obtained after removal of solvent (*caution: avoid overheating*) was chromatographed (silica gel column, EtOAc–hexane, 1:4) to give triazole **7** (60 mg, 46%) in 90% purity. This was further purified by PLC (EtOAc/hexane, 1:4) to give **7** as a colorless solid: mp 220 °C; IR (KBr) 3000–2200 (br, NH), 1250, 1030, 810 cm^{-1}; ^1H NMR (DMSO-d_6, 200 MHz) δ 4.57 (s, 2 H), 7.20–7.85 (m, 7 H); ^1H NMR ($CDCl_3$, 200 MHz) δ 4.68 (s, 2 H), 7.50–8.00 (m, 7 H); HRMS (EI) calcd for $C_{13}H_9N_3$ 207.0796, found 207.0791. Due to the unstable nature of this compound, a satisfactory elemental analysis was not obtained. Anal. Calcd for $C_{13}H_9N_3 \cdot 1.3H_2O$: C, 67.70; H, 5.07; N, 18.22. Found: C, 68.11; H, 4.57; N, 17.73. (For oxazole **8**: Anal. Calcd for $C_{14}H_9NO$: C, 81.14; H, 4.38; N, 6.76).

Triazole 9. Formate **6** was treated with $P(OEt)_3$ as described above (0.63 mmol scale). After 20 min the solvent was removed to give a red residue. Analysis of this product by ^1H NMR indicated that complete conversion of the starting materials to compound **9** and $P(O)(OEt)_3$ had occured. The crude mixture was triturated with hexane and the solid was crystallized from CH_2Cl_2/hexane to afford crystals of **9** (123 mg, 83%): mp 143–5 °C; IR (KBr) 1730 (CO) cm^{-1}; ^1H NMR δ 4.54 (s, 2 H), 7.45 (m, 3 H), 7.20 (d, J = 7, 1 H), 7.85 (d, J = 8, 1 H), 8.13 (d, J = 7, 1 H), 9.24 (s, 1 H); ^{13}C NMR δ 27.22, 121.80, 121.89, 126.16, 126.34, 126.95, 127.15, 128.95, 129.43, 130.80, 133.94, 148.00, 149.10, 156.55; HRMS (EI) calcd for $C_{14}H_9N_3O$ 235.0747, found 235.0747.

2-Azido-1-phenylvinyl Formate (12). To a stirred and cooled (−78 °C) solution of sodium bis(trimethylsilyl)amide (1.0 M solution in THF, 0.93 mL, 0.93 mmol) in THF (10 mL) was added dropwise a solution of α-azidoacetophenone **10**[11] (150 mg, 0.93 mmol) in THF (5 mL). The stirring was continued at −78 °C for 25 min, and the dark brown enolate was quenched by the addition of trimethylacetic formic anhydride (121 mg, 0.93 mmol). After another 10 min of stirring at −78 °C, the yellow solution was concentrated to one-third of its volume, diluted with H_2O (5 mL), and extracted with Et_2O (3 × 10 mL). The combined extracts were dried and evaporated to afford pale yellow crystals. This compound was further purified by crystallization from Et_2O/hexane to give **12** as a yellow crystalline solid (150 mg, 86%): mp 63–65 °C; IR (KBr) 2110, 1725 cm^{-1}; ^1H NMR (300 MHz) δ 6.70 (s, 1 H), 7.35 (m, 5 H), 8.21 (s, 1 H); ^{13}C NMR δ 115.82, 123.97, 128.82, 128.87, 132.08, 137.13, 158.03; HRMS (EI) calcd for $C_9H_7N_3O_2$ 189.0538, found 189.0546.

5-Phenyl-1*H*-1,2,3-triazole (13). To a solution of formate **12** (100 mg, 0.53 mmol) in $CHCl_3$ (10 mL) was added $P(OEt)_3$ (88 mg, 0.53 mmol). The exothermic reaction was complete within 10 min. The solvent was removed by rotary evaporation, and the residue was chromatographed (silica gel column, EtOAc–hexane, 1:4) to furnish **13** (48 mg, 62%) as a fluffy white solid: mp 145–7 °C (lit.[6c] mp 147–8 °C): ^1H NMR (300 MHz) δ 7.45 (m, 3 H), 7.84 (m, 2 H), 8.00 (s, 1 H). An authentic sample of **13** was prepared according to a literature procedure[6c] and was found to have an identical ^1H NMR spectrum: HRMS (EI) calcd for $C_8H_7N_3$ 145.0640, found 145.0634.

Acknowledgment. We thank The Upjohn Company for supporting this research.

Supplementary Material Available: ^1H NMR for compounds **4**, **6**, **7**, **9**, and **12** and ^{13}C NMR for compounds **4**, **6**, **9**, and **12** (13 pages). Ordering information is given on any current masthead page.

Stereocontrolled Oxazolidinone Formation by the Addition of 4,5-Disubstituted Iminodioxolane to Oxirane via a Spiro Compound

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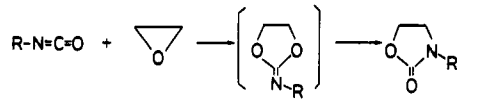
4,5-Disubstituted 2-imino-1,3-dioxolanes readily add to oxiranes in the presence of $AlCl_3$, furnishing 1,3-oxazolidin-2-ones in a stereospecific manner, where the configurations of oxiranes and iminodioxolanes are responsible for the configuration of products and the feasibility of the addition, respectively. A preliminary adduct, a spiro compound intermediate, is isolated, and its decomposition to oxazolidinone is demonstrated.

