Isomerization of *N*-Aryl-1-aziridinecarboximidoyl Chlorides to *N*-(2-Chloroalkyl)-*N*-aryl Carbodiimides

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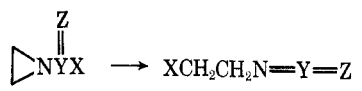
N-Aryl-1-aziridinecarboximidoyl chlorides prepared from aziridines and aryl isocyanide dichlorides undergo facile rearrangement to carbodiimides. The aziridines and carbodiimides were converted to imidazolidinetriones by treatment with oxalyl chloride followed by hydrolysis. The rearrangement to carbodiimides occurs in the neat liquid or in solution and is catalyzed by strong Brønsted acids; kinetic evidence suggests cationic intermediates formed by acid-assisted heterolysis of the C–Cl bond.

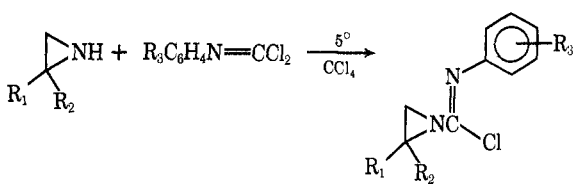
Recently we described a novel class of aziridine isomerizations which formally involved a 1,4 shift of X accompanied by the formation of an –N=Y=Z group. These rearrangements were skeletally analogous to the well-known homoallylic rearrangements that have been observed in the cyclopropane series.[1] To date this rearrangement has been utilized to prepare 2-substituted alkyl isothiocyanates,[2] isocyanates,[3,4] and *N*-sulfinylamines.[5] We now wish to report a further



extension of the rearrangement to include the isomerization of *N*-aryl-1-aziridinecarboximidoyl chlorides to *N*-(2-chloroalkyl)-*N*-aryl carbodiimides.

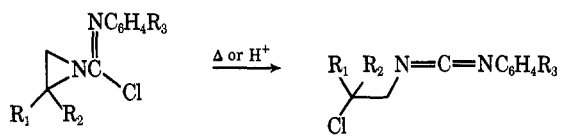
Results

The new class of aziridines, *N*-aryl-1-aziridinecarboximidoyl chlorides, was prepared by allowing equimolar amounts of aziridine to react with the aryl isocyanide dichlorides in the presence of triethylamine.



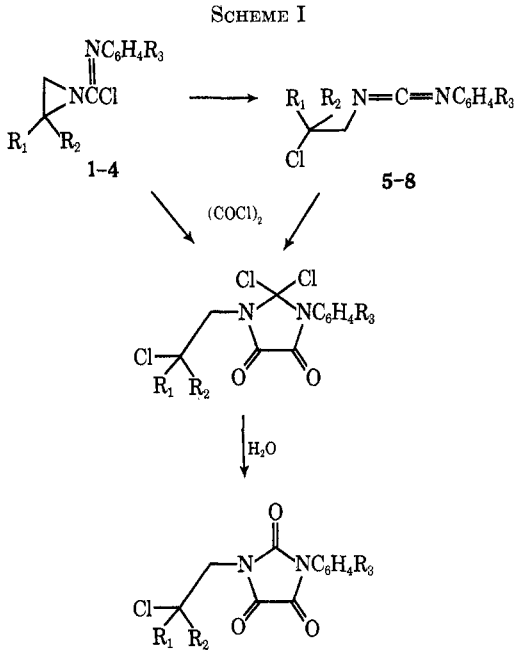
1, $R_1 = R_2 = R_3 = H$
2, $R_1 = R_2 = H$; $R_3 = p$-Cl
3, $R_1 = R_2 = H$; $R_3 = m$-NO_2
4, $R_1 = R_2 = CH_3$; $R_3 = m$-NO_2

It was found that the aziridinecarboximidoyl chlorides could be conveniently isomerized to carbodiimides for preparative experiments at elevated temperatures (*ca.* 40–60°) or at ambient temperatures (25–33°) with an acid catalyst in an aprotic solvent (acetone or acetonitrile). This reaction provided a facile method for preparing unsymmetrical carbodiimides. The acid-catalyzed method appeared to be superior to the thermal procedure since an unidentified polymeric material precipitated from the reaction at higher temperatures. The amount of polymer formation increased with increasing temperatures.



