Removal of solvent gave a solid residue which was recrystallized with hexane–chloroform mixture to give pure alcohol **12c** (2.3 g, 90.1% yield): mp 117.1 °C; ^{13}C NMR ($CDCl_3$) $\delta_{(^{13}C)}$ 14.1, 30.9, 63.2, 124.7, 124.8, 125.2, 125.3, 128.3, 129.5, 129.8, 129.9.

Preparation of Chlorides 4 and 12. Alcohol **4a** or **12c** (10 mmol) was dissolved in 100 mL of dry ether having 1 mL of pyridine. Thionyl chloride (10 mL) in 15 mL of dry ether was added slowly, and the reaction mixture was refluxed overnight. Cold reaction mixture was poured into ice water and extracted with chloroform (2 × 200 mL). The organic layer was successively washed with water, $NaHCO_3$ solution, and brine solution and dried over anhydrous $MgSO_4$. The crude product was purified by column chromatography (silica gel, hexane:chloroform) to give pure **4** (1.8 g, 75.6% yield), mp. 150.5 °C, or **12** (1.5 g, 60% yield), mp 139.5 °C. ^{13}C NMR ($CDCl_3$) for **4**: $\delta_{(^{13}C)}$ 31.6, 43.4, 123.6, 123.9, 125.0, 125.7, 126.3, 126.4, 127.1, 129.3. ^{13}C NMR ($CDCl_3$) for **12**: $\delta_{(^{13}C)}$ 14.2, 31.6, 43.5, 124.2, 124.8, 125.6, 125.7, 127.7, 129.6, 129.9, 130.4.

Preparation of Fluorides 7 and 14. These fluorides were made from the corresponding alcohols **4a** and **12c** by using Middleton's method.[12] Alcohol **4a** or **12c** (10 mmol) was dissolved in 25–30 mL of dry CH_2Cl_2 at −78 °C under dry nitrogen atmosphere. Diethylaminosulfur trifluoride (12 mmol) was added, and the reaction mixture was warmed up to room temperature. The mixture was stirred for additional 30 h. at room temperature and then poured into ice cold water and extracted with (2 × 50 mL) CH_2Cl_2. The methylene chloride layer was washed successively twice with water, once with $NaHCO_3$ solution, and finally with brine solution. Drying over anhydrous $MgSO_4$ and removal of solvent gave a solid residue, which was purified by column chromatography (silica gel, hexane) to give pure **7** as yellow niddles (1.5 g, 68.1% yield), mp 80–82 °C, or pure **14** as yellow flakes (1.6 g, 76.2% yield), mp 165–67 °C. ^{13}C NMR ($CDCl_3$) for **7**: $\delta_{(^{13}C)}$ 28.7 ($J_{C\text{-}F}$ = 21.3 Hz), 83.1 ($J_{C\text{-}F}$ = 171.6 Hz), 123.8, 124.8, 125.9, 126.8, 129.2, 130.2, 131.4, 133.4. ^{13}C NMR ($CDCl_3$) for **14**: $\delta_{(^{13}C)}$ 14.2, 28.9 ($J_{C\text{-}F}$ = 20.9 Hz), 83.2 ($J_{C\text{-}F}$ = 171 Hz), 124.4, 124.8, 125.5, 129.9, 130.0.

Preparation of Alcohol 19. Spiro ketone **10c** (2 g, 9.1 mmol) in dry THF (50 mL) under an N_2 atmosphere was reacted with phenyllithium (12 mmol). The reaction mixture was refluxed overnight. The cold reaction mixture was poured into ice cold water, extracted with (2 × 100 mL) ether, and dried over anhydrous $MgSO_4$. Removal of solvent gave a yellowish crystalline solid which was recrystallized with hexane–chloroform mixture to give pure **19** (2 g, 79% yield); mp 180.7 °C; ^{13}C NMR ($CDCl_3$) $\delta_{(^{13}C)}$ 17.6, 22.0, 25.5, 75.1, 121.2, 126.0, 126.2, 126.5, 127.2, 127.7, 127.9, 138.0, 142.5, 147.9.

Preparation of Alcohol 18. 10-Methylanthracene-9-carboxaldehyde (10 mmol) was dissolved into 100 mL of dry THF and methyllithium (12 mmol) was added slowly. The reaction mixture was refluxed overnight. The cold reaction mixture was poured into ice water and extracted with chloroform (2 × 100 mL), washed with brine solution, and evaporated. The solid residue was recrystallized with hexane–chloroform mixture to give pure alcohol **18** (2.1 g, 89% yield): mp 140 °C; ^{13}C NMR ($CDCl_3$) $\delta_{(^{13}C)}$ 14.4, 23.5, 67.1, 124.6, 124.8, 125.2, 125.4, 128.4, 129.9, 130.3, 134.5.

General Procedure for the Preparation of Ions. All the ions were prepared in the usual manner in the NMR tubes by adding 200–250 mg of the neat solid in small portions to a well-stirred solution of approximately 0.5 mL of acid in 2 mL of SO_2ClF or SO_2 at −78 °C or lower temperature. The NMR tube is well stirred on Vortex and placed at low temperature into the NMR probe to record its spectrum.

Acknowledgment. Support of our work by the National Institutes of Health is gratefully acknowledged.

α-Amino Carbanions via Formamidines.[1] Alkylation of Pyrrolidines, Piperidines, and Related Heterocycles

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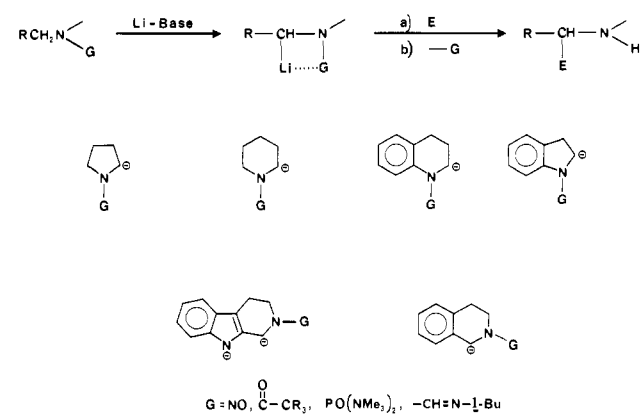
Abstract: α-Metalation of piperidine, pyrrolidine, hexahydroazepine, 1,3-thiazolidine, and 1,3-thiazane has been accomplished via their *N-tert*-butylformamidine derivatives. Alkylation of these α-amino carbanions via their lithio or cuprate derivatives leads to good yields of α-substituted heterocycles. Similarly, 1,2,5,6-tetrahydropyridine metalates at the 2 position, but alkylates at the 4 position. Reduction leads to 4-substituted piperidines. Evidence is presented to show that electron-transfer processes occur when the C–Li bond is not orthogonal to the plane of the formamidine moiety.

Although alkylation of the α carbanion of amino derivatives using an electronically modified nitrogen function is now a well-known process (Scheme I),[2] several serious limitations to this methodology still exist. For example, the extensive studies by Seebach using nitrosoamines[3] are affected by the potential health hazards in employing these substances, while metalation–alkylation of hindered amides studied by Beak[4a] and Seebach[4b,c] is limited to certain substituents and, on occasion, to harsh conditions to regenerate the amine after alkylation. Furthermore, evidence is mounting that the dipole-stabilized anion intermediate requires that the carbon–lithium bond be orthogonal to the π system,[4,5] which results in some serious side reactions leading to poor yields and/or mixtures of products. Specifically, the alkylation using alkyl halides of simple *unsubstituted* heterocycles such as piperidine, pyrrolidine, and perhydroazepine give poor (<20%) yields of alkylation when hindered amides or formamidines are used as the N-activating groups. Thus, as shown in Scheme II, the

Scheme I



(1) Part 8 on carbanions derived from formamidines. For previous reports on this work see: Meyers, A. I.; Fuentes, L. M. *J. Am. Chem. Soc.* **1983**, *105*, 117, and references cited. See also: Meyers, A. I.; Fuentes, L. M.; Kubota, Y. *Tetrahedron Symp.*, in press.

