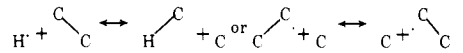
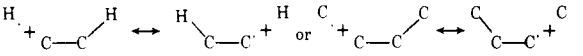
J. Chem., **48**, 955 (1970). Hedaya has reviewed his use of the method on other types of organic intermediates: E. Hedaya, *Acc. Chem. Res.*, **2**, 367 (1969).
(10) T. Koenig, T. Balle, and W. Snell, *J. Am. Chem. Soc.*, **97**, 662 (1975); T. Koenig, R. Wielesek, T. Balle, and W. Snell, *ibid.*, **97**, 3225 (1975).
(11) The interpretation of the spectra of **5** and **6** are unimportant for the present purposes and will be discussed in a future publication.
(12) The temperatures required for complete reaction of **5** or **6** are ca. 200 °C higher in our system than those reported in ref 2b. The pyrocatechol carbonate was unreactive in our system.
(13) Sharp bands for CO at 14.01 ($^2\Sigma_g^+$), 16.54 (ν 1600 cm^{-1}, $^2\Pi_u$), and 19.69 eV ($^2\Sigma_u$) were present starting with either **5** or **6**. D. Turner, C. Baker, A. Baker, and C. R. Brundle, "Molecular Photoelectron Spectroscopy", Wiley-Interscience, New York, N.Y., 1970, p 49.
(14) (a) Sharp bands for SO at 10.38 eV (lit.[14b] 10.34 μ) (ν 1210 cm^{-1}, $^2\Pi$) and 14.96 eV (lit.[14a] 14.96 eV) (ν 970 cm^{-1}) were present in the spectra of **5** at intermediate temperatures. (b) N. Jonathan, D. J. Smith, and K. J. Ross, *Chem. Phys. Lett.*, **9**, 217 (1971).
(15) The resolution during the pyrolysis of **6** (30 meV) was better than that during the pyrolysis of **5** (60 meV), which gives some differences in the appearance of the peak shapes.
(16) P. J. Derrick, L. Åsbrink, O. Edquist, and B.-Ö. Jonsson, *Int. J. Mass Spectrom. Ion Phys.*, **6**, 203 (1971); *Spectrochim. Acta, Part A*, **27**, 2525 (1971). The main vibrational spacing in the first band of **3** is ~1400 cm^{-1}, like that of cyclopentadiene. There are also lower frequency spacings present in this band which have not been completely resolved for **3** though they have been for cyclopentadiene. The main vibrational spacing of the second band in the spectrum of **3** is ~800 cm^{-1}, like that observed for the n_0 band of most ketones. Our criterion of assignment is like that used[5a,6] make the difficult choice of the ground state of the tropone radical cation as Π ($^2B_1$, $\tilde{\nu}$ ~1530 cm^{-1}, IP$_{obsd}$ 8.89 eV) under n_0 ($^2B_2$, $\tilde{\nu}$ ~830 cm^{-1}, IP$_{obsd}$ 9.25 eV). See ref 18.
(17) W. T. Simpson, *J. Am. Chem. Soc.*, **75**, 597 (1953); W. T. Simpson and C. W. Looney, *ibid.*, **76**, 6285, 6293 (1954); R. A. Wielesek and T. Koenig, *Tetrahedron Lett.*, 2429 (1974).
(18) (a) The entire assignment scheme proposed here should be regarded as tentative and is certainly not rigorously established by the experimental information available. Indeed, a referee has suggested that the assignments of the first and second bands be reversed. The primary basis of his argument is that the spacing of the two Π bands of the spectrum of **3** should be the same as observed for cyclopentadiene (2.0 eV). Taking the 12 eV band of **3** as Π_s ($^2B_1$) would then put the Π_a ($^2A_2$) band at 10.0 eV. We strongly disagree with the postulate. The spacing of the two Π bands of **3** could only *fortuitously* be the same as cyclopentadiene. The interaction constant for the CH_2 pseudo Π group and a neighboring olefinic group is +1.74 eV[20] while that between an exocyclic Π ion (like the carbonyl) and an adjacent transoid Π group should be +1.44 eV (e.g., butadiene). The bond ionization potential of a carbonyl can be taken directly from the observed spectrum of formaldehyde, 14.4 eV. This difference in interaction parameters for a $\underline{C}H_2$ vs. C=O group with an olefin should be magnified by a factor of ca. $\sqrt{2}$ (~0.4 eV) in the observed splitting between the Π_a and Π_s bands. To be sure, the polar character of the CO group is problematical, but there is no good reason to expect that this effect would just reduce the split back to the value of the hydrocarbon. Similar additivity arguments have been used in a recent review[18b] where the Π band position of acetone is placed at 13.4 eV (vertical). This assignment may be correct but the argument made for it[18b] is highly questionable. Additivity would certainly not be expected of a hyperconjugative origin of the shifts with methylation. The Π bond ionization potential of the *localized* carbonyl group of **3** should certainly be closer to that of formaldehyde (14.4 eV) than that of acetone. (b) J. L. Meeks, H. J. Maria, P. Brint, and S. P. McGlynn, *Chem. Rev.*, **75**, 603 (1975).
(19) Following the arguments of ref 5b the appropriate HMO coefficients for the diene unit are 0.602 and the inductive shift is given as $2C_{ij}^2$ (3.14 eV) = 2.27 eV. This increment is added to the observed first ionization potential of cyclopentadiene (8.56 eV).
(20) T. Koenig and H. R. Longmaid, *J. Org. Chem.*, **39**, 560 (1974).
(21) J. A. Pople, D. A. Beveridge, and P. A. Dobosh, *J. Chem. Phys.*, **47**, 2026 (1967).
(22) R. C. Benson, W. H. Flygare, M. Oda, and R. Breslow, *J. Am. Chem. Soc.*, **95**, 2772 (1973).
(23) M. Rouault and Z. L. Waziutynaska, *Acta Crystallogr.*, **10**, 804 (1957).
(24) C. L. Norris, R. C. Benson, P. Beak, and W. H. Flygare, *J. Am. Chem. Soc.*, **95**, 2766 (1973).
(25) The elements of the energy matrix for this approximate calculation include the bond ionization potentials for the C–C and C–H σ bonds involving "sp^2" hybridized carbon atoms. These values were 17.65 and 17.17 eV, respectively. The n_0 lone pair diagonal value was 12.62 eV, the value for the $^2B_1$ ionization potential for water. The geminal interaction constants were



