The Role of Solvent in Conjugate Additions Leading to *cis* and *trans*-1-Alkyl-2-aryl-3-carbo(aroyl)aziridines

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In the formation of *cis*- and *trans*-1-alkyl-2-aryl-3-carbo(aroyl)aziridines a change in solvent from benzene to methanol in the α-bromochalone-primary amine reaction produced an increase in *cis* isomer. However, the same solvent change resulted in a decrease in the *cis*/*trans* ratio when these same aziridines were prepared by the chalcone-halogen-primary amine reaction. These results are rationalized in terms of both an open and chelated enol intermediate thought to be crucial in the relative product formations. Other mechanistic considerations in the product formations are presented.

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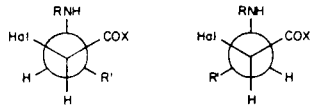
Since earlier work in these laboratories has revealed the equimolar reaction of primary amines with α-bromo-α,β-unsaturated ketones to afford *d,l-erythro*- and *d,l-threo*-α-bromo-β-aminoketones (1-3) (see *A* and *B*) whereupon subsequent reaction with additional amine results



erythro A *threo B*

in the simultaneous formation of the respective *trans*- and *cis*-1-alkyl-2-aryl-3-carbo(aroyl)aziridines, further investigations as to the role of solvent in these reactions appeared warranted. Albeit the experimental data (Table I) from several of our synthetic studies had been correlated (4) with steric controls in conjugate addition, it appeared as if these effects were related to the factors of asymmetric induction postulated by Cram (5). That is to say, a rule was formulated which was successful in correlating and predicting the stereochemical direction in which a new asymmetric center is created adjacent to an old one by means of 1,2-additions to carbonyl groups and was found to apply to 1,4-additions to α,β-unsaturated carbonyl compounds as well. The summary of these effects has been discussed previously (4).

Since investigation in our laboratories has revealed that a change in aprotic solvent (benzene) to protic solvent (methanol) in the α-bromochalcone-primary amine reaction produced an increase in the proportion of the *cis* isomer while the same change of solvent decreased the *cis*/*trans* ratio when the chalcone-halogen-primary amine reaction

Table I

Summary of Effects of *N*-Alkyl and β-Substituent Size in the Synthesis of Epimeric Arylaroylaziridines and Alkylaroylaziridines in Benzene

Substrate (a)	Amine	Halogen	% *trans*	(% *cis*) (b)	Yield	Reference
PhCH=CBrCOAr	$H_2NC_6H_{11}$	--	48	(52)	91	25
PhCH=CBrCOAr	H_2NCH_3	--	68	(32)	99	26
RCH=CBrCOAr	$H_2NC_6H_{11}$	--	35	(65)	95	8
RCH=CBrCOAr	H_2NCH_3	--	43	(57)	85	8
PhCH=CHCOAr	$H_2NC_6H_{11}$	I_2	94	(--) (c)	94	8
PhCH=CHCOAr	H_2NCH_3	I_2	74	(--) (c)	74	8
RCH=CHCOAr	$H_2NC_6H_{11}$	I_2	90	(--) (c)	90	27
RCH=CHCOAr	H_2NCH_3	I_2	77	(--) (c)	77	8

(a) Ar = p-$C_6H_5C_6H_4$-, R = CH_3. (b) Isolated percentages. (c) Presence of *cis* isomer not reported.

was employed, a study has been undertaken to further substantiate and elucidate this phenomena. Investigations as to the effect of *N*-alkyl and β-substituents upon the stereochemical outcome of these reactions have been carried out.

Discussion.

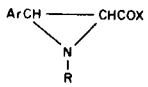
The previously unreported *N*-isopropyl and *N*-ethylarylaroylaziridines, synthesized by the reaction of the appropriate primary amine with α-bromochalcone (see Experimental), are listed with the isomer ratios obtained along with the related methyl 1-alkyl-2-aryl-3-aziridinecarboxylates in Table II. A change in solvent from benzene to methanol resulted in an increase in the proportion of *cis* aziridine esters produced by the action of a primary amine on an α-bromo-α,β-unsaturated ester. In the arylaroylaziridine series a small increase in the amount of *trans* isomer was observed as the steric requirement of the *N*-alkyl group was decreased, irrespective of the method of synthesis.