(2) For a review on this subject, see: (a) Beak, P.; Reitz, D. B. *Chem. Rev.* **1978**, *78*, 275. (b) Beak, P.; Zajdel, W. J.; Reitz, D. B. *Ibid.*, in press.

(3) Seebach, D.; Enders, D. *Angew. Chem., Int. Ed. Engl.* **1975**, *14*, 15.

(4) (a) Beak, P.; Zajdel, W. J. *J. Am. Chem. Soc.* **1984**, *106*, 1010. (b) Seebach, D.; Lohman, J. J.; Syfrig, M. A.; Yoshifuji, M. *Tetrahedron* **1983**, *39*, 1963. (c) Schlecker, R.; Seebach, D. *Helv. Chim. Acta* **1977**, *60*, 1459.

(5) Seebach, D.; Wykpiel, W.; Lubosch, W.; Kalinowski, H. O. *Helv. Chim. Acta* **1978**, *61*, 3100.

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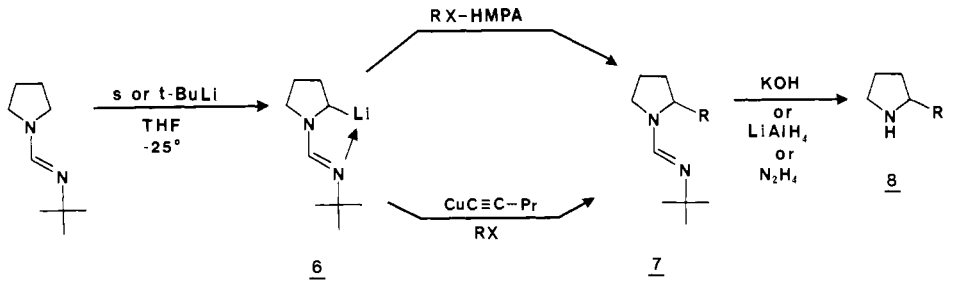


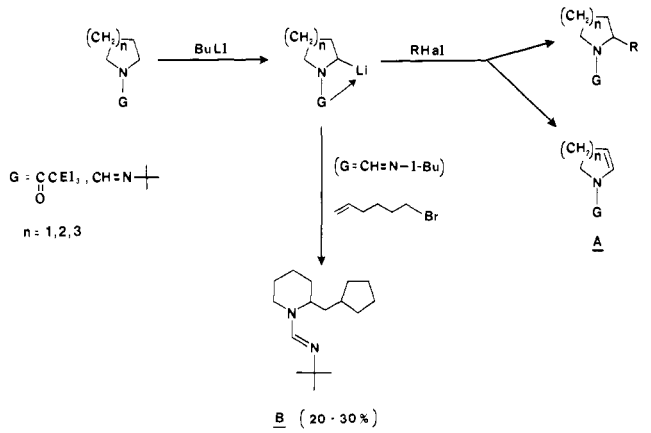
(1)

Table I. Alkylation of Pyrrolidines to 8 via 6

electrophile	method[a]	% 7	formamidine removal	% 8	R in 8
MeI	A	63	NH_2NH_2	87	Me
	B	73	KOH	85	Me
n-BuBr	A	75	NH_2NH_2	70	*n*-Bu
allyl Br	A or B	30–40	KOH	80	$-CH_2CH{=}CH_2$
$PhCH_2Br$	A or B	20–30	KOH	90	CH_2Ph
$CH_2{=}CHCHO$	C	62	$LiAlH_4$	61	$-CH(OH)CH{=}CH_2$[c]
PhCHO	C	74	$LiAlH_4$	89	$-CH(OH)Ph$[c]
$ClCO_2Me$	C	85	*b*		
PhSeSePh	C	70	*b*		
Bu_3SnCl	C	95	*b*		

[a] Method A: metalation with *sec*- or *tert*-butyllithium in THF at −78 °C addition of HMPA, followed by electrophile. Method B: metalation with *sec*- or *tert*-butyllithium in THF at −78 °C followed by addition of pentynylcopper. Method C: same procedure as A except no HMPA was used. For complete description see Experimental Section. [b] Formamidine not removed. [c] A mixture of diastereomers (1:1) was obtained.

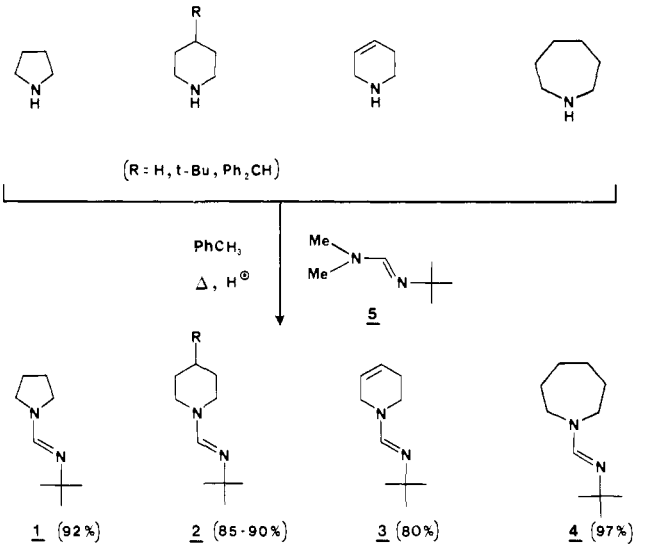
Scheme II



metalation of *N*-acyl or formamidine heterocycles proceeds efficiently (as determined by D_2O quench); however, addition of alkyl halides leads to 30–50% yields of α-alkylated products. The major side reaction, using formamidines, leads to oxidation products, A, presumably through an electron-transfer process. The latter has not yet been observed with the amides.[6] Support for an electron-transfer process in Scheme II was gathered by alkylation of the lithiated piperidine formamidine (**10**) with 6-bromo-1-hexene, furnishing, in addition to A ($n = 2$), a 20–30% yield of the 2-cyclopentylmethyl product *B*.[7] Furthermore, carbonyl compounds (e.g., benzophenone) which readily accept electrons are reduced by the lithioformamidines rather than added (Scheme V; vide infra). This behavior was also observed for lithiopyrrolidine and lithioperhydroazepine as their formamidine derivatives.

We now describe a methodology which overcomes these difficulties for α-amino carbanions and, coupled with the ease of formamidine removal under several different conditions, renders this synthetic route one of considerable potential. In a future paper, further synthetic routes for reaching multiply substituted heterocycles, via A, will be described.

The formamidines of the heterocycles examined (**1–4**) were all



prepared by exchange of the secondary amine with the dimethyl *tert*-butylformamidine **5**[8] simply by heating in toluene with a catalytic amount of ammonium sulfate. In the absence of the catalyst, the reaction proceeded as well, albeit somewhat slower.

Alkylation of Pyrrolidines

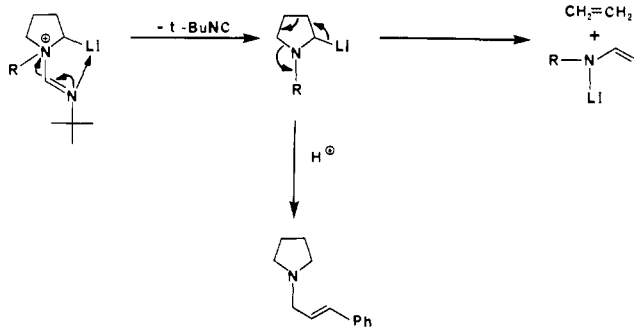
The electron-transfer process shown in Scheme II was circumvented by addition of 1.5 equiv of hexamethylphosphoramide (HMPA) prior to addition of the alkyl halide. This added solvate may not have significantly inhibited the electron transfer as much as it may have enhanced the substitution process. Thus, addition of 1.1 equiv of *sec*-butyllithium or *tert*-butyllithium at −78 °C in THF and warming to −25 ± 5 °C gave the yellow lithio species **6** (eq 1) (40 min with *t*-BuLi, 125 min with *sec*-BuLi). Cooling the anion solution to −78 °C followed by HMPA addition and

(6) Private communication from Professor Beak who informs us that only low yields of alkylation were observed, but he has not examined the reaction for oxidation products.

