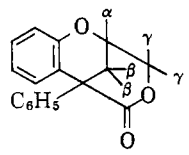
mutual spin–spin splitting by the methylene hydrogens is unexpected. Nevertheless, it is in line with the surprisingly simple spectrum of the following isomeric lactone.[2]



In this case, both β-CH_2 and γ-CH_2 absorptions occur as two doublets (J = 2.8 c.p.s.) centered at 7.63 and 5.37 τ, respectively, and the α-CH appears as a quintet (J = 2.8 c.p.s.) centered at 5.25 τ. This shows that neither the β-CH_2 nor the γ-CH_2 protons undergo appreciable mutual spin–spin splitting in this molecule.

cis-2-Hydroxymethyl-4-phenyl-4-chromancarboxylic Acid (B8). —A suspension of 1.8 g. (0.005 mole) of methyl *cis*-2-bromomethyl-4-phenyl-4-chromancarboxylate (B1)[2] in 15 ml. of 10% aqueous potassium hydroxide was refluxed for 64 hr. Isolation in the usual manner gave 1.2 g. (89%, m.p. 173–176°) of crude product which was recrystallized twice from aqueous ethanol to give pure *cis*-hydroxy acid B8 (0.77 g.), m.p. 176–177°; λ_{max}^{Nujol} (μ) 2.95 (w), 5.87 (s).

Anal. Calcd. for $C_{17}H_{16}O_4$: C, 71.82; H, 5.67; O, 22.51. Found: C, 71.44; H, 5.79; O, 22.58.

Acknowledgment —Grateful appreciation is due Mr. W. H. Washburn for the infrared spectra; Dr. T. F. Page, Jr., Battelle Memorial Institute, Dr. R. W. Mattoon, and Dr. J. Tadanier for the n.m.r. spectra and for aid in their interpretation; and Mr. E. F. Shelberg and Mr. O. Kolsto for the microanalyses.

The Reaction of Oxalyl Chloride with Amides. II. Oxazolidinediones and Acyl Isocyanates

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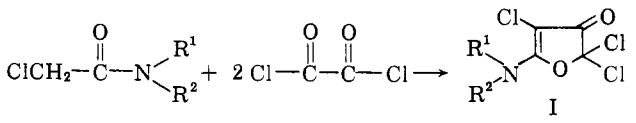
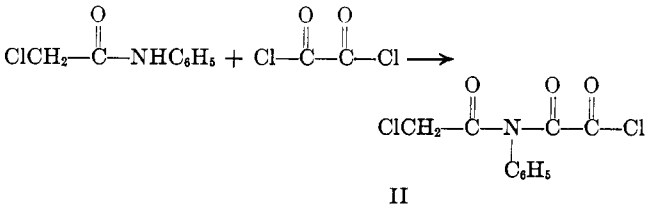
The reaction of oxalyl chloride with N-monosubstituted amides has been shown to yield acyloxamic acid chlorides or 2-methyleneoxazolidine-4,5-diones depending on the structure of the amide and experimental conditions. Treatment of primary amides with oxalyl chloride was found to be a general preparation of acyl isocyanates. A mechanism for the reaction of oxalyl chloride with various amides is discussed.

The reaction of oxalyl chloride with N,N-disubstituted chloroacetamides has been shown to yield trichlorofuranone amines I.[1]



I

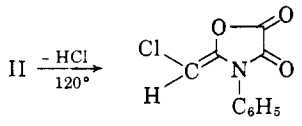
Since the formation of furanone amines would be very unlikely from N-monosubstituted chloroacetamides and oxalyl chloride, it was of interest to determine the course of this reaction. Interaction of α-chloroacetanilide and oxalyl chloride in carbon tetrachloride at 60° for twenty-four hours led to the isolation of N-chloroacetyloxanilic acid chloride (II).



II

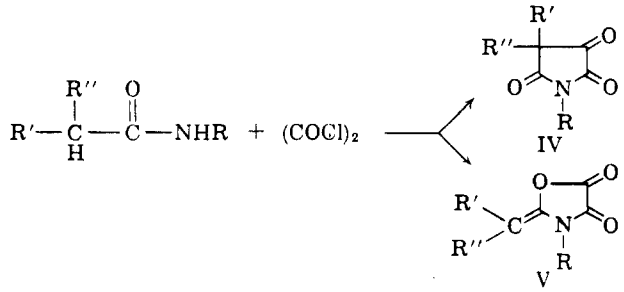
It exhibited carbonyl absorption at 1855, 1840, and 1765 cm.$^{-1}$ (Nujol) but none in the NH region. Treatment of II with methanol gave methyl N-chloroacetyl oxanilate which absorbed in the infrared at 1768, 1748, and 1720 cm.$^{-1}$ (chloroform). N.m.r. spectrum of the ester showed the presence of five protons with a complex aromatic absorption centered at 2.55 τ, two protons in a singlet at 5.90 τ, and three protons in a singlet at 6.11 τ.

On heating II at 120° for 5 min., hydrogen chloride was evolved and III was isolated. III had infrared absorption at 1827, 1745, and 1682 cm.$^{-1}$ (Nujol) with bands indicative of a vinyl proton at 3100 and 862 cm.$^{-1}$. Ultraviolet maxima were found at 235 mμ (log ϵ 3.62) and 300 mμ (log ϵ 3.82). Its n.m.r. spectrum showed the five aromatic protons centered at 2.43 τ and a singlet, perhaps due to a vinyl proton, at 4.75 τ. On the basis of the foregoing data, the structure of the compound is formulated as 2-chloromethylene-3-phenyloxazolidine-4,5-dione (III).



III

The reaction of oxalyl chloride with N-monosubstituted acetamide derivatives has led to some controversy. Figee[2] first reported that the products were pyrrolidinetriones IV without apparent justification or consideration of isomeric structures. Since the product from the reaction of oxalyl chloride and acetanilide was easily hydrolyzed to acetic acid and oxanilic acid, Stolle and Luther[3] considered the product to be the



IV

V

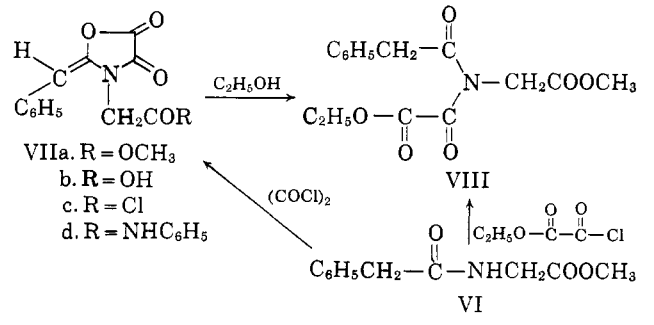
(1) A. J. Speziale and L. R. Smith, *J. Org. Chem.*, **27**, 4361 (1962).