Since the primary amine should add to these α,β-unsaturated systems in a 1,4-fashion the stereochemistry of the product would be expected to be determined in the ketonization step (4), *i.e.*, protonation or halogenation of an intermediate enol. It seems reasonable to suggest that at least three variable steric factors contribute to the course of the ketonization step and include (1) the relative populations among possible conformations of an intermediate enol, (2) the sizes and reactivities of the protonating or halogenating molecules present in the reaction mixture, and (3) the degree of steric hindrance which the various conformations of the amine enol present to the approach of the protonating or halogenating agents of different sizes. It must be emphasized that the approach of the protonating or halogenating agent to the α-carbon of the enol intermediate will be a preferential rather than an exclusive mode (see Figure 1). Hence the most favored conformation of the enol is as indicated in the transition state with the protonating agent approaching the enolic double bond from the side occupied by the two smaller groups on the β-chiral atom (H and M).

In light of the extensive data now available, a combination of the theories previously advanced (4,6) which emphasize the importance of bulk interactions between

Table II

The Role of the Solvent in Formation of Epimeric Aziridine Ketones and Esters (19)



cis,trans	Compound Ar	Compound R	Compound X	Solvent	Method (a)	% *trans* / % *cis*
1a,1b	*p*-$C_6H_5C_6H_4$	C_2H_5	OCH_3	CH_3OH	A	0.19 (b)
2a,2b	*p*-$C_6H_5C_6H_4$	*i*-C_3H_7	OCH_3	C_6H_6	A	1.22 (c)
				CH_3OH	A	0.41 (c)
3a,3b	*p*-$C_6H_5C_6H_4$	*c*-C_6H_{11}	OCH_3	C_6H_6	A	1.27 (c)
				CH_3OH	A	0.49 (c)
4a,4b	C_6H_5	*t*-C_4H_9	OCH_3	CH_3OH	A	1.00 (c)
5a,5b	*p*-$C_6H_5C_6H_4$	C_2H_5	C_6H_5	C_6H_6	B	4.00 (c)
6a,6b	C_6H_5	C_2H_5	C_6H_5	C_6H_6	B	4.00 (c)
				C_6H_6	C	1.33 (c)
7a,7b	*p*-$C_6H_5C_6H_4$	*i*-C_3H_7	C_6H_5	C_6H_6	B	2.85 (b)
8a,8b	C_6H_5	*i*-C_3H_7	C_6H_5	C_6H_6	B	2.03 (c)
				CH_3OH	B	3.35 (c)
				C_6H_6	C	1.08 (c)
9a,9b	*p*-$C_6H_5C_6H_4$	*t*-C_4H_9	C_6H_5	C_6H_6	B	0.25 (c,d)

(a) A, RNH_2 + **10** (or **11**); *B*, RNH_2 + I_2 + **12**; *C*, RNH_2 + **13**

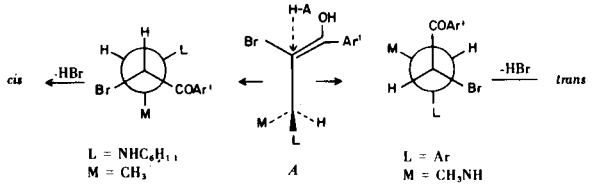
10 = *p*-$C_6H_5C_6H_4CH(Br)CH(Br)CO_2CH_3$ **12** = $ArCH{=}CHCOC_6H_5$

11 = C_6H_5-$CHBrCHBrCO_2CH_3$ **13** = $C_6H_5CH{=}CBrCOC_6H_5$

(b) Isolated. (c) Determined by ^1H nmr spectroscopy. (d) ±10%.