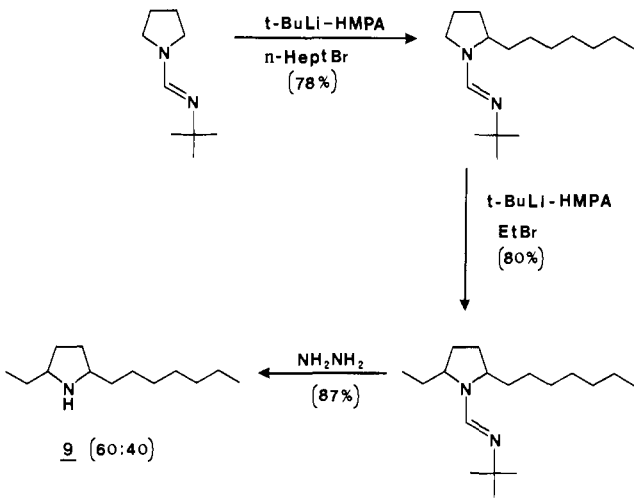
(7) Lal, D.; Griller, S.; Husband, S.; Ingold, K. U. *J. Am. Chem. Soc.* **1974**, *96*, 6355.

(8) Brinkmeyer, R. S.; Abdulla, R. F. *Tetrahedron* **1979**, *35*, 1680. Meyers, A. I., Ten Hoeve, W. *J. Am. Chem. Soc.* **1980**, *102*, 7125.

Scheme III



Scheme IV



the alkyl halide gave the 2-substituted pyrrolidine **7**. No oxidation products were observed under these conditions. The formamidine was readily removed using hydrazine–acetic acid–ethanol (55 °C) or KOH–MeOH (60 °C), producing the 2-substituted pyrrolidines **8** in good yield. When electrophiles other than alkyl iodides or bromides were employed (carbonyls, acid chlorides, etc.), which are not prone to electron-transfer reactions, no HMPA was required in the alkylation step. Alternatively, the alkylation may be performed by initially adding pentynylcopper to **6** and then the alkyl halide. This avoids the *use* of HMPA and furnishes **7** in comparable yields. Table I summarizes the alkylations of pyrrolidines.

The poor yields of alkylation from either procedure when benzyl or allyl halides are employed may be due to ring fragmentation since less than 50% of the material was recovered after workup. It is possible that highly reactive halides (allylic, benzylic) kinetically alkylate on the ring nitrogen (Scheme III) which enhances cleavage of the formamidine moiety leaving the α-lithiopyrrolidine. The latter cleaves in a manner reminiscent of α-lithiotetrahydrofuran[9] to ethylene and the aza enolate of acetaldehyde imine. Evidence for this mode of cleavage has been found by isolation of small quantities of *N*-cinnamylpyrrolidine whose identity was confirmed by independent synthesis (cinnamyl bromide, pyrrolidine, THF, reflux).

The scope of this pyrrolidine alkylation was demonstrated by the synthesis of the fire ant venom, 2-ethyl-5-heptylpyrrolidine (**9**), in 52% overall yield (Scheme IV) as a 60:40 mixture of diastereomers.[10] The ratio was determined by NMR assessment of the *N*-benzyl derivative. In a similar fashion 2,5-dimethylpyrrolidine was prepared and gave an 80:20 mixture of trans–cis isomers. Thus, the stereochemistry of these sequential alkylations does not, to date, appear to be readily controllable.

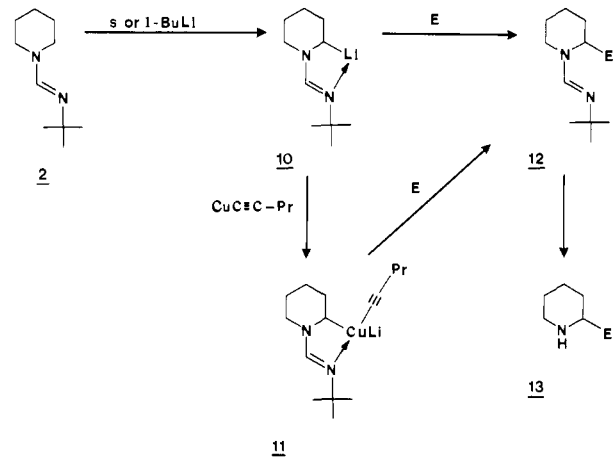
Table II. Alkylation of Piperidines to 12 and 13

electrophile	% yield via 10	% yield[a] via 11	formamidine removal	% 13	E in 13
MeI	18	81			
n-PrI	<5	80	KOH	83	Pr
n-BuI	13	81	KOH	92	Bu
allyl Br	30	81	KOH	85	allyl
$PhCH_2Br$	20	55	KOH	87	$PhCH_2$
PhSeSePh	90[b]				
MeOCOCl	87[b]				
PhCHO	93[b]		$LiAlH_4$	77	PhCH(OH)
$Br(CH_2)_3Cl$	0	76			

[a] All yields are based on chromatographed material and are homogeneous by TLC and VPC. [b] No HMPA was added to 10 prior to addition of these electrophiles. All others in this column were treated with alkyl halides after HMPA was added to 10. See Experimental Section for complete procedures employed.

Alkylation of Piperidines

The metalation of unsubstituted piperidine formamidines **2** proceeded well in the presence of *sec*-butyl- or *tert*-butyllithium using ether–THF (4:1) as the solvent. It was previously shown that solvent plays a major role in the rate of metalation for various formamidines.[11] However, alkylation of piperidines became a serious problem when reducible alkyl halides were employed (iodides, bromides). Addition of HMPA to **10**, which proved



useful in the pyrrolidine series, had no favorable effect in the piperidine series, and yields of alkylation, to **12**, remained unsatisfactory (<30%). Electrophiles, not readily reducible via electron-transfer processes, such as aldehydes, acyl chlorides, etc., reacted smoothly with **10** to give the elaborated products **12** (Table II). The major side reaction in alkylation of **10** has already been mentioned and outlined in Scheme II. However, when the lithiated piperidine **10** was treated with pentynylcopper to furnish, presumably, the mixed cuprate **11** and then treated with alkyl halides, good yields of alkylation product **12** were obtained. Table II compares the yields of alkylated products **12** with and without the cuprate intermediate. Removal of the formamidine to produce the 2-substituted piperidines **13** was accomplished using either KOH–MeOH, NH_2NH_2–HOAc–EtOH, or $LiAlH_4$.

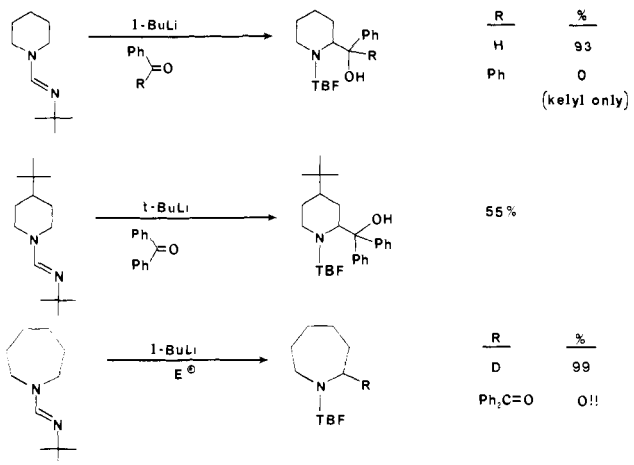
The alkylation of piperidines, via the cuprate, represents the first successful example of this process. Beak[4] has previously shown that the amides of piperidine alkylate *with alkyl halides* only if there is a 4-substituent present in the piperidine ring. Seebach,[3] on the other hand, described alkylation of piperidines via their nitroso derivative. However, both the previous groups

(9) For earlier observations of tetrahydrofuran cleavage via its α-lithio anion see: Bartlett, P. D.; Stiles, M. *J. Am. Chem.* **1955**, *77*, 2806. Tamboulian, P. *J. Org. Chem.* **1973**, *38*, 322. Meyers, A. I.; Kovelesky, A. C.; Jurjevich, A. F. *Ibid.* **1973**, *38*, 2136. Bates, R. B.; Kroposki, L. M.; Potter, D. E. *Ibid.* **1972**, *37*, 560. Jung, M. E.; Blum, R. B. *Tetrahedron Lett.* **1977**, 3791.

