Cycloaddition Reaction of Heterocumulenes with Oxiranes Catalyzed by an Organotin Iodide–Lewis Base Complex

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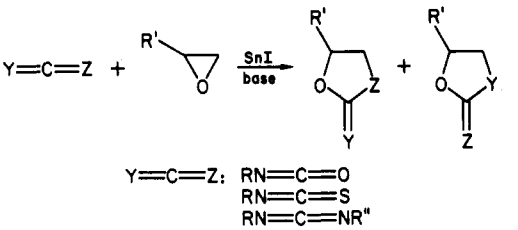
Organotin halide–Lewis base complexes are versatile catalysts for the cycloaddition of heterocumulenes with oxiranes and afford good yields of five-membered heterocyclic compounds under mild and neutral conditions. The catalysts are sufficiently active that reaction of PhNCO with oxiranes gave a variety of 2-oxazolidinones without the appreciable trimerization of PhNCO. 2-Dioxolanimines, 2-oxathiolanimines, and 2-oxazolidinimines could be also obtained from the reactions of isocyanates, isothiocyanates, and carbodiimides, respectively. These heterocyclic compounds have not been isolated by using previous catalysts, although they are considered as intermediates.

Oxiranes are useful intermediates in organic synthesis because of their easy accessibility and high reactivity being accompanied with their ring opening. In particular, oxiranes react with heterocumulenes in a fashion of the 1,3-cycloaddition, giving five-membered heterocyclic compounds,[2] and a number of catalysts have been developed with varying degrees of success. However, in the reactions using these catalysts, vigorous reaction temperatures and somteimes reactive polar solvents are required,[2] and so they are accompanied by undesirable reactions such as the trimerization of isocyanates and addition to solvents.

Recently, many organotin reagents have become widely used in organic synthesis.[3] Some important features of tin compounds are great affinity toward a sulfur or a halogen atom and facile insertion of heterocumulenes such as RNCO, RNCS, RNCNR, CO_2, and CS_2 toward a Sn–O bond.[4] With these features, a variety of heterocyclic compounds are obtained by using equimolar organotin reagents.[5] In a preliminary report, we also described the synthesis of heterocyclic compounds from the equimolar reactions of tri-*n*-butyltin ω-haloalkoxides [(n-Bu_3SnO-$(CH_2)_nX$, n = 2, 3, X = halogen] with heterocumulenes.[6] This type of tin reagent can be regarded as an adduct of oxirane or oxetane with n-Bu_3SnX.[7] Of importance is that the addition of Lewis bases significantly accelerates this reaction. A facile complex formation of organotin halides with Lewis bases is widely known. These facts led us to investigate whether complexes of organotin halides and Lewis bases can be employed as excellent catalysts for the cycloaddition of heterocumulenes with oxiranes. Although the structures and stabilities have been intensively investigated,[8] these complexes are not used extensively in organic synthesis.[9] We have found that these complexes are characteristically effective, and the following observations are worth noting. Cycloadditions took place under very mild conditions in the presence of a catalytic amount of complex. Moreover, several new types of heterocycles which have not been obtained with conventional catalysts can be isolated. Thus, 2-dioxolanimines, 2-oxathiolanimines, and 2-oxazolidinimines were isolated in the reaction with isocyanates, isothiocyanates, and carbodiimides, respectively (Scheme I).

Scheme I



A part of the study on the cycloaddition of isocyanates with oxiranes has been published as a communication.[10] In addition to these results, we herein wish to report an improvement of catalysts and mechanistic considerations.

Results and Discussion

The Cycloaddition of Isocyanates with Oxiranes. Initially, the catalytic activity of in situ generated organotin halide–Lewis base complexes (10 mol %) was investigated in terms of the cycloaddition of PhNCO with propylene oxide. Table I shows these results (entries 1–10). The organotin iodide alone had low activity (entry 1), but satisfactory results were obtained by complexation with Lewis bases. The cycloaddition was performed under very mild conditions (40 °C, 2 h) to yield 5-methyl-3-phenyl-1,3-oxazolidin-2-one (1) in excellent yields. This is remarkable because very severe conditions are necessary when previous catalysts such as lithium halides,[11] quaternary ammonium salts,[12] Lewis bases[13] and Lewis acids

(1) For reviews, see: (a) Behrens, C. H.; Sharpless, K. B. *Aldrichimica Acta* **1983**, *16*, 67. (b) Rao, A. S.; Paknikar, S. K.; Kirtane, J. G. *Tetrahedron* **1983**, *39*, 2323. (c) Smith, J. G. *Synthesis* **1984**, 629.

(2) (a) Ulrich, H. *Cycloaddition Reaction of Heterocumulenes*; Academic: New York, 1967. (b) Dyen, M. E.; Swern, D. *Chem. Rev.* **1967**, *67*, 197. (c) Ozaki, S. *Chem. Rev.* **1972**, *72*, 457.

(3) For reviews, see: (a) Sawyer, A. K. *Organotin Compounds*; Marcel Dekker: New York, 1971. (b) Negishi, E. *Organometallics in Organic Synthesis*; Wiley: New York, 1980; Vol. 1, p 394. (c) Davies, A. G.; Smith, P. J. *Comprehensive Organometallic Chemistry*; Pergamon: Oxford 1982; Vol. 2, p 519.

(4) (a) Bloodworth, A. J.; Davies, A. G. *J. Chem. Soc.* **1965**, 5238. (b) Bloodworth, A. J.; Davies, A. G.; Vasishtha, S. C. *J. Chem. Soc. C* **1967**, 1309.

(5) (a) Sakai, S.; Asai, Y.; Kiyohara, Y.; Itoh, K.; Ishii, Y. *Organomet. Chem. Synth.* **1970**, *1*, 45. (b) Sakai, S.; Fujimura, Y.; Ishii, Y. *J. Organomet. Chem.* **1973**, *50*, 113. (c) Sakai, S.; Niimi, H.; Kobayashi, Y.; Ishii, Y. *Bull. Chem. Soc. Jpn.* **1977**, *50*, 3271.

(6) Baba, A.; Kishiki, H.; Shibata, I.; Matsuda, H. *Organometallics* **1985**, *4*, 1329.

(7) (a) Delmond, B.; Pommier, J. C.; Valade, J. *J. Organomet. Chem.* **1972**, *35*, 91. (b) Delmond, B.; Pommier, J. C.; Valade, J. *J. Organomet. Chem.* **1973**, *47*, 337.

(8) See, for example: (a) Sawyer, A. K. *Organotin Compounds*; Marcel Dekker: New York, 1971; Vol. 1, p 81. (b) Bolles, T. F.; Drago, R. S. *J. Am. Chem. Soc.* **1966**, *88*, 5730.

(9) (a) Nomura, R.; Kimura, M.; Teshima, S.; Ninagawa, A.; Matsuda, H. *Bull. Chem. Soc. Jpn.* **1982**, *55*, 3200. (b) Baba, A.; Meishou, H.; Matsuda, H. *Makromol. Chem., Rapid Commun.* **1984**, *5*, 655.

(10) Baba, A.; Shibata, I.; Masuda, K.; Matsuda, H. *Synthesis* **1985**, 1144.

(11) (a) Gulbins, K.; Hamann, K. *Angew. Chem.* **1958**, *70*, 705. (b) Gulbins, K.; Benzing, G.; Maysenhölder, R.; Hamann, K. *Chem. Ber.* **1960**, *93*, 1975. (c) Herweh, J. E.; Foglia, T. A.; Swern, D. *J. Org. Chem.* **1968**, *33*, 4029. (d) Irwin, W. J.; Wheeler, D. L. *J. Chem. Soc. C* **1971**, 3166. (e) Herweh, J. E.; Kauffman, W. J. *Tetrahedron Lett.* **1971**, 809. (f) Herweh, J. E.; Kauffman, W. J. *J. Heterocycl. Chem.* **1971**, *8*, 983.

(12) Speranza, G. P.; Peppel, W. J. *J. Org. Chem.* **1958**, *23*, 1922.

