The Acid-catalyzed Reaction of Isocyanide with Oxetane

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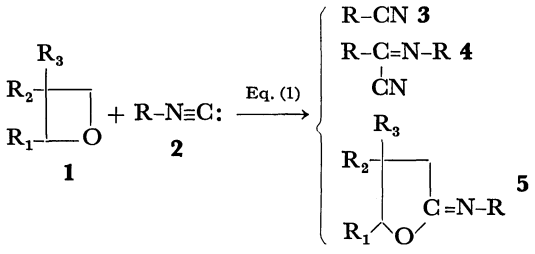
The reaction of isocyanide with oxetane in the presence of $BF_3 \cdot OEt_2$ was studied; in this reaction a 1:1 cyclic adduct, 2-iminotetrahydrofuran, was formed. From 2-methyloxetane, 2-imino-5-methyltetrahydrofuran was exclusively formed. These findings suggest an S_N2 mechanism for the cleavage of the oxetane ring. Oxetanes with electron-withdrawing substituents gave γ-alkoxybutyronitrile as the main product, along with 2-iminotetrahydrofuran. A reaction scheme involving an imidoyl cation was proposed to explain the formation of cyclic and linear products.

Several papers have been reported on the cycloaddition reaction of isocyanide.[1] We have reported the Lewis-acid-catalyzed cyclizations reaction of isocyanide with ketone, aldehyde, and a Schiff base.[2-4] In addition, we have presented a preliminary report[5] upon a new cycloaddition reaction of isocyanide with four-membered cyclic ethers (oxetanes) with a BF_3 catalyst, in which reaction 2-iminotetrahydrofuran was produced.

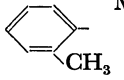
In this paper we wish to report on our further studies of the scope of the reaction of isocyanide with substituted oxetanes and some mechanistic studies.

Results and Discussion

In the reaction of oxetane (**1a**) with *t*-butyl isocyanide (**2a**) in the presence of $BF_3 \cdot OEt_2$ at room temperature, 2-*t*-butyliminotetrahydrofuran (**5a**) was produced, along with *t*-butyl cyanide (**3a**) and *N*-*t*-butylpivalimidoyl cyanide (**4a**). The two by-products, **3a** and **4a**, were found to be produced from **2a** with $BF_3 \cdot OEt_2$ in the absence of **1a** (Eq. (1)).



1a, $R_1=R_2=R_3=R_4=H$

2, 3, 4: **a**, R = *t*-Bu-; **b**, R = Me-C(Et)(Et)-; **c**, R = *t*-Bu-CH_2-C(Me)(Me)-; **d**, R = 

5a, $R_1=R_2=R_3=R_4=H$, R = *t*-Bu

Some results of the reaction of **1a** with **2a** are shown in Table 1. As the catalyst, an equimolar amount of $BF_3 \cdot Et_2O$ was required. A smaller amount of $BF_3 \cdot Et_2O$ gave a poorer result. The reaction proceeded rapidly at room temperature. At lower temperatures the conversion percent was low and the starting materials were recovered unchanged. As the reaction solvent, CH_2Cl_2 gave better results. Basic solvents like tetrahydrofuran and acetonitrile gave poor yields.

TABLE 1. REACTION OF *t*-BUTYL ISOCYANIDE (**2a**) WITH OXETANE (**1a**)[a]

t-BuNC (mmol)	 (mmol)	$BF_3 \cdot OEt_2$ (mmol)	Solvent (5 ml)	(**5a**) Yield (%)[b]
5	5	0.75	CH_2Cl_2	10
5	5	5	CH_2Cl_2	48
10	5	5	CH_2Cl_2	70
5	10	5	CH_2Cl_2	34
5	5	5	CH_2Cl_2	33[c]
5	5	5	CH_2Cl_2	14[d]
5	5	5	C_6H_6	32
5	5	5	*n*-C_7H_{16}	6
5	5	5	THF	9
5	5	5	CH_3CN	7
10	5	5	Et_2O	38

a) Reaction at room temperature for 2 hr.
b) Determined by glpc.
c) Reaction at 0°C.
d) Reaction at −78°C.

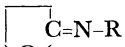
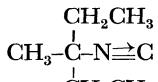
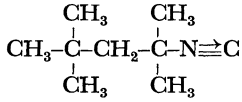
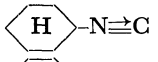
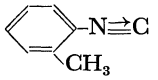
The structure of **5a** was established by elemental analysis and by a study of its IR and NMR spectra, as well as by the acid hydrolysis product. In the acid hydrolysis of **5a** with silicic acid, γ-butyrolactone (**6a**) was formed. The conversion of **5** to **6** has already been reported by Stirling.[6]

The same reaction was observed with other *t*-alkyl and phenyl isocyanides. The results are shown in Table 2. In the case of cyclohexyl isocyanide, the cationic polymerization of cyclohexyl isocyanide predominated and the iminotetrahydrofuran could not be isolated. However, the IR spectrum of the reaction mixture showed an absorption at 1715 cm^{-1} which was attributed to the cyclic imino group.