The structures for both the *N*-aryl-1-aziridinecarboximidoyl chlorides and their corresponding rearrangement products, the carbodiimides, were confirmed by infrared and nmr spectroscopy. The nmr data indicated that only one double bond isomer was present, but the configuration was not determined. The conversion of the aziridinecarboximidoyl chlorides and the isomeric carbodiimides to parabanic acids (**9**, **10**, **11**, **12**) has given additional support to the assigned structures. The aziridinecarboximidoyl chlorides or the isomeric carbodimides reacted with oxalyl chloride and yielded dichloroimidazolidinediones which were subsequently converted to the imidazolidinetriones (parabanic acids) when hydrolyzed with water (see Scheme I). The

SCHEME I



9, $R_1 = R_2 = H$; $R_3 = H$
10, $R_1 = R_2 = H$; $R_3 = Cl$ (*p*)
11, $R_1 = R_2 = H$; $R_3 = NO_2$ (*m*)
12, $R_1 = R_2 = CH_3$; $R_3 = NO_2$ (*m*)

(1) P. De Mayo, "Molecular Rearrangements," Vol. I, Interscience, New York, N. Y., 1964, p 259.
(2) D. A. Tomalia, *J. Heterocycl. Chem.*, **3**, 384 (1966).
(3) D. A. Tomalia and J. N. Paige, *ibid.*, **4**, 178 (1967).
(4) D. A. Tomalia, D. P. Sheetz, and G. E. Ham, *J. Org. Chem.*, **35**, 47 (1970).
(5) D. A. Tomalia, *Tetrahedron Lett.*, 2559 (1967).

reaction of carbodiimides with oxalyl chloride and conversion to parabanic acids is a known reaction.[6]

The rates of isomerization of 1-(*m*-nitrophenyl)-aziridinecarboximidoyl chloride (**3**) to *N*-(2-chloroethyl)-*N*-(*m*-nitrophenyl)carbodiimide (**7**) were monitored by nmr to give data in Tables I and II. Several

TABLE I

EFFECT OF SOLVENT POLARITY ON THE ISOMERIZATION OF **3** AT 33°

Solvent	Dielectric constant	Relative rate
DMSO-d_6	47	22,900
Acetonitrile-d_3	37	282
Acetone-d_3	21	199
CH_2Cl_2	9	59
CCl_4	2	1

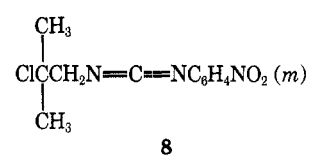
TABLE II

ACID-CATALYZED ISOMERIZATION OF **3** TO THE CARBODIIMIDE **7** IN ACETONE-d_6 AT 33°

	(Acid)·10^{+3} mol/l.	k_{obsd}·10^{+5} sec^{-1}	$t_{1/2}$ obsd
Perchloric acid catalysis	40.8	430 ± 39	2.7 min
	30	237 ± 14	4.9 min
	20.4	110 ± 8	10.5 min
	12	28 ± 3	41 min
	0	0.9 ± 0.03	27.5 hr
Hydrochloric acid catalysis	26.7	377 ± 18	3.1 min
	21.3	188 ± 10	5.2 min
	16	51 ± 5	22.5 min
	10.65	10 ± 14	117 min
	0	0.9 ± 0.03	27.5 hr

observations indicated that a cationic specie or species were involved as intermediates during the thermal isomerization. It was found that the rate of thermal isomerization (non acid catalyzed) increased with solvent polarity (see Table I). The marked increase with DMSO may be due to solvent participation. It is known that DMSO does react with alkyl halides to form O- or S-alkylated adducts that contain a halide ion.[7,8] It should be noted that the adventitious acid content of the solvents listed in Table I was not known. Hence, these results may not be directly comparable to the acid-catalyzed isomerizations (*vide infra*). The rate of isomerization was retarded by electron-withdrawing groups in the phenyl ring (**1** > **2** > **3**).

In the isomerization of the methyl-substituted aziridinecarboximidoyl chloride (**4**), the presence of two products, **8** and **13** (*ca.* 15%), was indicated by nmr. The



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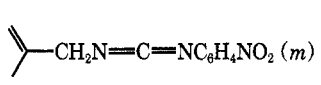

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formation of these compounds could be rationalized by a carbonium ion on the carbon bearing the gem dimethyl group.

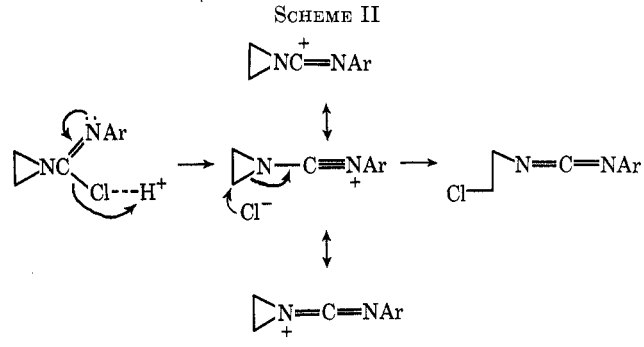
It was observed that the rate of isomerization of **3** to **7** in an aprotic solvent (acetone) was enhanced by addition of catalytic quantities of a strong Brønsted acid. The rates of these acid-catalyzed isomerizations were observed using hydrochloric and perchloric acids as catalysts. The results from these rate studies are summarized in Table I.