Figure 1

Configurational Controls in Conjugate Additions



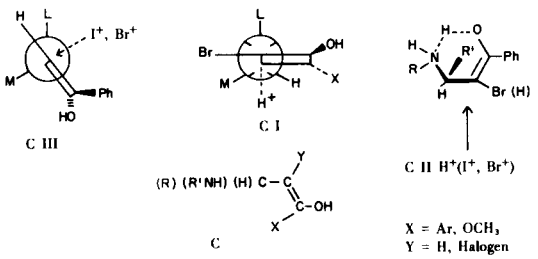
A

Transition State

On the chiral β-carbon atom in *A* the sizes of the groups are arranged as:

$$\text{Aromatic} > CH_3NH > H$$
$$C_6H_{11}NH > CH_3 > H$$

groups on the α- and β-carbon atoms of the enol *CI*, appear to provide a reasonably complete basis for predicting the stereochemical outcome of the conjugate addition of amines to α-bromo-α,β-unsaturated ketones and esters. Zimmerman (6) has indicated that enolic intermediates



such as *C* have the geometric configuration about the enolic double bond which allows greater accessibility of the oxygen atom to solvent. Thus, it seems reasonable to suggest that if the chelated conformer *CII* were responsible for the observed solvent effect, its presence would be more likely in the solvent benzene than in methanol since the latter solvent might be expected to highly solvate the amine and hydroxyl groups through intermolecular hydrogen bonding. This type of solvation could conceivably have the effect of increasing the size of the β-amino group and thereby favor protonation of *CI* where L = solvated RNH as indicated. This is particularly evident when two groups on the β-carbon are of nearly the same size. The absence of a solvent effect in the reaction of methylamine with α-bromo-4'-phenylchalcone, reactions in which protonating agents are of nearly the same size, is also in support of an open conformation of the enol intermediate in both benzene and methanol. The fact that nearly identical *cis/trans* ratios were obtained in benzene and methanol when two of the β-substituents are large also reflects the importance of the size of the protonating agent. The observed effect of decreasing the steric requirements of the β-substituent in the starting α-bromo-α,β-unsaturated ketone from phenyl to methyl while holding the *N*-alkyl substituent constant in benzene is in the opposite direction as would be predicted using the chelated model.

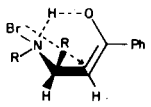
In the one instance studied (7), a marked difference in the *cis/trans* isomer ratio may have been observed as the α-halogen in the starting ketone was varied from bromine to iodine. Thus α-iodo-β-chloro-*p*-phenylcrotonophenone upon reaction with cyclohexylamine afforded a 74% yield of the *trans* aziridine while α-bromo-*p*-phenylchalcone reacted with this same amine to give only 35% *trans* product (8,9).

The most striking contrast in the stereochemical outcome of the conjugate addition of amines and *N*-haloamines to α,β-unsaturated systems is found in the reactions of morpholine with α-bromochalcone and of *N*-bromomorpholine with chalcone (10,11). Single diastereomers were formed in each case, the latter reaction affording the *erythro* stereoisomer while the *threo* was obtained from the former. The configurations of the diastereomeric α-bromo-β-morphilino ketones were initially assigned by Southwick (11a) and later confirmed by two independent investigations (12). The reaction of *N*-iodomorpholine with chalcone afforded α,β-dimorpholino ketone identical with that obtained from treatment of *erythro*-α-bromo-β-morpholinobenzylacetophenone with morpholine thereby indicating that both *N*-iodo- and *N*-bromomorpholine react with chalcone to initially produce *erythro*-α-halo-β-morpholinoketone (10a, 13). More recently (14), the conjugate 1,4-addition of morpholine and piperidine to *trans*-α-methylchalcone produced single diastereomers of the respective Micheal adducts, the configurations of which were tentatively assigned as the *threo* forms on the basis of ^1H nmr (4).