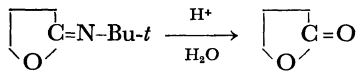
Then, the reaction of **2a** with various alkyl-substituted oxetanes was examined. The results are shown

1) B. Zeeh, *Synthesis*, **1969**, 65.
2) T. Saegusa, N. Taka-ishi, and H. Fujii, *Polym. Lett.*, **5**, 779 (1967).
3) T. Saegusa, N. Taka-ishi, and H. Fujii, *Tetrahedron*, **24**, 3795 (1968).
4) T. Saegusa, N. Taka-ishi, I. Tamura, and Fujii, *J. Org. Chem.*, **34**, 1145 (1969).
5) T. Saegusa, N. Taka-ishi, and Y. Ito, *Synthesis*, **1970**, 475.
6) C. J. M. Stirling, *J. Chem. Soc.*, **1960**, 255.

Table 2. Reaction of isocyanides with oxetane[a]

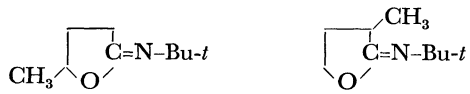
	R–N≡C (mmol)		 (mmol)	CH_2Cl_2 (ml)	Reaction time (hr)	 yield (%)
(**2b**)		8	10	10	13	23 (**5b**)
(**2c**)		30	15	30	24	54 (**5c**)
		10	10	10	13	not isolated
(**2d**)		20	10	20	16	45[b] (**5d**)

a) Reaction conditions: r.t., $BF_3 \cdot OEt_2$ (equimolar amount to oxetane).
b) Identified by the comparison of the glpc retention time and IR spectrum with the authentic sample.[7]



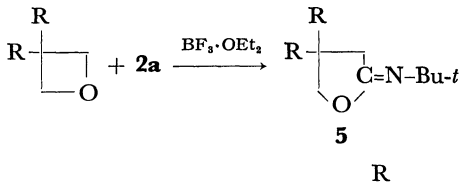
5a **6a**

in Table 3. 2-*t*-Butyliminotetrahydrofuran derivatives were obtained in relatively high yields. 2-Methyloxetane (**1e**), the unsymmetrical oxetane, gave 2-*t*-butylimino-5-methyltetrahydrofuran (**5e**) exclusively. The structure of **5e** was confirmed by its acid hydrolysis with silicic acid, where by γ-valerolactone was formed. The alternative possible product, 2-*t*-butylimino-3-methyltetrahydrofuran (**7**), could not be found in the reaction mixture.



5e **7**

In the cases of oxetanes with two electron-withdrawing substituents at the 3-position, the linear product, γ-alkoxybutyronitrile derivative (**8**), was produced along with the cyclic adduct, **5** (Eq. (2)). The results are summarized in Table 4.

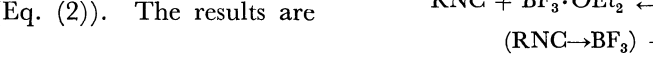


(2)

(R: $ClCH_2$–, ICH_2–, $EtOCH_2$–)

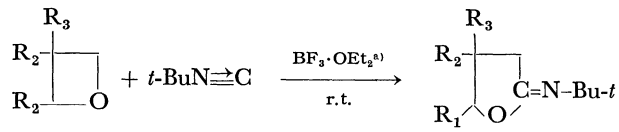
Reaction Scheme

Considering the cationic isomerization of **2**, which takes place along with the formation of **5**, a reaction scheme involving the *t*-alkyl cation and the imidoyl cation as the key intermediates may be presented as follows:



(3)

Table 3. Reaction of *t*-butyl isocyanide with substituted oxetanes

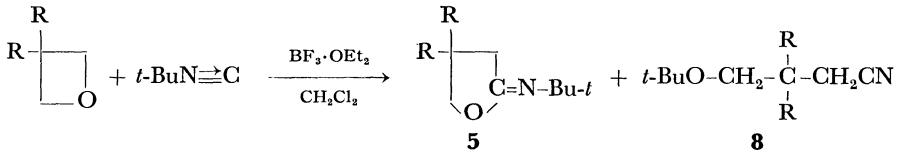


Compound	Oxetane (mmol) R_1	R_2	R_3		*t*-BuN≡C (mmol)	CH_2Cl_2 (ml)	Reaction time (hr)	Yield (%)[b]
5e	CH_3	H	H	30	45	30	1	47
5f	H	$-(CH_2)_2-$		20	40	30	7	60
5g	H	CH_3	H	30	60	30	3	74
5h	H	CH_3	CH_3	20	40	20	3	80
5i	H	Et	Et	8.8	17.5	10	3	42
5j	H	$-(CH_2)_5-$		10	20	20	12	87

a) Equimolar amount to oxetane. b) Based on oxetane.