(10) Fraser, R. R.; Passananti, S. *Synthesis* **1976**, 540.

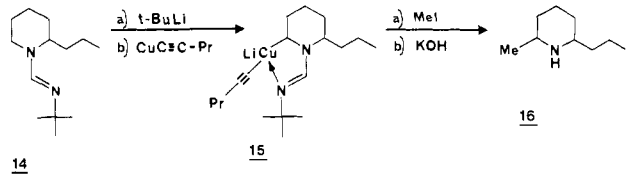
(11) Meyers, A. I.; Rieker, W. F.; Fuentes, L. M. *J. Am. Chem. Soc.* **1983**, *105*, 2082.

Scheme V



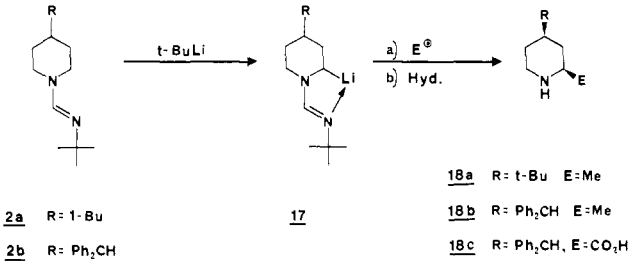
have successfully used carbonyl electrophiles in various cyclic amines.

A second alkylation was also investigated using the 2-(*n*-propyl)piperidine **14**. Addition of *t*-BuLi–pentynylcopper gave



the cuprate **15**, and addition of methyl iodide, followed by hydrolysis of the formamidine group, gave the 2,6-disubstituted piperidine **16** in 71% yield as a 1:1 mixture of cis and trans isomers. In the absence of the cuprate **15** and using only the α-lithio derivative, addition of methyl iodide failed to produce any disubstituted piperidine, the major products being those derived from the electron-transfer process.

We also investigated the metalation–alkylation of 4-substituted piperidines as the formamidine derivative **2**. Metalation, with lithium bases, proceeded smoothly in ether–THF or 2,5-dimethyltetrahydrofuran to give **17** which was alkylated with methyl iodide or carbon dioxide and then subjected to hydrazinolysis to give **18a–c** as the cis products (determined by ^1H and ^{13}C NMR).



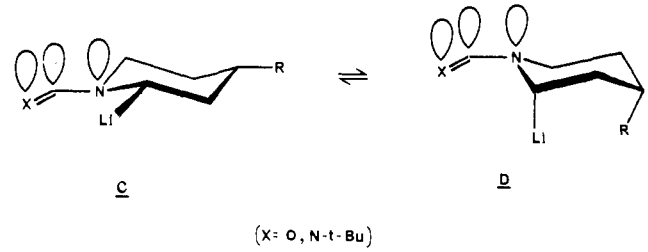
The overall yields were in the range of 50–70%, and little or no evidence of oxidation products (Scheme II, A) was found. Thus, "anchored" piperidines or those containing a large ring substituent to inhibit conformational motion appeared to metalate and alkylate without the need of the copper intermediate **11**. To further support the "anchoring effect" to retard electron transfer to readily reducible electrophiles, piperidine, 4-*tert*-butylpiperidine, and perhydroazepine were metalated as their formamidine derivatives (Scheme V). It can be seen that benzaldehyde added in good yield even to the unsubstituted piperidine, while no product was obtained using the easily reduced benzophenone. On the other hand, 4-*tert*-butylpiperidine gave the alkylated product with benzophenone in 55% isolated yield. Thus, the anchoring effect of the *tert*-butyl group inhibited electron transfer and the reduction of benzophenone. For the perhydroazepine in Scheme V lithiation occurred without event giving the 2-deuterio derivative in 99% yield while addition of benzophenone gave no product. Similar

Table III. Alkylation of Hexahydroazepines 4

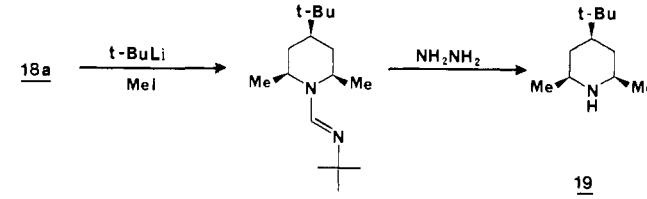
electrophile	% yield 20	% yield 21	E in 21
n-PrI	79[c]	77[a]	*n*-Pr
n-Heptyl I	80[d]	80[b]	*n*-Heptyl
PhSeSePh	81[e]		
$ClCO_2Me$	91[e]		

[a] Formamidine removal performed using KOH–MeOH. [b] Formamidine removal performed using NH_2NH_2–HOAc–EtOH. [c] Alkylation carried out on cuprate of **20** (E = LiCuC≡CPr). [d] HMPA (1.3 equiv) added to **20** (E = Li) prior to alkylation step. [e] Electrophile added directly to lithio anion **20** (E = Li).

successes with 4-substituted piperidines were observed by Beak[4] and Seebach[12] and further indicate that the conformation which allows the C–Li bond to be orthogonal to the π system of the amides or the formamidines will be most stable (C). When the piperidine substituent R is small (e.g., H), then ring flipping is allowed, forcing the C–Li bond to become coplanar to the π system (D). This latter conformation has been calculated[13] to be 22 kcal



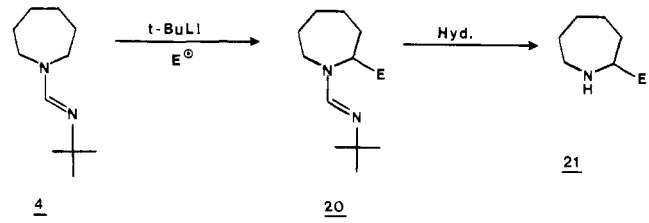
higher in energy than C and, at least for the formamidines, appears to undergo single electron transfer as discussed earlier. Presumably the cuprate **11** forms a formamidine complex much stronger than the lithio species **10** and retards ring flipping (C to D). Since **18a–c** were shown to be the cis products, it is in full accord with observations earlier[4,12] that the electrophile enters C with retention of configuration. Furthermore, alkylation of **18a** via its lithio



derivative using methyl iodide gave *cis*-2,6-dimethyl-4-*tert*-butylpiperidine (**19**) as the only product, further suggesting the formation of equatorial deprotonation and alkylation.[5]

Alkylation of Perhydroazepines

The seven-membered ring heterocycle, as its formamidine **4**, was examined and found to metalate smoothly in THF with *t*-BuLi. Deuterium oxide quench gave the α-D derivative **20** (E = D) in 99% yield with 94% D incorporation. Use of other



electrophiles was found to proceed similarly. For alkyl halides, addition of 1–1.5 equiv of HMPA was required prior to introduction of the electrophile. Transformation of the α-lithio de-

(12) Schlecker, R.; Seebach, D.; Lubosch, W. *Helv. Chim. Acta* **1978**, *61*, 512. Wykypiel, W.; Lohman, J.; Seebach, D. *Ibid.* **1981**, *64*, 1337.
(13) Bach, R. D.; Braden, M. L.; Wolber, G. J. *J. Org. Chem.* **1983**, *48*, 1509. See also: Rondan, N. G.; Houk, K. N.; Beak, P.; Zajdel, W. J.; Chandrasekhar, J.; Schleyer, P. v. R. *Ibid.* **1981**, *46*, 4108.