(2) T. Figee, *Rec. trav. chim.*, **34**, 289 (1915).

(3) R. Stolle and M. Luther, *Ber.*, **53**, 314 (1920).

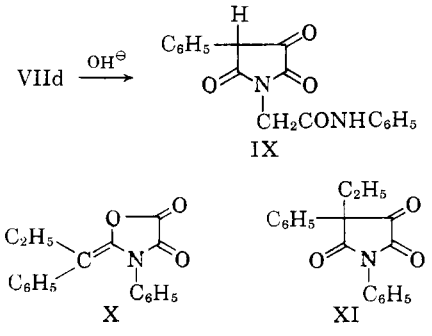
oxazolidinedione V (R′ = R″ = H, R = C_6H_5) rather than the alternate pyrrolidinetrione IV.

Spielman[4] reported that ethanolysis of the reaction product from oxalyl chloride and methyl phenaceturate (VI) led to VIII which was identical with the compound produced from VI and ethoxalyl chloride. The oxalyl chloride reaction product VIIa was assigned, therefore, the oxazolidinedione structure.

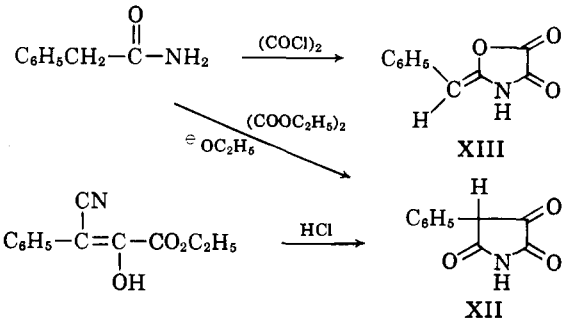


A series of twenty-five compounds was prepared by Skinner and Perkins[5] by the action of oxalyl chloride on amides. The assignment of the pyrrolidinetrione structure was based on infrared absorption at 5.6, 5.8, and 6.0 μ (1786, 1724, and 1667 cm.$^{-1}$) interpreted as three carbonyl bands. In addition, the reaction of oxalyl chloride with 2-phenylbutyranilide led to two crystalline isomers having similar infrared absorption. These were reported as multifunctional *cis–trans* isomers of 1,4-diphenyl-4-ethylpyrrolidinetrione.

Sheehan and Corey,[6] in the course of their work on penicillin synthesis,[7] examined the infrared spectra of several derivatives of the product (type VII) from the reaction of phenaceturic acid and oxalyl chloride. They felt that the absorptions at 5.50, 5.73, and 5.95 μ (1818, 1745, and 1681 cm.$^{-1}$) were in better agreement with oxazolidinediones than pyrrolidinetriones. Treatment of the anilide VIId with aqueous sodium hydroxide solution gave a compound isomeric with the starting material. The isomeric product was formulated as the pyrrolidinetrione IX because it possessed two bands at 5.62 and 5.88 μ (1779 and 1701 cm.$^{-1}$). It was further suggested that the "multifunctional *cis–trans* isomers" of Skinner and Perkins[5] were actually the oxazolidinedione X and the pyrrolidinetrione XI, since the former showed a band at 6.0 μ (1667 cm.$^{-1}$) and the latter did not.



Skinner[8] acknowledged that the previously reported pyrrolidinetriones[5] were in reality oxazolidinediones but stated that the formation of isomers having different reaction characteristics is not absolute proof of the structure of either. He then demonstrated that the pyrrolidinetrione XII, prepared from ethyl β-cyano-α-hydroxycinnamate and hydrogen chloride or from phenylacetamide and ethyl oxalate, was not identical with the oxazolidinedione XIII prepared from phenylacetamide and oxalyl chloride.

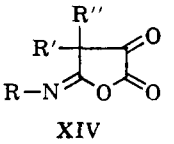


In most instances, including the 2-ethylbutyranilide case, the crude oxalyl chloride reaction products were recrystallized from ethanol. The isomerization of a series of oxazolidinediones to pyrrolidinetriones by boiling in ethanol subsequently was reported.[9]

Although the preceding work indicates that the oxazolidinedione structure is reasonable for the products of the reaction of amides with oxalyl chloride, conclusive proof is lacking. Hydrolysis data are not convincing since, in some cases,[9] pyrrolidinetriones and oxazolidinediones yield the same amides. For example, we have observed that the isomeric products formed on interaction of 2-ethylbutyranilide and oxalyl chloride both give 2-ethylbutyranilide on alkaline hydrolysis. The isolation of oxamic and acetic acid derivatives on hydrolysis of the oxalyl chloride reaction products substantiates the oxazolidinedione structure since the formation of these products from a pyrrolidinetrione would involve the unlikely cleavage of a carbon–carbon bond. However, the pyrrolidinetrione ring represents an especially reactive 1,3-dicarbonyl system and unexpected hydrolysis behavior could conceivably occur.[6] Finally, the facile isomerization of oxazolidinediones in ethanol makes it difficult to determine which isomer is present in hydroxylic solvents. The alcoholysis experiments[4] are, therefore, also inconclusive.

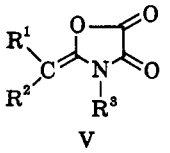
The infrared evidence is compelling but the differences between two carbonyl groups and a carbon–carbon double bond (oxazolidinediones) and three carbonyl groups (pyrrolidinetriones) appear to be subtle and misinterpreted easily.

The isolation of isomers[6,8] as a proof of structure must be rejected regardless of their method of synthesis. They could be *cis–trans* isomers of oxazolidinediones rather than isomeric five-membered rings.[6] The ketoimine XIV has not been considered by previous



(4) M. A. Spielman, "The Chemistry of Penicillin," Princeton University Press, Princeton, N. J., 1949, p. 239.
(5) G. S. Skinner and J. F. Perkins, *J. Am. Chem. Soc.*, **72**, 5569 (1950).
(6) J. C. Sheehan and E. J. Corey, *ibid.*, **74**, 360 (1952).
(7) J. C. Sheehan, E. L. Buble, E. J. Corey, G. D. Laubach, and J. J. Ryan, *ibid.*, **72**, 3828 (1950).
(8) G. S. Skinner and C. B. Miller, *ibid.*, **75**, 977 (1953).
(9) G. S. Skinner and R. E. Ludwig, *ibid.*, **78**, 4656 (1956).