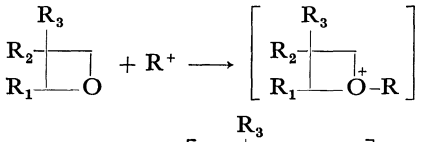
7) T. Mukaiyama and K. Sato, This Bulletin, **36**, 99 (1963).

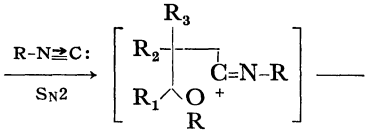
TABLE 4. REACTION OF *t*-BUTYL ISOCYANIDE WITH OXETANES HAVING BY ELECTRON WITHDRAWING SUBSTITUENTS[a)]

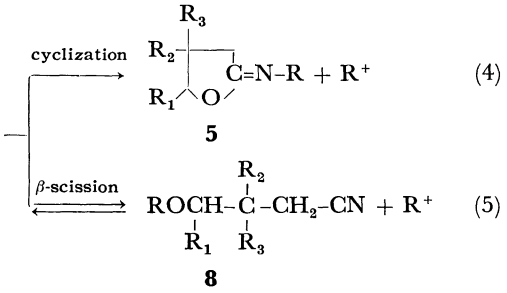


	Oxetane (mmol) R		*t*-BuN≡C (mmol)	$BF_3 \cdot OEt_2$ (mmol)	CH_2Cl_2 (ml)	Yield (%) 5	Yield (%) 8
1k	$ClCH_2$	30	30	11	30	17[b)]	7
1k	$ClCH_2$	12.5	11	10	10	6[b)]	22
1k	$ClCH_2$	1	2	1	1	—	32
1l	ICH_2	10	20	10	20	—	24
1m	$EtOCH_2$	20	40	20	20	69	6

a) Reaction time was 1 day. b) Isolated as a complex with catalyst.





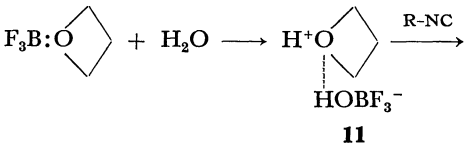


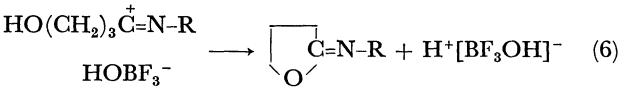
(4)

(5)

The initial generation of the *t*-butyl cation complex (Eq. (3)) has been shown in a previous paper.[8] As both 1-ethyl-1-methylpropyl isocyanide (**2b**) and 1,1,3,3-tetramethylbutyl isocyanide (**2c**) were isomerized by $BF_3 \cdot OEt_2$ to the corresponding nitriles, (**3b**) and (**3c**), the initiation reaction producing the *t*-alkyl carbonium ion is supported. The cyclic trialkyloxonium ion of oxetane (**9**) undergoes ring-cleavage as a result of the attack of isocyanide as a nucleophile.

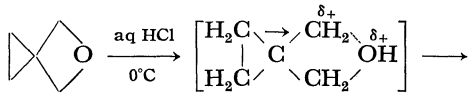
An alternative scheme starting with the cyclic dialkyloxonium ion of oxetane (**11**) may also be assumed for the formation of the cyclic adduct (Eq. (6)). Especially, the second scheme of Eq. (6) can be taken to explain the reaction of *o*-tolyl isocyanide, where no isomerization of the isocyanide takes place. The water responsible for the protonic-acid complex may be ascribed to the incomplete dehydration of the reagents. The protonic-acid complex due to the water impurity has been assumed in the initiation of the BF_3-catalyzed polymerization of oxetane.[9,10]

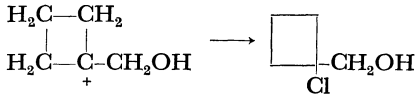




(6)

In the reaction of **1e** with **2a**, the formation of **5e** *via* the cleavage of the ether linkage at the less substituted carbon suggests an S_N2 mechanism for the ring cleavage. The S_N2 mechanism is also supported by the reaction of oxetane-3-spirocyclopropane (**1f**). When a mixture of **1f** and **2a** was treated with $BF_3 \cdot OEt_2$ at room temperature, only the oxetane ring was cleaved to form 2-*t*-butyliminotetrahydrofuran-4-spirocyclopropane (**5f**). If the cleave of the oxetane ring of **1f** proceeded *via* S_N1 mechanism, the isomerization of the cyclopropyl ring would have occurred, *i.e.*, the treatment of **1f** with aqueous hydrochloric acid has been reported, and in it the cleavage of the ether linkage and the enlargement of the carbocyclic ring occurred.[11]