Addition of chloride ion (from tetramethylammonium chloride) did not catalyze the isomerization of **3** to **7** in acetone-d_6 at 33°. The rate of isomerization was 2.2×10^{-5} sec^{-1}; the small increase of this compared to the rate in pure acetone-d_6 (0.9×10^{-5} sec^{-1}) was ascribed to a salt effect since the rate of isomerization of **3** to **7** was found to be 1.8×10^{-5} sec^{-1} when tetramethylammonium fluoroborate was added instead of the chloride salt (the concentration of both quaternary salts was 0.03 *M*). It was interesting to observe that isomerization of **3** to **7** in acetone-d_6 appeared to be catalyzed by the addition of lithium chloride ($k = 8 \pm 0.7 \times 10^{-5}$ sec^{-1}, acetone d_6 saturated with lithium chloride). The small lithium ion probably acted as a catalyst for the isomerization in a manner similar to the proton. However, an unusual salt effect has not been eliminated as a possible explanation for the apparent lithium chloride catalysis.

The effect of acid upon the isomerization of **3** to carbodiimide **7** was not completely understandable, and, thus, one can only speculate on the role of the catalyst. The acid-catalyzed nature of the reaction was very apparent (see Table II). However, the order of the acid dependence and the variables (*e.g.*, the effect of increased electrolyte on the activity of the protonic species and chloride ion) created by addition of acid to the reaction were not determined.

One interpretation of the data would require the acid catalyst to assist the cleavage of the carbon–chlorine bond. An alkylated nitrilium salt (or one of its resonance forms) would be the resultant intermediate. The nitrilium salt could be transformed to a carbodiimide when attacked by chloride ion. This reaction pathway is shown in Scheme II. Bartlett

SCHEME II



and Pöckels interpreted the autocatalysis of the camphene hydrochloride solvolysis as an acid solvation of a leaving chloride ion.[9] Thus, utilization of the acid catalyst for the solvation of the leaving chloride ion seemed justified. Furthermore, the weakness of the carbon–chlorine bond in aziridine **3** was demonstrated when a dichloromethane solution of **3** was allowed to react with silver tetrafluorobroate. An exothermic reaction ensued and a precipitate of silver chloride was observed immediately.

The acid catalyst did, however, not appear to be acting in the "classical" sense for acid-catalyzed

(6) H. Ulrich and A. A. R. Sayigh, *J. Org. Chem.*, **30**, 2781 (1965).
(7) S. G. Smith and S. Winstein, *Tetrahedron*, **3**, 317 (1958).
(8) R. Kuhn and H. Trischmann, *Justus Liebigs Ann. Chem.*, **611**, 117 (1958).
(9) P. D. Bartlett and I. Pöckels, *J. Amer. Chem. Soc.*, **60**, 1585 (1938).

aziridine ring ruptures (*i.e.*, protonation of the aziridinyl nitrogen atom followed by ring cleavage). If protonation is indeed a step in the course of isomerization of these aziridines to carbodiimides, resonance arguments for the delocalization of the ensuing positive charge can be invoked to explain why protonation should occur on the imidoyl nitrogen rather than on the aziridinyl nitrogen atom. Furthermore, it has been demonstrated that electrophillic attack on (1-aziridinyl)-2-oxazolines, a system very analogous to these aziridineimidoyl chlorides, occurs exclusively at the nitrogen atom β to the aziridine ring.[10]

Experimental Section

Nuclear magnetic resonance (nmr) spectra were recorded on a Varian A-60 spectrometer. Chemical shifts are reported as parts per million (δ) relative to tetramethylsilane. The ambient temperature of the probe of the Varian A-60 spectrometer was maintained at 33° by a large volume (40 gal) of recirculating, deionized, cooling water. The cooling water was maintained at constant temperature with a refrigeration apparatus. The temperature of the probe was determined by the shift of the signal for the hydroxyl and methyl protons of methanol.[11] Infrared spectra were recorded on a Beckman IR-5 spectrometer. Melting points were determined on a Thomas-Hoover melting point apparatus and are uncorrected. Deuterated solvents were purchased from Stohler Isotope Chemicals.

The *p*-chlorophenylisocyanide dichloride was purchased from Eastman Organic Chemicals. Phenylisocyanide dichloride and 3-nitrophenylisocyanide dichloride were prepared by reaction of formanilide and 3-nitroformanilide (K & K Laboratories) with thionyl chloride and sulfuryl chloride, respectively.[12]