Table IV. Alkylation of 1,2,5,6-Tetrahydropyridines via 3

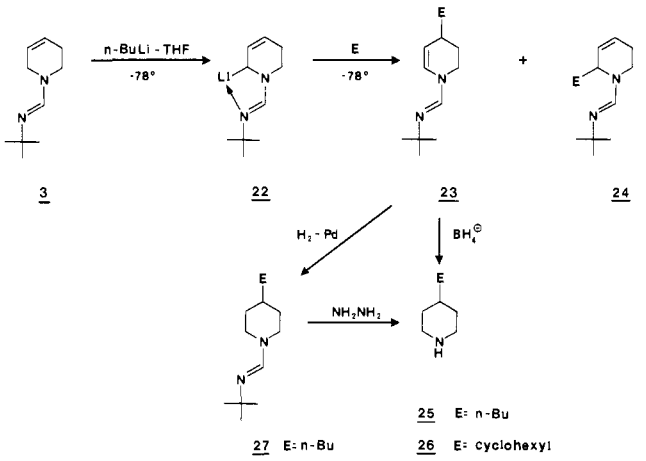
electrophile (−78 °C)	23:24[a]	% yield 23[b]	E in 23
MeI	100:0	58	Me
n-BuBr	5:1	60	*n*-Bu
$PhCH_2Cl$	14:1	63	$PhCH_2$
PhCHO	100:0[c]	66	PhCH(OH)
Cyclohexyl I	2.6:1	40	
PrCHO	100:0	71	EtCH(OH)
D_2O	100:0	95	D
MeOH	2:1	95	D

[a] Determined by NMR by observing the 2,3-vinyl protons in 23 as multiplets at δ 4.5 and 6.3, whereas in 24 the 3,4-vinyl protons appeared clustered at δ 5.7. [b] Pure materials were obtained by flash chromatography. See Experimental Section. [c] Obtained as a 2:1 ratio of threo-erythro isomers.

rivative **20** (E = Li) into its cuprate by introduction of pentynylcopper also gave comparable yields of alkylation product. The use of very reactive electrophiles (PhSeSePh, $MeCO_2Cl$) provided good yields of alkylation even in the absence of HMPA or cuprate. Table III summarizes the examples for alkylation of hexahydrazepines to their α-substituted derivatives **21**.

Alkylation of 1,2,5,6-Tetrahydropyridines

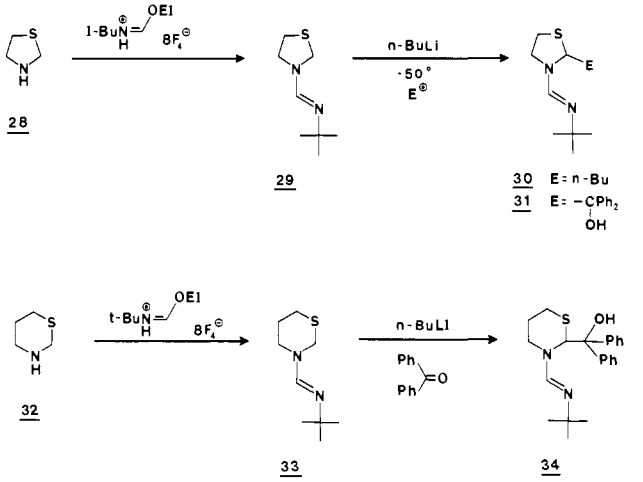
The tetrahydropyridine formamidine **3** was investigated with regard to its metalation and regiochemistry of alkylation. Metalation could be accomplished by use of the weaker base, *n*-butyllithium, owing to the allylic nature of the α protons. The



resulting orange-colored anion was then treated with a variety of electrophiles and gave, as the major product in almost each case, the 4-substituted piperidine system **23**. Table IV summarizes the products obtained and the ratio of α- to γ-alkylation. No meaningful explanation is currently offered for the ratios of 2- and 4-deuterated products observed when D_2O or MeOD was employed. Pure γ-alkylated product **23** could be readily obtained by chromatography, and two simple procedures were found to transform **23** into 4-substituted piperidines **25**. Acidic (pH 6) borohydride reduced the enamidines **23** while simultaneously cleaving the formamidine group. This has already been observed in this laboratory for open-chain enamidines.[14] Thus **26** was obtained directly from **23** in 50–60% yield. Alternatively, reduction of the double bond in **23** occurred smoothly, using Pd–C catalyst, to afford **27** which was transformed into the 4-butylpiperidine using hydrazine (60% for the two steps).

The methodology reported for tetrahydropyridines now allows a route to 4-substituted piperidines by direct alkylation of **3**[15] and extends this formamidine chemistry to either 2- or 4-substitution. In a future report, we will describe useful routes to 2,4- and 2,4,6-trisubstitution patterns by further metalation–alkylation of **23**.

Finally, we wish to mention that thiazolidine **28** and 1,3-thiazine **32** are also efficiently metalated via their respective formamidines (**29** and **33**) and, after quenching with deuterium oxide, gave >90% deuteration at the 2 position (E = D). Addition of



electrophiles (*n*-BuBr or benzophenone) produced the alkylated thiazolidine derivatives **30** and **31** in 50–55% yield. However, this reaction is accompanied by 40–50% fragmentation products similar to what had been observed with the pyrrolidine series mentioned earlier. Addition of 1-bromobutane to the lithiothiazolidine (**30**, E = Li) required, one again, the presence of 1.3 equiv of HMPA prior to introduction of the alkyl halide. The thiazine derivative **33** was also shown to react with benzophenone, affording the adduct **34** in 50% yield. No HMPA was required in either system (**29** or **33**) when carbonyls were employed as the electrophile.

The preparation of the formamidines **29** and **33** could not be accomplished by direct exchange with dimethyl-*tert*-butylformamidine **5** and required reaction with the imidate salt of *tert*-butylformamide. In this fashion the formamidine **29** was produced in 88% yield and the thiazine formamidine **33** obtained in 40% yield.

Metalation–alkylation of the sulfur-containing heterocycles at the 2 position to give the elaborated systems **30**, **31**, and **34** now opens a potentially useful route to interesting systems related to the penams and cepham antibiotics. Further studies on this and other systems are under active investigation.

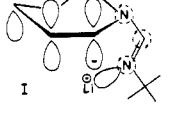
Experimental Section

General procedures to effect metalation and alkylation of the heterocycles reported herein are given below. For many of the final products obtained, whose identity is readily discerned by the usual analytical techniques, their physical data are provided as supplementary material.

***N*,*N*-Dimethyl-*N'*-*tert*-butylformamidine (5).** A stirred solution of 155 mL (2.0 mol) of *N*,*N*-dimethylformamide and 190 mL (2.0 mol) of dimethyl sulfate as heated at 80–90 °C for 3 h and then cooled to 0 °C. A solution of 231 mL (2.2 mol) of *tert*-butylamine in 400 mL of methylene chloride was added over a 30-min period to the stirred reaction mixture and then refluxed for 15–20 h. The reaction mixture was cooled and poured into 2 L of a 20% potassium hydroxide solution. The organic

(14) Meyers, A. I.; Jagdmann, G. E., Jr. *J. Am. Chem. Soc.* **1982**, *104*, 877.

(15) It is interesting to note that α-lithio anion **22** which may be formed using the weaker base, *n*-butyllithium, is probably due to the lower kinetic acidity of the allylic proton. Models indicate that the C–Li bond may overlap with the π orbitals of the C=C bond and still retain orthogonality with the π orbitals of the formamidine group (I). This orbital arrangement may be



responsible for the γ-alkylation in **22**.

layer was removed and the aqueous layer extracted three times with 200 mL of methylene chloride. The combined extracts were washed with a saturated sodium chloride solution, dried over sodium sulfate, and concentrated by slow distillation at atmospheric pressure. The resulting liquid was fractionally distilled to provide 229.0 g (90%) of *N,N*-dimethyl-*N'*-*tert*-butylformamidine as a colorless liquid (bp 133–134 °C):[16] IR ($CHCl_3$) 2960, 1640, 1370, 1355, 1260, 1095 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.15 (9 H, s), 2.75 (6 H, s), 7.25 (1 H, s).