The re-cyclization of **10** to **5** (Eq. (4)) has been supported by a reference reaction in which 3,3-bis-(chloromethyl)-4-*t*-butoxybutyronitrile (**8k**) was treated with triethyloxonium fluoroborate to give β,β-bis-(chloromethyl)-γ-butyrolactone (**6k**) (Eq. (7)). The treatment of ω-benzyloxybutyronitrile (**13**) with triethyloxonium fluoroborate, followed by the hydrolysis of the reaction mixture, gave γ-butyrolactone in a yield of 31% (Eq. (8)).

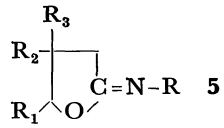
8) T. Saegusa, N. Taka-ishi, and Y. Ito, *J. Org. Chem.*, **34**, 4040 (1969).

9) J. B. Rose, *J. Chem. Soc.*, **1956**, 546.

10) J. Furukawa and T. Saegusa, "Polymerization of Aldehydes and Oxides", Wiley (Interscience), New York (1963).

11) S. Searles and E. F. Lutz, *J. Amer. Chem. Soc.*, **81**, 3674 (1959).

Table 5. Characterizations of 2-iminotetrahydrofuran



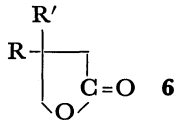
5

Compound 5	R_1	R_2	R_3	R	Bp, °C (mmHg)	NMR absorption, τ (Solvent: a) $CDCl_3$, b) CCl_4)
a	H	H	H	*t*-Bu	76 (22)	[a] 5.70 (2H, t, $-CH_2O-$) 7.50 (2H, m, $-CH_2-C=N$) 7.90 (2H, m, $-CH_2-CH_2-CH_2-$) 8.71 (9H, s, *t*-Bu)
b	H	H	H	$CH_3-\overset{Et}{\underset{Et}{C}}-$	87 (7)	[a] 5.80 (2H, t, $-CH_2O-$) 7.58 (2H, m, $-CH_2-C=N$) 7.90 (2H, m, $-CH_2-CH_2-CH_2-$) 8.52 (4H, m, $2CH_3CH_2-$) 8.92 (9H, s, *t*-Bu) 9.10 (3H, s, CH_3-C-Et) 9.21 (6H, t, $2CH_3CH_2-$)
c	H	H	H	$t\text{-Bu}-CH_2-\overset{CH_3}{\underset{CH_3}{C}}-$	90 (5)	[b] 5.77 (2H, t, $-CH_2O-$) 7.65 (2H, m, $-CH_2-C=N-$) 7.94 (2H, m, $-CH_2-CH_2-CH_2-$) 8.40 (2H, s, *t*-$BuCH_2-$) 8.76 (6H, s, $2CH_3$) 9.02 (9H, s, *t*-Bu–)
e	CH_3	H	H	*t*-Bu–	78 (20)	[b] 5.52 (1H, m, CH_3CHO-) 7.40—8.40 (4H, m, $-CH_2-CH_2-$) 8.66 (3H, d, CH_3CH-) 8.82 (9H, s, *t*-Bu)
f	H	$\{CH_2\}_2$		*t*-Bu	95 (19)	[b] 5.94 (2H, s, $-CH_2O-$) 7.57 (2H, s, $-CH_2-C=N$) 8.78 (9H, s, *t*-Bu) 9.20—9.50 (4H, m, $-CH_2-CH_2-$)
g	H	CH_3	H	*t*-Bu	75 (18)	[b] 6.00 (2H, m, $-CH_2O-$) 7.65 (3H, m, $CH_3CH-CH_2-C=N$) 8.79 (9H, s, *t*-Bu) 8.90 (3H, m, CH_3)
h	H	CH_3	CH_3	*t*-Bu	80 (19)	[b] 6.16 (2H, s, $-CH_2O-$) 7.77 (2H, s, $-CH_2-C=N$) 8.80 (9H, s, *t*-Bu) 8.85 (6H, s, $2CH_3$)
i	H	Et	Et	*t*-Bu	100 (11)	[b] 6.11 (2H, s, $-CH_2O-$) 7.77 (2H, s, $-CH_2-C=N$) 8.30—8.80 (4H, m, $2CH_3CH_2-$) 8.81 (9H, s, *t*-Bu) 9.09 (6H, t, $2CH_3CH_2-$)
j	H	$\{CH_2\}_5$		*t*-Bu	112 (8)	[a] 6.09 (2H, s, $-CH_2O-$) 7.66 (2H, s, $-CH_2-C=N$) 8.35—8.65 (10H, m, $\{CH_2\}_5$) 8.78 (9H, s, *t*-Bu)
m	H	$EtOCH_2-$	$EtOCH_2-$	*t*-Bu	107 (4)	[b] 5.98 (2H, s, $-CH_2O-$) 6.50 (4H, q, $2CH_3CH_2-$) 6.64 (4H, s, $2CH_3CH_2OCH_2-$) 7.68 (2H, s, $-CH_2-C=N$) 8.79 (6H, t, $2CH_3CH_2-$) 8.80 (9H, s, *t*-Bu)