***N*-Aryl-1-aziridinecarboximidoyl Chlorides (1–3).**—While stirring a solution of aryl isocyanide dichloride (0.1 mol) in 75 ml of carbon tetrachloride at 0–5°, a solution of aziridine (0.1 mol, Dow Chemical Co.) and triethylamine (0.1 mol) in 75 ml of carbon tetrachloride was added dropwise over a period of 1.5 hr. The reaction temperature was maintained below 5° during addition by external cooling with ice. (Reaction leading to **3** was very exothermic.) The mixture stirred for 1–2 hr at room temperature; then triethylamine hydrochloride was removed from the reaction by filtration. The aziridines **1**, **2**, and **3** were isolated from these filtrates by removal of solvent with a vacuum as room temperature. Compound **1** was isolated as a light yellow, thermolabile oil; compounds **2** and **3** were obtained as crystalline solids, mp 23–25° (from hexane with Dry Ice cooling) and 68–70° (from diethyl ether, Dry Ice cooling), respectively. Both **2** and **3** could be stored in a freezer (−5 to 0°) for several months without appreciable decomposition. In one instance a neat sample of compound **2** polymerized exothermally to an intractable mass containing carbodiimide while being stored in a refrigerator. Yields of *N*-aryl-1-aziridinecarboximidoyl chlorides varied between 88 and 100%.

Spectral and analytical data for these compounds are as described below.

1: Infrared spectrum 1950 cm^{-1} (N=C); nmr spectrum (CCl_4) δ 2.36 (4 H, singlet, aziridine protons), 7.52–6.62 (5 H, complex multiplet, aromatic protons). It (**1**) was too unstable to purify for combustion analyses.

2: Infrared spectrum 1660 cm^{-1} (N=C); nmr spectrum (CCl_4) δ 2.40 (4 H, s, aziridine protons), 7.22 (2 H, d, aromatic protons), 6.72 (2 H, d, aromatic protons).

Anal. Calcd for $C_9H_8Cl_2N_2$: C, 50.3; H, 3.72; N, 13.0. Found: C, 50.2; H, 3.57; N, 13.07.

3: Infrared spectrum 1650 cm^{-1} (N=C); nmr spectrum (CCl_4) δ 2.51 (4 H, s, aziridine protons), 7.02–8.09 (4 H, multiplet, aromatic protons).

Anal. Calcd for $C_9H_8ClN_3O_2$: C, 48.0; H, 3.55; N, 18.7. Found: C, 48.3; H, 3.57; N, 18.5.

***N*-(*m*-Nitrophenyl-1-(2,2-dimethylaziridine)carboximidoyl Chloride (4).**—According to the above procedure, a solution of 2,2-dimethylaziridine (0.1 mol, Dow Chemical Co.) and triethylamine (0.1 mol) in 75 ml of carbon tetrachloride was added to a solution of 3-nitrophenyl isocyanide dichloride (0.1 mol) also in 75 ml of carbon tetrachloride. After removing triethylamine hydrochloride and solvent in the usual manner, a low melting, white crystalline product precipitated from the carbon tetrachloride filtrate upon storing in a freezer (−20°) overnight. This compound was identified as *N*-(*m*-nitrophenyl)-1-(2,2-dimethylaziridine)carboximidoyl chloride (**4**): mp 26–28° (with an exotherm and spontaneous isomerization to carbodiimide); infrared spectrum (CCl_4) 1650 cm^{-1} (N=C); nmr spectrum (CCl_4) δ 1.44 [6 H, s, $C(CH_3)_2$], 2.42 (2 H, s, CH_2), 7.0–8.06 (4 H, multiplet, aromatic protons).

Anal. Calcd for $C_{11}H_{12}ClN_3O_2$: C, 52.1; H, 4.73; N, 16.5. Found: C, 52.1; H, 4.76; N, 16.3.

Rate Determinations.—The rates of isomerization of **3** in various solvents was accomplished by first weighing a sample (40 mg) of **3** into an nmr tube. Dibenzyl ether (35 μl) and the solvent (250 μl) in question were added to the nmr tube. The integral of the aziridinyl protons at δ 2.51 was compared to the methylene protons of dibenzyl ether at δ 4.55 with respect to time. The tube was placed in a constant temperature bath set at 33° and periodically removed to record the relative integrals of the two signals. The following results were obtained: solvent ($k \times 10^5$ sec^{-1}), DMSO (100 ± 0.1), acetonitrile-d_3 (1.23 ± 0.05), acetone-d_6 (0.9 ± 0.03), CH_2Cl_2 (0.251 ± 0101), CCl_4 (*0.00437 ± 0.0006*).

A stock solution of perchloric acid in acetone-d_6 was prepared for the perchloric acid catalyzed isomerizations of **3** in acetone-d_6 at 33°. The solution was made by diluting 60 × 10^{-6} l. (60 μl) of 5.71 *N* perchloric acid to 1.0 ml with acetone-d_6. A sample (40 mg) of compound **3** was weighed into an nmr tube. Dibenzyl ether (35 μl) and acetone-d_6 (250 μl − *X*; *X* = microliters of stock perchloric acid–acetone-d_6 solution) were added at time zero. The integral of the azirdinyl protons at δ 2.51 was compared to the methylene protons of dibenzyl ether at δ 4.55. A known volume of the stock perchloric acid–acetone-d_6 solution was added to the nmr tube, the tube was quickly inverted, and a timer was activated. The integral of the two signals at δ 2.51 and 4.55 were monitored with respect to time. The results are recorded in Table II.