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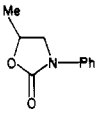
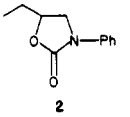
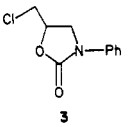
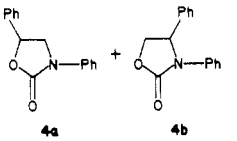
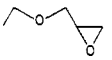
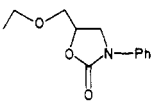
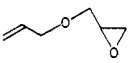
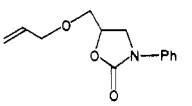
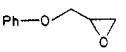
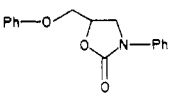
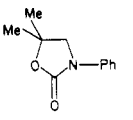
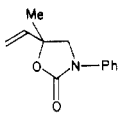
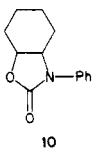
Table I. The Cycloaddition of PhNCO with Oxiranes[a]

entry	oxirane	cat. system	product	yield, %[b]
1		*n*-Bu_3SnI	 1	*e*
2		*n*-Bu_3SnI–Ph_3P		73
3		*n*-Bu_3SnI–Ph_3PO		96
4		*n*-Bu_3SnI–Et_3N		34
5		*n*-Bu_3SnI–DBU		41
6		*n*-Bu_3SnCl–Ph_3P		10
7		*n*-Bu_3SnBr–Ph_3P		35
8		*n*-Bu_2SnI_2–Ph_3P		94
9		*n*-Bu_2SnI_2–Ph_3PO		76
10		*n*-Bu_2SnI_2–Et_3N		69
11		*n*-Bu_3SnI–Ph_3P	 2	97
12		*n*-Bu_3SnI–Ph_3PO		100
13		*n*-Bu_3SnI–Ph_3P	 3	39
14		*n*-Bu_3SnI–Ph_3PO		90
15		*n*-Bu_3SnI–Ph_3P	 4a 4b	*e*
16		*n*-Bu_3SnI–Ph_3PO		58 (37:63)[c]
17		*n*-Bu_3SnI–Ph_3PO	 5	100
18		*n*-Bu_3SnI–Ph_3PO	 6	89
19		*n*-Bu_3SnI–Ph_3PO	 7	88
20		*n*-Bu_3SnI–Ph_3PO	 8	12
21		*n*-Bu_2SnI_2–Ph_3P		13
22		Me_2SnI_2–HMPA		100
23		*n*-Bu_3SnI–Ph_3PO	 9	9
24		Me_2SnI_2–HMPA		22
25		*n*-Bu_3SnI–Ph_3PO	 10	*e*
26		Me_2SnI_2–HMPA		*e* (70)[d]

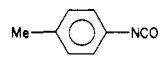
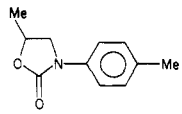
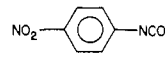
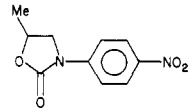
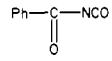
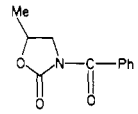
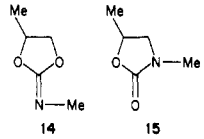
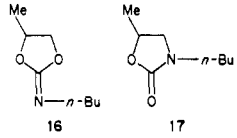
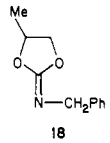
[a] PhNCO, 10 mmol; oxirane, 50 mmol; tin halide, 1 mmol; base, 1 mmol; temperature, 40 °C; time, 2 h. [b] Based on PhNCO, GLC yield. [c] Determined by GLC. [d] PhNCO was added dropwise at 80 °C. [e] Trace.

are used.[14] As far as we know, even the current method of choice uses LiBr–*n*-Bu_3PO or LiBr–HMPA as a catalyst at above 80 °C.[11e,f]

One disturbing side reaction using these catalysts is the trimerization of isocyanates. This trimerization proceeds so smoothly in the presence of Lewis bases[15] that dropwise addition is necessary to depress it when using the LiCl–DMF[11c,d] or the LiBr–*n*-Bu_3PO[11e,f] system as a catalyst. Without dropwise addition of the isocyanate, we observed that LiBr–HMPA gave 1 in only 34% yield at 40 °C for 2 h and that the rest of isocyanate was converted to its trimer, as was confirmed by IR spectra [1700 cm^{-1} (C=O)].

(13) Weiner, M. L. *J. Org. Chem.* **1961**, *26*, 951.
(14) Braun, D.; Weinert, J. *Liebigs Ann. Chem.* **1979**, 200.
(15) (a) Tsuzuki, R.; Ishikawa, K.; Kase, M. *J. Org. Chem.* **1960**, *25*, 1009. (b) Jones, J. I.; Savill, N. G. *J. Chem. Soc.* **1957**, 4392.

Table II. The Cycloaddition of Isocyanates with Propylene Oxide[a]

entry	RN=C=O	product	yield, %[b]
1		 11	100
2		 12	21
3		 13	85
4	Me-NCO	 14 15	100 (89:11)[c]
5	*n*-Bu-NCO	 16 17	100 (74:26)[c]
6	$PhCH_2$-NCO	 18	57

[a] Isocyanate, 10 mmol; propylene oxide, 50 mmol; *n*-Bu_3SnI, 1 mmol; Ph_3PO, 1 mmol; temperature, 40 °C; time, 2 h. [b] Based on RNCO, GLC yield. [c] Determined by GLC.

In contrast with these systems, our catalysts are very effective toward the cycloaddition, and the trimerization of PhNCO is no longer a problem. Therefore, the dropwise addition of PhNCO is not necessary.

The combination of organotin halides and Lewis bases is very important. Tri-*n*-butyltin iodide (*n*-Bu_3SnI) was more effective with Ph_3PO than with Ph_3P, whereas this order was reversed in the case of di-*n*-butyltin diiodide (*n*-Bu_2SnI_2) (entries 2, 3, 8, and 9). Reaction proceeded more smoothly when catalyzed by the iodide than the chloride or the bromide (entries 2, 6, and 7). Strong Lewis bases such as Et_3N and DBU were unfavorable (entries 4, 5, and 10).

Table I shows the results of the cycloaddition of PhNCO with oxirances to yield 2-oxazolidinones **2–10** (Table I, entries 11–26), in which PhNCO was added at once. The reactivity of monosubstituted oxiranes could be compared by using *n*-Bu_3SnI–Ph_3P as a catalyst, which is less effective than *n*-Bu_3SnI–Ph_3PO and *n*-Bu_2SnI_2–Ph_3P. Butylene oxide, with an electron-donating substituent, was very reactive (entry 11), whereas epichlorohydrin, with an electron-withdrawing one, showed relatively poor reactivity entry 13) and styrene oxide hardly reacted (entry 15). However, an active complex, *n*-Bu_3SnI–Ph_3PO, afforded good yields of 2-oxazolidinones **3–7** from the cycloaddition of PhNCO with various monosubstituted oxiranes (entries 11–19). Reactions of aliphatic oxiranes proceeded via the regioselective cleavage at the unsubstituted carbon–oxygen bond of the oxirane (β-cleavage), giving 5-substituted 2-oxazolidinones only. On the other hand, styrene oxide gave 4-substituted 2-oxazolidinone **4b** as a mixture with 5-substituted isomer **4a** (entries 15 and 16).

Table III. The Cycloaddition of MeNCO with Propylene Oxide[a]

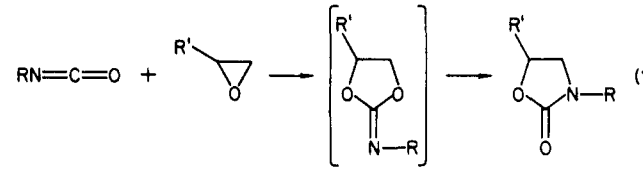
entry	additive	yield, %[b]	14:15[c]
1	*n*-Bu_3SnI	100	44:56
2	*n*-Bu_3SnI–Ph_3P	100	62:38
3	*n*-Bu_3SnI–Bu_3P	90	88:12
4	*n*-Bu_3SnI–Ph_3PO	93	94:6

[a] MeNCO, 5 mmol; propylene oxide, 50 mmol; *n*-Bu_3SnI, 5 mmol; base, 5 mmol; temperature, 25 °C; time, 1 h. [b] Based on MeNCO, GLC yield. [c] Determined by GLC.