Introduction

The cycloaddition of heterocumulenes with oxiranes seems to be a versatile tool for stereocontrolled introduction of heteroatoms because of facile availability of various types of heterocumulenes and sterically pure oxiranes.[1] In particular, 1,3-oxazolidin-2-ones, adducts of isocyanates and oxiranes, have attracted attention[2,3] because they are important biologically active compounds[4] and precursors of β-amino alcohols.[5] Unfortunately, many formations of 4,5-disubstituted oxazolidinones have used β-amino alcohols as precursors,[6] and so other synthetic pathways have been ardently investigated.[7] Their stereocontrolled synthesis by the cycloaddition, however, has been limited to some extent perhaps due to the lower reactivity of 2,3-disubstituted oxiranes[8] and due to the occurrence of other types of products such as isocyanurates[9] and iminodioxolanes.[3] The iminodioxolanes are generally considered to be the preliminary adduct, being readily arranged to

Scheme I



(1) (a) Sharpless, K. B.; Behrens, C. H.; Katsuki, T.; Lee, A. W. M.; Martin, V. S.; Takatani, M.; Viti, S. M.; Walker, F. J.; Woodward, S. S. *Pure. Appl. Chem.* **1983**, *55*, 589. (b) Rosenberg, M.; Neukom, C.; Aig, E. R. *J. Am. Chem. Soc.* **1983**, *105*, 3656.

(2) (a) Hayashi, T.; Yamamoto, A.; Ito, Y. *Tetrahedron Lett.* **1988**, *29*, 99. (b) Trost, B. M.; Sudharkar, S. R. *J. Am. Chem. Soc.* **1988**, *110*, 7933. (c) Murthy, K. S. K.; Dhar, D. N. J. *Heterocycl. Chem.* **1984**, *21*, 1721. (d) Genet, J. P.; Denis, A.; Vilar, A.; Schoofs, A. R.; Alard, P. *Tetrahedron Lett.* **1990**, *31*, 515 and references cited in.

(3) Trost, B. M.; Sudharkar, A. R. *J. Am. Chem. Soc.* **1987**, *109*, 3792.

(4) Shinozaki, M. *Gen. Pharm.* **1988**, *19*, 163.

(5) (a) Cardillo, G.; Orena, M.; Sandri, S.; Tomashini, C. *Tetrahedron* **1987**, *43*, 2505. (b) Rao, A. V. R.; Dhar, T. G. M.; Chakraborty, T. K.; Gurjar, M. K. *Tetrahedron* **1988**, *29*, 2069.

(6) For a review, see: Dyen, M. E.; Swern, D. *Chem. Rev.* **1967**, *67*, 197.

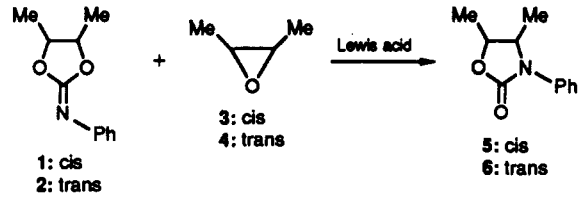
(7) (a) Pyrolysis of carbamates. Foglia, T. A.; Swern, D. *J. Org. Chem.* **1969**, *34*, 1680. (b) Elimination of HBr from bromo carbamates Wohl, A. *J. Org. Chem.* **1973**, *38*, 3858. (c) Intramolecular cyclization of epoxycarbamates. Reference 2d.

(8) Kich, H.; Millini, R.; Wang, I. *Chem. Ber.* **1986**. *119*, 1090.

(9) (a) Kogan. I. C. *J. Am. Chem. Soc.* **1959**, *78*, 4911. (b) Sehovic, H.; Sendjarevic, A.; Sodaso, V. S. *J. Polym. Sci., Part A: Polym. Chem.* **1987**, *25*, 2729.

0022-3263/91/1956-2684$02.50/0

Table I. Effect of Oxirane and Lewis Acid on Reaction[a]

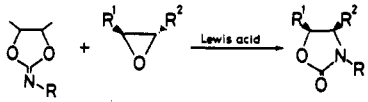


entry	iminodioxolane	oxirane	Lewis acid	product[b] (%) 5	6
1	1	4	$AlCl_3$	100	0
2	1	4	$TiCl_4$	47	0
3	1	4	$BF_3{\cdot}Et_2O$	50	0
4[c]	1	4	Me_2SnI_2·HMPA	7	0
5	1	3	$AlCl_3$	11	87
6	1	3[d]	$AlCl_3$	trace	92
7	2	3	$AlCl_3$	0	100
8	2	4	$AlCl_3$	90	4
9[e]	1		$AlCl_3$	23	11

[a] Iminodioxolane/oxirane/Lewis acid = 1/1.3/0.05 mmol, benzene 1 mL, room temperature, 2 h. [b] GLC yield. [c] 80 °C, 22 h. [d] 2.5 mmol of oxirane was used. [e] 50 °C, 2 h, all iminodioxolane was consumed.

oxazolidinones (Scheme I).[3,10] Although iminodioxolanes are easily accessible from the corresponding diols,[11] their susceptibility to polymerization[12,13] and hydrolysis to the original diols are limitations in synthetic applications.[14]

In the course of our study on a stereospecific cycloaddition of oxiranes with heterocumulenes,[15] it has been found that iminodioxolanes react with oxiranes in the presence of Lewis acids to form spiro compounds that finally give oxazolidinones in a stereospecific manner. Thus, we report herein the versatility of iminodioxolanes as masked isocyanates.