Table 5. (Continued)

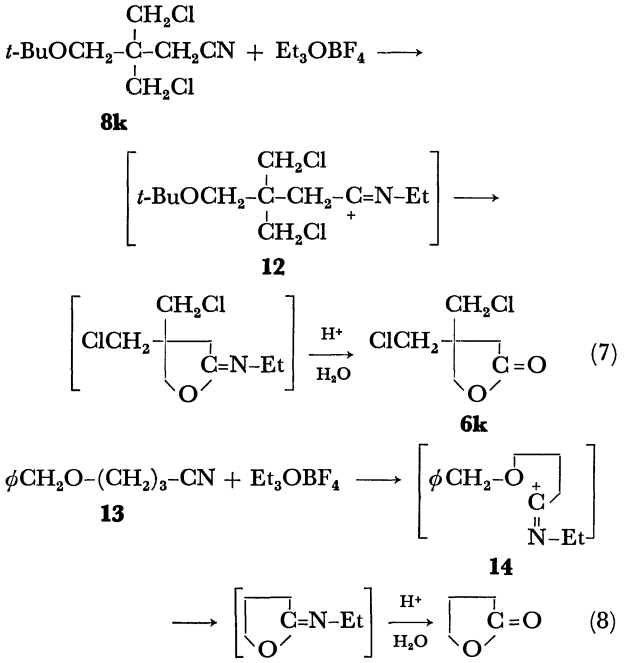
Compound 5	R_1	R_2	R_3	R	Bp, °C (mmHg)	NMR absorption, τ (Solvent: a) $CDCl_3$, b) CCl_4)
n	H	*t*-$BuOCH_2$–	*t*-$BuOCH_2$–	*t*-$BuCH_2$–C(–CH_3)(CH_3)–	120 (2)	[a] 6.09 (2H, s, $-CH_2O-$) 6.75 (4H, s, 2*t*-$BuOCH_2$–) 7.75 (2H, s, $-CH_2-C=N-$) 8.45 (2H, s, *t*-$BuCH_2$–) 8.79 (6H, s, $2CH_3$) 8.84 (18H, s, 2*t*-BuO–) 9.05 (9H, s, *t*-$BuCH_2$–)

Table 6. Elemental analyses of lactones



6

Compound	R	R′	Formula	Calcd, % C	Calcd, % H	Found, % C	Found, % H
6f	$-(CH_2)_2-$		$C_6H_8O_2$	64.27	7.19	64.24	7.37
6g	CH_3	H	$C_5H_8O_2$	59.98	8.05	60.81	8.34
6h	CH_3	CH_3	$C_6H_{10}O_2$	63.13	8.83	62.98	9.10
6i	Et	Et	$C_8H_{14}O_2$	67.57	9.93	67.79	9.98
6j	$-(CH_2)_5-$		$C_9H_{14}O_2$	70.10	9.15	70.34	9.12
6k	$ClCH_2$	$ClCH_2$–	$C_6H_8O_2Cl_2$	39.37	4.40	39.15	4.33
6m	$EtOCH_2$	$EtOCH_2$–	$C_{10}H_{18}O_4$	59.38	8.97	59.80	9.14
6n	*t*-$BuOCH_2$–	*t*-$BuOCH_2$–	$C_{14}H_{26}O_4$	65.08	10.14	64.79	10.17



The imidoyl cations, **12** and **14**, are considered as the reaction intermediates in these reference reactions. Similar cyclization reactions to 2-iminotetrahydrofuran have been reported in the reaction of ω-hydroxy nitrile[12] and unsaturated nitrile.[13]

The cyclization of the imidoyl cation intermediate to 2-iminotetrahydrofuran seems to proceed rapidly. Any amide which might be derived from the imidoyl cation, if any was present, was not detected in the hydrolysis mixture of the reaction system.