Disubstituted oxiranes showed poor reactivity in comparison with monosubstituted oxiranes. For instance, isobutylene oxide gave low yields of **8** (entries 20 and 21). However, the complex Me_2SnI_2–HMPA led to **8** in a quantitative yield (entry 22). This complex has a significant catalytic activity in comparison with other complexes mentioned above. Cyclohexene oxide did not gave **10** at all under the same conditions (entries 25 and 26), however, compound **10** could be obtained in 70% yield by adding PhNCO dropwise at 80 °C in order to depress the trimerization of PhNCO (entry 26, in parenthesis). Isoprene oxide gave **9** in a poor yield even when Me_2SnI_2–HMPA was used as a catalyst (entry 24).

Other isocyanates also yielded cycloadducts with propylene oxide when catalyzed by *n*-Bu_3SnI–Ph_3PO (Table II). Aromatic and benzoyl isocyanates gave the corresponding 2-oxazolidinones **11–13** (entries 1–3). An electron-withdrawing substituent on the aromatic ring of an isocyanate decreased the reactivity. For example, *p*-nitrophenyl isocyanate gave **12** in 21% yield (entry 2), although *p*-tolyl isocyanate gave **11** in a quantitative yield (entry 1).

On the other hand, the formation of 2-dioxolanimines **14**, **16**, and **18** in the reaction of propylene oxide with aliphatic isocyanates, such as MeNCO, *n*-BuNCO, and $PhCH_2NCO$, is noteworthy (entries 4–6). 2-Dioxolanimines have not been isolated in the reactions activated by previous catalysts,[16] although they are considered as a precursor in the formation of 2-oxazolidinones[11b,17] (eq 1).


(1)

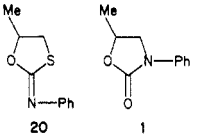
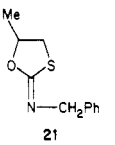
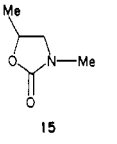
In the stoichiometric reaction of MeNCO with propylene oxide in the presence of an equimolar amount of *n*-Bu_3SnI, a mixture of 2-dioxolanimine **14** and 2-oxazolidinone **15** was obtained (Table III, entry 1), the addition of Lewis bases lowered the proportion of **15** (entries 2–4). In these reactions, compound **15** may be formed by the isomerization of **14**. Authentic compound **14** is transformed into **15** in 61% yield after 3 h upon treatment with an equimolar amount of *n*-Bu_3SnI (Figure 1). It is noteworthy that the isomerization was depressed by adding bases, especially Ph_3PO.

Contrary to the *N*-alkyl-2-dioxolanimines mentioned above, we confirmed that no isomerization of *N*-phenyl-2-dioxolanimine **19** to the corresponding *N*-phenyl-2-oxazolidinone **1** takes place in the presence of an equimolar

(16) Only an activated isocyanate, chlorosulfonyl isocyanate (CSI), is reported to react with oxiranes across the C=O group, yielding 2-dioxolanimines: Keshava Murthy, K. S.; Dhar, D. N. *J. Heterocycl. Chem.* **1984**, *21*, 1721.

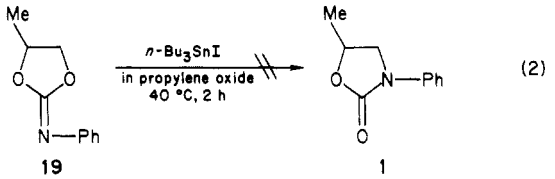
(17) (a) Gulbins, K.; Hamann, K. *Angew. Chem.* **1961**, *73*, 434. (b) Mukaiyama, T.; Fujisawa, T.; Nohira, H.; Hyugaji, T. *J. Org. Chem.* **1962**, *27*, 3337.

Table IV. The Cycloaddition of Isothiocyanates with Propylene Oxide[a]

entry	RN=C=S	cat. system	time, h	product	yield, %[b]
1	PhNCS	n-Bu_3SnI–Ph_3PO	2	 **20** **1**	9
2			24		88 (72:28)[c]
3		Me_2SnI_2–HMPA	2		100 (100:0)[c]
4	$PhCH_2NCS$	Me_2SnI_2–HMPA	2	 **21**	59
5	MeNCS	Me_2SnI_2–HMPA	2	 **15**	*d*
6			30		75

[a] Isothiocyanate, 10 mmol; propylene oxide, 50 mmol; tin halide, 1 mmol; base, 1 mmol; temperature, 40 °C. [b] Based on RNCS, GLC yield. [c] Determined by GLC. [d] Trace.

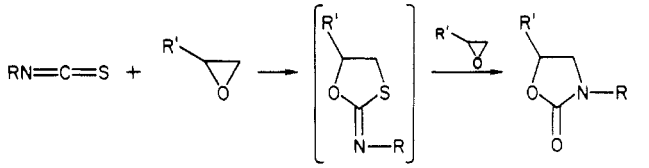
amount of n-Bu_3SnI and an excess of propylene oxide under conditions similar to those noted in Table I (eq 2). A higher reaction temperature is necessary to achieve this isomerization, as reported in our previous paper.[6]



(2)

From these facts, in the catalytic cycloaddition (Table II), it appears that *N*-alkyl-2-dioxolanimines **14**, **16**, and **18** are formed first and then *N*-alkyl-2-oxazolidinones, **15** and **17** may be formed via the isomerization. On the other hand, *N*-aryl-2-oxazolidinones are thought to be formed directly, and not via the isomerization of the corresponding 2-dioxolanimine.

The Cycloaddition of Isothiocyanates with Propylene Oxide. Isothiocyanates reacted with propylene oxide across the C=S group catalyzed by organotin halide–Lewis base complexes to yield 2-oxathiolanimines (Table IV). This is noteworthy, because in the cycloaddition of isothiocyanates with oxiranes, 2-oxathiolanimines are detected only when using activated isothiocyanates such as acetyl and benzoyl isothiocyanates.[18] Aromatic and aliphatic isothiocyanates usually do not give 2-oxathiolanimines[19] because of the facile conversion to 2-oxazolidinones in the presence of oxiranes[5c] (eq 3).



(3)

With the organotin halide–Lewis base complexes as catalysts, isothiocyanates showed lower reactivity in comparison with isocyanates. For example, PhNCS reacted with propylene oxide to give 2-oxathiolanimine **20** in 9% yield when catalyzed by n-Bu_3SnI–Ph_3PO at 40 °C for 2 h (entry 1),[20] although PhNCO gave **1** quantitatively (table I, entry 3). A prolonged reaction time (24 h) was necessary to achieve a higher yield (entry 2). In this case, 2-oxazolidinone **1** was formed as a byproduct. However, complex Me_2SnI_2–HMPA showed a greater catalytic activity to yield 2-oxathiolanimine **20** in a quantitative yield at 40 °C for 2 h (entry 3). This complex is so active that the cycloaddition is complete under mild conditions before the isomerization of **20** to **1** takes place. *N*-Benzyl-2-oxathiolanimine **21** was also obtained from the cycloaddition of $PhCH_2NCS$ with propylene oxide (entry 4), although the reactivity was lower than PhNCS. In the case of

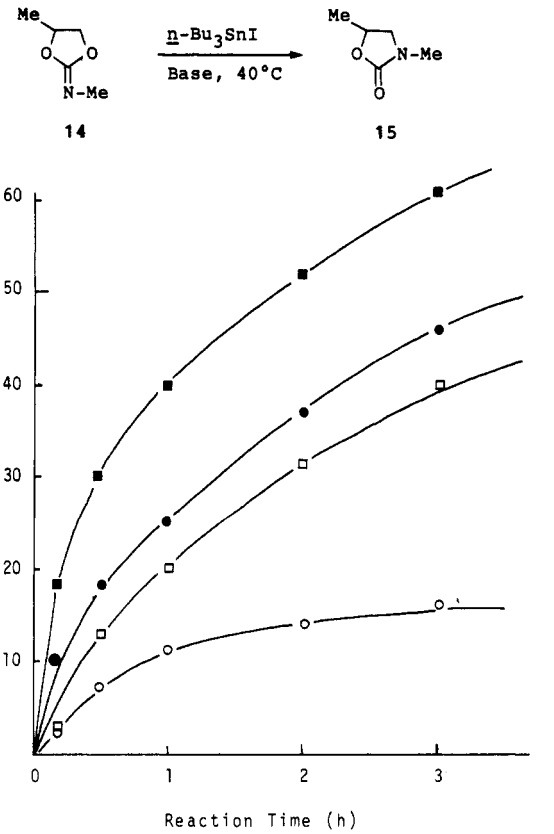
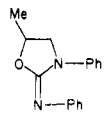
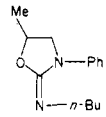
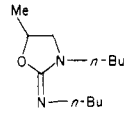


Figure 1. The isomerization of **14** to **15** in the presence of n-Bu_3SnI and a base at 25 °C: **14**, 5 mmol; n-Bu_3SnI, 5 mmol; base, 5 mmol; propylene oxide, 50 mmol; (■) no base, (●) Ph_3P, (□) Bu_3P, (○) Ph_3PO.