+2.31 and +2.62 eV. The vicinal interaction constants were $S_{CH,CC}$ =



$S_{CH,CH} = S_{CC,CC} = 0.25 + 0.75 \cos\Theta$, where Θ is the dihedral angle between the interacting bonds. The hyperconjugative interaction constant between the oxygen vacancy structure (**1d**) and that with the vacancy in an adjacent C–C bond (**1c**) was +2.5 eV. These values arise from the SR analysis of smaller molecules such as ethylene and formaldehyde.
(26) P. Eaton and R. Hudson, *J. Am. Chem. Soc.*, **87**, 2769 (1965).
(27) A. Greene, *J. Chem. Soc.*, 500 (1927).
(28) R. Willstäter and A. Pfannenstile, *Chem. Ber.*, **37**, 4744 (1904).
(29) D. C. DeJongh and D. A. Brent, *J. Org. Chem.*, **35**, 4204 (1970).

Addition of Nitronic Esters to Alkynes. Formation under Kinetic Control of Aziridine Invertomers. Study of the Transposition of 4-Isoxazolines to Acylaziridines

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Abstract: The addition of nitronic esters **1** and **2** to alkynes has been studied. This reaction which leads to *N*-methoxyaziridines is stereospecific for the nitrogen atom; the *Z* nitronic esters give only two aziridines which differ in the configuration of the ring carbon atoms. The *E* isomers give quantitatively two other aziridines, which are invertomers of the two *Z* nitronic esters products. A two step mechanism is suggested for this reaction. Each of the isomeric 1,3 dipoles leads under kinetic control to only one of the two diastereoisomeric 4-isoxazolines which in turn isomerize stereospecifically to aziridines. In these examples, a study of the transposition of 4-isoxazolines to acylaziridines has been realized stereochemically for the first time. The various possible mechanisms are discussed. 1,3-Sigmatropic shifts with retention of configuration at the migrating nitrogen atom seems most probable. However, a mechanism involving the intermediacy of biradicals may not be completely ruled out.