TABLE I
2-METHYLENEOXAZOLIDINE-4,5-DIONES



V

	R¹	R²	R³	M.p., °C	$\nu_{C=O}$[a] (cm.⁻¹) (Nujol)	$\nu_{C=C}$ (cm.⁻¹) (Nujol)	λ_{max}[b] (log ε) ether
a.	C_2H_5	C_2H_5	C_6H_5	71–72	1805, 1735	1687	235 (3.57), 310 (4.00)
b.	(III)Cl	H	C_6H_5	162–163	1825, 1745	1681	235 (3.62), 300 (3.82)
c.	Cl	Cl	4-$CH_3C_6H_4$	132–133	1838, 1745	1672	230 (3.87), 307 (3.54)
d.	C_6H_5	C_6H_5	C_2H_5[9]	164–165	1820, 1733	1654	242 (4.20), 330 (4.13)

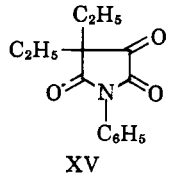
[a] Beckman IR 5A. [b] Beckman DK2.

investigators but a rational mechanism for its formation can be written for both the basis condensation and the oxalyl chloride reaction. The latter could find precedent in our work with N,N-disubstituted amides.

Since the oxazolidinediones–pyrrolidinetriones appear to be easily isomerized[6,8] and since the proof of structure is based mainly on infrared data,[6] the formation of isomers,[6,8] and somewhat inconclusive hydrolysis,[3] aminolysis,[5] and alcoholysis[4] experiments, a conclusive structure proof seemed in order. This is particularly true for the product from chloroacetanilide and oxalyl chloride since it was formed at a higher temperature than those previously reported and was prepared from an isolated intermediate (II). It also contains a chloride atom—the effect of which is unknown.

The enamine chromophore of an oxazolidinedione, fortified by the ester oxygen atom, should provide a significant and conclusive absorption in the ultraviolet. Conversely, the pyrrolidinetriones should not exhibit significant absorption above 220 mμ.

The —N—C—C— system (in ethyl N,N-dimethyloxamate) does not absorb above 220 mμ. Ultraviolet data of the products from the reaction of several amides with oxalyl chloride are shown in Table I.

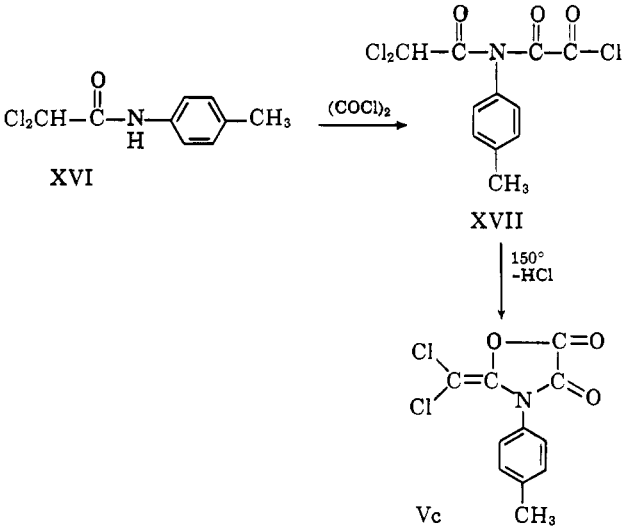


XV

The ultraviolet spectrum of the oxazolidinedione Va (λ_{max} 235 mμ, log ε 3.57, λ_{max} 310 mμ, log ε 4.00) from the reaction of oxalyl chloride with 2-ethylbutyranilide[5,9] compares very favorably with the values of the chloroacetanilide product Vb (III) (λ_{max} 235 mμ, log ε 3.62, λ_{max} 300 mμ, log ε 3.82). The pyrrolidinetrione XV, prepared by the method of Skinner[9] from Va, exhibited only a maximum at 272 mμ (log ε 3.46).

The n.m.r. spectrum of the oxazolidinedione Va should exhibit nonequivalent ethyl groups since one is shielded by the phenyl group (absorption at higher field) and the other is not (lower field). The product of the reaction showed complex aromatic absorption of five protons centered at 2.55 τ, one ethyl group as a quadruplet at 7.75 τ and a triplet at 8.98 τ and the second ethyl group as a quadruplet at 8.46 τ and a triplet at 9.32 τ. The coupling constants for methyl and methylene groups were 7.5 C/S. Clearly the presence of two *nonequivalent* ethyl groups confirm the oxazolidinedione structure Va. The comparable ultraviolet spectra also confirm that the chloroacetanilide product Vb is an oxazolidinedione. The n.m.r. spectrum of the compound produced by boiling Va in ethanol[9] exhibited complex aromatic absorption of five protons centered at 2.85 τ, absorption of four protons in a quadruplet at 8.15 τ (coupling constant 7.5 C/S), and of six protons in a triplet at 9.04 τ (coupling constant 7.5 C/S). The ethyl groups of this compound are, therefore, equivalent as would be expected for the pyrrolidinetrione XV.

The reaction was extended to monosubstituted dichloroacetamides. Treatment of N-*p*-tolyl-2,2-dichloroacetamide (XVI) with oxalyl chloride at 60° for twenty-four hours gave N-dichloroacetyl-N-*p*-tolyloxamic acid chloride (XVII).



XVI XVII

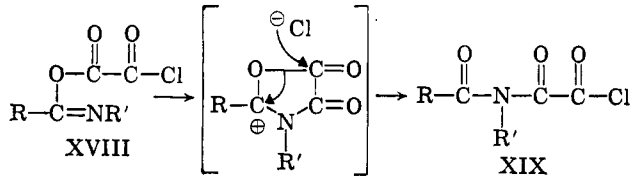
Vc

Acid hydrolysis of XVII led to N-*p*-tolyloxamic acid. The cyclization of XVII occurred less readily than the α-monochloro derivative, 150° for one hour being required.