It is of interest that **8** is formed only when oxetane is substituted by electron-withdrawing groups. This observation is explained by the low nucleophilicity of the ether oxygen of the imidoyl cation, **10**. The cyclization of **10** to **5** may be slow in these oxetanes; consequently, the formation of **8** by the β-scission of **10** may be predominant. In oxetanes substituted by chloromethyl and iodomethyl groups which have large σ_m values, the ratio of **8** to **5** in the product is high in comparison with that in 3,3-bis(ethoxymethyl)oxetane (**1m**). It has been known that substituent groups exert an influence on the basic strength of the ether oxygen of 3,3-disubstituted oxetanes.[14] Therefore, it is not unreasonable to assume that the nucleophilicity of the ether oxygen of **10** is influenced by substituent groups. Interference by the steric effect of the substituent for re-cyclization is less probable, because **8** was not formed in the cases of 3,3-diethyloxetane (**1i**) and oxetane-3-spirocyclohexane (**1j**), where substituent groups are as bulky as these of **1k** and **1l**. The formation of **8** by the β-scission of **10** is analogous to the β-scission of the imidoyl cation observed in the cationic isomerization and dimerization reaction of *t*-alkyl isocyanide.

12) E. M. Schultz, C. M. Robb, and J. M. Sprague, *J. Amer. Chem. Soc.*, **69**, 2454 (1947).
13) R. F. Raffauf, *ibid.*, **74**, 4460 (1952).
14) S. Iwatsuki, N. Takigawa, M. Okada, Y. Yamashita, and Y. Ishii, *Kogyo Kagaku Zasshi*, **67**, 1236 (1964).

Experimental

Reagents. *Oxetane*: Published procedures were utilized for the preparation of oxetane,[9] 2-methyloxetane,[15] oxetane-3-spirocyclopropane,[11] 3-methyloxetane,[15] 3,3-dimethyloxetane,[16] 3,3-diethyloxetane,[16] oxetane-3-spirocyclohexane,[17] 3,3-bis(iodomethyl)oxetane,[18] and 3,3-bis(ethoxymethyl)oxetane.[19] The 3,3-bis(chloromethyl)oxetane was a commercial sample which was purified by rectification under nitrogen prior to use. The 3,3-bis(*t*-butoxymethyl)oxetane was a new compound which was prepared, by a modification of Farthing's method,[19] in a yield of 12%; bp 94—95°C/7 mmHg. Found: C, 67.43; H, 11.98%. Calcd for $C_{13}H_{26}O_3$: C, 67.19; H, 12.15%. The structure was confirmed by a study of the NMR and IR spectra.

Isocyanide: Cyclohexyl isocyanide and *t*-butyl isocyanide were prepared according to Ugi's procedure.[20] 1-Ethyl-1-methylpropyl isocyanide was prepared according to Otsuka's method.[21] 1,1,3,3-Tetramethylbutyl isocyanide[21] was prepared by a modification of Ugi's method.[20] *o*-Tolyl isocyanide was prepared according to Ugi's procedure.[22] Triethyloxonium tetrafluoroborate ($Et_3O^+BF_4^-$) was prepared according to the method of Meerwein.[23] γ-Benzyloxybutyronitrile was prepared according to the method of Bennett *et al.*[24] $BF_3 \cdot Et_2O$ was a commercial reagent which was used without purification. The solvents were purified by the usual methods.

2-t-Butyliminotetrahydrofuran (5a). Into a solution of *t*-butyl isocyanide (**2a**) (0.83 g, 10 mmol) and oxetane (**1a**) (0.29 g, 5 mmol) in 5 m*l* of methylene chloride, $BF_3 \cdot Et_2O$ (0.71 g, 5 mmol) was added drop by drop with stirring at 0°C. After being allowed to stand at room temperature for 2 hr, the reaction mixture was poured into aqueous NaOH. The organic layer was then separated from the aqueous phase, and the aqueous phase was extracted twice with 5 m*l* portions of methylene chloride. The combined organic extracts were dried over magnesium sulfate and then subjected to distillation. From the volatile fraction, *t*-butyl cyanide (**3a**) and *N*-*t*-butylpivalimidoyl cyanide (**4a**) were obtained; they were identified by comparison with authentic samples. From the second fraction (bp 76°C/22 mmHg), **5a** was obtained in a yield of 70%. The IR spectrum of **5a** showed an absorption at 1712 cm^{-1} which was attributed to cyclic imidate. The NMR spectrum data are listed in Table 5. γ-Butyrolactone was obtained on the treatment of **5a** with silicic acid.

Found: C, 67.18; H, 10.57; N, 9.76%. Calcd for $C_8H_{15}NO$: C, 68.04; H, 10.71; N, 9.92%.

2-Iminotetrahydrofurans Other than 5a. Into a solution of an isocyanide and an oxetane (mol ratio, 2:1) in methylene chloride, an equimolar amount of $BF_3 \cdot Et_2O$ was added drop by drop with stirring at 0°C. The mixture was warmed to room temperature and then allowed to stand for the prescribed length of time shown in Table 2 and Table 3. The procedure employed for the isolation of **5** was almost the same as that used for **5a**. The NMR spectra data of **5** are given in Table 5. Elemental analysis was carried out upon the corresponding lactones, **6**, which were obtained by the treatment of **5** with silicic acid. The analytical data of **6** are shown in Table 6.