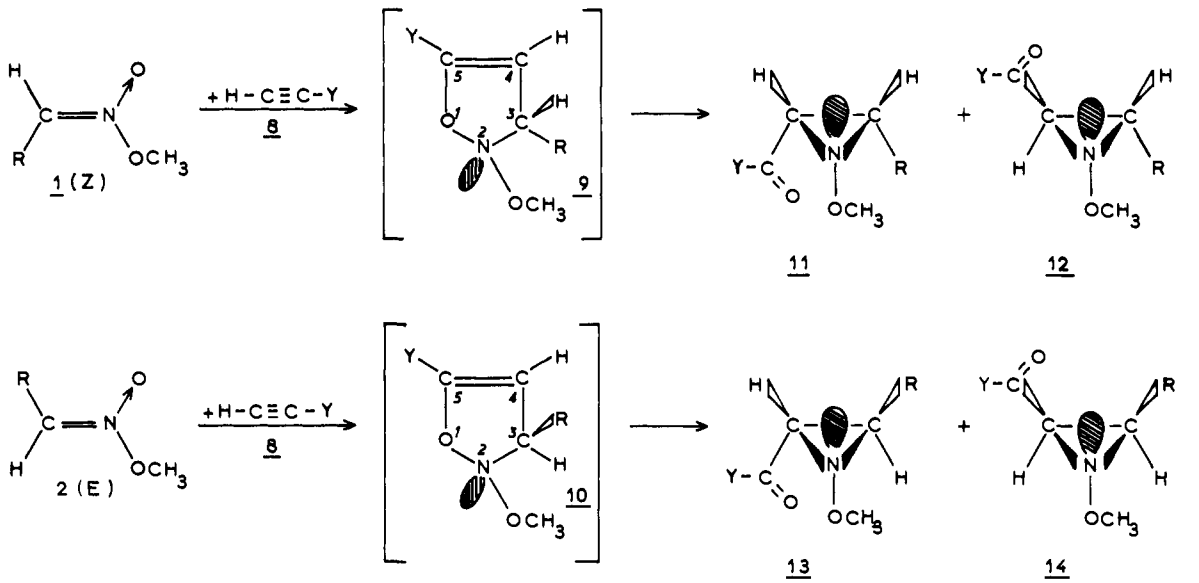
Baldwin et al.[2] have shown that 1,3-dipolar cycloadditions of nitrones to alkynes lead to 4-isoxazolines which rearrange easily to acylaziridines. Very few additional reports have dealt specifically with this reaction[3] and in particular its stereochemistry has never been studied. The major complication is that 4-isoxazolines generally exhibit only one asymmetric center owing to fast nitrogen inversion under the conditions of rearrangement.

We have previously shown[4] that 1,3-dipolar addition of nitronic esters to alkenes takes place with formation under kinetic

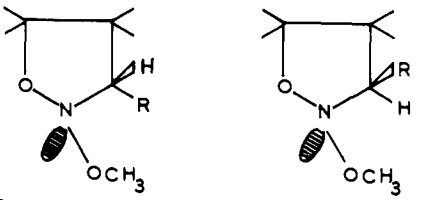
Table I. Relative Proportions of Aziridines

	Percent of **11** from **1**			Percent of **13** from **2**		
	Y			Y		
R	COC_6H_5	$COCH_3$	CO_2CH_3	COC_6H_5	$COCH_3$	CO_2CH_3
CN	96	96	Ref. 8	19	20	Ref. 8
CO_2CH_3	94	88	75	36	38	45

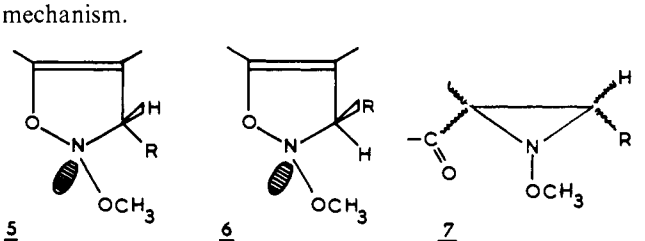
Scheme I. Nitronic Esters Addition to Alkynes



control of *N*-alkoxyisoxazolidines which are stable invertomers. Thus, *Z* nitronic esters **1** lead exclusively in all cases to heterocycles **3** (R and OCH_3 in cis position) while *E* isomers **2** give only compounds **4** (R and OCH_3 in trans position).