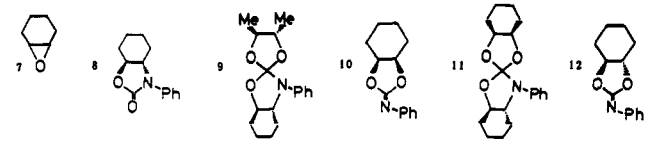


(1)

Results and Discussion

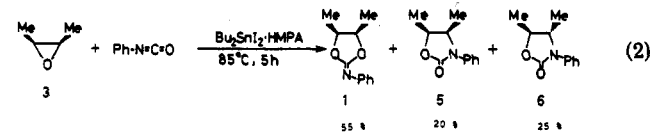
Table I lists the additions of 2-(phenylimino)-4,5-dimethyl-1,3-dioxolane (cis isomer, **1**; trans isomer, **2**) with 2,3-dimethyloxiranes (cis, **3**; trans, **4**) in the presence of Lewis acids. The most effective one investigated, $AlCl_3$, gave 4,5-dimethyl-3-phenyl-1,3-oxazolidin-2-ones (cis, **5**; trans, **6**) in excellent yields at ambient temperature. This transformation is characteristic of $AlCl_3$ since polymerization of iminodioxolanes occurred by the action of $TiCl_4$ and BF_3. The Me_2SnI_2–HMPA (hexamethylphosphoric triamide) catalyst, which remarkably effects the direct oxazolidinone formation from oxiranes and isocyanates as already reported (entry 4)[16] was not effective at all. Lewis acids were preferred to be added to the mixture of oxirane and iminodioxolane in benzene, otherwise polymerization of substrates proceeded in some extent. It is noteworthy that all the resulting oxazolidinones possessed the opposite configuration to that of the oxirane, irrespective of iminodioxolanes. For example, cis–trans **1**–**4** and cis–cis **1**–**3** combinations produced *cis*- **5** and *trans*-oxazolidinone **6**, respectively. In the latter combination, the occurrence of **5** was depressed by the use of excess amounts (2.5 equiv) of **3** (entry 6). Consequently, the configuration of the oxazolidinones could be controlled by only the oxiranes added. In these cases, the intramolecular rearrangement of iminodioxolanes, being assumed and carried out so far by the action of $AlCl_3$[12] or LiCl[10], was ruled out since nonstereospecific formation of **5**, lower yields, and rather high reaction temperature were observed when no oxirane was added (entry 9). On the other hand, the Sn-complex-catalyzed cycloaddition of **3** and phenyl isocyanate nonstereospecifically proceeded to give *cis*-iminodioxolane **1** and *cis*- **5** and *trans*-oxazolidinone **6**, where it is noteworthy that there is no detection of the *trans*-iminodioxolane **2** (eq 2).[15]

Table II. Effect of Iminodioxolane on Oxazolidinone Formation[a]



entry	iminodioxolane	oxirane	Lewis acid	temp (°C)	time (h)	product	yield[b] (%)
1	1	7	$AlCl_3$	rt	2	8	84[c]
2	2	7	$AlCl_3$	rt	2	9	79[d]
3	10	7	$AlCl_3$	rt	1	11	92[d]
4	12	7	$AlCl_3$	rt	1	8	97
5	12	2	Me_2SnI_2	80	24	5	61
6	10	2	Me_2SnI_2	80	24	5	0

[a] Iminodioxolane/oxirane/Lewis acid = 2/3/0.1 mmol, benzene 2 mL. [b] Yields determined by GLC based on dioxolane. [c] The formation of 4 was detected (14% yield based on 1). [d] Isolated yield.



(2)

Table II reveals the remarkable dependence of oxazolidinone formation on the configuration of iminodioxolanes. The participation of oxiranes is again clear from the fact that the addition of *cis*-iminodioxolane **1** with cyclohexene oxide (**7**) resulted in the selective formation of *trans*-4,5-tetramethylene-3-phenyl-1,3-oxazolidin-2-one (**8**) (84% yield) together with **4**. This formation of *trans*-oxirane **4** indicates that an inversion of configuration is included. The formation of the *trans*-oxazolidinone **8** demonstrates a potential of this method. The direct cycloaddition of oxiranes with phenyl isocyanate gave no **8** because of the absence of *trans*-cyclohexene oxide.[17] On the other hand, the *trans*-iminodioxolane **2** gave not the oxazolidinone **8** but a 1:1 adduct **9** of **2** and **7**, although the ^{13}C NMR spectrum suggested a mixture of two stereoisomers. Although this mixture could not be separated chromato-

(10) (a) Gulbins, E.; Morlock, R.; Hamann, K. *Ann.* **1966**, *698*, 180. (b) Gulbins, K.; Hamann, K. *Chem. Ber.* **1961**, *94*, 3287.

