **150**. We can equally account for the formation of the tetracyclic amines **143** and **144**, if the lactam **148** forms another carbene with the silyllithium reagent. Some of these steps supply the protons, which are needed only in catalytic amounts, to give the lactam **148** from its anionic precursors. The final intermediate before the quench must be an organolithium reagent, but we have been unsuccessful in pinning down its details. The work-up with methyl iodide mentioned above did not give us recognisable methylation products derived from the final organolithium intermediate, but merely reduced substantially the yield of the tetracyclic amines **143** and **144**. In one run, we did isolate in 43% yield the *C*-methyl derivative **152** derived from the enolate of the lactam **148**, together with the product **151** from *C*-methylation of the starting lactam **142**. We have only established the outline of a possible mechanism. Our mechanism cannot be involved in the earlier preparations of the tetracyclic amines, although they were formed, in 30% and 7% yield, respectively, when we treated the lactam **148** with lithium aluminium hydride, indicating that it could be an intermediate in that case. We have not pursued the details any further, since this is far from being a general reaction.

With the corresponding β-lactam, ring opening was the only detectable pathway, and with the corresponding piperidone **153** (Scheme 27), the yield of the analogous tetracyclic products **154** was low, a product **155** analogous to the intermediate **148** barely recognisable, and the major product was the ketone **156**, presumably derived by hydrolysis of an enediamine, which takes us back to where we came in.



Scheme 27

Experimental

Details of all the experimental work can be found in the Supplementary material.† The following descriptions are representative of each of the significant procedures.

Z-1,2-Bis(dimethylamino)-1,2-dicyclohexylethene 11a

Dimethyl(phenyl)silyllithium[1] (6.6 cm^3 of a 1 mol dm^{-3} solution in THF, 6.6 mmol) was added slowly to a stirred solution of *N*,*N*-dimethylcyclohexylcarboxamide **6a** (930 mg, 6 mmol) in THF (10 cm^3) under argon at −78 °C. The mixture was kept for 1 h at this temperature, and for 1 h at −20 °C. The solution was quenched with sodium bicarbonate solution (saturated, 10 cm^3), and extracted with ether (2 × 30 cm^3). The organic phase was extracted with hydrochloric acid (3 mol dm^{-3}, 2 × 25 cm^3), and the aqueous layer was extracted with dichloromethane (25 cm^3), basified with sodium hydroxide (10% solution), and extracted with ether (2 × 30 cm^3). The ether extract was washed with brine, dried ($MgSO_4$) and concentrated under reduced pressure to give the Z-*enediamine* (692 mg, 83%), mp 80–84 °C; a sample was recrystallised to give needles, mp 89–90 °C (from MeOH); R_f(Al_2O_3, light petroleum) 0.1; ν_{max}(Nujol)/cm^{-1} no assignable peaks <2000; δ_H(250 MHz; $CDCl_3$) 2.41 (12 H, s, NMe_2), 2.07 (2 H, br s, CH), 1.78–1.58 (6 H, m, CH_2), 1.58–1.40 (8 H, m,

CH_2) and 1.36–1.16 (6 H, m, CH_2); δ_C($CDCl_3$) 150.1, 44.0, 39.7, 31.3, 26.9 and 26.1; δ_H(400 MHz; CD_2Cl_2 at 260 K) 2.41 (6 H, br s, NMe_2), 2.12 (8 H, br s, NMe_2 and CH), 1.86–1.50 (6 H, m, CH_2), 1.50–1.28 (8 H, m, CH_2) and 1.28–0.98 (6 H, m, CH_2); δ_H(400 MHz; CD_2Cl_2 at 230 K) 2.41 (6 H, s, NMe_2), 2.21 (2 H, tt, *J* 11.5 and 3.0, CH), 2.12 (6 H, s, NMe_2), 1.84–1.26 (14 H, m, CH_2) and 1.26–0.98 (6 H, m, CH_2); δ_C(CD_2Cl_2 at 230 K) 149.9, 149.5, 44.3, 42.2, 34.7, 31.8, 29.5, 26.8, 26.1 and 25.8; δ_H(400 MHz; $C_6D_5CD_3$ at 350 K) 2.48 (12 H, s, NMe_2), 2.19 (2 H, tt, *J* 11.5 and 3.0, CH), 1.77–1.57 (14 H, m, CH_2) and 1.35–1.16 (6 H, m, CH_2); δ_C($C_6D_5CD_3$ at 350 K) 150.4, 44.5, 41.2, 32.3, 27.6 and 26.6; *m*/*z* (EI) 278 (100%, M^+), 263 (62, M − Me), 248 (10, M − 2 × Me) and 218 (45, M − 4 × Me)(Found: C, 77.6; H, 12.5; N, 10.0; M^+, 278.2729. $C_{18}H_{34}N_2$ requires C, 77.6; H, 12.3; N, 10.1%; *M*, 278.2722).