The addition of nitronic esters to alkynes that we report herein was undertaken with the following objectives: (a) synthesis of diastereoisomeric 4-isoxazolines **5** and **6** in which the nitrogen atom is a second asymetric center, and (b) study of the stereochemistry of the rearrangement of these isoxazolines to acylaziridines **7** in an attempt to elucidate the reaction mechanism.



Results

The configurations of the nitronic esters were established previously.[5] It has also been shown that these compounds are not isomerized under the conditions of the cycloaddition reaction with mono- and diactivated olefins.[4a,6] It is known that nitronic esters react with acetylenic compounds to give *N*-methoxyaziridines, but the stereochemistry of this reaction has not been studied.[7]

We have observed that this reaction is fully stereospecific, with each isomeric nitronic ester leading to different invertomers of the aziridines (Scheme I).

The 1,3 dipoles **1** add to alkynes **8** to give quantitatively (NMR analysis) acylaziridines **11** and **12** (R and OCH_3 in cis position), while isomers **2** give only compounds **13** and **14** (R and OCH_3 in trans position).

The stereoselectivity of this reaction has been established by using either pure nitronic esters **2** or mixtures of **1** + **2** of known composition,[5] in the latter case, the ratios ((**11** + **12**)/(**13** + **14**)) were always identical (as determined by NMR) with the ratios of the starting isomeric 1,3 dipoles.

These reactions were run at room temperature and the proportions of the aziridines resulting from each isomeric 1,3 dipole are given in Table I. They were determined by NMR integration of the crude reaction mixtures (C_6D_6 solutions).

It has not been possible to isolate or even to obtain spectroscopic evidence of the 4-isoxazolines, but their existence as intermediates allows, as we shall see, a logical interpretation of the reaction course.

Stereochemistry of the Aziridines

Aziridines bearing a halide, alkoxy, or amino substituent on the nitrogen atom may exist as stable invertomer forms.[9] In the case of *N*-alkoxyaziridines the inversion barriers are especially high.[10] We shall first establish the stereochemistry of the four isomeric aziridines **11a–14a** (R = CN; Y = COC_6H_5); the stereochemistry of the other aziridines will follow by analogy.

The physical characteristics of the four aziridines **11a–14a** are given in Table II. The signals of the ring protons H_α and H_β were assigned by using selectively deuterated nitronic esters;[6] H_α which is bonded to the carbon atom bearing the R substituent was always the more shielded.

Table II. Spectroscopic Data of Aziridines **11a–14a**

Compd	F, °C	NMR[a] δ_{H_α}	δ_{H_β}	$J_{\alpha\beta}$, Hz	δ_{OCH_3}	IR, cm^{-1} [b]
						2260
11a	56	1.88	3.10	7.4	3.16	1705
						1672
						2250
12a	95	2.74	3.72	5.6	3.32	1704
						1666
						2255
13a	90	2.87	3.25	5.6	2.87	1706
						1664
						2254
14a	95	2.23	3.51	8.4	3.16	1700
						1664

[a] In parts per million from Me_4Si, solvent C_6D_6. [b] $\nu C{=}O$ and $\nu C{\equiv}N$.

Through assessment of coupling constants it proved to be possible to distinguish between the aziridines having H_α and H_β protons in cis position ($J_{\alpha\beta}$ = 7.4 and 8.4 Hz) and their trans isomers ($J_{\alpha\beta}$ = 5.6 Hz). J values of the same magnitude have been found for *N*-chloro- and *N*-aminoaziridines.[11]

The stereochemistry at nitrogen in **12a** was established by x-ray analysis.[12] The OCH_3 group bonded to the nitrogen atom is in cis position with respect to the CN group and trans to the $COCOC_6H_5$ (Scheme I). The stereochemistry of its invertomer **13a** is then self-evident.

For **11a** and **14a,** stereochemistry was assigned as with the *N*-chloroaziridines[13] by examining the relative stability of the two invertomers. The most sterically crowded **11a** leads quantitatively to a mixture of the three other aziridines after being heated for 5 h in refluxing toluene,[14] **14a** (25%), **12a** (49%), and **13a** (16%).