(11) Sakai, S.; Niimi, H.; Kobayashi, Y.; Ishii, Y. *Bull. Chem. Soc. Jpn.* **1977**, *50*, 3271.

(12) Mukaiyama, T.; Fujisawa, T.; Norira, T.; Higaji, T. *J. Org. Chem.* **1962**, *27*, 3337.

(13) Fujisawa, T.; Tamura, Y.; Mukaiyama, T. *Bull. Chem. Soc. Jpn.* **1964**, *37*, 793.

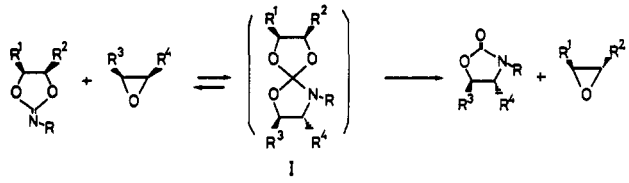
(14) In the absence of catalyst, some reactions with electrophiles such as acid halides and acid anhydrides have been performed under severe conditions (200 °C). Mukaiyama, T.; Tamura, Y.; Fujisawa, T. *Bull. Chem. Soc. Jpn.* **1964**, *37*, 628.

(15) Baba, A.; Seki, K.; Matsuda, H. *J. Heterocycl. Chem.*, in press. The cycloaddition of oxiranes to isocyanates has been reported to give stereospecifically the mixture of iminodioxolanes and oxazolidinones though in limited cases.

(16) Shibata, I.; Baba, A.; Iwasaki, H.; Matsuda, H. *J. Org. Chem.* **1986**, *51*, 2177.

(17) We already reported the selective formation of *cis*-4,5-tetramethylene-1,3-oxazolidin-2-one from **7** and PhNCO. Fujiwara, M.; Baba, A.; Tomohisa, Y.; Matsuda, H. *Chem. Lett.* **1986**, 1963.

Scheme II

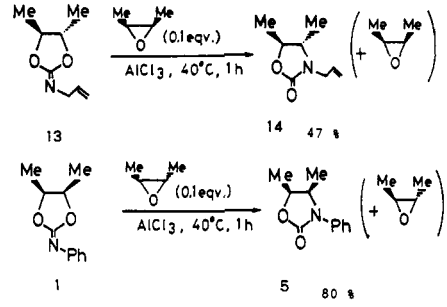


graphically because of its sensitivity to acid, its pyrolysis at 230 °C gave the *trans*-oxazolidinone **8** (25%) and *cis*-oxirane **3** (28%). On the other hand, fortunately, a stable 1:1 adduct, a spiro compound **11**, was quantitatively isolated without chromatographic treatment by the reaction of *cis*-4,5-tetramethylene-2-(phenylimino)-1,3-dioxolane (**10**) and **7**, while trans isomer **12** gave **8** in 97% yield under similar conditions. Another noteworthy example is the case of the addition of *trans*-oxirane **4** with **10** or **12**, where only trans isomer **12** produced the oxazolidinone **5** (entries 5 and 6). Thus, the configuration of iminodioxolanes is responsible not for the configuration of oxazolidinones but for the feasibility of oxazolidinone formation.

From these results, the reaction path is explainable in terms of an initial addition of oxiranes to the C=N group of iminodioxolanes by the action of a Lewis acid, followed by elimination of oxiranes from the resulting spiro compound I (Scheme II).[18] Because Lewis acids such as BF_3 are generally known to polymerize either iminodioxolanes or oxiranes,[19] this effective formation of oxazolidinones suggests a rapid addition of oxiranes to iminodioxolanes. As shown in Scheme II, two inversions of the configuration would be involved, furnishing oxazolidinones and oxiranes in a stereospecific manner. The reason that excess amounts of *cis*-oxirane are required for high selectivity (Table I, entry 6) appears to be the generation of the *trans*-oxirane, which may react again with the iminodioxolane to produce the *cis*-oxazolidinone. Moreover, the lack of *trans*-iminodioxolane in eq 2 is also rationalized by this reaction path; the direct cycloaddition would stereospecifically proceed to give the cis **1** and **5** at first, then the addition of **1** with *cis*-oxirane leads to the formation of trans **6**. Consequently, no formation of *trans*-iminodioxolane **2** occurs in this case, and the nonstereospecificity of the direct cycloaddition could be rationalized. The remarkable dependence of reactivity on a configuration of the iminodioxolanes indicates the importance of the elimination step of oxirane from spiro compound I. In the spiro compound **11**, the elimination of *trans*-cyclohexene oxide, being impossible, should be required for oxazolidinone formation whilst the *cis*-cyclohexene oxide, being possible, could be eliminated to give **8** (Table II, entries 3 and 4). The difference between entries 5 and 6 may be due to the steric hindrance of the neighboring methyl group on the reaction site, the trans-positioned methyl group preventing the elimination of the *cis*-oxirane. The isolation of stable spiro intermediate **11** was perhaps due to the difficulty of elimination of cyclohexene oxide (entry 3).