(18) Feinauer, R.; Jacobi, M.; Hamann, K. *Chem. Ber.* **1965**, *98*, 1782.
(19) (a) Etlis, V. S.; Sineokov, A. P.; Razuvaev, G. A. *Zh. Obshch. Khim.* **1964**, *34*, 4018; *Chem. Abstr.* **1965**, *62*, 9132f. (b) Etlis, V. S.; Sineokov, A. P.; Razuvaev, G. A. *Zh. Obshch. Khim.* **1964**, *34*, 4090; *Chem. Abstr.* **1965**, *62*, 10423h.

(20) In contrast with isocyanates, isothiocyanates did not trimerize, and the unreacted ones were recovered.

Table V. The Cycloaddition of Carbodiimides with Propylene Oxide[a]

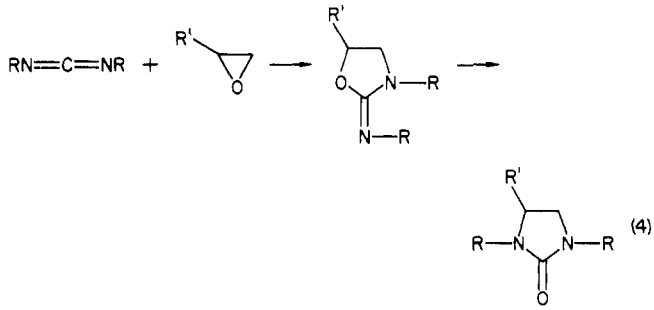
entry	RN=C=NR″	cat. system	product	yield, %[b]
1	PhN=C=NPh	n-Bu_3SnI	 22	44
2		n-Bu_3SnI–Ph_3P		57
3		n-Bu_3SnI–Ph_3PO		80
4		n-Bu_2SnI_2–Ph_3P		92
5	n-BuN=C=NPh	n-Bu_2SnI_2–Ph_3P	 23	100
6	n-BuN=C=N-n-Bu	n-Bu_3SnI–Ph_3P	 24	9
7		n-Bu_2SnI_2–Ph_3P		85

[a] Carbodiimide, 10 mmol; propylene oxide, 50 mmol; tin halide, 1 mmol; base, 1 mmol; temperature, 40 °C; time, 2 h. [b] Based on RNCNR′, GLC yield.

MeNCS, the reactivity was much lower, and N-methyl-2-oxathiolanimine could not be isolated, and only **15**, the converted product, was obtained (entry 6).

The Cycloaddition of Carbodiimides with Propylene Oxide. The cycloaddition of carbodiimides with propylene oxide yielded 2-oxazolidinimines (Table V). In the reaction of PhNCNPh, the complex n-Bu_2SnI_2–Ph_3P was most effective, affording **22** in high yield (entry 4).

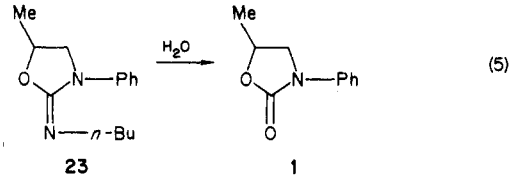
From earlier observations, 2-imidazolidinones are major products under severe conditions using several catalysts,[21] and they are considered to be formed by isomerization of 2-oxazolidinimines[22] (eq 4). These results indicate that



(4)

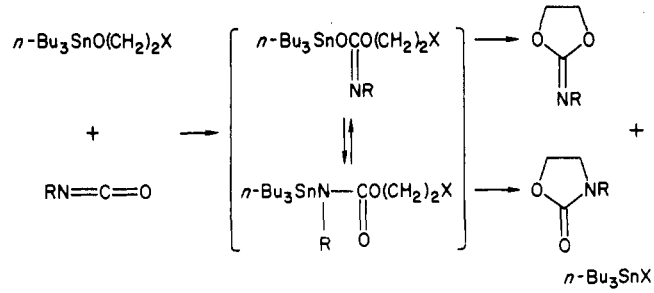
the catalytic activity of organotin halide–Lewis base complexes is very high, and hence the reaction conditions are mild enough to trap the intermediate quantitatively without the isomerization.

In the reaction with an unsymmetrical carbodiimide such as n-BuNCNPh, the cycloaddition took place selectively across the PhN=C group of n-BuNCNPh rather than the n-BuN=C group to yield 3-phenyl-2-oxazolidin-N-butylimine (**23**) (entry 5). Structural evidence was afforded by hydrolysis to give 2-oxazolidinone 1 (eq 5).

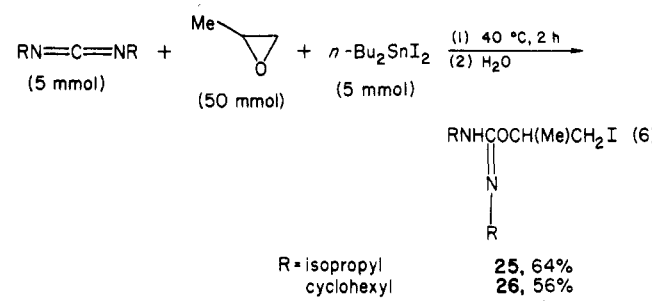


(5)

Scheme II. Reaction of Tri-n-butyltin β-Haloethoxide with an Isocyanate



Aliphatic carbodiimides were less reactive than PhNCNPh. The cycloaddition of n-BuNCN-n-Bu gave **24** in 9% yield when catalyzed by n-Bu_3SnI–Ph_3P (entry 6), although compound **22** was obtained from PhNCNPh in 57% yield under the same conditions (entry 2). However, n-Bu_2SnI_2–Ph_3P was more active, affording **24** in 85% yield (entry 7). Other bulky carbodiimides such as diisopropyl- and dicyclohexylcarbodiimide did not give cycloadducts. Treatment of these carbodiimides with an equimolar amount of n-Bu_2SnI_2 followed by hydrolysis gave acyclic carbamimidate adducts (eq 6).



Mechanism. We have already reported that the reaction of tri-n-butyltin β-haloethoxides (n-$Bu_3SnO(CH_2)_2X$) with heterocumulenes gives five-membered heterocyclic compounds.[6] In this reaction, the addition of the Sn–O bond to a heterocumulene is followed by intramolecular alkylation (Scheme II).

The following features were observed. (1) Tri-n-butyltin β-iodoethoxide (n-$Bu_3SnO(CH_2)_2I$) is more reactive than the chloride or the bromide. (2) Addition of a Lewis base accelerates the reaction. (3) 2-oxazolidinones are obtained predominantly in the reactions with aromatic isocyanates, whereas, the reaction with aliphatic isocyanates leads to the predominant formation of 2-dioxolanimines. (4) The reaction with PhNCNPh gives 2-oxazolidinimines, and the reactivity of PhNCNPh is greater than that of PhNCO.