At equilibrium, NMR analysis indicated the absence of **11a.** Thus it seems reasonable to assign it the indicated structure. It should be noted that **11a** and **14a** exhibit different coupling constants. The observed $J_{\alpha\beta}$, as in the case of *N*-chloroaziridines,[11a] is smaller when the protons are cis to the lone pair on nitrogen.[15]

The other aziridines **11–14** exhibit the same characteristics and in particular reveal the following general features: $J_{\alpha\beta}^{trans}$ are smaller than $J_{\alpha\beta}^{cis}$; $J_{\alpha\beta}$ of aziridines **11** are smaller than for aziridines **14;** aziridines **11** are invariably thermodynamically less stable.

The NMR data for these compounds are given in Table III. The assignments H_α and H_β are based on the use of deuterated nitronic esters. All of these aziridines (except **11b**) were characterized only by NMR: it did not prove possible to crystallize them and attempted thin layer chromatographic purification led to decomposition.

Thus, each 1,3 dipole yields two aziridines, one having cis hydrogen atoms ($J_{\alpha\beta}$ = 7.4–9.2 Hz) and the other trans ($J_{\alpha\beta}$ = 5.6 Hz). The large similarity of their NMR properties with those of **11a–14a** led us to assign them the same stereochemistry for the nitrogen atom.

Intermediate Formation of Two Diastereoisomeric 4-Isoxazolines

It seems a priori difficult to admit that the nitronic esters **1** and **2** and the alkynes **8** lead directly in one step to the aziridines **11–14.** The stereoselectivity of this reaction implies the intermediate formation of two diastereoisomeric 4-isoxazolines which were assigned the structures **9** and **10** for the following reasons. The addition of nitrones to alkynes to give 4-isoxazolines and their subsequent rearrangement to acylaziridines is well known in the literature.[2,3] Nitronic esters add to activated alkenes with formation, under kinetic control, of only one invertomer of an isoxazolidine.[4] It seems reasonable to assume that the same process occurs with alkynes **8** so that **1** leads only to **9** (R and OCH_3 cis) and **2** leads to **10** (R and OCH_3 trans). These two heterocycles are then diastereoisomers and this allows a differentiation between the behavior of the two isomeric 1,3 dipoles.

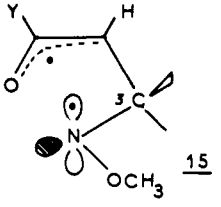
Nitrogen stereochemistry in these 4-isoxazolines was assigned by analogy with the corresponding isoxazolidines.[4] This is also in agreement with the interpretation given for the formation of only one invertomer under kinetic control, which was shown to be independent from the dipolarophile.[4]

Finally, it should be noted that primary 1,3 dipolar cycloaddition is regiospecific in agreement with theoretical predictions. As in the case of monoactivated alkenes,[4] the observed orientation is the same as that predicted by perturbation theory restricted to the frontier orbitals.[17]

Mechanism of the Rearrangement

The rearrangement of vinylcyclopropane to cyclopentene has been extensively studied;[18] 1,3 sigmatropic migrations allowed or forbidden by the symmetry rules, or processes going through biradicals, may be involved. In the case of the rearrangement of 4-isoxazolines to acylaziridines, two points may be noted. (a) The reaction is a ring contraction. This is probably due to the weakness of the N–O bond; examination of the molecular models shows also that these heterocycles are highly strained. (b) The migrating atom is a nitrogen, and little is known about stereoselectivity in the case of migrating heteroatoms. However, it may be expected that they introduce an important perturbation during 1,3 sigmatropic processes, as has been discussed for substituents of various "polarities".[19]

Biradical Mechanism. In order to examine the reaction from this point of view, it is necessary to make some assumptions relating to the structure and properties of the biradical. Two extreme possibilities may prevail. (a) The biradical is of type **15** with a planar structure at the nitrogen and rotation occurs



15

freely around the C_3–N bond. If so, the biradical mechanism is excluded because the results imply a retention of relative configuration at the nitrogen atom and the neighboring C atom during the rearrangement. Structure **15** seems reasonable a priori, because the *N*-alkoxy aminyl radicals have been shown to be planar.[20] (b) The biradical is not planar at nitrogen and exhibits some particular dynamic properties[18j,k] (continuous biradical). In this case, the biradical mechanism may not be ruled out but several drastic conditions have to be satisfied. Scheme II shows that the configuration change (C_3 and N) would result from a nitrogen inversion followed by a rotation around C_3–N bond (or rotation followed by inversion).