The previous hypothesis on the reaction path prompted us to try the catalytic use of oxiranes on the stereospecific rearrangement of iminodioxolanes to oxazolidinones in the presence of $AlCl_3$, where the resulting oxirane is reused as shown in Scheme III. Stereospecific rearrangement of *cis*-iminodioxolane **1** to *cis*-oxazolidinone **5** (80% yield) was

Scheme III



Scheme IV

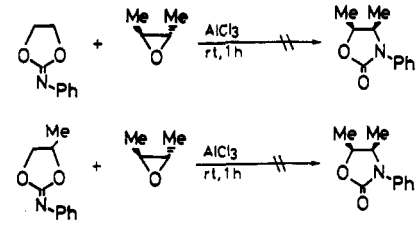
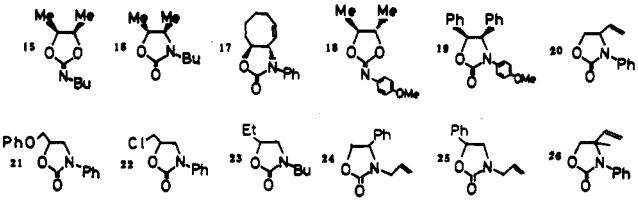


Table III. Preparation of Oxazolidinone from Iminodioxolane and Oxirane[a]



entry	iminodioxolane	oxirane	time (h)	product	yield (%)
1	**13**	**3**	0.3	**14**	93
2	**15**	**4**	0.3	**16**	78
3	**1**		1.5	**17**	47
4	**18**		1.0	**19**	40
5	**1**		1.0	**20**	58
6	**1**		1.0	**21**	77
7	**1**		1.0	**22**	82
8	**15**		1.0	**23**	100
9	**13**		1.0	**24** and **25**	94 (74:26)[b]
10	**1**		1.0	**26**	48

[a] Iminodioxolane/oxirane/$AlCl_3$ = 2/3/0.1 mmol, benzene 2 mL, room temperature. [b] Ratio of **24** and **25**.

achieved by catalytic amounts (0.1 equiv) of *trans*-oxirane **4**. As already noted, the addition of oxiranes was essential to this effective rearrangement (Table I, entry 9).

In next stage, we attempted to use 4,5-nonsubstituted and 4-monosubstituted iminodioxolanes instead of 4,5-disubstituted ones particularly because of the availability of the former from inexpensive ethylene glycol (Scheme IV). However, no transformation of iminodioxolane to oxazolidinone was observed. This result indicates that the dioxolane ring cleavage by Lewis acid is also significant

(18) A similar pathway is assumed in the reaction of methyloxirane with oxazolidine-2-thione at 170–180 °C. Ueno, Y.; Nakai, T.; Okawara, M. *Bull. Chem. Soc. Jpn.* **1970**, *43*, 168.

(19) Furukawa, J.; Saegusa, T. *Polymerization of Aldehydes and Oxides*; Wiley: New York, 1963; Chapter 3.

as oxirane activation and that more stable oxiranes bearing substituents are more easily eliminated from spiro intermediates.

Table III exemplifies a variety of oxazolidinone formations. The facile addition of low-reactive *trans*-2,3-diphenyloxirane demonstrates the versatility of this method, where the addition went to completion in 1 h (entry 4). Monosubstituted oxiranes also produced the corresponding oxazolidinones in good yields, where labile moieties such as vinyl, phenoxymethyl, and chloromethyl ones were tolerant. Phenyloxirane was predominantly cleaved at the substituted site to give 4-phenyloxazolidinone **24** in a 74% selectivity (entry 9). Moreover, 2-methyl-2-vinyloxirane gave a moderate yield (entry 10); this oxirane has resulted in less efficient cycloaddition with opposite regioselectivity in our previous catalytic system.[16]

4,5-Disubstituted iminodioxolanes are promising as masked isocyanates to give oxazolidinones because of mild reaction conditions, good yields, and stereocontrolled cycloaddition. In particular, the high reactivity toward 2,3-disubstituted oxiranes is noteworthy since the direct cycloaddition with isocyanates does not proceed smoothly in a stereospecific manner.

Experimental Section

Melting points were taken on a Yanako melting point apparatus and are uncorrected. ^{1}H NMR and ^{13}C NMR spectra were determined on a Hitachi R-90H or a JEOL JNM-GSX-400 spectrometer. Infrared spectra were recorded with a Hitachi 260-30 instrument. Mass spectra were obtained with a JEOL JMS-DS 303 spectrometer. Analytical GLC was performed on a SHIMAZU GC-8A with FID. Short-path distillations of products were carried out in a Kugelrohr apparatus.

$AlCl_3$, $BF_3{\cdot}Et_2O$, and $TiCl_4$ (Aldrich) were used without purification. Me_2SnBr_2 and Me_2SnI_2 were prepared by reported methods.[20] All iminodioxolanes were prepared by the addition of isothiocyanates with 2,2-dibutyldioxastannolane.[11] 2-Methyl-2-vinyloxirane,[21] vinyloxirane,[21] cyclooctadiene monooxide,[22] and *trans*-2,3-diphenyloxirane[23] were prepared by reported methods. Other oxiranes were purchased and used after distillation from CaH_2.