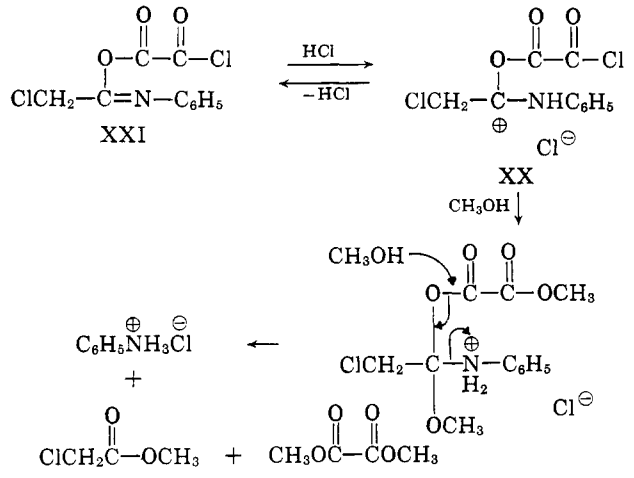
Protonation,[10,11] alkylation,[12,13] and acylation[14] of amides have been shown to occur primarily at the oxygen atom. The formation of acyl oxamic acid chlorides, however, indicates that acylation could also occur at the

(10) W. D. Kumler, *J. Am. Chem. Soc.* **83**, 4983 (1961).
(11) A. R. Katritsky andR. A. Y. Jones, *Chem. Ind.* (London), 722 (1961).
(12) M. Matsui, *Mem. Coll. Sci. Eng. Kyoto*, **2**, 37 (1909–1910).
(13) *Brit. Chem. Abstr.*, **98** (1), 695 (1910).
(14) H. K. Hall, *J. Am. Chem. Soc.*, **78**, 2717 (1956).

nitrogen atom. With oxalyl chloride, the initially formed O-acylated product XVIII can rearrange to the N-acylated product XIX.

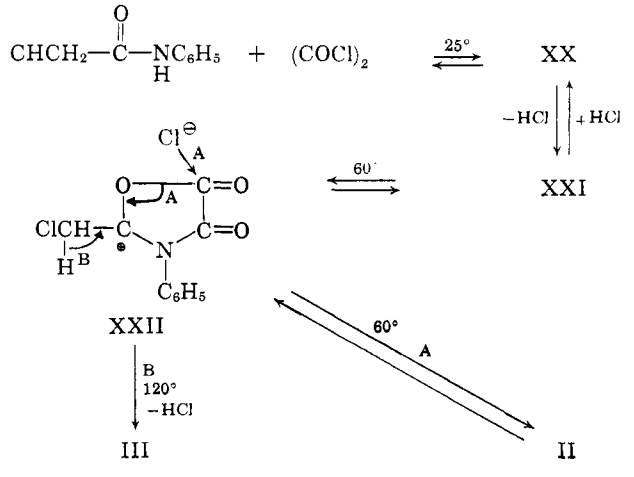


In order to determine where the initial acylation of α-chloroacetanilide occurred, the amide was treated with oxalyl chloride at room temperature and then an excess of methanol was added. The products were methyl oxalate, methyl chloroacetate, and aniline hydrochloride. These must have been formed by way of the O-acylated adduct XX.



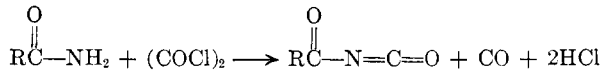
As stated earlier, treatment of the N-acylated II with ethanol gave the ester, methyl N-chloroacetyloxanilate.

The over-all reaction of N-monosubstituted acetamides with oxalyl chloride is visualized as shown for α-chloroacetanilide.



The interaction of oxalyl chloride and chloroacetanilide leads to the O-acylated product XX which loses hydrogen chloride reversibly to form XXI. Cyclization of XXI by N-acylation gives the cyclic intermediate XXII. Attack of chloride ion on the ester carbonyl carbon atom of XXII would open the ring to give the N-acylated product II (path A). At higher temperatures II could react by intramolecular acylation of the amide carbonyl oxygen atom to regenerate XXII which could lose hydrogen chloride irreversibly to produce the oxazolidinedione III (path B). This formulation would explain why α-chloroamides undergo the cyclization with more difficulty than α-alkylamides. The acylation step (II → XXII) would occur more easily with a more nucleophilic carbonyl oxygen atom. Electron-withdrawing chlorine atoms on the α-carbon atom of the amide would reduce the nucleophilicity of the oxygen atom and would thus retard the intramolecular acylation. The formation of the oxazolidinedione from N-ethyl-α,α-diphenylacetamide at temperatures similar to those for the α,α-diethylamide indicates that in the former the oxazolidinedione Vd may be formed directly from an intermediate similar to XXII by the loss of hydrogen chloride (path B) and that the N-acylated product (similar to II) may not be formed at all. This could be explained on the basis of the high acidity of the α-hydrogen atom in the diphenyl case and in the resonance stability of the product. Cyclization in the diphenyl case could also occur *via* the enol.

The reaction was further extended to unsubstituted acetamides. The reaction of chloroacetamide with oxalyl chloride at 80° for twenty-four hours led to the isolation of chloroacetyl isocyanate in 64% yield. This was shown by a strong isocyanate absorption in the infrared spectrum of the product at 2250 cm.$^{-1}$ and by the formation of N-chloroacetyl-N′-(3,4-dichloro-



phenyl)urea on treatment with 3,4-dichloroaniline. Reaction of chloroacetyl isocyanate with water gave chloroacetamide. The formation of acyl isocyanates from primary amides and oxalyl chloride appears to be general and thus constitutes a new and convenient synthesis of acyl isocyanates (Table II).

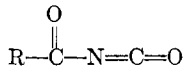
The isocyanates were, in general, too reactive toward atmospheric moisture to be analyzed and were, therefore, characterized as derivatives of 3,4-dichloroaniline. Small yields of diacylureas were isolated as by-products in the preparations of trichloroacetyl and benzoyl isocyanate. These must have been formed by the reaction of the isocyanate with the starting amide. The isolation of diacyl ureas from the reaction of amides with oxalyl chloride has been reported by Bornwater[15] by interaction of one mole of oxalyl chloride with two moles of the amide. The diacylureas, however, may be converted to acyl isocyanates by pyrolysis. For example, the pyrolysis of 1,3-bis(trichloroacetyl)-urea led to trichloroacetyl isocyanate and trichloroacetamide. An attempt to recrystallize 1,3-bis(trichloroacetyl)urea from methanol gave trichloroacetylurea. Authentic samples of trichloroacetylurea and 1,3-bis(trichloroacetyl)urea were prepared by the trichloroacetylation of urea. Attempts to prepare 1,3-dibenzoylurea by treatment of urea with benzoyl chloride led only to the monobenzoyl derivative.

In the reaction of phenylacetamide and diphenylacetamide with oxalyl chloride, yellow solids were isolated which on pyrolysis gave the isocyanates. Skinner[9] also reported the isolation of these intermediates and

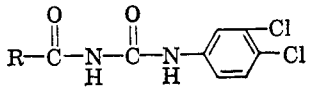
(15) M. J. Bornwater, *Rec. trav. chim.*, **31**, 118 (1912).