General Procedure for Preparation of Formamidines 1–4. A solution of 300 mmol of amine, 390 mmol of *N,N*-dimethyl-*N'*-*tert*-butylformamidine, and a catalytic amount of ammonium sulfate in 50 mL of toluene was heated at reflux and the reaction monitored by either VPC or TLC. After consumption of starting material, the solvent was removed under reduced pressure and the product purified by vacuum distillation *from* CaH_2 or by flash chromatography on silica gel, eluting with 7% triethylamine/hexanes. The formamidines should be stored over CaH_2 to maintain dryness.

Physical Properties of Formamidines 1–4. 1: Oil; purified by distillation from CaH_2 [bp 185–188 °C (760 torr)]; yield 92%; IR (film) 1655 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.17 (9 H, s), 1.65–1.98 (4 H, m), 3.15–3.42 (4 H, m), 7.52 (1 H, s). Anal. Calcd for $C_9H_{18}N_2$: C, 70.08; H, 11.76; N, 18.16. Found: C, 69.96; H, 11.73.

2 (R = H): Oil; purified by distillation from CaH_2 [bp 60 °C (2.0 torr)]; yield 93%; IR (film) 1660 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.12 (9 H, s), 1.32–1.68 (6 H, m), 3.00–3.32 (4 H, m), 7.22 (1 H, s). Anal. Calcd for $C_{10}H_{20}N_2$: C, 71.38; H, 11.98; N, 16.64. Found: C, 71.17; H, 11.55.

2 (R = *t*-Bu): Oil; purified by distillation from CaH_2 [bp 80 °C (0.6 torr)]; yield 85%; IR (film) 1650 cm^{-1}; ^1H NMR ($CDCl_3$) δ 0.85 (9 H, s), 1.15 (9 H, s), 1.50 (5 H, m), 2.60 (2 H, m), 3.80 (2 H, br d, J = 12 Hz), 7.25 (1 H, s). Anal. Calcd for $C_{14}H_{28}N_2$: C, 74.94; H, 12.58. Found: C, 74.88; H, 12.43.

2 (R = Ph_2CH): Mp 99–100 °C; purified by flash chromatography on silica gel eluting with 7% triethylamine/hexanes; yield 60%; IR (film) 1650 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.10 (9 H, s), 1.50 (3 H, m), 2.40 (4 H, m), 3.50 (1 H, d, J = 10 Hz), 3.70 (2 H, m), 7.10 (11 H, s). Anal. Calcd for $C_{23}H_{30}N_2$: C, 82.58; H, 9.04. Found: C, 82.90; H, 9.30.

3: Oil, purified by distillation from CaH_2 [bp 50 °C (0.05 torr)]; yield 76%; IR (film) 1645 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.16 (9 H, s), 2.16 (2 H, m), 3.32 (2 H, t, J = 5.9 Hz), 3.77 (2 H, m), 5.73 (2 H, m), 7.37 (1 H, s). Anal. Calcd for $C_{10}H_{18}N_2$: C, 72.24; H, 10.91. Found: C, 71.66; H, 10.73.

4: Oil; purified by distillation from CaH_2 [bp 95 °C (2.3 torr)]; yield 97%; IR (film) 1655 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.16 (9 H, s), 1.32–1.96 (8 H, m), 3.12–3.45 (4 H, m), 7.32 (1 H, s). Anal. Calcd for $C_{11}H_{22}N_2$: C, 72.47; H, 12.17. Found: C, 72.19; H, 12.09.

Formamidines 29 and 33 from the *N*-*tert*-Butylimidate Tetrafluoroborate Salt. A solution of 160 mmol of $EtO_3^+BF_4^-$ and 108 mmol of *tert*-butylformamide in 200 mL of 1,2 dichloroethane was stirred at room temperature under argon for 16 h. To this mixture was added dropwise a solution of 100 mmol of thiazolidine or thiazine[17] and 100 mmol of triethylamine in 20 mL of 1,2-dichloroethane. The reaction mixture was stirred at room temperature for 1 h, and then heated to 40 °C for 1 h. The solution was extracted with diethyl ether and the organic layer washed with a 20% KOH solution. The aqueous layer was extracted with diethyl ether, and the ethereal phases were combined and dried over anhydrous $MgSO_4$. The crude product was flash chromatographed on silica gel eluting with 7% Et_3N in hexanes. These products deterioriated after several hours at room temperature making elemental analyses difficult.

Physical Properties of Formamidines 29 and 33. 29: Oil; purified by flash chromatography on silica gel eluting with 7% Et_3N in hexanes; yield 88%; IR (film) 2970, 2865, 1660, 1375, 1220, 1055 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.15 (9 H, s), 2.85 (2 H, t, J = 6 Hz), 3.65 (2 H, t, J = 6 Hz), 4.40 (2 H, s), 7.35 (1 H, s).

33: Oil; purified by flash chromatography on silica gel eluting with 7% Et_3N in hexanes; yield 40%; IR (film) 2950, 2920, 2860, 1655, 1440, 1380, 1350, 1255, 1090, 1025, 955, 675 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.2 (9 H, s), 1.8 (2 H, m), 2.9 (2 H, m), 3.3 (2 H, t, J = 5 Hz), 4.5 (2 H, s), 7.2 (1 H, s).

General Procedure for Alkylation of Formamidines 1, 2, and 4 without HMPA or Pentynylcopper. To a −78 °C, 0.5 M solution of the *dry* piperidine or hexahydroazepine formamidine in 80% ether/THF, or the pyrrolidine formamidine in THF, was added 1.1 equiv of *tert*-butyllithium. The yellow solution was stirred at −20 °C for 1 h resulting in formation of a white precipitate in the case of the piperidine and hexahydroazepine formamidines, and a faint yellow solution in the case of the pyrrolidine formamidine. The reaction mixture was cooled to −78 °C, 1.3 equiv of electrophile added, and the mixture slowly warmed to 0 °C over 3 h. The reaction mixture was poured into either 3 N HCl or a saturated solution of ammonium chloride and washed with ether; the latter was discarded. The aqueous layer was made basic (pH 12) with 20% NaOH and extracted several times with dichloromethane. The combined organic extracts were dried over K_2CO_3/Na_2SO_4 and the solvents removed at reduced pressure. The crude product was purified by flash chromatography on silica gel deactivated with 5–10% triethylamine and either hexanes or ethyl acetate, eluting with same. For specific conditions see physical data in the supplementary material.

General Procedure for Alkylation of Formamidines 1, 2, and 4 with HMPA. To a −78 °C, 0.05 M solution of the *dry* piperidine or hexahydroazepine formamidine in 80% ether/THF, or the pyrrolidine formamidine in THF, was added 1.1 equiv of *tert*-butyllithium, and the yellow solution was stirred at −20 °C for 1 h resulting in formation of a white precipitate in the case of the piperidine and hexahydroazepine formamidines, and a faint yellow solution in the case of pyrrolidine formamidine. The reaction mixture was cooled to −78 °C and a 1:1 solution of HMPA (1.5 equiv) in THF was added. After the solution was stirred for 10 min, 1.3 equiv of electrophile was added and the solution warmed to 0 °C over 3 h. The reaction mixture was quenched and extracted as in the previous procedure. The crude product was purified by flash chromatography on silica gel deactivated with 5–10% triethylamine and either hexanes or ethyl acetate, eluting with same. For specific conditions see physical data in the supplementary material.

General Procedure for Alkylation of Formamidines 1, 2, and 4 with Pentynylcopper. To a −78 °C, 0.5 M solution of the *dry* piperidine or hexahydroazepine formamidine in 80% ether/THF, or pyrrolidine formamidine in THF, was added 1.3 equiv of *tert*-butyllithium, and the yellow solution was stirred at −20 °C for 1 h resulting in formation of a white precipitate in the case of the piperidine and hexahydroazepine formamidines, and a faint yellow solution in the case of pyrrolidine formamidine. A suspension of 1.4 equiv of pentynylcopper in a volume of THF equal to the volume of the original solution was added; the heterogeneous mixture was stirred at −20 °C for an additional 0.5 h and cooled to −78 °C. To this, 1.6 equiv of electrophile was added and the mixture stirred at −20 °C until TLC indicated no further consumption of starting material. The mixture was poured into 3 N HCl and stirred until all the *yellow* solid was digested; then the copper was precipitated with a saturated solution of sodium sulfide. The aqueous mixture was filtered through Celite, washed with ether, and made basic (pH 12) with 20% NaOH. The aqueous layer was extracted with dichloromethane; the combined organic extracts were dried over K_2CO_3/Na_2SO_4 and the solvents removed at reduced pressure. The crude product was purified by flash chromatography on silica gel deactivated with 5–10% triethylamine and either hexanes or ethyl acetate, eluting with same. For specific conditions see physical data in the supplementary material.