General Procedure for the Oxazolidinone Preparation. An iminodioxolane (1 mmol), an oxirane (1.3 mmol), and dry benzene (1 mL) were stirred at 10 °C for 10 min under nitrogen. The addition of $AlCl_3$ (0.05 mmol) resulted in gentle exothermic reaction, and the mixture was stirred at ambient temperature. After the consumption of iminodioxolane was monitored, 30 mL of *n*-hexane and benzene (1:1) was added and the precipitates were filtered off. After determination of the yield with GLC and removal of volatiles, an oxazolidinone was isolated by distillation or silica gel column treatment (eluted by benzene).

***trans*-7,8-Dimethyl-*trans*-2,3-tetramethylene-1-phenyl-4,6,9-trioxa-1-azaspiro[4.4]nonane (9) (mixture of two stereoisomers).** To the mixture of *trans*-4,5-dimethyl-2-(phenylimino)-1,3-dioxolane (**2**; 2 mmol), cyclohexene oxide (**7**; 3 mmol), and 2 mL of benzene was added $AlCl_3$ (0.1 mmol) at 0 °C. After the solution was stirred for 2 h at ambient temperature, 30 mL of *n*-hexane was added to remove the precipitated $AlCl_3$. The volatiles were removed in vacuo, and the spiro compound, a mixture of two stereoisomers, was obtained by distillation (0.46 g, 79% yield). Further purification either by deactivated silica gel column with Et_3N or by gas chromatography was unsuccessful. As the mixture: bp 120 °C (0.01 mmHg); IR (neat) no C=O absorption; ^{1}H NMR ($CDCl_3$) δ 0.98 (d, J = 5.86 Hz, CH_3), 1.20 (d, J = 6.34 Hz, CH_3), 1.35 (d, J = 6.34 Hz, CH_3), 1.40 (d, J = 6.35 Hz, CH_3), 1.20–2.20 (broad m, 8 H, $-(CH_2)_4-$), 3.20–4.00 (m, 4 H, –OCHCHO– and –OCHCHN–), 6.98–7.31 (m, 5 H, Ar); ^{13}C NMR ($CDCl_3$) δ 16.2, 16.6, 17.3, 18.6, 23.7, 24.06, 24.08, 28.04, 28.9, 29.1, 62.2, 62.5, 77.9, 78.0, 78.5, 80.2, 80.3, 80.7, 120.5, 121.4, 122.5, 122.7, 128.45, 128.51, 129.3, 142.4, 142.5; MS m/e 289 (M^+). Anal. Calcd for $C_{17}H_{23}NO_3$: C, 70.56; H, 8.01; N, 4.84. Found: C. 70.46; H, 8.02, N, 4.78.

1-Phenyl-*cis*-7,8:*trans*-2,3-bis(tetramethylene)-4,6,9-trioxa-1-azaspiro[4.4]nonane (11). The reaction was performed in a similar manner as above. After the removal of volatiles, the crystallized residue was recrystallized from hexane: mp 164 °C; IR (KBr) no C=O absorption; ^{1}H NMR ($CDCl_3$) δ 1.02–2.18 (m, 16 H, methylene), 3.20–3.28 (m, 1 H, –CHN–), 3.64–3.78 (m, 2 H, two OCH), 4.15–4.25 (m, 1 H, OCH), 7.02–7.35 (m, 5 H, Ar); ^{13}C NMR ($CDCl_3$) δ 19.9, 21.7, 23.8, 24.1, 27.4, 27.8, 29.1, 62.1, 74.3, 76.0, 80.4, 122.8, 123.3, 128.3, 129.4, 142.1; MS m/e 315 (M^+). Anal. Calcd for $C_{19}H_{25}NO_3$: C, 72.35; H, 7.99; N, 4.44. Found: C, 72.39; H, 7.98; N, 4.52.

Pyrolysis of Spiro Compound 9. The spiro compound **9** (0.16 g, 0.65 mmol) was heated without solvent at 230 °C for 1 h in a sealed glass tube. After the compound was heated, the resulting oil was dissolved in 10 mL of benzene and the yield (28%) of *trans*-2,3-dimethyloxirane was determined by GLC (Porapak N, 180 °C), and then the oxazolidinone **6** was isolated by distillation, upon which it crystallized, bp 145 °C (0.01 mmHg) (0.035 g, 0.16 mmol, 25% yield).

***cis*-4,5-Dimethyl-3-phenyl-1,3-oxazolidin-2-one (5):**[24] mp 36–39 °C; IR (neat) 1740 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.24 (d, 3 H, J = 7.2 Hz, CH_3), 1.46 (d, 3 H, J = 6.8 Hz, CH_3), 4.28–4.65 (m, 1 H, NCH), 4.65–5.02 (m, 1 H, OCH), 7.06–7.85 (m, 5 H, Ar); ^{13}C NMR ($CDCl_3$) δ 12.9, 14.8, 55.9, 73.3, 121.7, 124.9, 129.1, 137.1, 155.2; MS m/e 191 (M^+).

***trans*-4,5-Dimethyl-3-phenyl-1,3-oxazolidin-2-one (6):**[24] mp 53–55 °C; IR (neat) 1730 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.32 (d, 3 H, J = 6.3 Hz, CH_3), 1.52 (d, 3 H, J = 6.3 Hz, CH_3), 3.90–4.16 (m, 1 H, NCH), 4.16–4.45 (m, 1 H, OCH), 7.10–7.60 (m, 5 H, Ar); ^{13}C NMR ($CDCl_3$) δ 12.8, 14.8, 55.9, 73.3, 121.6, 124.8, 129.0, 137.0, 155.1; MS m/e 191 (M^+).