A stock solution of hydrochloric acid was prepared for the hydrochloric acid catalyzed isomerization of **3** in acetone at 33°. The solution was made by diluting 30 × 10^{-6} l. (30 μl) of 11.6 *N* hydrochloric acid to 1.0 ml with acetone-d_6. A sample of **3** (40 mg) was weighed into an nmr tube. Benzyl benzoate (70 μl) and acetone-d_6 (240 μl − *X*; *X* = microliters of stock hydrochloric acid–acetone-d_6 solution) were added at time zero. Also sufficient deuterium oxide was added to the reaction solution in addition to the H_2O introduced with the hydrochloric acid stock solution such that the total amount of "water" present was 3.6 × 10^{-4} mol. The integral of the aziridinyl protons at δ 2.51 was compared to the methylene protons of benzyl benzoate at δ 5.34. Then a known volume of the stock hydrochloric acid–acetone-d_6 solution was added to the nmr tube, the tube was quickly inverted, and a timer was activated. The integral of the two signals at δ 2.51 and 5.34 were monitored with respect to time. The results are recorded in Table II.

The rate coefficients, k_{obsd}, where reckoned as −2.30 times the slopes of plots of log (1 − C_d) against time. The slopes were determined by a least-squares treatment of the data, and the errors reported in the rate coefficients were the standard deviations of the slopes. The conversion fraction, 1 − C_d, was defined as the amount of aziridine compound **3** present at time = *t* divided by the amount of aziridine compound **3** at time = zero (beginning of reaction). The quantity, 1 − C_d, was experimentally obtained from the quotient: the millimeters of integration for the aziridinyl protons at time = *t* divided by the millimeters of integration for the aziridinyl protons at time = zero. Integrations were normalized with respect to the millimeters of integration for the internal standard at time = *t* with the median millimeters of integration obtained for the internal standard during the course of a kinetic run. Kinetic runs were generally followed to 70–80% completion, but the slopes were usually obtained by plotting the first 50% of the isomerization since the quantity 1 − C_d became increasingly difficult to determine accurately.

Isomerization of 1 to Carbodiimide 5.—A sample of **1** (4 g)

(10) D. A. Tomalia, N. D. Ojho, and B. P. Thill, *J. Org. Chem.*, **34**, 1400 (1969).

(11) Varian Analytical Instrument Division, Palo Alto, Calif., Publication 87-202-006, pp 4–12.

(12) E. Kuhle, *Angew. Chem.*, **74**, 861 (1962).

was dissolved in carbon tetrachloride (20 ml) and heated in a constant temperature bath at 40°. The conversion from **1** to **5** could be monitored by nmr spectroscopy. After heating for 14 hr the signal for the aziridine protons at δ 2.40 had disappeared. The carbon tetrachloride was removed under reduced pressure to yield a water-white liquid identified as carbodiimide **5**: infrared spectrum 2140 cm^{-1} (N=C=N); nmr spectrum (CCl_4) δ 3.62 (4 H, s, $ClCH_2CH_2N$=), 6.6–7.5 (5 H, m, aromatic protons).

The 1-(2-chloroethyl)-3-phenyl-2,2-dichloroimidazolidine-4,5-dione can be prepared by the reaction of either carbodiimide **5** or aziridine **1** with oxalyl chloride. A sample (4 g, 0.0221 mol) of either carbodiimide **5** or aziridine **1** was dissolved in carbon tetrachloride (16 ml). The carbon tetrachloride solution was added to a solution of oxalyl chloride (4.3 g, 0.033 mol, Eastman Organic Chemicals) in dichloromethane (30 ml) over a period of 10 min. The reaction solution was then heated at 43–45° for 1 hr. The solvent was removed under reduced pressure and a light yellow solid (6.25 g, 92%) was obtained whose spectral data were consistent with 1-(2-chloroethyl)-3-phenyl-2,2-dichloroimidazolidine-4,5-dione: infrared spectrum (Fluorolube) 1766 cm^{-1} (carbonyl); nmr spectrum (acetonitrile-d_3) δ 7.6 (5 H, s, aromatic protons), 4.4–3.7 (4 H, m, $ClCH_2CH_2N$). Ulrich and Sayigh reported a carbonyl absorption of 1766 cm^{-1} for 1,3-dicyclohexyl-2,2-dichloroimidazolidine-4,5-dione.[6]

1-(2-Chloroethyl)-3-phenylimidazolidine-2,4,5-trione (9).—A sample (5.7 g) of the crude 1-(2-chloroethyl)-3-phenyl-2,2-dichloroimidazolidine-4,5-dione was mixed with water (100 ml) and allowed to sit at room temperature for 18 hr. The crystalline product (4.1 g, 88%) was collected by vacuum filtration. The product was recrystallized from dichloromethane–ether to yield a material identified as 1-(2-chloroethyl)-3-phenylimidazolidine-2,4,5-trione (**9**): mp 110–112°; infrared spectrum 1735 cm^{-1} (carbonyl); nmr spectrum (acetonitrile-d_3) δ 7.6–7.2 (5 H, m, aromatic protons), 4.2–3.6 (4 H, 9-line multiplet, spacing = 4 Hz, $ClCH_2CH_2N$).