In order to explain the observed retention of configuration (at C_3 and N) it would be necessary either that ring closure to aziridine arises faster than the inversion rotation process of biradical **16** or that the nitrogen inversion barrier is high enough, such that only rotation takes place before the formation of the aziridine.

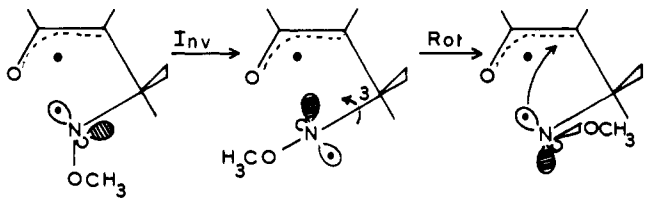
Another problem relating to the "continuous biradical" hypothesis is the question of preferred rotation of this biradical (Scheme III) in contrast to the case studied by Doering[18k] and the bicycloheptene examples;[21] rotation occurs preferentially at the more sterically crowded side, so that the R and COY groups are in cis position in the aziridines. This is particularly

Table III. NMR Data of Aziridines 11–14[a]

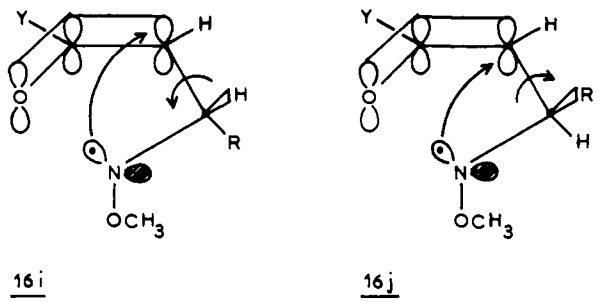
	11b	12b	13b	14b	11c	12c	13c	14c	11d	12d	13d	14d	11e	12e	13e	14e
δ_{H_α}	1.91	2.86	3.10	2.73	2.82	*b*	3.80	3.14	2.80	*b*	3.54	2.97	2.93	*b*	3.60	3.06
δ_{H_β}	2.91	3.98	3.74	3.85	3.28	4.27	3.96	3.66	2.93	4.36	3.93	3.39	3.02	4.20	3.84	3.42
$J_{\alpha\beta}$	7.4	5.6	5.6	8.4	7.9	5.6	5.6	9.0	8.0	5.6	5.6	9.0	7.8	5.6	5.6	9.2

[a] In parts per million from Me_4Si, J in Hz, solvent C_6D_6. [b] Reference 16.

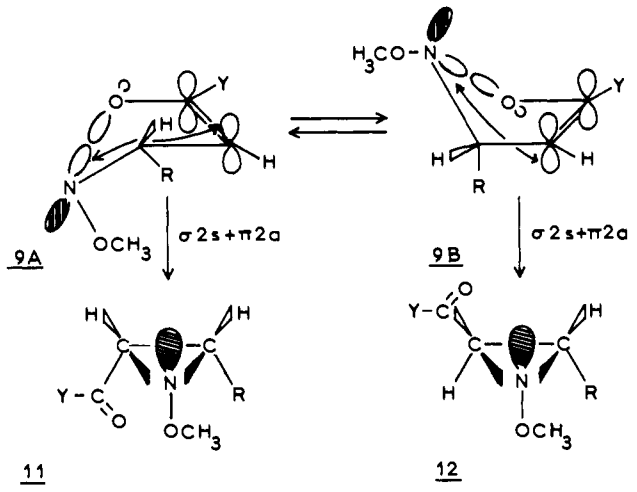
Scheme II. Interconversion of Nonplanar Nitrogen Radicals 16



Scheme III. Preferred Rotations During the Ring Closure of Biradicals 16



Scheme IV. 1,3 Sigmatropic Rearrangements of 4-Isoxazolines under Conformational Equilibrium



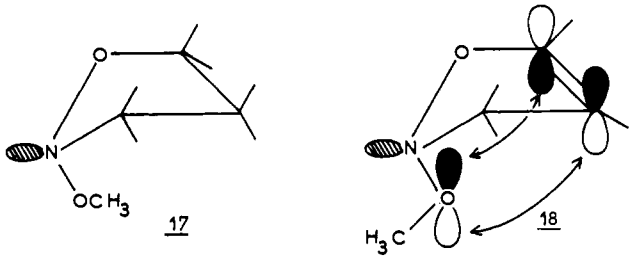
striking in the case of the biradical **16i** which leads with great selectivity to aziridines **11** bearing three substituents on the same side of the ring. Therefore, some other factors would need to be found to explain the stereoselectivity of aziridine formation.