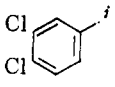
TABLE II

ACYL ISOCYANATES

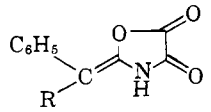


Derivative

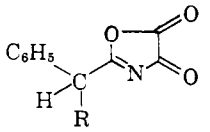


R	Yield, %	B.p., °C. (mm.)	$n_D(T°)$	ν_{NCO} (cm.$^{-1}$) pure liquid	M.p., °C.	Calcd. C	Calcd. H	Calcd. N	Calcd. Cl	Found C	Found H	Found N	Found Cl
$ClCH_2$–	64[b]	50–55 (20)	1.4580 (21.5)	2250	160[g]	38.39	2.51	9.95	37.78	38.81	2.48	9.94	37.72
Cl_2CH–	68	135 (35)	1.4600 (25)	2250	157–159[g]	34.21	1.91	8.86	44.88	34.71	2.05	8.90	45.25
Cl_3C–	60	80–85 (20)	1.4755 (25)	2250	175[g]	30.84	1.44	8.00	50.59	30.86	1.81	8.11	50.68
$C_6H_5CH_2$–	36[a]	85 (3)[e]	...	2250	205–206[h]	55.74	3.74	8.67	21.94	55.89	3.46	8.68	21.65
$(C_6H_5)_2CH$–	37	136–140 (1–12)	...	2225	206–207[g]	62.85	4.52	6.98	17.69	63.04	3.64	6.98	17.37
	97[c]	105.5 (1.6)	...	2275[d]	259–260.5[h]	...	..	7.41	37.22	...	..	7.33	37.28
C_6H_5–	75	97–98 (23)[f]	1.5472 (25)	2225									

[a] Over-all from two-step reaction including isolation of intermediate. [b] *Anal.* Calcd. for $C_3H_2ClNO_2$: C, 30.15; H, 1.69; N, 11.72. Found: C, 31.03; H, 2.18; N, 11.15. [c] *Anal.* Calcd. for $C_8H_3Cl_2NO_2$: C, 44.45; H, 1.39; N, 6.48; Cl, 32.90. Found: C, 44.35; H, 1.44; N, 6.26; Cl, 33.30. [d] In chloroform. [e] Reported[20] 118° (20 mm.). [f] Reported[20] 90° (20 mm.). [g] Recrystallized from methylene chloride–hexane. [h] Recrystallized from methanol. [i] Benzoylurea identical with an authentic sample (K and K Laboratories, Jamaica, N. Y.). [j] With P. J. Stoffel.



XXIIIa. R = H
b. R = C_6H_5



XXIV

assigned the benzilideneoxazolidinedione structure XXIII.

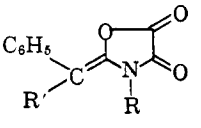
Since oxazolinedione XXIV is also possible for these compounds, their ultraviolet spectra were examined. The results appear in Table III. The similarity of the spectra of the N-substituted oxazolidinediones (R = C_2H_5 or CH_3), which must have the enamine form, to those of the unsubstituted compounds (R = H) is sufficient to conclude that the enamine form XXIII is correct. For comparison, ultraviolet data for some model enamines are given in Table IV. The spectra of the oxazolidinediones XXIII are comparable to those of the enamines. The bathochromic shift of 30 mμ produced by the ester oxygen atom of the oxazolidinediones is not unusual.[16]

The oxalyl chloride method appears superior to the only other reported preparation of acyl isocyanates which involves the reaction of acyl chlorides with silver cyanate.[20] This new method should be superior to the silver cyanate method when compounds sensitive to silver salts are involved (*i.e.*, α-halo carbonyl compounds).

The preparation of alkyl or aryl isocyanates from the reaction of amines with phosgene is not applicable to the preparation of acyl isocyanates since the reaction of primary amides with phosgene has been shown to yield nitriles[21] and complex mixtures. O-Acylation

TABLE III

ULTRAVIOLET SPECTRA OF BENZILIDENEOXAZOLIDINE-4,5-DIONES

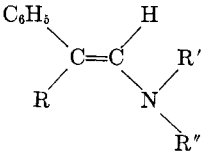


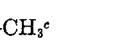
R′	R	λ_{max} (log ε) ether
H	H	240 (4.12), 330 (4.16)
C_6H_5	H	244 (4.20), 338 (4.11)
C_6H_5	C_2H_5	242 (4.20), 330 (4.13)
H	CH_3	... 330 (4.16)[a]

[a] See ref. 4.

TABLE IV

ULTRAVIOLET SPECTRA OF STYRYLAMINES



R	R′	R″	λ_{max} (log ε)	Solvent
H		$(CH_2)_5$[a]	225 (4.04), 295 (4.39)	...
C_6H_5	CH_3	CH_3[b]	... 305 (4.19)	Cyclohexane
C_6H_5	H		... 277 (4.30)	Ether

[a] See ref. 17. [b] See ref. 18. [c] See ref. 19.

(16) E. A. Braude, *Ann. Rept. Progr. Chim. (Chem. Soc. London)*, **42**, 105 (1945).

(17) R. Dulou, E. Elkik, and A. Veillard, *Bull. soc. chim.*, 967 (1961).

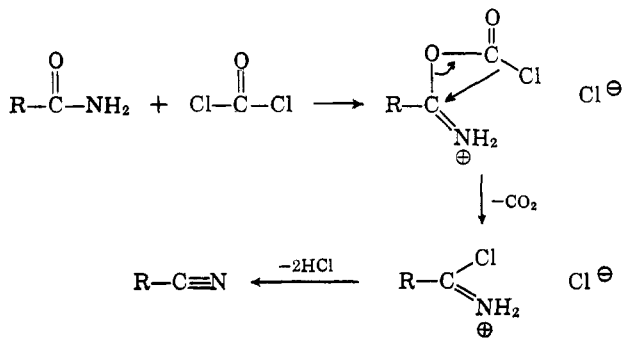
(18) J. A. Kampmeier, Ph.D. thesis, University of Illinois, 1960.

(19) We are indebted to Professor David Y. Curtin for a sample of this material.