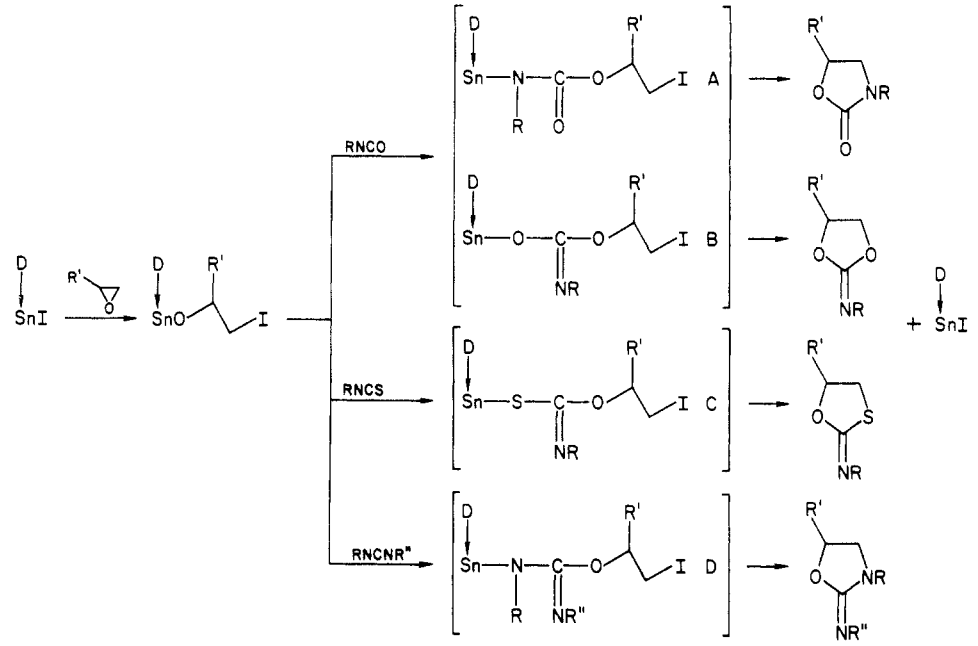
These features are consistent with the direct addition of heterocumulenes to oxiranes such that the cycloaddition may proceed via an organotin β-haloethoxide.

Accordingly, the following mechanism can be proposed (Scheme III). (1) Initially, an organotin β-iodoalkoxide is formed via the cleavage of oxiranes by the tin–halogen bond. (2) This is followed by the addition of the Sn–O bond to heterocumulenes to yield intermediates A–D. (3) The intramolecular alkylation produces five-membered heterocyclic compounds.

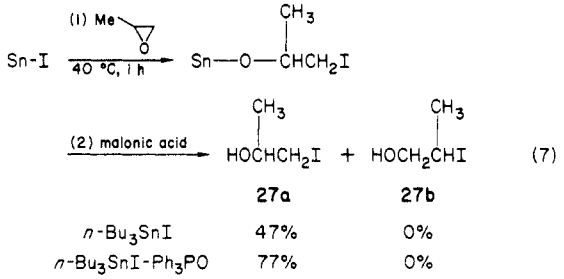
Organotin halides are effective for ring opening of oxiranes, such as the polymerization of oxiranes[23] and the formation of halohydrins.[24] Fiorenza et al. have reported

(21) Gulbins, K.; Hamann, K.; *Chem. Ber.* **1961**, *94*, 3287.
(22) (a) Vowinkel, E.; Gleichenhagen, P. *Tetrahedron Lett.* **1974**, 143. (b) Beachell, H. C.; Ngoc Son, C. P.; Tinh, N. H. *J. Org. Chem.* **1972**, *37*, 422.
(23) (a) Matsuda, S.; Matsuda, H.; Ninagawa, A.; Iwamoto, N. *J. Chem. Soc. Jpn., Ind. Chem. Sec.* **1968**, *71*, 2054. (b) Iwamoto, N.; Ninagawa, A.; Matsuda, H.; Matsuda, S. *J. Chem. Soc. Jpn., Ind. Chem. Sec.* **1969**, *72*, 1847.

Scheme III. A Plausible Catalytic Cycle



that Me_3SnI cleaves propylene oxide readily to give trimethyltin β-iodoalkoxide (Me_3SnOCH_2CHMeI).[24b] They have reported cleavage at the hindered MeCH–O bond (α-cleavage) rather than at the CH_2–O bond (β-cleavage) of propylene oxide. Contrary to this fact, in our study, the heterocyclic compounds obtained are 5-substituted ones only, which are formed via β-cleavage of oxiranes. Actually, we confirmed that treatment of *n*-Bu_3SnI with propylene oxide followed by destannylation with malonic acid afforded 1-methyl-2-iodo-ethanol **27a** selectively, and addition of Ph_3PO increased the yield (eq 7). This fact



	27a	27b
n-Bu_3SnI	47%	0%
n-Bu_3SnI-Ph_3PO	77%	0%

(7)

indicates that the reaction proceeds via an organotin β-iodoethoxide which is formed by the regiospecific β-cleavage of oxiranes (step 1). In the case of styrene oxide, because of the stabilization of a positive charge by conjugative electron release from the π-orbital of an aromatic substituent,[25] α-cleavage may accompany β-cleavage, giving 4-phenyl-2-oxazolidinone **4b** along with the 5-phenyl isomer **4a**.

The types of products are determined in step 2. In the case of isocyanates, two types of intermediates, A and B, can be considered. As described in our previous paper,[6] the formation of 2-dioxolanimines indicates the possibility of the addition of the Sn–O bond across the C=O group of an isocyanate, although the Sn–O bond has been reported to add only across the N=C group of an isocyanate.[4] In the case of isothiocyanates, because of the great affinity of a tin atom toward a sulfur atom, we propose only C as an intermediate. 2-Oxathiolanimines are obtained via intramolecular S-alkylation. The order of the reactivity of RNCS in the cycloaddition was R = aryl > benzyl > alkyl, which is consistent with the order of reactivity in the addition of the Sn–O bond to RNCS as described by Sakai et al.[5c] As for carbodiimides, intermediate D is proposed. This was trapped as destannylated compounds, **25** and **26**, in the reaction of diisopropyl- or dicyclohexylcarbodiimide. In this case, bulky substituents on the nitrogen atom may prevent the intramolecular cyclization. The addition of the Sn–O bond occurs across the aryl—N=C group rather than the alkyl—N=C group in the reaction of *n*-BuNCNPh. For this reason, the cycloaddition is contrasted with the fact that an alkyl—N=C group normally reacts rather than an aryl—N=C group.[26]

In next stage of step 3, Lewis bases play an important role. The coordination of a base to the tin atom increases the basicity of the adjacent hetero atom, and hence the intramolecular alkylation is accelerated, giving heterocyclic compounds. The Sn–I bond is formed in this step.

In conclusion, organotin halide–Lewis base complexes are efficient catalysts for producing high yields of five-membered heterocyclic compounds under mild and neutral conditions. Moreover, these complexes can enlarge the scope of the cycloaddition of oxiranes with heterocumulenes.

Experimental Section

General Data. Melting points were obtained by using a Yanaco Micromelting point apparatus and are uncorrected. IR spectra were recorded on a Hitachi 260-30 spectrometer using KBr pellets or KRS-5 cells. ^1H NMR and ^{13}C NMR spectra were performed on JEOL Model PS-100 and on JEOL Model FX-60 spectrometers, respectively. Analytical GLC was performed on the following instrument by using a 2 m × 3 mm glass column packed with Silicone OV-17 on Uniport HP (5%, 60–80 mesh); a SHIMADZU GC-3B with TCD, helium as a carrier gas. Column chromatography was performed on silica gel (Wakogel C-200).

Materials. All oxiranes were freshly distilled from CaH_2. All Lewis bases were purified by general procedures. PhCONCO,[27] $PhCH_2NCO$,[28] *n*-BuNCN*n*-Bu,[29] *n*-BuNCNPh,[29] and PhNCNPh[30]

(24) (a) Iwamoto, N.; Ninagawa, A.; Matsuda, H.; Matsuda, S. *J. Chem. Soc. Jpn., Ind. Chem. Sec.* **1971**, *74*, 118. (b) Fiorenza, M.; Ricci, A.; Taddei, M.; Tassi, D. *Synthesis* **1983**, 640.

(25) Parker, R. E.; Isaacs, N. S. *Chem. Rev.* **1959**, *59*, 737.

(26) Lacey, R. N.; Ward, W. R. *J. Chem. Soc.* **1958**, 2134.