A biradical mechanism therefore does not appear to be very likely in the present case. The kinetic studies of Huisgen and Niklas with other 4-isoxazolines are also not in agreement with such a mechanism.[3i]

Sigmatropic Mechanism. A mechanism involving 1,3 sigmatropic shifts appears to be in better agreement with the observed results. The 4-isoxazolines (**11–14**) contain only two asymmetric centers and, in order to discuss this mechanism, it is necessary to make a further assumption. Two possibilities exist.

A. These 4-isoxazolines adopt a preferred conformation of nearly "envelope" type and may enter into conformational equilibration without nitrogen inversion.[22] In this case it is possible to obtain the aziridines by $[\sigma 2_s + \pi 2_a]$ processes allowed by the Woodward–Hoffmann rules.[23] This is shown in Scheme IV for the case of isoxazoline **9**: from **9A**, aziridine **11** is formed and by the same process aziridine **12** results from **9B**, These two reactions take place with retention of configuration at the migrating nitrogen atom. In the same way the diastereoisomeric 4-isoxazoline **10** gives **13** and **14**. By combining, in the appropriate way, the rates of equilibration and cyclization, it is therefore possible to explain the stereoselectivity in aziridine formation. In particular (and this differs from the biradical mechanism), the formation of the more sterically crowded aziridines (**11** for instance) as the major products can be rationalized.

However, we have previously observed[4] that *N*-alkoxy isoxazolidines adopt, as a result of the anomeric effect,[24] conformations of the type **17**, with the OCH_3 group in the axial



position. This thermodynamic preference should again be of consequence in the related unsaturated cycles as has been observed for pyranoses.[25] In the 4-isoxazoline examples there is also another possibility for stabilization of this conformation due to an interaction of the p lone pair of the oxygen atom with the unoccupied orbital of the cyclic double bond **18**. So it becomes necessary to discuss another possibility for the mechanism of the rearrangement.

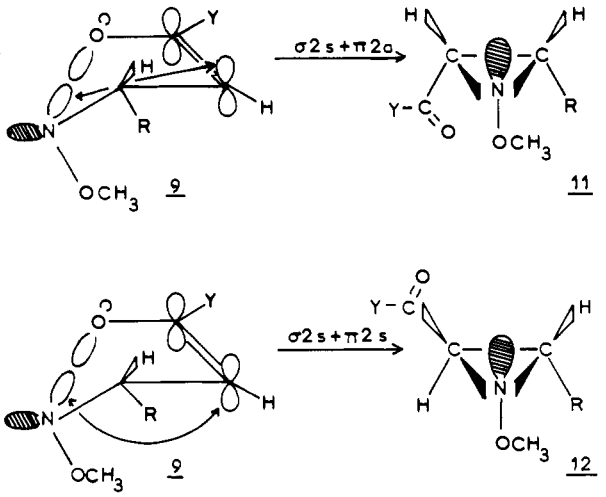
B. These 4-isoxazolines adopt restricted conformations, such that the OCH_3 group is always axially positioned. In this case, the formation of different aziridines is explained by a competition between $[\sigma 2_s + \pi 2_a]$ processes (allowed) and $[\sigma 2_s + \pi 2_s]$ (forbidden by the Woodward–Hoffmann rules) as shown in Scheme V for **9**.

The $[\sigma 2_s + \pi 2_a]$ process leads to aziridine **11** and isomer **12** is obtained by the $[\sigma 2_s + \pi 2_s]$ pathway. The allowed reaction is predominant (80–96% of **11**). In the same way, starting from isoxazolidine **10** we obtain aziridines **13** and **14**. In this case, the forbidden process predominates (55–81%).