Anal. Calcd for $C_{11}H_9N_2O_3Cl$: C, 52.3; H, 3.59; N, 11.1. Found: C, 51.9; H, 3.69; N, 11.1.

Isomerization of 2 to Carbodiimide 6.—A sample of **2** (0.04 g) was dissolved in carbon tetrachloride (0.3 ml) and heated in a water bath at 40°. The conversion from **2** to **6** could be monitored by nmr spectroscopy. After being heated for 31 hr the signal for the aziridine protons at δ 2.36 had completely disappeared. Evaporation of the carbon tetrachloride yielded a liquid which was identified as carbodiimide **6**: infrared spectrum 2130 cm^{-1} (N=C=N); nmr spectrum (CCl_4) δ 6.8–7.4 (4 H, m, aromatic protons), 3.7 (4 H, s, $ClCH_2CH_2N$=).

The 1-(2-chloroethyl)-3-(*p*-chlorophenyl)-2,2-dichloroimidazolidine-4,5-dione can be prepared by the reaction of either aziridine (**2**) or carbodiimide (**6**) with oxalyl chloride. A sample (1.96 g, 0.0091 mol) of either **2** or carbodiimide **6** was dissolved in dichloromethane (10 ml). This solution was added dropwise to a solution of oxalyl chloride (1.73 g, 0.0136 mol, Eastman Organic Chemicals) in dichloromethane (40 ml) over a period of 10 min. When the addition was complete the reaction was refluxed for 45 min. The dichloromethane was removed under a reduced pressure to yield a crude material (2.7 g, 87%, mp 125–35°) whose spectral data were consistent with 1-(2-chloroethyl)-3-(*p*-chlorophenyl)-2,2-dichloroimidazolidine-4,5-dione: infrared spectrum (Fluorolube) 1765 and 1750 cm^{-1} (carbonyl); nmr spectrum (acetonitrile-d_3) δ 3.8–4.3 (4 H, m, $ClCH_2CH_2N$), 7.6–7.0 (4 H, m, aromatic protons).

1-(2-Chloroethyl)-3-(*p*-chlorophenyl)imidazolidine-2,4,5-trione (10).—A sample (2.5 g) of the crude 1-(2-chloroethyl)-3-(*p*-chlorophenyl)-2,2-dichloroimidazolidine was stirred with water (75 ml) for 3 hr. The product was collected by vacuum filtration and allowed to dry at room temperature overnight to yield 2 g (95%). After recrystallization from dichloromethane–ether this material was identified as 1-(2-chloroethyl)-3-(*p*-chlorophenyl)imidazolidine-2,4,5-trione: mp 137–138°; infrared spectrum (Fluorolube) 1730 cm^{-1} (carbonyl); nmr spectrum (acetonitrile-d_3) δ 7.2–7.8 (4 H, m, aromatic protons), 3.6–4.2 (4 H, 6-line multiplet, spacing = 5–4–4–4–5 Hz, $ClCH_2CH_2N$).

Anal. Calcd for $C_{11}H_8N_2O_3Cl_2$: C, 46.02; H, 2.89; N, 9.77. Found: C, 46.07; H, 2.92; N, 9.78.

Isomerization of 3 to Carbodiimide 7.—A sample (0.3 g, 1.33 mmol) of **3** was placed in a tube fitted with a condenser and drying tube. The tube was heated in a water bath at 68° for 12 min. The resultant yellow liquid (0.3 g, 100%) was identified as carbodiimide **7**: infrared spectrum 2145 cm^{-1} (N=C=N); nmr spectrum (CCl_4) δ 3.82 (4 H, s, $ClCH_2CH_2N$=), 7.4–8.1 (4 H, m, aromatic protons).

Anal. Calcd for $C_9H_8ClN_3O_2$: C, 48.0; H, 3.55. Found: C, 48.5; H, 3.53.

1-(2-Chloroethyl)-3-(*m*-nitrophenyl)imidazolidine-2,4,5-trione (11).—The 1-(2-chloroethyl)-3-(*m*-nitrophenyl)-2,2-dichloroimidazolidine-4,5-dione can be prepared by the reaction of either aziridine **3** or carbodiimide **7** with oxalyl chloride. A sample (0.5 g, 2.22 mmol) of either carbodiimide **3** or aziridine **7** was taken up in dichloromethane and added portionwise to a stirred solution of oxalyl chloride (0.423 g, 3.33 mmol, Eastman Organic Chemicals) in 8 ml of dichloromethane over a period of 10 min. The reaction was very exothermic. After being refluxed for 30 min, the solvent was removed under reduced pressure to yield a white, crystalline residue (0.95 g, 96%) and melted at 147–150°. Spectral data were consistent with the proposed product, 1-(2-chloroethyl)-3-(*m*-nitrophenyl)-2,2-dichloroimidazolidine-4,5-dione: infrared spectrum (Fluorolube) 1766 cm^{-1} (carbonyl).