Reaction of 1a with 1,1,3,3-Tetramethylbutyl Isocyanide (2c). This reaction was carried out under the conditions given in Table 2. According to a procedure similar to that used in the isolation of **5a**, the methylene chloride layer was subjected to distillation. From the volatile fraction, 2,2,4,4-tetramethylpentanenitrile (**3c**) was obtained; bp 75°C/23 mmHg. The IR spectrum of **3c** showed an absorption at 2225 cm^{-1} ($\nu_{C\equiv N}$). The NMR spectrum of **3c** in $CDCl_3$ showed three singlets, at τ 8.47 (2H, $-CH_2-$), 8.60 (6H, $2CH_3$), and 8.90 (9H, *t*-Bu).

Found: C, 77.90; H, 12.12; N, 10.33%. Calcd for $C_9H_{17}N$: C, 77.63; H, 12.31; N, 10.06%. From the second fraction (bp 90°C/5 mmHg), 2-(1,1,3,3-tetramethylbutyl)iminotetrahydrofuran (**5c**) was obtained in a yield of 54%. The NMR spectrum data of **5c** are given in Table 5. **5c** was treated with silicic acid to give γ-butyrolactone.

Reaction of 3,3-Bis(chloromethyl)oxetane (1k) with 2a. Into a solution of **2a** (2.49 g, 30 mmol) and **1k** (4.65 g, 30 mmol) and 30 m*l* of methylene chloride, $BF_3 \cdot Et_2O$ (1.56 g, 11 mol) was added dropwise with stirring at 0°C. The reaction mixture was then left to stand at room temperature for 1 day. After the removal of needle crystals (mp 177—178°C), the reaction mixture was quenched with 10% aqueous NaOH. The methylene dichloride layer was distilled to give 3,3-bis(chloromethyl)-4-*t*-butoxybutyronitirle (**8k**), bp 100—120°C/5 mmHg, in a yield of 7%. The IR spectrum of **8k** showed an absorption at 2235 cm^{-1} ($\nu_{C\equiv N}$). The NMR spectrum of **8k** in CCl_4 showed signals at τ 6.35 (4H, s, $2ClCH_2-$), 6.58 (2H, s, *t*-BuOCH_2-), 7.43 (2H, s, $-CH_2-CN$), and 8.75 (9H, s, *t*-Bu).

Found: C, 51.21; H, 7.45; N, 5.97%. Calcd for $C_{10}H_{17}NOCl_2$: C, 50.43; H, 7.20; N, 5.88%. The needle crystals were washed twice with ethyl ether and, by analysis, were found to be the catalyst complex of 2-*t*-butylimino-4,4-bis(chloromethyl)tetrahydrofuran (**5k**). The IR spectrum of this complex showed an absorption at 1708 cm^{-1} which was attributed to cyclic imidate. The NMR spectrum in d_6-DMSO showed signals at τ 5.19 (2H, s, $-CH_2O-$), 6.10 (4H, s, $2ClCH_2-$), 6.80 (2H, s, $-CH_2CN$), and 8.65 (9H, s, *t*-Bu–).

Found: C, 36.96; H, 5.69; N, 4.53%. Calcd for $C_{10}H_{17}NOCl_2$–BF_3: C, 39.26; H, 5.60; N, 4.58%. β,β-Bis(chloromethyl)-γ-butyrolactone (**6k**) was obtained by the treatment of the catalyst complex of **5k** with aqueous NaOH; bp 100—120°C (5 mmHg). The IR spectrum of **6k** showed an absorption at 1770 cm^{-1} ($\nu_{C\equiv N}$). The NMR spectrum of **6k** in $CDCl_3$ showed signals at τ 5.75 (2H, s, $-CH_2O-$), 6.24 (4H, s, $2ClCH_2-$), and 7.33 (2H, s, $-CH_2-C=O$). The analytical data are shown in Table 6.

Reaction of 3,3-Bis(iodomethyl)oxetane (1l) with 2a. This reaction was carried out under the conditions shown in Table 5. According to a procedure similar to that used in the isolation of **5a**, the methylene chloride extract was concentrated and subjected to glpc analysis. 3,3-Bis(iodomethyl)-4-*t*-butoxybutyronitrile (**8l**) was isolated by preparative glpc in a yield of 24%. The IR spectrum of **8l** showed an absorption at 2240 cm^{-1} ($\nu_{C\equiv N}$). The NMR spectrum of **8l** in CCl_4 showed signals at τ 6.57 (4H, s, $2ICH_2-$), 6.60 (2H, s, $-CH_2O-$), 7.39 (2H, s, $-CH_2CN$), and 8.72 (9H, s, *t*-Bu).