The use of primary amines in the *N*-haloamine reactions produced mixtures of the diastereomeric α-halo-β-aminoketone intermediates evidenced by the isolation of the *cis* and *trans* forms of the aziridine ketones. With *p*-phenylcrotonophenone-cyclohexylamine and *N*-chlorocyclohexylamine-cyclohexylamine mixtures afforded *cis* products almost exclusively in benzene or *t*-butyl alcohol as solvent while the reverse was obtained when the halogen was iodine (7-8, 15). An increase in the proportion of the *trans* form was observed in methanol as solvent, irrespective of halogen.

The data available for the synthesis of aziridine ketones by the action of *N*-haloamine-primary amine mixtures on

α,β-unsaturated ketones are not extensive and neither the chelated nor open enol models adequately explain the observed results, especially the solvent effect and the marked difference between bromine (or chlorine) and iodine. If, however, a chelated intermediate is involved an attractive possibility is that *N*-brominated intermediates such as *CII'* might be formed by *N*-bromination of the initial amine adduct and might be capable of undergoing



C II'

bromination at the α-carbon via intramolecular transfer of bromine occurring across one side of the chelated ring. The result would be an α-bromo-β-aminoketone of the *erythro* configuration leading to the *cis* aziridine ketone; however, this model may lack stereospecificity as nearly equivalent amounts of *cis* ketoaziridine were produced by reaction of *p*-phenylcrotonophenone with bromine-cyclohexylamine *vs.* *N*-bromocyclohexylamine with the appropriate substrate (see reference (7) for details).

The marked differences in the stereochemical outcome of the additions of *N*-bromocyclohexylamine and of *N*-bromomorpholine to chalcone could be the result of steric effects, since a β-cyclohexylamino group would offer more interference toward bromination at the α-carbon of an enol intermediate than does a β-morpholino group. The use of larger, *i.e.*, more space demanding, secondary amines such as diisopropyl amine in the *N*-bromoamine reactions with chalcone could conceivably elucidate this point.

EXPERIMENTAL

Melting points are determined by the capillary method and are uncorrected. Elemental analyses were performed by Micro-Tech Laboratories, Skokie, Illinois. The infrared spectra were determined on Perkin-Elmer Model 21 and 237 instruments as solutions (carbon tetrachloride, chloroform), potassium bromide disks, or neat. The 60 MHz nmr spectra were determined on a Varian A-60 spectrometer and the chemical shifts are reported in parts per million (δ) relative to internal tetramethylsilane (δ 0.0).

The following 1-alkyl-2-aryl-3-carboaziridines (listed in Table II) were prepared by known procedures: **1a** and **1b** (16), **2a** and **2b** (17), **3a** and **3b** (16), **5a** and **5b** (16), **7a** and **7b** (16), **9a** and **9b** (18).

Methyl 1-*t*-Butyl-2-phenyl-3-aziridinecarboxylate, *cis* and *trans* (**4a, 4b**).

The procedure described for the synthesis of *cis*- and *trans*-methyl 1-*t*-butyl-2-(*p*-biphenyl)-3-aziridinecarboxylate (16) was applied to a sample of methyl 2,3-dibromo-3-phenylpropionate (19). The crude product was obtained as a pale yellow liquid after work-up and was chromatographed on Silica Gel. Initial elution with low boiling (30-60°) petroleum ether afforded a mixture of the *cis* and *trans* forms of methyl α-bromocinnamate (40%). Pure **4b** was eluted with 2% ether-petroleum ether (b.p. 30-60°); nmr (deuteriochloroform): δ 1.15, s (9H, three methyls); 2.71 and 3.64, two d, J = 2.8 Hz (1H each, C_2-H and C_3-H, respectively), 3.71, s (3H, methoxy); and 7.1-7.5, m (5H aromatic); ir (Neat); ν C=O 1727 cm^{-1}.

Continued elution with a 5% ether-petroleum ether (b.p. 30-60°) mixture gave the corresponding *cis* aziridine **4a**; nmr (deuteriochloroform): δ 1.00, s (9H, three methyls); 2.68 and 3.16, two d, J = 7.0 Hz (1H each, C_2-H and C_3-H respectively); 3.43, s (3H, methoxy); and 7.1-7.5, m (5H, aromatic); ir (Neat): ν C=O, 1730 and 1755 cm^{-1}.