Reaction of 10 with 6-Bromo-1-hexene. Metalation of piperidine **2** (R = H, 0.30 g, 1.8 mmol) furnished **10** which was then treated with 6-bromo-1-hexene (0.38 g, 2.3 mmol) according to the general procedure for alkylation of formamidines without HMPA or pentynylcopper. Purification by preparative TLC, developing with 10% triethylamine/ethyl acetate, afforded 90–120 mg (30–40%) of enamidine A (n = 2) and 90–134 mg (20–30%) of cyclopentylmethyl adduct B.

A (n = 2): Oil; IR ($CHCl_3$) 2960, 2862, 1640, 1468, 1416, 1362, 1287, 1200, 1176, 1133, 1073, 995, 965, 700 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.17 (9 H, s), 1.5–2.3 (4 H, m), 3.50 (2 H, t, J = 6 Hz), 4.60 (1 H, m), 6.31 (1 H, dd, J = 2 and 8 Hz), 7.32 (1 H, s).

B: Oil; IR (film) 2962, 2865, 1645, 1455, 1420, 1385, 1360, 1271, 120, 1009, cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.17 (9 H, s). 1.18–1.90 (17 H, m), 2.80 (1 H, m), 3.55 (2 H, m), 7.25 (1 H, s); ^{13}C NMR ($CDCl_3$) δ 20.14, 2499, 25.28, 29.43, 31.29, 32.52, 32.87, 36.08, 36.84, 39.82, 52.49, 53.89, 150.52.

Authentic Preparation of 2-Cyclopentylmethylpiperidine (B). The piperidine formamidine **2** (R = H, 0.30 g, 1.8 mmol) was metalated and alkylated with cyclopentylmethyl iodide (0.59 g, 2.8 mmol) according to the general procedure of alkylation with pentynylcopper. Purification by preparative TLC (10% triethylamine–ethyl acetate) gave 323 mg (72%) of B whose spectral, VPC, and TLC properties were identical with those of B prepared from **10** and 6-bromo-1-hexene.

Reaction of 4-*tert*-Butylpiperidine 2 with Benzophenone. A 0.5 M solution of 4-*tert*-butylpiperidine-*N'*-*tert*-butylformamidine (**2**), R = *t*-Bu; 0.469 g, 2.10 mmol) in 2,5-dimethyltetrahydrofuran was metalated using the general procedure without HMPA or pentynylcopper. The resulting anion was alkylated with 1.1 equiv of benzophenone at −78 °C. After workup, as in the general procedure, the crude product was recrystallized from 4:1 hexane–methylene chloride to afford 0.457 g (55%) of the

(16) Harris, D. L.; Wellman, K. M. *Tetrahedron Lett.* **1968**. Wilson, J. D.; Wagner, J. S.; Weingarten, H. *J. Org. Chem.* **1971**, *36*, 1613.

(17) Cook, M. J.; Jones, Richard A. Y.; Katritzky, A. R.; Moreno Manas, M.; Richards, A. C.; Sparrow, A. J.; Trepanier, D. L. *J. Chem. Soc., Perkin Trans. 2* **1973**, *4*, 325.

product as a white, crystalline monohydrate, mp 163–164 °C: ^{1}H NMR ($CDCl_3$) δ 0.7 (9 H, s), 1.0 (9 H, s), 1.0–1.7 (6 H, m), 2.6–4.2 (3 H, m), 7.0–7.8 (11 H, m). Anal. Calcd for $C_{27}H_{40}N_2O_2$: C, 77.93; H, 9.43. Found: C, 77.81; H, 9.30.

Formation of *N*-Cinnamylpyrrolidine (Scheme III). The pyrrolidine formamidine **1** (0.50 g, 3.20 mmol) was metalated as described in the general procedure. The anion was quenched at −78 °C with 0.95 g (1.5 equiv) of freshly distilled cinnamyl bromide. The reaction mixture was worked up as in the general procedure, and the crude material was subjected to radial chromatography (1-mm silica gel plate eluting with 5% Et_3N in hexanes) to afford 30 mg (5%) of *N*-cinnamylpyrrolidine as the only isolable product. VPC comparison (SE-30 column, 100–200 °C at 16 °C/min) of this product with an authentic sample of *N*-cinnamylpyrrolidine showed them to be identical: ^{1}H NMR ($CDCl_3$) δ 1.9 (4 H, m), 2.6 (4 H, m), 3.3 (2 H, d, J = 5 Hz), 6.4 (2 H, m), 7.2 (5 H, m).

The authentic sample of *N*-cinnamylpyrrolidine was prepared by refluxing a solution of 0.29 g (4.0 mmol) of pyrrolidine and 0.26 g (1.0 mmol) of cinnamyl bromide in 20 mL of THF for 12 h. The solvent was removed under vacuum and the crude product was taken up in diethyl ether. A saturated bicarbonate solution wash of the ethereal phase followed by concentration in vacuo afforded 0.18 g (95%) of the product as a light yellow oil. No further purification was undertaken as spectral and chromatographic data compared identically with the *N*-cinnamylpyrrolidine obtained in the previous reaction.

General Procedure for Alkylation of Formamidine 3. To a 0.5 M solution of *dry* 1,2,5,6-tetrahydropyridine *N'-tert*-butylformamidine in THF under argon at −78 °C was added 1.1 equiv of *n*-butyllithium; the resulting yellow solution was allowed to stir upon warming to −50 °C for 1–1.5 h. The reaction mixture was cooled to −78 °C and the anion quenched with 1.3 equiv of the electrophile. Upon slow warming to ambient temperature, the reaction mixture was dissolved in hexane and extracted several times with 1 N HCl or saturated NH_4Cl solution. The aqueous layer was made basic (pH 12) with a 20% KOH solution and extracted several times with diethyl ether. The ethereal layers were combined and dried over anhydrous Na_2SO_4. The crude product was flash chromatographed on silica gel (deactivated with 5% Et_3N in hexanes) eluting with hexane. Diagnostic spectral characteristics: IR (film) 1635–1620 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 4.5 (1 H, dd, J = 3, 8 Hz), 6.3 (1 H, d, J = 8 Hz). Complete physical data are given in the supplementary material.

Alkylation of the Thiazine and Thiazolidine *N'-tert*-butylformamidines (29 and 33). To a 0.2 M solution of the thiazine or thiazolidine *N'-tert*-butylformamidine in THF under argon at −78 °C was added 1.1 equiv of *n*-butyllithium, and the yellow reaction mixture was allowed to warm to −50 °C. After stirring at that temperature for 1 h, the solution was cooled to −78 °C and 1.1 equiv of the electrophile was added.[18] Upon warming, the reaction mixture was diluted with ether, filtered, and concentrated in vacuo. The crude product was purified by flash chromatography on silica gel with 5–10% Et_3N in hexanes.

General Procedure for Hydrolysis of Formamidines. A solution containing 1 mmol of formamidine in 5 mL of methanol, 3 mL of water, and 0.4 g of KOH was heated at 60 °C for 12 h; the amine was extracted with dichloromethane. The dichloromethane extract was dried over sodium sulfate/potassium carbonate, the solvents were removed at reduced pressure, and the free amine was isolated by bulb-to-bulb distillation or chromatography on silica gel eluting with 10% triethylamine/ethyl acetate.