Reaction of 3,3-Bis(ethoxymethyl)oxetane (1m) with 2a. This

15) S. Searles, K. A. Pollart, and F. Block, *J. Amer. Chem. Soc.*, **79**, 952 (1957).
16) S. Searles, D. G. Hummel, S. Nukina, and P. E. Throckmorton, *ibid.*, **82**, 2928 (1960).
17) T. W. Campbell and V. S. Foldi, *J. Org. Chem.*, **26**, 4654 (1961).
18) T. W. Campbell, *ibid.*, **22**, 1029 (1957).
19) A. C. Farthing, *J. Chem. Soc.*, **1955**, 3648.
20) I. Ugi and R. Meyr, *Chem. Ber.*, **93**, 239 (1960).
21) S. Otsuka, K. Mori, and K. Yamagami, *J. Org. Chem.*, **31**, 4170 (1966).
22) I. Ugi, U. Fetzer, U. Eholzer, H. Knupfer, and K. Offermann, *Angew. Chem.*, **77**, 492 (1965).
23) H. Meerwein, E. Battenberg, H. Gold, E. Pfeil, and G. Willfang, *J. Prakt. Chem.*, **154**, 83 (1940).
24) G. M. Bennett and A. L. Hock, *J. Chem. Soc.*, **1927**, 472.

reaction was carried out under the conditions shown in Table 4. According to a procedure similar to that used in the isolation of **5a**, the fraction boiling at 100—110°C (4 mmHg) was collected and then subjected to glpc analysis. By preparative glpc, 2-*t*-butylimino-4,4-bis(ethoxymethyl)tetrahydrofuran (**5m**) and 3,3-bis(ethoxymethyl)-4-*t*-butoxybutyronitrile (**8m**) were isolated separately in yields of 69% and 6% respectively. The IR spectrum of **4m** showed an absorption at 1715 cm^{-1} ($\nu_{C\equiv N}$). The NMR spectrum data of **5m** are given in Table 5. Elemental analysis was carried out upon the corresponding lactone (**6m**) (Table 6). The IR spectrum of **8m**, showed an absorption at 2235 cm^{-1} ($\nu_{C\equiv N}$). The NMR spectrum of **8m** in CCl_4 showed signals at τ 6.51 (4H, q, $2CH_3CH_2O$–), 6.60 (4H, s, $2CH_3CH_2OCH_2$–), 6.65 (2H, s, *t*-$BuOCH_2$–), 7.58 (2H, s, $-CH_2-CN$), 8.75 (9H, s, *t*-Bu), and 8.78 (6H, t, $2CH_3CH_2O$–).

Found: C, 65.96; H, 10.81; N, 5.43%. Calcd for $C_{14}H_{27}NO_3$: C, 65.33; H, 10.57; N, 5.44%.

*Reaction of 3,3-Bis(*t*-butoxymethyl)oxetane (**1n**) with **2c**.* Into a solution of **1n** (1.15 g, 5 mmol) and **2c** (1.39 g, 10 mmol) in 20 m*l* of methylene chloride, $BF_3 \cdot OEt_2$ (0.78 g, 5 mmol) was added dropwise with stirring at 0°C. The reaction mixture was then allowed to stand at room temperature for 3 days. According to a procedure similar to that used in the isolation of **5a**, 2-(1,1,3,3-tetramethylbutyl)imino-4,4-bis(*t*-butoxymethyl)tetrahydrofuran (**5n**) was obtained in a yield of 38%; bp 110—120°C/2 mmHg. The IR spectrum of **5n** showed an absorption at 1715 cm^{-1} ($\nu_{C\equiv N}$). The NMR spectrum data of **5n** are given in Table 5. Elemental analysis was carried out upon the corresponding lactone (**6n**) (Table 6).

Reaction of 8k with $Et_3O^+BF_4^-$. A solution of **8k** (0.43 g, 1.8 mmol) and $Et_3O^+BF_4^-$ (0.68 g, 4 mmol) in 10 m*l* of methylene chloride was allowed to stand at room temperature for 5 days. Then the reaction mixture was poured into aqueous NaOH, and the methylene chloride layer was treated with silicic acid. **6k** was thus obtained in a yield of 31%, as determined by glpc analysis.

*Reaction of β-Benzyloxybutyronitrile (**13**) with $Et_3O^+BF_4^-$.* A solution of **13** (0.88 g, 5 mmol) and $Et_3O^+BF_4^-$ (0.85 g, 5 mmol) in 5.5 m*l* of methylene chloride was allowed to stand at room temperature for 6 days. According to procedures similar to the above, γ-butyrolactone was thus obtained in a yield of 31% as determined by glpc analysis.