The aziridine esters **4a** and **4b**, isolated in a combined yield of 50%, were liquids and were not characterized further. The crude material consisted of nearly equal amounts of the epimeric aziridines as determined by nmr spectroscopy (20).

1-Ethyl-2-phenyl-3-benzoylaziridine, *cis* and *trans* (**6a,6b**).

A sample (2.08 g., 0.01 mole) of chalcone was added to a cooled (10°) benzene solution containing 2.54 g. (0.01 mole) of iodine and 2.45 g. (0.05 mole) of ethylamine and the resulting solution allowed to warm to room temperature with stirring. Stirring was continued for 6 hours and the reaction mixture worked up according to the general procedure. The pale yellow crude product was chromatographed on Silica Gel (40 g.) and initially eluted with 300 ml. of petroleum ether (b.p. 30-60°) to afford small amounts of benzaldehyde. Further elution with 5% ether-petroleum ether (b.p. 30-60°) gave 1.7 g. (74%) of pure *trans*-1-ethyl-2-phenyl-3-benzoylaziridine (**6b**) as a pale yellow oil which rapidly decomposed even when refrigerated; nmr (deuteriochloroform): δ 1.08, t, J = 7.3 Hz (3H, methyl); 2.85, broad q, J ≃ 7 Hz (2H, methylene); 3.47, broad d, J ≃ 2.5 Hz (1H, C_2-H); 3.54, d, J = 2.8 Hz (1H, C_3-H); 7.2-7.5 and 8.0-8.2, two m (10H, aromatic); ir (Neat): ν C=O 1675 cm^{-1}.

The corresponding *cis* aziridine **6a** (0.6 g., 26%) was obtained as a crystalline solid, m.p. 85-86°, upon elution with 25% ether-petroleum ether (b.p. 30-60°); nmr (deuteriochloroform): δ 1.26, t, J = 7.1 Hz (3H, methyl); 2.13-2.96, m (2H, methylene); 3.09, 3.26, two d, J = 7.0 Hz (1H each, C_2-H and C_3-H, respectively); 7.0-7.5 and 7.8-8.0, two m (10H, aromatic); ir (deuteriochlroform): ν C=O, 1666 and 1695 cm^{-1}.

Anal. Calcd. for $C_{17}H_{17}NO$: C, 81.24; H, 6.81; N, 5.57. Found: C, 81.31; H, 6.86; N, 5.54.

The combined yield of the isomeric aziridines was 92%. The nmr spectrum of the crude material indicated the *cis*/*trans* ratio to be 1:4.

1-Isopropyl-2-phenyl-3-benzoylaziridine, *cis* and *trans* (**8a,8b**).

A sample (1.04 g., 5.0 mmoles) of chalcone was added to a solution of 1.27 g. (5.0 mmoles) of iodine and 0.875 g. (25.0 mmoles) of isopropylamine in 25 ml. of benzene. The solution was stirred for 6 hours. The yellow oil remaining after work up was chromatographed on Silica Gel (25 g.) and initially eluted with low boiling (30-60°) petroleum ether (150 ml.). Subsequent elution with 200 ml. of 2% ether-petroleum ether (b.p. 30-60°) (1.2 l.) afforded 0.795 g. (67%) of pure *trans*-1-isopropyl-2-phenyl-3-benzoylaziridine (**8b**) as a pale yellow oil which rapidly decomposed even when refrigerated; nmr (deuteriochloroform): δ 0.91 and 1.18, two d, J = 6.4 Hz (6H, isopropyl methyls): 2.66-3.33, m (1H, isopropyl methine); 3.54, broad d, J = 2.8 Hz (1H, C_2-H); 3.61, d, J = 2.3 Hz (1H, C_3-H); 7.05-7.60 and 7.85-8.15, two m (10H, aromatic); ir (Neat): ν C=O, 1672 cm^{-1}.