General Procedure for Hydrazinolysis of Formamidines. A solution of 2 mmol of the formamidine, 16 mmol of hydrazine, and 6 mmol of glacial acetic acid in 20 mL of 95% ethanol was heated at 50 °C under argon for 15 h. Upon cooling, the solvent was removed under vacuum and the crude product extracted with diethyl ether. The ether layer was washed with a saturated sodium bicarbonate solution and dried over anhydrous Na_2SO_4. The product was purified by vacuum distillation.

General Procedure for Reductive Cleavage of Formamidines. To a stirred solution of 500 mg of formamidine in 25 mL of THF was added 500 mg of $LiAlH_4$; the resulting suspension was heated at reflux for 12 h. The reaction was then quenched with 0.5 mL of H_2O, 0.5 mL of 15% NaOH, and 15 mL of H_2O. After stirring for 1 h, anhydrous sodium sulfate was added; the mixture was stirred an additional 1 h and filtered through Celite. The solvents was removed at reduced pressure, and the free amine was purified by bulb-to-bulb distillation.

4-Cyclohexylpiperidine via Reductive Hydrolysis of Formamidine 3 (R = Cyclohexyl). To a solution of 0.30 g (1.20 mmol) of formamidine **3** (R = cyclohexyl) in 3 mL of 95% EtOH at pH 6 at −15 °C was added 0.14 g (3.70 mmol) of $NaBH_4$ in 3 mL of 95% EtOH over a 30-min period while the solution was maintained at pH 6 with addition of a 10% HCl solution. Upon completion of the addition, the solution was allowed to stir an additional 30 min at 0 °C. The reaction mixture was made basic with solid NaOH and extracted with diethyl ether; the organic layer was concentrated. The crude material was dissolved into a solution of 1 mL of 10% HCl solution in 6 mL of THF and allowed to stir for 1 h at room temperature. The solution was diluted with 10% HCl solution and extracted with diethyl ether. The ether layer was discarded, and the aqueous layer was made basic with a 20% KOH solution. Extraction with diethyl ether of the aqueous layer followed by concentration under vacuum afforded the product as an oily white solid. Sublimation of the crude product produced white crystals (0.1 g, 50%), mp 75–78 °C (uncorrected) (lit.[19] mp 80–82 °C): ^{1}H NMR ($CDCl_3$) δ 1.1 (9 H, m), 1.6 (8 H, m), 2.5 (2 H, m), 3.0 (2 H, m).

4-*n*-Butylpiperidine via Hydrogenation/Hydrazinolysis of Formamidine 23 (E = *n*-Bu). A solution of 1.35 g (6.10 mmol) of formamidine **23** (E = *n*-Bu) and 150 mg of 10% Pd on carbon in 15 mL of absolute ethanol was placed under a 50-psi hydrogen atmosphere at room temperature for 20 h. The reaction mixture was filtered through Celite, and the filtrate was diluted with 10 mL of 95% EtOH. Anhydrous hydrazine (1.6 mL, 48.8 mmol) and glacial acetic acid (1.0 mL, 16.6 mmol) were added to the ethanolic solution and the mixture was heated at 50 °C under argon for 16 h. After cooling to room temperature, the ethanol was removed in vacuo. The crude product was extracted with CH_2Cl_2, and the organic phase was washed with a saturated sodium bicarbonate solution before being dried over anhydrous K_2CO_3. Concentration and bulb-to-bulb distillation (117 °C (15 torr)) afforded 0.52 g (60%) of the amine as a colorless liquid: IR (film) 3270, 2930, 2850, 2805, 2730, 1600, 1450, 1375, 1330, 1140, 1110, 1000, 945, 750 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 0.9 (3 H, m), 1.2 (11 H, m), 2.5 (3 H, m), 3.0 (2 H, m).[20]

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Registry No. 1, 85152-51-8; **2** (R = H), 85152-52-9; **2** (R = *t*-Bu), 89656-21-3; **2** (R = Ph_2CH), 89656-22-4; **3**, 89656-23-5; **4**, 85152-53-0; **7** (R = Me), 89656-27-9; **7** (R = Bu), 89656-28-0; **7** (R = CH_2=$CHCH_2$), 89656-29-1; **7** (R = $PhCH_2$), 89656-30-4; **7** (R = CH_2=$CHCH(OH)$), 89656-31-5; **7** (R = PhCH(OH)), 89656-32-6; **7** (R = CO_2Me), 89656-33-7; **7** (R = PhSe), 89656-34-8; **7** (R = Bu_3Sn), 89656-35-9; **8** (R = Me), 765-38-8; **8** (R = Bu), 3446-98-8; **8** (R = CH_2=$CHCH_2$), 89656-36-0; **8** (R = $PhCH_2$), 35840-91-6; **8** (R = $CH_2CHCH(OH)$) (isomer 1), 89656-37-1; **8** (R = CH_2=CHCH(OH)) (isomer 2), 89656-63-3; **8** (R = PhCH(OH)) (isomer 1), 75598-05-9; **8** (R = PhCH(OH)) (isomer 2), 75598-06-0; **12** (R = Me), 89656-38-2; **12** (E = Pr), 89656-39-3; **12** (E = Bu), 89656-40-6; **12** (R = CH_2=$CHCH_2$), 89656-41-7; **12** (E = $PhCH_2$), 89656-42-8; **12** (E = Cl-$(CH_2)_3$), 89656-43-9; **13** (E = Pr), 10388-95-1; **13** (E = Bu), 72939-22-1; **13** (E = CH_2=$CHCH_2$), 89656-44-0; **13** (E = $PhCH_2$), 32838-55-4; **13** (E = PhCH(OH)), 23702-98-9; **20** (E = CO_2Me), 89656-48-4; **20** (E = Pr), 89656-45-1; **20** (E = $CH_3(CH_2)_6$), 89656-46-2; **20** (E = PhSe), 89656-47-3; **21** (E = Pr), 13748-14-6; **21** (E = $CH_3(CH_2)_6$), 89656-49-5; **23** (E = Me), 89656-50-8; **23** (E = Bu), 89656-51-9; **23** (E = $PhCH_2$), 89656-52-0; **23** (E = PhCH(OH)) (isomer 1), 89656-53-1; **23** (E = PhCH(OH)) (isomer 2), 89656-64-4; **23** (E = cyclohexyl), 89656-54-2; **23** (E = $CH_3CH_2CH(OH)$), 89656-55-3; **23** (E = D), 89656-56-4; **23** (E = MeO), 89656-57-5; **24** (E = Bu), 89656-58-6; **24** (E = cyclohexyl), 89656-59-7; **24** (E = MeO), 89656-60-0; **26**, 14446-73-2; **28**, 504-78-9; **29**, 89656-25-7; **32**, 543-71-5; **33**, 89656-26-8; A (*n* = 2; G = CH=NBu-*t*), 89656-61-1; **B**, 89656-62-2; $HCONMe_2$, 68-12-2; *tert*-butylamine, 75-64-9; *N,N*-dimethyl-*N'*-butylformamide, 3717-82-6; pyrrolidine, 123-75-1; piperidine, 110-89-4; 4-*tert*-butylpiperidine, 24152-39-4; 4-(diphenylmethyl)piperidine, 19841-73-7; 1,2,3,6-tetrahydropyridine, 694-05-3; hexahydro-1*H*-azepine, 111-49-9; *tert*-butyl(ethoxymethyl)-ammonium tetrafluoroborate, 89656-24-6; 6-bromo-1-hexene, 2695-47-8; benzophenone, 119-61-9; cinnamyl bromide, 4392-24-9; *N*-cinnamylpyrrolidine, 79089-39-7; cyclopropylmethyl iodide, 27935-87-1; 4-*n*-butylpiperidine, 4945-48-6.

Supplementary Material Available: Physical data for final products (13 pages). Ordering information is given on any current masthead page.

(18) When alkyl halides were used, 1 equiv of a 1:1 solution of HMPA/THF was added 10 min preceding addition.

(19) Booth, H.; Little, J. *Tetrahedron* **1967**, *23*, 291.

(20) Prasad, K. B.; Al-Jallo, H. N.; Al-Dulaimi, K. S. *J. Chem. Soc. C* **1969**, *16*, 2134.