E-1,2-Bis(dimethylamino)-1,2-dicyclohexylethene 12a

The *Z*-enediamine (35 mg, 0.13 mmol) in methanol (2 cm^3) was stirred with platinum(IV) oxide (5 mg) under argon at 50 °C for 15 min. The mixture was filtered and the solvent was removed under reduced pressure, to give the E-*enediamine* (34 mg, 97%), mp 167–173 °C. A sample was recrystallised to give needles, mp 175–6 °C (from MeOH); R_f(Al_2O_3, light petroleum) 0.7; ν_{max}(Nujol)/cm^{-1} no assignable peaks <2000; δ_H(250 MHz; $CDCl_3$) 2.39 (12 H, s, NMe_2), 2.07 (2 H, tt, *J* 11.5 and 3, CH), 1.74–1.58 (8 H, m, CH_2), 1.50–1.42 (4 H, m, CH_2), 1.30–1.14 (8 H, m, CH_2); δ_C($CDCl_3$) 151.2, 43.9, 40.5, 31.4, 27.1 and 26.3; *m*/*z* (EI) 278 (100%, M^+), 263 (50, M − Me) and 218 (38, M − 4 × Me)(Found: C 77.5; H, 12.4; N, 10.0; M^+, 278.2731. $C_{18}H_{34}N_2$ requires C, 77.6; H, 12.3; N, 10.1%; *M*, 278.2722).

2,3-Bis(dimethylamino)-1,1,4,4-bis(pentamethylene)buta-1,3-diene 15a

The enediamine **11a** (300 mg, 1.08 mmol) and palladium (50 mg, 5% on charcoal) were stirred in methanol (30 cm^3) at room temperature for 4 h. The mixture was filtered, and the filtrate basified with sodium hydroxide (10% solution). The mixture was extracted with ether (2 × 40 cm^3), and the combined organic layers were dried ($MgSO_4$) and concentrated under reduced pressure to give the *dienediamine* (247 mg, 83%); R_f(Al_2O_3, light petroleum–Et_2O, 98 : 2) 0.6; ν_{max}(film)/cm^{-1} 1686 (C=C), 1639 (C=C) and 1621 (C=C); δ_H(250 MHz; $CDCl_3$) 2.50 (12 H, s, NMe_2), 2.30–2.20 (4 H, m, C=CCH_2), 2.10–2.00 (4 H, m, C=CCH_2) and 1.55–1.35 (12 H, m, CH_2); δ_C($CDCl_3$) 137.6+, 126.8+, 43.0−, 31.6+, 29.5+, 27.7+, 27.6+ and 27.1+; *m*/*z* (EI) 276 (75%, M^+), 261 (21, M − Me), 246 (4, M − 2 × Me), 231 (84, M − 3 × Me), 231 (22, M − 4 × Me) and 138 (100, $C_9H_{16}N$)(Found: M^+, 276.2566. $C_{18}H_{32}N_2$ requires *M*, 278.2565).