The corresponding *cis* isomer **8a** (0.395 g., 33%) was obtained on further elution with 10% ether-petroleum ether (b.p. 30-60°). Crystalline material, m.p. 89-90°, was obtained by dilution of the

oil with pentane and cooling; nmr (deuteriochloroform): δ 1.20, d, J = 6.0 Hz (6H, isopropyl methyls); 1.86, m (1H, isopropyl methine); 3.13, d, J = 7.4 Hz (1H, C_2-H); 3.27, d, J = 7.2 Hz (1H, C_3-H); 7.0-7.5 and 7.8-8.0, two m (10H, aromatic); ir (carbon tetrachloride): ν C=O, 1665 and 1690 cm^{-1}.

Anal. Calcd. for $C_{18}H_{19}NO$: C, 81.74; H, 7.22; N, 5.26. Found: C, 81.70; H, 7.85; N, 5.37.

The *cis* and *trans* aziridines **8a** and **8b** were isolated in 90% yield. The *cis*/*trans* ratio of 1:2 was not appreciably altered when the reaction was conducted in ether. In methanol as solvent, the percentage of the *cis* and *trans* forms were determined to be *ca.* 23:77, respectively, from the nmr spectrum of the crude material.

Method A.

General Procedure for the Synthesis of Epimeric Methyl 1-Alkyl-2-(*p*-biphenyl)-3-aziridine Carboxylates Employing Different Solvents.

1) In Benzene (21).

A solution of methyl 2,3-dibromo-3-(*p*-biphenyl)-propionate (**10**) (17) dissolved in benzene was treated with a 15-fold excess of alkylamine, where alkyl = isopropyl or cyclohexyl. After being stirred for 48 hours at room temperature, the reaction mixture was diluted with ether, the precipitated amine salt removed by filtration, and the soltuion evaporated to dryness under reduced pressure without heating. The residue was recrystallized from methanol to afford 55 and 56% of the respective *trans*-carboxylates.

Flash evaporation of the methanol filtrate yielded an oil which was diluted with low-boiling (b.p. 30-60°) petroleum ether. Cooling produced 45 and 44% of the respective *cis*-carboxylates (22).

2) In Methanol.

A suspension of **10** in methanol containing a 15-fold excess of alkylamine, where alkyl=isopropyl or cyclohexyl, was stirred for 48 hours at room temperature during which time all solid material eventually dissolved. The solvent and excess amine were removed under reduced pressure and without heating. The residue was then diluted with ether; the precipitated amine salt collected, the ether filtrate washed with water, and dried (anhydrous magnesium sulfate). After flash evaporation of the solvent, the crude material was examined by nmr and found to be 71% for **2a** (29% for **2b**) and 67% for **3a** (33% for **3b**) (23), respectively.

Method B.

General Procedure for the Reaction of Chalcones with Iodine and Primary Amines.

The reactions were performed with anhydrous solvents in a one-necked flask at room temperature (*ca.* 27°). The appropriate chalcone was added to a benzene or methanol solution of iodine and the primary amine of choice (see Tables I and II) and the reaction mixture was stirred until the initial red color discharged. The reaction mixtures were diluted with ether, the precipitated amine salt removed by filtration, and the filtrates were washed with water. The dried (anhydrous magnesium sulfate) extracts were evaporated to mininum volume under reduced pressure without heating and, in some instances, the residue was examined by nmr (see again, Tables I and II). With methanol as the solvent, the solutions were evaporated to dryness, diluted with ether, filtered, and then washed with water. Isolation of the *cis* and *trans* forms of the carboaziridines was accomplished either by fractional recrystallization or column chromatography.

Method C.

General Procedure for the Reaction of α-Bromochalcone (1,24) (**11**) with Primary Amines.

Two molar equivalents of the primary amine of choice was added to a stirred solution of **11** in benzene. Stirring was continued for 24 hours at which time the solution was diluted with ether and the precipitated hydrobromide salt removed by filtration through a small amount of alumina. The solvent was evaporated under reduced pressure without heating and the residue analyzed by nmr. The isomeric aziridines were separated by either fractional recrystallization or column chromatography.

Acknowledgement.