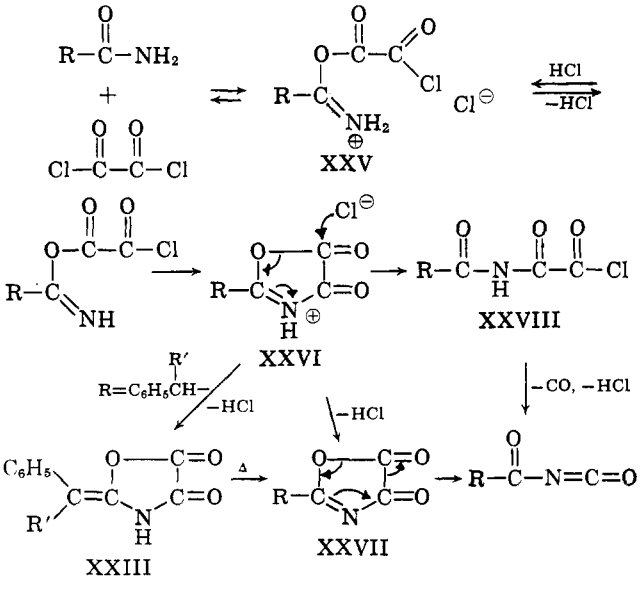
(20) A. J. Hill and W. M. Degnan, *J. Am. Chem. Soc.*, **62**, 1595 (1940).

(21) R. Greenhalgh (to Imperial Chemical Industries, Ltd.), British Patent 488,036 (June 29, 1938).

of the amide with phosgene followed by loss of carbon dioxide yields the imidoyl chloride hydrochloride which is converted to the nitrile by loss of two moles of hydrogen chloride.



This O-acylation occurs also in the reaction of oxalyl chloride with amides, but the initially formed product XXV can rearrange, by way of the cyclic intermediate XXVI. With α-phenyl- and α,α-diphenylacetamides, the α-hydrogen atom is acidic enough to be lost as hydrogen chloride yielding the benzilideneoxazolidinediones XXIII. On pyrolysis the latter may tautomerize to yield XXVII which may, by way of a reverse Diels–Alder type of reaction, yield the isocyanate and carbon monoxide. In the case of derivatives other than the α-phenylacetamides, the hydrogen atom attached to nitrogen may be lost directly giving the isocyanate again by way of the oxazoline XXVII or, alternately, attack of chloride ion could open the ring giving the acyloxamic acid chloride XXVIII which can decompose to yield the isocyanate. There is no evidence for the latter reaction, but since acyl oxamic acid chlorides are formed from reaction of N-monosubstituted amides with oxalyl chloride, they may also be formed with primary amides. An oxanilic acid chloride will indeed yield an isocyanate on pyrolysis. Treatment of oxanilic acid with thionyl chloride (presumably yielding oxanilic acid chloride) led to phenyl isocyanate on distillation.



Some evidence for the initial O-acylation was found in the reaction of chloroacetamide with oxalyl chloride. In this case the reaction was run at low temperature and methanol was added shortly after the oxalyl chloride. The products were ammonium chloride and methyl chloroacetate. These must have been formed from XXV by a mechanism similar to that in the case of chloroacetanilide.

As stated earlier, in the case of monosubstituted amides (*e.g.*, chloroacetanilide) compounds of the type XXVIII (R = $ClCH_2$–, H = C_6H_5) may be isolated and these give the acyloxamic acid ester on treatment with methanol.

Experimental[22]

N-Chloroacetyloxanilic Acid Chloride (II).—A mixture of α-chloroacetanilide (34.3 g., 0.20 mole), oxalyl chloride (28.8 g., 0.23 mole), and carbon tetrachloride (200 ml.) was stirred and heated at 60° for 24 hr. The resulting solution was cooled and evaporated to a semisolid residue. The residue was dissolved in methylene chloride and the solution was treated with charcoal. The addition of hexane caused a yellowish solid to separate. Two recrystallizations from methylene chloride–hexane gave N-chloroacetyloxanilic acid chloride (33.2 g., 0.12 mole, 60%), m.p. 107–109°; $\nu_{C=O}$ ($cm.^{-1}$) 1855, 1840, 1765 in Nujol.

Anal. Calcd. for $C_{10}H_7Cl_2NO_3$: N, 5.39. Found: N, 5.39.

2-Chloromethylene-3-phenyloxazolidine-4,5-dione (III).—N-Chloroacetyloxanilic acid chloride (3.0 g., 0.012 mole) was heated at 120° for 5 min. and was allowed to cool. The solid residue was recrystallized (with charcoal) from methylene chloride–hexane. This produced 2-chloromethylene-3-phenyloxazolidine-4,5-dione (2.1 g., 0.0093 mole, 78%), m.p. 162–163°.

Anal. Calcd. for $C_{10}H_6ClNO_3$: C, 53.72; H, 2.70; N, 6.26; Cl, 15.85. Found: C, 53.28; H, 2.77; N, 6.33; Cl, 16.06.

Reaction of α-Chloroacetanilide with Oxalyl Chloride and Methanol.—A solution of α-chloroacetanilide (17.0 g., 0.10 mole) in methylene chloride (50 ml.) was stirred while oxalyl chloride (25.4 g., 0.20 mole) was added dropwise. The solution was stirred for 4 hr. at room temperature and methanol (110 ml.) was added. The solution was evaporated to dryness and benzene (100 ml.) was added. Filtration separated aniline hydrochloride (10.0 g., 0.077 mole, 77%), m.p. 198°; reported[23] m.p. 198°. Its infrared spectrum was identical with that of an authentic sample.[24] The filtrate was placed on a column of alumina packed wet with hexane. Elution with benzene gave liquid fractions. Distillation of the recombined fractions gave methyl chloroacetate (6.2 g., 0.057 mole, 57%). The infrared spectrum was identical with that of an authentic sample.[24] Recrystallization of the distillation residue (with charcoal) from acetone–water gave dimethyl oxalate (11.1 g., 0.103 mole, 52%). The infrared spectrum was identical with that of an authentic sample.[24]

Methyl N-Chloroacetyloxanilate.—Methanol (0.32 g., 0.01 mole) was added to a solution of N-chloroacetyloxanilic acid chloride (2.6 g., 0.01 mole) in methylene chloride (25 ml.) and the solution was allowed to stand for 1 hr. The methylene chloride was evaporated and recrystallization of the residue from carbon tetrachloride gave methyl N-chloroacetyloxanilate (0.45 g., 0.0018 mole, 18%), m.p. 94°; $\nu_{C=O}$ ($cm.^{-1}$) 1768, 1748, 1720 in chloroform.