(27) Speziale, A. J.; Smith, L. R. *J. Org. Chem.* **1962**, *27*, 3742.

were prepared according to described methods. Other isocyanates and isothiocyanates were commercial ones and used without further purification. Organotin iodides, n-Bu_3SnI, n-Bu_2SnI_2, and Me_2SnI_2, were produced according to described methods.[31]

5-Methyl-3-phenyl-1,3-oxazolidin-2-one (1). To a solution of n-Bu_3SnI (0.42 g, 1 mmol) and Ph_3PO (0.27 g, 1 mmol) in propylene oxide (2.90 g, 50 mmol) was added PhNCO (1.19 g, 10 mmol) with stirring under dry nitrogen. The resulting mixture was stirred at 40 °C for 2 h, and the yield of 1 was monitored by GLC (1.70 g, 96%). The reaction mixture no longer contained the isocyanate. The excess propylene oxide was removed in vacuo, and the residue was subjected to purification by column chromatography on silica gel. Compound 1 (1.65 g, 93%) was obtained as white needles, which were recrystallized from benzene–hexane: mp 78–80 °C (lit.[2b] mp 80–82 °C); IR (KBr) 1740 cm^{-1} (C=O); ^1H NMR ($CDCl_3$) δ 1.50 (d, J = 6 Hz, 3 H), 3.60 (dd, J = 7 and 8 Hz, 1 H), 4.10 (t, J = 8 Hz, 1 H), 4.60–4.95 (m, 1 H), 7.00–7.60 (m, 5 H); MS, m/e 177 (M^+).

The following compounds (2–13) were obtained in a similar manner by using suitable organotin iodide–base complexes as shown in Table I.

5-Ethyl-3-phenyl-1,3-oxazolidin-2-one (2): bp 124 °C (1.5 mmHg); IR (neat) 1750 cm^{-1}; ^1H NMR ($CDCl_3$) δ 0.98 (t, J = 7 Hz, 3 H), 1.50–1.90 (m, 2 H), 3.50 (dd, J = 7 and 9 Hz, 1 H), 3.95 (t, J = 9 Hz, 1 H), 4.30–4.65 (m, 1 H)8 7.00–7.60 (m, 5 H); ^{13}C NMR ($CDCl_3$) δ 8.3 (q), 27.5 (t), 49.6 (t), 73.9 (d), 117.8 (d), 123.4 (d), 128.6 (d), 138.2 (s), 154.7 (s); MS, m/e 191 (M^+). Anal. Calcd for $C_{11}H_{13}O_2N$: C, 69.09; H, 6.85; N, 7.33. Found: C, 68.69; H, 6.77; N, 7.47.

5-(Chloromethyl)-3-phenyl-1,3-oxazolidin-2-one (3): mp 98–100 °C (lit.[2b] mp 103 °C); IR (KBr) 1740 cm^{-1} (C=O); ^1H NMR ($CDCl_3$) δ 3.78 (d, J = 5 Hz, 2 H), 3.80–4.30 (m, 2 H), 4.70–5.00 (m, 1 H), 7.00–7.60 (m, 5 H); MS, m/e 211.5 (M^+). Compounds **4a** and **4b** were identified by comparison with the authentic data.[11d]

3,5-Diphenyl-1,3-oxazolidin-2-one (4a): mp 130 °C (lit.[11d] mp 128–129 °C); IR (KBr) 1740 cm^{-1} (C=O); ^1H NMR ($CDCl_3$) δ 3.90 (dd, J = 8 and 9 Hz, 1 H), 4.30 (t, J = 9 Hz, 1 H), 5.60 (dd, J = 8 and 9 Hz, 1 H), 7.10–7.60 (m, 10 H); MS, m/e 239 (M^+).

3,4-Diphenyl-1,3-oxazolidin-2-one (4b): mp 79 °C (lit.[11d] mp 78–79 °C); IR (KBr) 1750 cm^{-1} (C=O); ^1H NMR ($CDCl_3$) δ 4.15 (dd, J = 6 and 9 Hz, 1 H), 4.75 (t, J = 9 Hz, 1 H), 5.40 (dd, J = 6 and 9 Hz, 1 H), 7.00–7.50 (m, 10 H); MS, m/e 239 (M^+).

5-(Ethoxymethyl)-3-phenyl-1,3-oxazolidin-2-one (5): bp 124 °C (1.5 mmHg); IR (neat) 1750 cm^{-1} (C=O); ^1H NMR ($CDCl_3$) δ 1.18 (t, J = 10 Hz, 3 H), 3.40–3.65 (m, 4 H), 3.70–4.10 (m, 2 H), 4.55–4.85 (m, 1 H), 7.00–7.60 (m, 5 H); ^{13}C NMR ($CDCl_3$) δ 14, 7 (q), 46.8 (t), 66.9 (t), 70.3 (t), 71.3 (d), 117.9 (d), 123.6 (d), 128.7 (d), 138.1 (s), 154.5 (s); MS m/e 221 (M^+). Anal. Calcd for $C_{12}H_{15}O_3N$: C, 65.14; H, 6.83; N, 6.33. Found: C, 64.96; H, 6.72; N, 6.03.

5-[(Allyloxy)methyl]-3-phenyl-1,3-oxazolidin-2-one (6): bp 159 °C (10^{-3} mmHg) (lit.[2b] bp 176 °C (0.06 mmHg)); IR (neat) 1750 cm^{-1} (C=O); ^1H NMR ($CDCl_3$) δ 3.60 (d, J = 7 Hz, 2 H), 3.70–4.10 (m, 4 H), 4.50–4.90 (m, 1 H), 5.00–5.40 (m, 2 H), 5.60–6.10 (m, 1 H), 7.00–7.60 (m, 5 H); MS, m/e 233 (M^+).

3-Phenyl-5-(phenoxymethyl)-1,3-oxazolidin-2-one (7): mp 139 °C (lit.[2b] mp 137–138 °C); IR (KBr) 1740 cm^{-1} (C=O); ^1H NMR ($CDCl_3$) δ 3.95–4.30 (m, 4 H), 4.90–5.10 (m, 1 H), 6.80–7.65 (m, 10 H); MS, m/e 269 (M^+).

5,5-Dimethyl-3-phenyl-1,3-oxazolidin-2-one (8): mp 94–95 °C (lit.[32] mp 98–99.5 °C); IR (KBr) 1740 cm^{-1} (C=O); ^1H NMR ($CDCl_3$) δ 1.50 (s, 6 H), 3.75 (s, 2 H), 7.00–7.60 (m, 5 H); MS, m/e 191 (M^+).

5-Methyl-3-phenyl-5-vinyl-1,3-oxazolidin-2-one (9): bp 83 °C (10^{-3} mmHg); IR (neat) 1750 cm^{-1} (C=O); ^1H NMR ($CDCl_3$) δ 1.60 (s, 3 H), 3.75 (d, J = 9 Hz, 1 H), 3.90 (d, J = 9 Hz, 1 H), 5.15–5.60 (m, 2 H), 5.80–6.20 (dd, J = 10 and 17 Hz, 1 H), 7.00–7.60 (m, 5 H); ^{13}C NMR ($CDCl_3$) δ 25.7 (q), 56.4 (t), 77.9 (s), 115.1 (t), 118.5 (d), 124.1 (d), 129.1 (d), 138.7 (s), 139.1 (d), 154.3 (s); MS, m/e 203 (M^+).

4,5-(Hexahydrobenzo)-3-phenyl-1,3-oxazolidin-2-one (10): mp 93–94 °C; IR (KBr) 1740 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.05–2.30 (m, 8 H), 4.15–4.40 (m, 1 H), 4.55–4.80 (m, 1 H), 7.00–7.60 (m, 5 H); ^{13}C NMR ($CDCl_3$) δ 19.1 (t), 19.9 (t), 26.0 (t), 26.6 (t), 55.9 (d), 73.2 (d), 120.9 (d), 124.6 (d), 129.1 (d), 137.2 (s), 155.9 (s); MS, m/e 217 (M^+). Anal. Calcd for $C_{13}H_{15}O_2N$: C, 71.87; H, 6.96; N, 6.45. Found: C, 71.45; H, 6.93; N, 6.36.