The above crude product (0.75 g) was allowed to stir with water (25 ml) at room temperature for several hours. A white crystalline product was collected by filtration and washed with four 10-ml portions of cold water. The aqueous filtrate was very acidic (pH ≅ 1). The air-dried crude product melted at 116–119° (0.4 g, 63%). Three recrystallizations from dichloromethane–ether gave a material identified as 1-(2-chloroethyl)-3-(*m*-nitrophenyl)imidazolidine-2,4,5-trione (**11**): mp 117–119°; infrared spectrum (Fluorolube) 1724 and 1742 cm^{-1} (carbonyl); nmr spectrum (acetonitrile-d_3) δ 7.6–8.4 (4 H, m, aromatic protons), 3.96 (4 H, 8-line multiplet, spacing = 3–4–4–4–4–4–3 Hz, $ClCH_2CH_2N$).

Anal. Calcd for $C_{11}H_8ClN_3O_5$: C, 44.4; H, 2.69; N, 14.1. Found: C, 44.0; H, 2.72; N, 14.3.

Isomerization of 4 to Carbodiimide 8.—A sample of **4** (0.3 g) was placed in a test tube equipped with a thermocouple. Upon warming to 28°, the white crystals melted and an exothermic reaction began. Temperature rose to 44°. This melt was analyzed by nmr and infrared spectroscopy and found to be completely converted to the carbodiimide. The infrared spectrum showed that the band at 1660 cm^{-1} (N=C) had disappeared, whereas an intense band at 2130 cm^{-1} (N=C=N) had appeared. Characteristic nmr signals (CCl_4) for the aziridine ring in **4** were absent. New resonance bands were present at δ 1.78 (6 H, singlet), 3.65 (2 H, singlet), and two complex multiplets centered at 7.94 and 7.42 (4 H). These were assigned to CH_3C-CH_3, CH_2, and the aromatic ring, respectively, in *N*-(2-chloro-2-methylpropyl)-*N*-*m*-nitrophenylcarbodiimide (**8**). Two broadened singlets at δ 1.85 (CH_3) and 4.01 (CH_2), as well as a finely split multiplet at δ 5.02 were assigned to a small amount of *N*-methylallyl-*N*-*m*-nitrophenylcarbodiimide (**13**). Both methyl and methylene group integrations indicated that about 15–18 mol % of unsaturated carbodiimide was present in this melt.

1-(2-Chloro-2-methylpropyl)-3-(*m*-nitrophenyl)imidazolidine-2,4,5-trione (12).—A dichloromethane solution (10 ml) of crude **8** (3.3 g) was added dropwise to a solution of oxalyl chloride (2.48 g, 0.0195 mol, Matheson Coleman and Bell) in dichloromethane (20 ml) over a period of 10 min. The reaction solution was allowed to reflux for 30 min after the addition was complete. The dichloromethane was removed under reduced pressure and 1-(2-chloro-2-methylpropyl)-3-(*m*-nitrophenyl)-2,2-dichloroimidazolidine-4,5-dione, a light tan crystalline material, was isolated (4.25 g, 82%): mp 154–167°; infrared spectrum (Fluorolube) 1760 cm^{-1} (carbonyl). Crude dichloroimidazolidine-4,5-dione (4.1 g) was stirred with water (75 ml) for 2 hr and a product (3.3 g, 98%) was collected by vacuum filtration. The product was recrystallized from dichloromethane–ether and was identified as 1-(2-chloro-2-methylpropyl)-3-(*m*-nitrophenyl)imidazolidine-2,4,5-trione (**12**): mp 183–185°; infrared spectrum (Fluorolube) 1735 cm^{-1} (carbonyl); nmr spectrum (acetonitrile-d_3) δ 7.6–8.4 (4 H, m, aromatic protons), 3.99 (2 H, s, $ClCH_2C$), 1.65 [6 H, s, $C(CH_3)_2$].

Anal. Calcd for $C_{13}H_{12}N_3O_5Cl$: C, 47.8; H, 3.95; N, 12.9. Found: C, 47.6; H, 3.83; N, 13.0.