Anal. Calcd. for $C_{11}H_{10}ClNO_4$: C, 51.67; H, 3.94; N, 5.48; Cl, 13.87. Found: C, 51.62; H, 3.92; N, 5.44; Cl, 13.84.

N-Dichloroacetyl-N-*p*-tolyloxamic Acid Chloride (XVII).—A mixture of N-dichloroacetyl-*p*-toluidine (15.93 g., 0.073 mole) and benzene (75 ml.) was stirred and heated at 60° while oxalyl chloride (11.5 g., 0.0905 mole) was added dropwise. The mixture was stirred and heated at 60° for 24 hr. The benzene and excess oxalyl chloride were removed *in vacuo* and the residue was recrystallized from methylene chloride–hexane. This produced N-dichloroacetyl-N-*p*-tolyloxamic acid chloride (19.33 g., 0.0625 mole, 86%), m.p. 112.5–114°; $\nu_{C=O}$ ($cm.^{-1}$) 1850, 1765 in chloroform.

Anal. Calcd. for $C_{11}H_8Cl_3NO_3$: C, 42.81; H, 2.62; N, 4.54; Cl, 34.47. Found: C, 42.97; H, 2.67; N, 5.21; Cl, 34.16.

Hydrolysis of N-Dichloroacetyl-N-*p*-tolyloxamic Acid Chloride.—A solution of N-dichloroacetyl-N-*p*-tolyloxamic acid chloride (0.8 g., 0.0026 mole) in acetone (20 ml.) and 20% hydrochloric acid (1 ml.) was allowed to stand for 72 hr. The addition of

(22) Melting and boiling points are uncorrected.
(23) F. Ullmann, *Ber.*, **31**, 1699 (1899).
(24) Eastman Kodak Co., Rochester, N. Y.

water and chilling caused separation of N-*p*-tolyloxamic acid (0.34 g., 0.0019 mole, 73%), m.p. 170°; reported[25] m.p. 168–170°. The infrared spectrum was identical with that of an authentic sample.[25]

2-Dichloromethylene-3-*p*-tolyloxazolidine-4,5-dione (Vc).—N-Dichloroacetyl-N-*p*-tolyloxamic acid chloride (3.0 g., 0.00975 mole) was heated at 150° for 1 hr. and the resulting solid was recrystallized (with charcoal) from methylene chloride–hexane. An additional recrystallization from methylene chloride–hexane gave 2-dichloromethylene-3-*p*-tolyloxazolidine-4,5-dione (1.16 g., 0.0043 mole, 44%), m.p. 132–133°.

Anal. Calcd. for $C_{11}H_7Cl_2NO_3$: C, 48.55; H, 2.59; N, 5.15. Found: C, 49.04; H, 2.64; N, 5.16.

2-Diethylmethylene-3-phenyloxazolidine-4,5-dione (Va.)—A mixture of 2-ethylbutyranilide (38.2 g., 0.20 mole) and benzene (150 ml.) was stirred at 60° while oxalyl chloride (27.0 g., 0.215 mole) was added dropwise. The mixture was refluxed for 24 hr. and the benzene was removed *in vacuo*. Distillation produced a yellowish liquid, b.p. 161–164° (0.4–0.45 mm.), which solidified on standing. Recrystallization from methylene chloride–hexane gave 2-diethylmethylene-3-phenyloxazolidine-4,5-dione (39.9 g., 0.163 mole, 81%), m.p. 71–72°; reported[9] m.p. 70–71°.

Anal. Calcd. for $C_{14}H_{15}NO_3$: C, 68.55; H, 6.16; N, 5.71. Found: C, 68.62; H, 5.93; N, 5.76.

Acyl Isocyanates.—A mixture of the amide (1 mole) and ethylene dichloride was stirred while oxalyl chloride (1.25 moles) was added rapidly. The mixture was stirred and refluxed for 16 hr. The ethylene dichloride was distilled *in vacuo* and the acyl isocyanate was isolated by distillation under reduced pressure (see Table II).

1,3-Dibenzoylurea.—The distillation residue from the reaction of benzamide (12.1 g., 0.10 mole) and oxalyl chloride was dissolved in hot acetone and the solution was treated with charcoal. On cooling the solution a white solid precipitated. Recrystallization from methanol–benzene produced 1,3-dibenzoylurea (2.5 g., 0.009 mole, 9%), m.p. 228–230°; reported[26] m.p. 221–222°, ν_{NH} (cm.$^{-1}$) 3225, $\nu_{C=O}$ 1754, 1689, 1664 in Nujol.

Anal. Calcd. for $C_{15}H_{12}N_2O_3$: C, 67.15; H, 4.51; N, 10.44. Found: C, 66.72; H, 4.06; N, 10.13.

1,3-Bis(trichloroacetyl)urea.—A. From Trichloroacetamide and Oxalyl Chloride.—During the reaction of 2,2,2-trichloroacetamide (8.1 g., 0.05 mole) and oxalyl chloride a white solid precipitated. An equal volume (50 ml.) of hexane was added and the white solid was separated by filtration. Recrystallization from methylene chloride–hexane gave 1,3-bis(trichloroacetyl)urea (3.5 g., 0.01 mole, 20%), m.p. 167–169°; ν_{NH} (cm.$^{-1}$) 3200, $\nu_{C=O}$ 1792, 1718 in Nujol.

Anal. Calcd. for $C_5H_2Cl_6N_2O_3$: C, 17.11; H, 0.62; N, 7.98; Cl, 60.61. Found: C, 17.32; H, 0.82; N, 7.95; Cl, 60.76.

An attempt to recrystallize 1,3-bis(trichloroacetyl)urea from methanol gave trichloroacetylurea, m.p. 158–159°; reported[27] m.p. 150°; ν_{NH} (cm.$^{-1}$) 3365, 3310, 3225, $\nu_{C=O}$ 1724, 1701 in Nujol.

Anal. Calcd. for $C_3H_3Cl_3N_2O_2$: C, 17.54; H, 1.47; N, 13.64; Cl, 51.78. Found: C, 17.67; H, 0.99; N, 13.40; Cl, 51.74.

B. From Urea and Trichloroacetyl Chloride.—A mixture of urea (6.0 g., 0.1 mole), trichloroacetyl chloride (36.4 g., 0.2 mole), and ethylene dichloride (170 ml.) was refluxed for 24 hr. Most of the ethylene dichloride was distilled *in vacuo* and the addition of hexane caused separation of a white solid. Recrystallization from methylene chloride–hexane gave 1,3-bis(trichloroacetyl)urea (23.7 g., 0.088 mole, 88%), m.p. 167–169°. The infrared spectrum was identical with that of the sample prepared as described previously.