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REFERENCES AND NOTES

(1) N. H. Cromwell, R. D. Babson and C. E. Harries, *J. Am. Chem. Soc.*, **65**, 312 (1943).

(2) N. H. Cromwell and J. Caughlan, *ibid.*, **67**, 2235 (1945).

(3) N. H. Cromwell, G. V. Hudson, R. A. Wankel and P. J. Vanderhorst, *ibid.*, **75**, 5384 (1953).

(4) N. H. Cromwell, *ibid.*, **81**, 4702 (1959).

(5) D. J. Cram and F. A. A. Elhafez, *ibid.*, **74**, 5828 (1952) and references cited therein.

(6) H. E. Zimmerman and W. Chang, *ibid.*, **81**, 3634 (1959) and references cited therein.

(7) Abstracted from the Ph.D. thesis of R. C. Badger, University of Nebraska (1963); see Table I for details.

(8) N. H. Cromwell, R. P. Cahoy, W. E. Franklin and G. D. Mercer, *J. Am. Chem. Soc.*, **79**, 922 (1957).

(9) There is no evidence to indicate that the reaction proceeded by initial dehydrochlorination of the dihaloketone to afford α-iodo-*p*-phenylcrotonophenone which subsequently reacted with the amine in the normal manner. Hence, the first formed product might have been α-amino-β-chloro ketone which then closed to form aziridine.

(10a) N. H. Cromwell, *J. Am. Chem. Soc.*, **62**, 2897 (1940); (b) R. H. Jordan, R. E. Lutz and D. F. Hinkley, Jr., *J. Org. Chem.*, **16**, 1442 (1951).

(11a) P. L. Southwick and R. J. Schozda, *J. Am. Chem. Soc.*, **81**, 1442 (1959); (b) P. L. Southwick and W. L. Walsh, *ibid.*, **77**, 405 (1955).

(12a) N. H. Cromwell, F. H. Shumacher and J. L. Adelfang, *ibid.*, **83**, 974 (1961); (b) N. J. Leonard, R. Y. Ning and R. L. Booth, *J. Org. Chem.*, **30**, 4357 (1965).

(13) P. L. Southwick and D. R. Christman, *J. Am. Chem. Soc.*, **74**, 1886 (1959).

(14) Abstracted from the Ph.D. thesis of E. Doomes, University of Nebraska (1968).

(15) N. H. Cromwell and R. J. Mohrbacher, *J. Am. Chem. Soc.*, **75**, 6252 (1963).

(16) D. L. Nagel, P. B. Woller and N. H. Cromwell, *J. Org. Chem.*, **36**, 3912 (1971).

(17) P. B. Woller and N. H. Cromwell, *ibid.*, **35**, 888 (1970).

(18) A. Padwa and W. Eisenhardt, *J. Am. Chem. Soc.*, **90**,

2442 (1968).

(19) J. J. Sundborough and K. J. Thompson, *J. Chem. Soc.*, **83**, 671 (1903).

(20) The mixture **4a** and **4b** has a satisfactory elemental analysis.

(21) For the epimers of methyl 1-*t*-butyl-2-phenylaziridine carboxylate the procedure is identical except that methyl 2,3-dibromo-3-phenylpropionate is used in lieu of **10**.

(22) Here the yields given are yields of the two geometrical isomers relative to one another with the net yield in each instance being 81%.

(23) For **1a** and **1b** the products were isolated and were found to be 84% and 16%, respectively.

(24) N. H. Cromwell and D. J. Cram, *J. Am. Chem. Soc.*, **65**, 301 (1943); N. H. Cromwell and R. S. Johnson, *ibid.*, **65**, 316 (1943).

(25) N. H. Cromwell and M. A. Graff, *J. Org. Chem.*, **17**, 414 (1952).

(26a) P. L. Southwick and R. J. Schozda, *J. Am. Chem. Soc.*, **82**, 2888 (1960) and references cited therein; (b) Reference (4).

(27) N. H. Cromwell and R. J. Mohrbacher, *J. Am. Chem. Soc.*, **72**, 6252 (1953).