Registry No.—**1**, 29494-60-8; **2**, 29494-61-9; **3**, 29494-62-0; **4**, 29576-45-2; **5**, 29494-63-1; **6**, 29494-64-2; **7**, 29494-65-3; **8**, 29494-66-4; **9**, 29494-67-5;

10, 29478-09-9; 11, 29478-10-2; 12, 29478-11-3; 1-(2-chloroethyl)-3-phenyl-2,2-dichloroimidazolidine-4,5-dione, 29478-12-4; 1-(2-chloroethyl)-3-(*p*-chlorophenyl)-2,2-dichloroimidazolidine-4,5-dione, 29576-46-3; 1-(2-chloroethyl)-3-(*m*-nitrophenyl)-2,2-dichloroimidazoline-4,5-dione, 29478-13-5; 1-(2-chloro-2-methylpropyl)-3-(*m*-nitrophenyl)-2,2-dichloroimidazolidine-4,5-dione, 29641-82-5.

Chlorination of Oximes. I. Reaction and Mechanism of the Chlorination of Oximes in Commercial Chloroform and Methylene Chloride

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The chlorination of benzaldoximes in commercial chloroform and methylene chloride was undertaken. It was found that substituted oximes which possess electron-wtihdrawing groups gave benzal chloride derivatives upon chlorination in methylene chloride and pure chloroform. On the other hand, benzhydroxamic chloride derivatives were obtained when chlorination was performed in commercial chloroform and methylene chloride containing 0.75% ethanol. In the presence of an electron-donating group, a mixture of benzal chloride and benzhydroxamic chloride derivatives was isolated irrespective of the solvent used. Benzhydroxamic chloride (I) was the sole product when chlorination was catalyzed by triethylamine. It appears that triethylamine and ethanol catalyzed the benzhydroxamic chloride formation. The abnormal chlorination reaction of benzaldoxime, *o*-hydroxybenzaldoxime (XI), and *p*-dimethylaminobenzaldoxime (XVII) in methylene chloride solution is particularly interesting. The mechanism of benzal chloride formation in the chlorination of oximes was examined. It is assumed that *p*-nitro-α-nitrosobenzyl chloride (XXa) emerged in the course of reaction; this was demonstrated by chemical evidence and spectroscopic studies. Two reaction mechanisms are proposed for the formation of benzal chloride. In the first of the mechanisms it is suggested that the chloronitroso intermediate decomposed unimolecularly to give a carbanion and a nitrosyl ion. In the second one, it can be considered as a nucleophilic displacement on the nitroso group, perhaps by chloride ion, and that the carbanion and nitrosyl chloride are thereby produced. The mechanism of isomerization of aromatic α-chloro-α-nitroso compounds was proposed according to the experimental results. Generally, it is assumed that the isomerization process could be separated into three categories. (1) One way is amine-catalyzed isomerization through a carbanion intermediate. (2) Ethanol-catalyzed isomerization gave a cyclic intermediate through intermolecular H bonding with electron-withdrawing substituted α-chloro-α-nitroso compound. (3) When electron-donating substituent is present, intramolecular isomerization *via* H bonding is operative.

The halogenation of oximes has been applied to the preparation of nitro compounds,[1] halonitro paraffins,[2] and, in particular, hydroxamic halide derivatives. The conversion of oximes to hydroxamic chlorides *via* chlorination was studied in some detail[3] since this is the first step in the synthetic route to nitrile oxides for sterically unhindered compounds.[4] Grundman and Richter[4] reported that nitrile oxides could be prepared by dehydrogenation of the corresponding aldoximes with *N*-bromosuccinimide in *N*,*N*-dimethylformamide solution. The reaction apparently proceeded first to the hydroxamic bromide which was subsequently dehydrobrominated by the base to the nitrile oxide. Solvents such as chloroform,[3c,d,g,9] ether,[3a,5] or 8.3 *N* aqueous hydrochloric acid solution[3a,e] have been employed in the chlorination of oximes. It was found that aromatic aldoximes bearing bulky ortho substituents could not be chlorinated to hydroxamic chlorides without a considerable additional uptake of chlorine by the molecule, presumably by substitution in the aromatic ring.[6] Furthermore, strong electron-donating substituents in the aromatic nucleus facilitated chlorination of the ring with the result that a mixture of chlorinated products was formed.[3a]

I wish to report some interesting results which were discovered in the course of investigating the chlorination of oximes. It was found that substituted aromatic oximes, especially in the presence of a nitro group in the ring, gave the corresponding benzal chloride derivatives upon treatment with chlorine in methylene chloride or pure chloroform solution at -20 to $0°$. However, when commercial (comm) chloroform[7] or methylene chloride which contained 0.75% ethanol was used as the solvent (at -15 to $20°$), substituted benzhydroxamic chlorides were obtained. For the purpose of mechanistic study of benzal chloride formation, a systematic investigation of the chlorination of oximes in commercial chloroform and methylene chloride was undertaken. The results were summarized in Table I.[8-10]

The use of benzhydroxamic chloride and its derivatives as precursors for 1,3-dipolar addition reactions has been studied extensively for the past 10 years. In spite of the wide application of benzhydroxamic chlo-

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