Pyrolysis of 1,3-Bis(trichloroacetyl)urea.—When 1,3-bis(trichloroacetyl)urea (8.0 g., 0.03 mole) was heated at 180–190° under reduced pressure (*ca.* 35 mm.), trichloroacetyl isocyanate distilled (1.2 g., 0.0064 mole, 21%). The infrared spectrum was identical with that of a sample prepared as described previously. The distillation residue was treated with hot methylene chloride and filtered to remove a white solid (0.27 g.), m.p. >300°. The filtrate was evaporated to a small volume and the addition of hexane precipitated trichloroacetamide (2.6 g., 0.016 mole, 53%). The infrared spectrum was identical with that of an authentic sample.[24]

Trichloroacetylurea.[27]—A mixture of urea (6.0 g., 0.1 mole), trichloroacetyl chloride (18.2 g., 0.1 mole), and ethylene dichloride (70 ml.) was refluxed for 3 hr. and the ethylene dichloride was removed *in vacuo*. Recrystallization of the residue from methanol gave trichloroacetylurea (6.24 g., 0.03 mole, 30%), m.p. 158–159°. The infrared spectrum was identical with that of the sample prepared as described previously.

Reaction of Chloroacetamide with Oxalyl Chloride and Methanol.—A mixture of α-chloroacetamide (4.7 g., 0.05 mole) and methylene chloride (50 ml.) was stirred for 3 hr. while oxalyl chloride (12.7 g., 0.1 mole) was added dropwise. The solution was refluxed for 1 hr. and the methylene chloride was removed *in vacuo*. The residue was dissolved in methanol and the solution on standing deposited ammonium chloride (1.9 g., 0.035 mole, 70%). Distillation of the filtrate gave methyl chloroacetate (1.5 g., 0.014 mole, 28%). The infrared spectrum was identical with that of an authentic sample.[23]

Reaction of Phenylacetamide and Oxalyl Chloride (XXIIIa).—A mixture of phenylacetamide (13.5 g., 0.1 mole) and ethylene dichloride (75 ml.) was stirred at 0° while oxalyl chloride (13.5 g., 0.103 mole) was added rapidly. The mixture was refluxed for 24 hr. and a yellow solid separated. The yellow solid was isolated by filtration, recrystallized from acetone, and identified as 2-benzilideneoxazolidine-4,5-dione (13.6 g., 0.072 mole, 72%), m.p. 182–184°; reported[8] m.p. 166–167°.

Anal. Calcd. for $C_{10}H_7NO_3$: C, 63.49; H, 3.73; N, 7.41. Found: C, 63.61; H, 3.63; N, 7.29.

Phenylacetyl Isocyanate.—When 2-benzilideneoxazolidine-4,5-dione (3.3 g., 0.017 mole) was heated *in vacuo* at *ca.* 190–200°, phenylacetyl isocyanate distilled (1.38 g., 0.0086 mole, 50%), b.p. 85° (3 mm.); reported[20] b.p. 118° (20 mm.); $\nu_{N=C=O}$ (cm.$^{-1}$) 2250.

Derivative: N-phenylacetyl-N′-(3,4-dichlorophenyl)urea, from methanol, m.p. 205–206°.

Anal. Calcd. for $C_{15}H_{12}Cl_2N_2O_2$: C, 55.74; H, 3.74; N, 8.67; Cl, 21.94. Found: C, 55.89; H, 3.46; N, 8.68; Cl, 21.65.

2-Diphenylmethyleneoxazolidine-4,5-dione (XXIIIb).—A mixture of 2,2-diphenylacetamide (1.23 g., 0.0058 mole), oxalyl chloride (0.91 g., 0.0072 mole), and benzene (15 ml.) was refluxed for 2 hr. and the benzene was removed *in vacuo*. The solid residue was dissolved in methylene chloride and the solution was treated with charcoal. Chilling and the addition of hexane caused separation of a yellow solid. Recrystallization from methylene chloride–hexane gave 2-diphenylmethyleneoxazolidine-4,5-dione (1.1 g., 0.0043 mole, 74%), m.p. 176–178°; reported[9] 159–160°.

Anal. Calcd. for $C_{15}H_{11}NO_3$: C, 71.13; H, 4.40; N, 5.55. Found: C, 71.92; H, 4.15; N, 5.19.

Pyrolysis of the product yielded 2,2-diphenylacetyl isocyanate. The infrared spectrum was identical with that of a sample prepared as described previously. Slow crystallization of the product from methylene chloride–hexane produced a lighter yellow dimorphic form, m.p. 169–172°. The Nujol infrared spectrum of the dimorph, m.p. 169–172°, is not identical with that of the dimorph, m.p. 176–178°. The infrared spectra of the dimorphs in chloroform and their ultraviolet spectra in ether are identical. The dimorph, m.p. 169–172°, may be converted to the dimorph, m.p. 176–178°, by rapid crystallization from methylene chloride–hexane.

3,3-Diethyl-1-phenylpyrrolidine-2,4,5-trione (XV).—Prepared by the method of Skinner.[9] A white solid, from ethanol–hexane, m.p. 61–62°; reported[9] m.p. 60–61°.

Anal. Calcd. for $C_{14}H_{15}NO_3$: C, 68.55; H, 6.16; N, 5.71. Found: C, 69.34; H, 6.20; N, 5.80.

2-Diphenylmethylene-3-ethyloxazolidine-4,5-dione (Vd).—Prepared by the method of Skinner.[5] A yellow solid from methylene chloride–hexane, m.p. 165–166°; reported[9] m.p. 165–166°.

Anal. Calcd. for $C_{18}H_{15}NO_3$: C, 73.70; H, 5.15; N, 4.78. Found: C, 72.98; H, 4.95; N, 4.70.

Reaction of Oxanilic Acid and Thionyl Chloride.—A mixture of oxanilic acid (8.2 g., 0.05 mole), thionyl chloride (6.0 g., 0.05 mole), and chloroform (70 ml.) was refluxed for 20 hr. The chloroform was removed *in vacuo* and vacuum distillation gave phenyl isocyanate (2.62 g., 0.022 mole, 44%). The infrared spectrum was identical with that of an authentic sample.[24]

(25) H. Klinger, *Ann.*, **184**, 286 (1876).
(26) H. Biltz, *ibid.*, **391**, 181 (1912).
(27) I. A. Pearl and W. M. Dehn, *J. Am. Chem. Soc.*, **61**, 1377 (1939).