2-(Dimethylamino)-1,2-dicyclohexylethan-1-one 13a

The *Z*-enediamine **11a** (120 mg, 0.43 mmol) was heated in hydrochloric acid (3 mol dm^{-3}, 5 cm^3) for 18 h at 75 °C. The solution was cooled, basified with sodium hydroxide (10% solution) and extracted with ether (2 × 25 cm^3). The extract was washed with brine, dried ($MgSO_4$) and the solvent removed under reduced pressure. The residue was chromatographed (light petroleum–Et_2O, 60 : 40) to give the *α-aminoketone* (100 mg, 92% from the *Z*-enediamine), mp 44–46 °C; a sample was recrystallised to give prisms, mp 46–46.5 °C (from MeOH); R_f(Al_2O_3, light petroleum–Et_2O, 90 : 10) 0.5; ν_{max}(film)/cm^{-1} 1703 (C=O); δ_H(250 MHz; $CDCl_3$) 3.05 (1 H, d, *J* 10, CHN), 2.33 (6 H, s, NMe_2), 2.28 (1 H, tt, *J* 11 and 3, CHCO), 1.95–1.55 (9 H, m, CH and CH_2), 1.48–1.06 (10 H, m, CH_2) and 0.97–0.75 (2 H, m, CH_2); δ_C($CDCl_3$) 213.8, 74.6, 52.4, 41.8, 36.5, 30.5, 30.4, 27.9, 27.1, 26.6, 26.1, 26.1, 26.0, 25.9 and 25.7; *m*/*z* (EI) 251 (<1%, M^+) and 140 (100, $C_7H_{12}NMe_2$)(Found: M^+, 251.2233. $C_{16}H_{29}NO$ requires *M*, 251.2249)(Found: C, 75.9; H, 11.6; N, 5.1. $C_{16}H_{29}NO$ requires C, 76.4; H, 11.6; N, 5.6%).

N,*N*-Dimethyl(cyclohexyl)[dimethyl(phenyl)silyl]methylamine 20a

The amide **6a** (223 mg, 1.44 mmol) in THF (3 cm^3) was added slowly to dimethyl(phenyl)silyllithium (3.2 cm^3 of a 1 mol dm^{-3} solution in THF, 3.2 mmol) under argon at −78 °C. The mixture was transferred to a freezer, and kept at −20 °C for 1 h. Sodium bicarbonate solution (saturated, 5 cm^3) was added, and the organic layer was extracted with hydrochloric acid (3 mol dm^{-3}, 2 × 25 cm^3). (The neutral products of the reaction were isolated from the organic fraction, which was dried ($MgSO_4$) and evaporated under reduced pressure. In this case they consisted only of byproducts from the silyllithium reagent, but in other cases the neutral products were informative.) For the basic products, the aqueous phase was basified with sodium hydroxide solution (10%) and extracted with ether (2 × 30 cm^3). This extract was dried ($MgSO_4$) and the solvent was evaporated under reduced pressure. The resdiue was chromatographed on a silica gel column using a graded series of eluants, consisting of light petroleum and ether, to give the *α-silylamine* (352 mg, 89%); R_f(Et_2O–MeOH, 50 : 50) 0.6; ν_{max}(film)/cm^{-1} 1248 (SiMe) and 1110 (SiPh); δ_H(400 MHz; $CDCl_3$) 7.55 (2 H, m, *o*-Ph), 7.37–7.31 (3 H, m, *m*- and *p*-Ph), 2.41 (6 H, s, NMe_2), 2.10 (1 H, d, *J* 5.5, CHN), 1.74–1.54 (6 H, m, CH and CH_2), 1.18–0.98 (5 H, m, CH_2), 0.42 (3 H, s, Si$Me_A$$Me_B$) and 0.39 (3 H, s, Si$Me_A$$Me_B$); δ_C($CDCl_3$) 140.9, 134.0, 128.5, 127.6, 63.3, 45.3, 39.1, 33.4, 32.8, 26.9, 26.8, 26.4, 0.3 and −0.9; *m*/*z* (EI) 275 (4%, M^+), 260 (1, M − Me), 192 (18, M − C_6H_{11}) and 140 (100, $C_9H_{18}N^+$)(Found: C, 73.9; H, 10.6; N, 5.3; M^+, 275.2068. $C_{17}H_{29}NSi$ requires C, 74.1; H 10.6; N, 5.1%; *M*, 275.2067).