5-Methyl-3-*p*-tolyl-1,3-oxazolidin-2-one (11): mp 65–66 °C (lit.[2b] mp 67.5 °C); IR (KBr) 1740 cm^{-1} (C=O); ^1H NMR ($CDCl_3$) δ 1.52 (d, J = 6 Hz, 3 H), 2.30 (s, 3 H), 3.58 (dd, J = 7 and 9 Hz, 1 H), 4.08 (t, J = 9 Hz, 1 H), 4.60–5.00 (m, 1 H), 7.00–7.80 (m, 4 H); MS, m/e 191 (M^+).

5-Methyl-3-(*p*-nitrophenyl)-1,3-oxazolidin-2-one (12): mp 131 °C; IR (KBr) 1750 cm^{-1} (C=O); ^1H NMR (Me_2SO-d_6) δ 1.45 (d, 3 H), 3.79 (dd, J = 7 and 8 Hz, 1 H), 4.28 (t, J = 8 Hz, 1 H), 4.85–5.00 (m, 1 H), 7.60–8.40 (m, 4 H); ^{13}C NMR (Me_2SO-d_6) δ 20.0 (q), 50.9 (t), 70.2 (d), 117.6 (d), 124.8 (d), 142.2 (s), 144.4 (s), 154.1 (s); MS, m/e 222 (M^+).

3-Benzoyl-5-methyl-1,3-oxazolidin-2-one (13): mp 105–106 °C (6it.[2b] mp 111 °C); IR (KBr) 1790, 1680 cm^{-1} (C=O); ^1H NMR ($CDCl_3$) δ 1.50 (d, J = 6 Hz, 3 H), 3.70 (dd, J = 7 and 9 Hz, 1 H), 4.18 (t, J = 9 Hz, 1 H), 4.60–4.90 (m, 1 H), 7.20–8.20 (m, 5 H); MS, m/e 205 (M^+).

***N*,4-Dimethyl-1,3-dioxolan-2-imine (14).** In a similar manner described above, compound 14 was prepared in 86% GLC yield as a mixture with 15 (14:15 = 89:11). Purification was accomplished by distillation: bp 45–48 °C (1 mmHg); IR (neat) 1690 cm^{-1} (C=N); ^1H NMR ($CDCl_3$) δ 1.40 (d, J = 6 Hz, 3 H), 2.85 (s, 3 H), 3.75–4.00 (m, 1 H), 4.30–4.90 (m, 2 H); MS, m/e 115 (M^+). Anal. Calcd for $C_5H_9O_2N$: C, 52.16; H, 7.88; N, 12.17. Found: C, 51.89; H, 8.04; N, 12.42.

***N*-*n*-Butyl-4-methyl-1,3-dioxolan-2-imine (16)**: bp 82–84 °C (1 mmHg); IR (neat) 1720 cm^{-1} (C=N); ^1H NMR ($CDCl_3$) δ 0.90 (t, J = 6z, 3 H), 1.20–1.60 (m, 7 H), 3.15 (t, J = 6 Hz, 2 H), 3.70–4.00 (m, 1 H), 4.20–4.85 (m, 2 H); MS, m/e 157 (M^+). Anal. Calcd for $C_8H_{15}O_2N$: C, 61.12; H, 9.62; N, 8.91. Found: C, 60.89; H, 9.69; N, 8.83.

***N*-Benzyl-4-methyl-1,3-dioxolan-2-imine (18)**: bp 135 °C (1 mmHg); IR (neat) 1750 cm^{-1} (C=N); ^1H NMR ($CDCl_3$) δ 1.35 (d, J = 6 Hz, 3 H), 2.92 (dd, J = 7 and 8 Hz, 1 H), 3.47 (t, J = 8 Hz, 1 H), 4.40 (s, 2 H), 4.40–4.80 (m, 1 H), 7.20–7.40 (m, 5 H); ^{13}C NMR ($CDCl_3$) δ 20.6 (q), 48.2 (t), 50.7 (t), 70.1 (d), 127.5 (d), 128.1 (d), 128.9 (d), 135.9 (s), 158.2 (s); MS, m/e 191 (M^+).

3,5-Dimethyl-1,3-oxazolidin-2-one (15). A mixture of 14 (0.57 g, 5 mmol) and n-Bu_3SnI (2.10 g, 5 mmol) was stirred under dry nitrogen at rom temperature. After 24 h, the compound 14 was completely transformed to 15 (100% yield by GLC). Purification was performed by column chromatography on SiO_2 with $CHCl_3$: bp 94–96 °C (5 mmHg) (lit.[2b] bp 92 °C (1.5 mmHg)); IR (neat) 1740 cm^{-1} (C=O); ^1H NMR ($CDCl_3$) δ 1.40 (d, J = 6 Hz, 3 H), 2.82 (s, 3 H), 3.10 (t, J = 7 Hz, 1 H), 3.65 (t, 1 H), 4.50–4.70 (m, 1 H); MS, m/e 115 (M^+).

3-Butyl-5-methyl-1,3-oxazolidin-2-one (17). This compound was also obtained by the transformation of 16: bp 93–95 °C (3 mmHg); IR (neat) 1740 cm^{-1} (C=O); ^1H NMR ($CDCl_3$) δ 0.80–1.70 (m, 10 H), 3.00–3.40 (m, 3 H), 3.65 (t, J = 8 Hz, 1 H), 4.45–4.80 (m, 1 H); ^{13}C NMR ($CDCl_3$) δ 13.4 (q), 19.5 (q), 20.4 (t), 29.1 (t), 43.4 (t), 51.0 (t), 69.7 (d), 157.9 (s); MS, m/e 157 (M^+).

***N*-Phenyl-5-methyl-1,3-oxathiolan-2-imine (20).** To a mixture of Me_2SnI_2 (0.40 g, 1 mmol) and HMPA (0.18 g, 1 mmol) in propylene oxide (2.90 g, 50 mmol) was added PhNCS (1.35 g, 10 mmol) with stirring under dry nitrogen. The resulting mixture was stirred at 40 °C for 2 h. The disappearance of characteristic band of PhNCS at 2100 cm^{-1} was observed in IR spectra. The yield of **20** was determined by GLC (1.93 g, 100%). Excess propylene oxide was removed in vacuo, and the residual high viscosity oil was chromatographed, yielding 1.90 g (98%) of **20** as a colorless clear wax: IR (neat) 1660 cm^{-1} (C=N); ^1H NMR ($CDCl_3$) δ 1.45 (d, J = 6 Hz, 3 H), 2.95 (dd, J = 9 and 10 Hz, 1 H), 3.30 (dd, J = 6 and 10 Hz, 1 H), 4.50–4.90 (m, 1 H), 6.95–7.60 (7, 5 H); ^{13}C NMR ($CDCl_3$) δ 18.7 (q), 37.3 (t), 78.4 (d), 121.0 (d), 123.8 (d), 128.7 (d), 148.7 (s), 163.6 (s); MS, m/e 193 (M^+).

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N-Benzoyl-5-methyl-1,3-oxathiolan-2-imine (21): IR (neat) 1660 cm^{-1} (C=N); ^1H NMR ($CDCl_3$) δ 1.45 (d, J = 6 Hz, 3 H), 3.00 (dd, J = 9 and 10 Hz, 1 H), 3.35 (dd, J = 6 and 10 Hz, 1 H), 4.40 (s, 2 H), 4.50–4.80 (m, 1 H), 7.20–7.40 (s, 5 H); ^{13}C NMR ($CDCl_3$) δ 19.0 (q), 37.7 (t), 57.3 (t), 77.6 (d), 126.6 (d), 127.4 (d), 128.2 (d), 139.5 (s), 162.5 (s); MS, m/e 207 (M^+).