***trans*-4,5-Tetramethylene-3-phenyl-1,3-oxazolidin-2-one (8):** bp 145 °C (0.01 mmHg); IR (neat) 1740 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.32–2.25 (m, 8 H, $-(CH_2)_4-$), 3.60–3.70 (m, 1 H, NCH), 3.95–4.06 (m, 1 H, OCH), 7.15–7.46 (m, 5 H, Ar); ^{13}C NMR ($CDCl_3$) δ 23.4, 23.7, 28.1, 28.4, 63.8, 81.2, 122.6, 125.3, 128.7, 137.1, 157.2; MS m/e 217 (M^+). Anal. Calcd for $C_{13}H_{15}NO_2$: C, 71.87; H, 6.96; N, 6.45. Found: C, 71.45; H, 6.93; N, 6.36.

***trans*-4,5-Dimethyl-3-allyl-1,3-oxazolidin-2-one (14):** bp 85 °C (2 mmHg); IR (neat) 1745 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.22 (d, 3 H, J = 6.4 Hz, CH_3CN), 1.40 (d, 3 H, J = 5.9 Hz, CH_3CO), 3.30–3.41 (m, 1 H, MeCHN), 3.61 (dd, 1 H, J = 15.9 and 8.4, one of NCH_2), 4.00–4.15 (m, 2 H, MeCHO and one of NCH_2), 5.20–5.29 (m, 2 H, CH_2=), 5.71–5.82 (m, 1 H, =CH); ^{13}C NMR ($CDCl_3$) δ 17.7, 19.4, 44.8, 58.1, 77.8, 118.4, 132.5, 157.7; MS m/e 155 (M^+). Anal. Calcd for $C_8H_{13}NO_2$: C, 61.91; H, 8.44; N, 9.03. Found: C, 61.62; H, 8.65, N, 9.21.

***cis*-4,5-Dimethyl-3-*n*-butyl-1,3-oxazolidin-2-one (16):**[15] bp 120 °C (3 mmHg); IR (neat) 1745 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 0.75–1.55 (m, 13 H, 2 CH_3 and $CH_3CH_2CH_2$), 3.41 (t, 2 H, J = 6.8 Hz, NCH_2), 3.70–3.98 (m, 1 H, NCH), 4.51–4.81 (m, 1 H, OCH); ^{13}C NMR ($CDCl_3$) δ 11.3, 12.5, 16.3, 18.7, 28.5, 40.0, 52.4, 72.1, 156.2; MS m/e 171 (M^+).

***trans*-4,5-(1,2-Didehydrohexamethylene)-3-phenyl-1,3-oxazolidin-2-one (17):** bp 120–123 °C (0.01 mmHg); IR (neat) 1740 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 1.25–2.50 (m, 8 H, $-(CH_2)_4-$), 3.97–4.06 (m, 1 H, CHN), 4.93–4.98 (m, 1 H, OCH), 5.50–5.57 (m, 1 H, one of CH=CH), 5.70–5.80 (m, 1 H, one of CH=CH), 7.10–7.42 (m, 5 H, Ar); ^{13}C NMR ($CDCl_3$) δ 21.2, 25.6, 26.5, 29.39, 61.0, 81.4, 120.9, 124.5, 127.0, 128.6, 131.7, 137.1, 155.8; MS m/e 243 (M^+). Anal. Calcd for $C_{15}H_{17}NO_2$: C, 74.05; H, 7.04; N, 5.76. Found: C, 74.15; H, 7.09, N, 5.71.

***cis*-4,5-Diphenyl-3-(*p*-methoxyphenyl)-1,3-oxazolidin-2-one (19):** mp 165–166 °C; IR (KBr) 1740 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 3.71 (s, 3 H, CH_3), 5.48 (d, 1 H, J = 7.75, NCH), 5.95 (d, 1 H, J = 7.75, OCH), 6.60–7.50 (m, 14 H, Ar); ^{13}C NMR ($CDCl_3$) δ 55.3, 66.4, 79.6, 114.1, 122.2, 126.2, 127.3, 127.8, 128.1, 128.2, 130.5, 134.0,

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134.3, 155.7, 156.5; MS m/e 345 (M^+). Anal. Calcd for $C_{22}H_{19}NO_3$: C, 76.50; H, 5.54; N, 4.06. Found: C, 76.04; H, 5.50; N, 4.11.

Oxazolidinones **20**,[25] **21**,[16] **22**,[26] and **23**[25] were identified by comparison with the authentic samples.

4-Phenyl-3-allyl-1,3-oxazolidin-2-one (24): bp 115 °C (0.1 mmHg); IR (neat) 1735 cm^{-1}; ^1H NMR ($CDCl_3$) δ 3.21 (dd, 1 H, J = 15.4 and 8.1 Hz, one of NCH_2), 4.12-4.22 (m, 2 H, one of NCH_2 and CHN), 4.63 (t, 1 H, J = 8.8 Hz, one of CH_2O), 4.77 (dd, 1 H, J = 8.8 and 6.8 Hz, one of CH_2O), 5.04 (d, 1 H, J = 17.1 Hz, one of $=CH_2$), 5.18 (d, 1 H, J = 10.3 Hz, one of $=CH_2$), 5.66-5.76 (m, 1 H, CH=), 7.33-7.45 (m, 5 H, Ar); ^{13}NMR ($CDCl_3$) δ 44.4, 58.9, 69.6, 118.7, 126.8, 128.0, 128.9, 131.1, 137.4, 157.7; MS m/e 203 (M^+). Anal. Calcd for $C_{12}H_{13}NO_2$: C, 70.92; H, 6.45; N, 6.89. Found: C, 70.60; H, 6.56, N, 6.66.