N,*N*-Dimethyl(3-methyl-1-phenylbut-2-yl)amine 51

The amide **6b** (0.57 g, 4.98 mmol) in THF (10 cm^3) was added *via* syringe to the silyllithium reagent (1 mol dm^{-3} in THF, 5.5 cm^3, 5.5 mmol) under argon at −78 °C. The mixture was stirred at −78 °C for 1 h, and benzyllithium [made by addition of MeLi (1.4 mol dm^{-3} in THF, 3.6 cm^3, 5 mmol) to triphenyl(phenylmethyl)tin (2.205 g, 5 mmol) in THF (25 cm^3) at −100 °C and kept for 3 h at −78 °C] was added at this temperature. The solution was kept at −20 °C for 1 h, and worked up for basic products to give the *amine* (0.45 g, 47%); R_f(Et_2O) 0.30; ν_{max}(film)/cm^{-1} no assignable peaks <2000; δ_H(250 MHz; $CDCl_3$) 7.28–7.23 (5 H, m, Ph), 2.83 (1 H, dd, *J* 14.3 and 7.8, PhCH_AH_B), 2.58 (1 H, dd, *J* 14.3 and 5.8, PhCH_AH_B), 2.46 (1 H, q, *J* 6.3, CHN), 2.28 (6 H, s, NMe_2), 1.83 (1 H, octet, *J* 6.7, Me_2CH), 0.96 (3 H, d, *J* 6.7, $Me_A$$Me_B$C) and 0.91 (3 H, d, *J* 6.7, $Me_A$$Me_B$C); δ_C($CDCl_3$) 142.7+, 129.0−, 128.1−, 125.4−, 71.6−, 41.8−, 33.0+, 30.8−, 21.3− and 20.8−; *m*/*z* (TES)(Found: MH^+, 192.1744. $C_{13}H_{22}N$ requires *M* + H, 192.1752).

N,*N*-Dimethyl-(2-methyl-3-phenylhex-5-en-3-yl)amine 53

The amide **6b** (204 mg, 1.78 mmol) in THF (4 cm^3) was added *via* syringe to the silyllithium reagent (1 mol dm^{-3} in THF, 1.95 cm^3, 1.95 mmol) under argon at −78 °C. The mixture was stirred at −78 °C for 1 h, and phenyllithium (2.7 mmol) in THF, was added at this temperature. The solution was kept at −20 °C for 1 h, and allyl bromide (2.5 mmol) added, and the mixture worked up for basic products to give the *amine* (243 mg, 63%); R_f(light petroleum–Et_2O, 90 : 10) 0.5; ν_{max}(film)/cm^{-1} 1638 (C=C) and 1598 (C=C); δ_H(250 MHz; $CDCl_3$) 7.49 (2 H, dd, *J* 7 and 1.5, *o*–Ph), 7.33 (2 H, tt, *J* 7 and 1.5, *m*–Ph), 7.23 (1 H, tt, *J* 7 and 1.5, *p*–Ph), 6.12 (1 H, dddd, *J* 16, 10, 7.5 and 6.5, C*H*=CH_2), 5.20 (1 H, dd, *J* 16 and 1.5, CH=CH_AH_B), 5.05 (1 H, dd, *J* 10 and 1.5, CH=CH_AH_B), 2.97 (1 H, ddt, *J* 15, 7.5 and 1.5, CH_AH_B), 2.91 (1 H, ddt, *J* 15, 6.5 and 1.5, CH_AH_B), 2.41 (6 H, s, NMe_2), 2.35 (1 H, septet, *J* 6.5, C*H*Me_2), 0.81 (3 H, d, *J* 6.5, CH$Me_A$$Me_B$) and 0.73 (3 H, d, *J* 6.5, CH$Me_A$$Me_B$); δ_C($CDCl_3$) 141.7, 137.0, 129.1, 126.8, 125.8, 116.0, 67.4, 39.8, 36.1, 32.0, 18.7 and 17.2; *m*/*z* 217 (2%, M^+), 216 (18, M − 1), 176 (100, M − C_3H_5) and 174 (39, M − C_3H_7)(Found: M^+, 217.1815. $C_{15}H_{23}N^+$ requires *M*, 217.1830).

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