N,3-Diphenyl-5-methyl-1,3-oxazolidin-2-imine (22). To the solution of n-Bu_3SnI (0.42 g, 1 mmol) and Ph_3PO (0.27 g, 1 mmol) in propylene oxide (2.90 g, 50 mmol) was added PhNCNPh (1.94 g, 10 mmol) with stirring under dry nitrogen. The resulting mixture was stirred at 40 °C for 2 h. IR spectra showed the disappearance of characteristic band of PhNCNPh at 2150 cm^{-1}. The yield of **22** was monitored by GLC (2.52 g, 100%). Excess of propylene oxide was removed in vacuo, and the residue was chromatographed, yielding **22** (2.14 g, 85%) as white needles, which were purified by recrystallization from benzene–hexane: mp 72–73 °C (lit.[20] 76–77 °C); IR (KBr) 1670 cm^{-1} (C=N); ^1H NMR ($CDCl_3$) δ 1.45 (d, J = 6 Hz, 3 H), 3.55 (dd, J = 7 and 8 Hz, 1 H), 4.05 (t, J = 8 Hz, 1 H), 4.50–4.90 (m, 1 H), 6.90–7.80 (m, 10 H); MS, m/e 252 (M^+).

N-Butyl-3-phenyl-5-methyl-1,3-oxazolidin-2-imine (23): bp 90 °C (2 mmHg); IR (neat) 1700 cm^{-1} (C=N); ^1H NMR ($CDCl_3$) δ 0.95–1.70 (m, 10 H), 3.30 (t, J = 7 Hz, 2 H), 3.45 (t, J = 7 Hz, 1 H), 3.95 (t, J = 7 Hz, 1 H), 4.50–4.80 (m, 1 H), 6.80–7.80 (m, 5 H); ^{13}C NMR ($CDCl_3$) δ 14.0 (q), 20.1 (q), 20.6 (t), 34.0 (t), 46.5 (t), 52.9 (t), 70.9 (d), 118.0 (d), 121.8 (d), 128.6 (d), 140.7 (s), 149.5 (s); MS, m/e 232 (M^+).

N,3-Dibutyl-5-methyl-1,3-oxazolidin-2-imine (24): bp 68 °C (2 mmHg); IR (neat) 1700 cm^{-1} (C=N); ^1H NMR ($CDCl_3$) δ 0.80–1.70 (m, 17 H), 2.95–3.50 (m, 5 H), 3.65 (t, J = 8 Hz, 1 H), 4.60–4.90 (m, 1 H); ^{13}C NMR ($CDCl_3$) δ 13.8 (q, 2 C), 19.9 (q), 20.2 (t, 2 C), 29.2 (t, 2 C), 33.4 (t), 45.3 (t), 53.2 (t), 73.6 (d), 155.5 (s); MS, m/e 212 (M^+).

β-Iodoisopropyl N,N'-diisopropylcarbamimidate (25): mp 128 °C; IR (KBr) 1680 cm^{-1} (C=N); ^1H NMR ($CDCl_3$) δ 1.20–1.70 (m, 15 H), 3.45 (t, 1 H), 4.00–4.30 (m, 2 H), 4.90–5.10 (m, 1 H), 5.20–5.50 (m, J = 7 and 10 Hz, 1 H), 7.50 (br 1 H). Anal. Calcd for $C_{10}H_{21}ON_2I$: C, 38.47; H, 6.78; N, 8.97. Found: C, 38.15; H, 6.72; N, 8.92.

β-Iodoisopropyl N,N'-dicyclohexylcarbamimidate (26): mp 209–211 °C; IR (KBr) 1670 cm^{-1} (C=N); ^1H NMR ($CDCl_3$) δ 1.00–2.10 (m, 24 H), 3.42 (dd, J = 7 and 9 Hz, 1 H), 3.50–3.90 (m, 1 H), 4.15 (t, J = 9 Hz, 1 H), 4.60–5.00 (m, 1 H), 5.15–5.50 (m, 1 H). Anal. Calcd for $C_{16}H_{29}ON_2I$: C, 48.98; H, 7.45; N, 7.14. Found: C, 48.79; H, 7.29; N, 6.82.

1-Iodo-2-propanol (27a). The solution of n-Bu_3SnI (2.10 g, 5 mmol) and Ph_3PO (1.35 g, 5 mmol) in propylene oxide (2.90 g, 50 mmol) was stirred under dry nitrogen at 40 °C for 1 h. Malonic acid (0.38 g, 2.5 mmol) was added[24b] to the reaction mixture, and the stirring was continued for 2 h. GLC analysis showed the formation of 1-iodo-2-propanol (**27a**, 0.72 g, 77%), which was purified by distillation. Spectral data of **27a** were identical with the authentic sample derived from the iodation of 1-chloro-2-propanol: bp 60 °C (10 mmHg); IR (neat) 3350 (OH), 1050 (C–O) cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.30 (d, J = 6 Hz, 3 H), 3.20–3.40 (m, 3 H), 3.60–3.90 (m, 1 H).

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Registry No. 1, 708-57-6; 2, 101835-17-0; 3, 711-85-3; 4a, 7426-72-4; 4b, 13606-71-8; 5, 101835-18-1; 6, 100372-80-3; 7, 1226-26-2; 8, 25557-96-4; 9, 101835-19-2; 10, 100371-98-0; 11, 99855-08-0; 12, 101835-20-5; 13, 7007-16-1; 14, 101835-21-6; 15, 15833-10-0; 16, 101835-22-7; 17, 95891-61-5; 18, 101835-23-8; 20, 101835-24-9; 21, 101835-25-0; 22, 13468-06-9; 23, 101835-26-1; 24, 101835-27-2; 25, 101835-28-3; 26, 101835-29-4; 27a, 996-21-4; DBU, 6674-22-2; HMPA, 680-31-9; PhNCO, 103-71-9; BuSnI, 7342-47-4; Ph_3P, 603-35-0; Ph_3PO, 791-28-6; Et_3N, 121-44-8; Bu_3SnCl, 1461-22-9; Bu_3SnBr, 1461-23-0; Bu_2SnI_2, 2865-19-2; Me_2SnI_2, 2767-49-9; 4-MeC_6h_4NCO, 622-58-2; 4-$O_2NC_6H_4NCO$, 100-28-7; PhCONCO, 4461-33-0; MeNCO, 624-83-9; BuNCO, 111-36-4; $PhCH_2NCO$, 3173-56-6; PhNCS, 103-72-0; $PhCH_2NCS$, 622-78-6; MeNCS, 556-61-6; PhN=C=NPh, 622-16-2; BuN=C=NPh, 21848-95-3; BuN=C=NBu, 693-64-1; Me_2CHN=C=$NCHMe_2$, 693-13-0; SnOCH(Me)CH_2I, 101835-30-7; dicyclohexylcarbodiimide, 538-75-0; methyloxirane, 75-56-9; ethyloxirane, 106-88-7; (chloromethyl)oxirane, 106-89-8; phenyloxirane, 96-09-3; (ethoxymethyl)oxirane, 4016-11-9; ((2-propenyloxy)methyl)oxirane, 106-92-3; (phenoxy)oxirane, 79526-11-7; 2,2-dimethyloxirane, 558-30-5; 2-ethenyl-2-methyloxirane, 1838-94-4; 7-oxabicyclo-[4.1.0]heptane, 286-20-4.

Synthesis of Indolizinones and a Pyridoazepinone: A New Method for the Annulation of Pyridinones[1]

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The synthesis of 2,3-dihydro-5(1*H*)-indolizinone (**1**), 6,7,8,9-tetrahydro-4(4*H*)-quinolizinone (**2**), and 7,8,9,10-tetrahydropyrido[1,2-*a*]azepin-4(6*H*)-one (**3**) is described. Regiospecific addition of a bifunctional organolithium reagent (**8**, **14**, **18**) to the 6-position of 2-methoxypyridine comprises the key bond-forming reaction for the annulation sequence. The resulting lactim is oxidized to a 2,6-disubstituted pyridine (**10**, **16**, and **20**). Under acidic conditions, **10** and **16** afford **1** and **2**, respectively. Compound **20** does not afford **3** under acidic conditions, but **20** is converted to **24**, which under basic conditions cyclizes to **3**. In addition, examples of the synthesis of 3-substituted indolizinones (**29**, **30**) are also presented.

The indolizinone and quinolizinone skeletons comprise the backbone of a number of biologically and structurally interesting molecules,[2] for example, the antitumor agent camptothecin (**4**),[3] and the alkaloid isosophoramine (**5**),[4] respectively. A general and useful route to these types of compounds could be developed by devising a straightforward synthesis of ring-fused pyridinones:[5] indolizinone (**1**), quinolizinone (**2**), and pyridoazepinone (**3**). Wenkert's

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