5-Phenyl-3-allyl-1,3-oxazolidin-2-one (25): bp 115 °C (0.1 mmHg); IR (neat) 1735 cm^{-1}; ^1H NMR ($CDCl_3$) δ 3.41 (dd, 1 H, J = 8.8 and 7.3 Hz, one of NCH_2CPh), 3.85-3.98 (m, 3 H, CH_2NCHCO), 5.21-5.27 (m, 2 H, one of $=CH_2$ and PhCHO), 5.50 (t, 1 H, J = 8.3 Hz, one of $=CH_2$), 5.74-5.84 (m, 1 H, CH=), 7.33-7.41 (m, 5 H, Ar); ^{13}C NMR ($CDCl_3$) δ 46.95, 51.79, 74.49, 118.84, 125.51, 128.81, 128.90, 131.89, 138.70, 157.71; MS m/e 203 (M^+). Anal. Calcd for $C_{12}H_{13}NO_2$: C, 70.92; H, 6.45; N, 6.89. Found: C, 71.02; H, 6.46; N, 6.79.

4-Methyl-4-vinyl-3-phenyl-1,3-oxazolidin-2-one (26):[3] mp 88-89 °C; IR 1740 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.48 (s, 3 H, CH_3), 4.15 (d, 1 H, J = 8.5 Hz, one of CH_2), 4.28 (d, 1 H, J = 8.5 Hz, one of CH_2), 5.25 (d, 1 H, J = 17 Hz, one of $C=CH_2$), 5.34 (d, 1 H, J = 10.5 Hz, one of $C=CH_2$), 6.10 (dd, 1 H, J = 10.5 and 17 Hz, -CH=C), 7.20-7.38 (m, 5 H, Ar); ^{13}C NMR ($CDCl_3$) δ 21.5, 63.5, 74.2, 117.0, 126.8, 127.0, 128.9, 135.3, 139.5, 156.4; MS m/e 203 (M^+).

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Direct Conversion of *N*-Alkoxy β-Lactams to Carbapenams: Application to the Synthesis of the Bicyclic PS-5 Keto Ester

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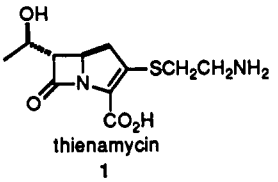
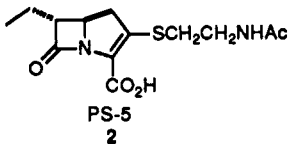
The synthesis and direct conversion of *N*-alkoxy β-lactams to the carbapenam ring system is described. This novel cyclization apparently proceeds by initial carbene-mediated ylide formation with concomitant rearrangement. The title reaction is applied to the construction of the methyl ester of the bicyclic β-lactam precursor of PS-5.

The carbapenem class of β-lactam antibiotics, of which thienamycin (**1**)[1] and PS-5 (**2**)[2] are representative, has received a great deal of attention from the synthetic community.[3] Recent papers have addressed enantioselective

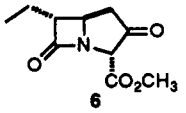


thienamycin
1



PS-5
2

syntheses[4] as well as new methods of ring construction to afford the fundamental bicyclic system.[5] It is in the latter area that we wish to report our efforts related to the synthesis of carbapenams. Since the initial disclosure of the synthesis of the *N*-benzyloxy β-lactam **3** and the direct carbene-mediated cyclization of **4** to **5** (Scheme I),[6] we have expanded the scope of this methodology to other O-alkylated β-lactams, while demonstrating direct applicability to the synthesis of the bicyclic PS-5 keto ester **6**.



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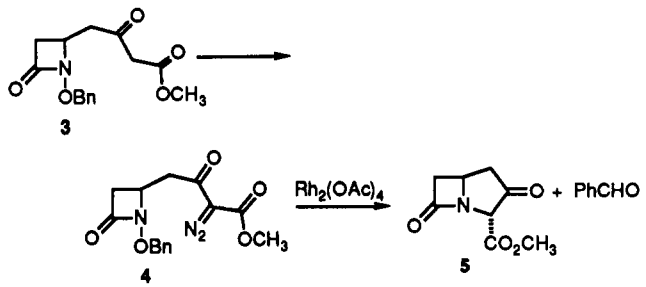
Scheme I



The literature contains numerous examples of the rhodium-catalyzed reaction of α-diazo β-keto esters to generate carbenoid intermediates that ultimately undergo net insertion into an azetidinone N-H bond. As originally reported by the Merck group, this methodology was demonstrated in the efficient conversion of **7** to carbapenam **8** (eq 1).[7] This process has proved equally as important

7 **8**

for the synthesis of carbacephems.[8] We are presently not

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