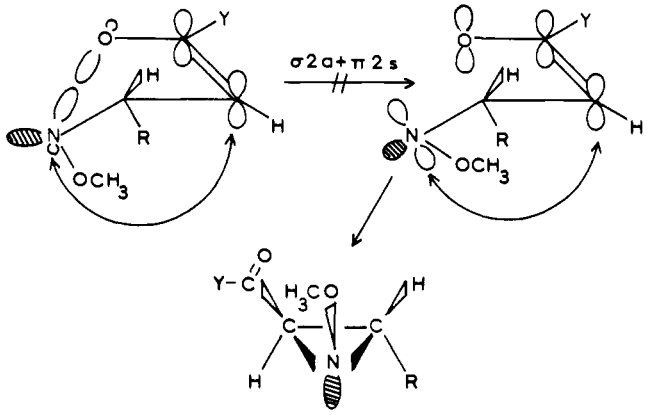
This mechanism, although it implies forbidden reactions, appears plausible. The occurrence of forbidden processes has already been theoretically explained.[26] Owing particularly to the presence of heteroatoms, the various factors which may apply in the present case are the role of lower lying orbitals,[26a] the dissymmetry of the allylic system,[26a] and the "polarity" difference between the migrating group and the center to which it migrates.[19]

The notion of a locked conformation also permits rationalization for the absence of the $[\sigma 2_a + \pi 2_s]$ process which is allowed and often observed in 1,3 sigmatropic reactions.[27] In such a process, the axial OCH_3 group may be directed toward

Scheme V. 1,3 Sigmatropic Rearrangements in the Case of 4-Isoxazoline 9 Having a Blocked Conformation



Scheme VI. Lack of $[\sigma 2_a + \pi 2_s]$ Process for 4-Isoxazoline 9 Having a Blocked Conformation



the inside of the ring (Scheme VI in the case of **9**) and this would result in a significant steric strain. This result is in agreement with that found by Berson in the rearrangement of bicycloalkenes.[27]

Conclusion

The reaction of nitronic esters with various alkynes allows the stereoselective synthesis of invertomers of *N*-methoxyaziridines. The rehybridization of the 1,3 dipoles leads to the formation of diastereoisomeric 4-isoxazolines under kinetic control. The asymmetric center which is created at the nitrogen atom is retained during the transformation to acylaziridines. This rearrangment can be satisfactorly rationnalized in terms of 1,3 sigmatropic reactions.

Experimental Section

Melting points are uncorrected. NMR spectra were obtained with a JEOL MH 100 instrument. The IR spectra were recorded on a Perkin-Elmer 225.

Benzoylacetylene and 4-butyn-2-one were prepared by oxidation of the corresponding alcohols.[28] Methyl propiolate was obtained by reaction of diazomethane with propiolic acid.

Aziridines 11a–14a. A. Aziridines 11a and 14a. To 4 g (4 mmol) of the distilled mixture[5] of nitronic esters **1** and **2** (R = CN, 62% **1**) in CCl_4 (30 mL) was added portionwise at 0 °C benzoylacetylene (5.2 g, 40 mmol). After 12 h at 0 °C, the solvent was vacuum distilled and the mixture allowed to stand for 6 days at room temperature. The NMR spectrum of the crude mixture showed the formation of four aziridines **11a–14a.** Addition of ether (5 mL) afforded 0.75 g of aziridine **14a.** Crystallization of the residue yielded 3.75 g of a mixture of **11a** and **14a.** Fractional crystallization from ether gave 0.80 g of **14a** and 1.65 g of **11a.** Yields are based on the starting mixture of nitronic esters. **14a:** mp 95 °C (ether), 1.55 g (17% yield). Anal. Calcd for $C_{12}H_{10}N_2O_3$: C, 62.61; H, 4.34; N, 12.17. Found: C, 62.59; H, 4.42; N, 12.22. **11a:** mp 56 °C (ether), 1.65 g (18% yield). Anal. Found: C, 62.61; H, 4.40; N, 12.27.

B. Aziridines 13a and 14a. The reaction was carried out in the same way with the pure nitronic ester **2** (R = CN).[5] The NMR spectrum of the crude mixture showed the quantitative formation of **14a** (81%) and **13a** (19%). Addition of ether (10 mL) yielded aziridine **14a** (4.0 g). The oily residue crystallized slowly in the refrigerator to give 3.5 g of a mixture. Fractional crystallization from ether yielded 0.9 g of **14a** and 0.82 g of **13a. 14a:** 4.90 g (53% yield). **13a:** 0.82 g (9% yield), mp 90 °C (ether). Anal. Found: C, 62.43; H, 4.32; N, 12.19.

C. Aziridine 12a. Aziridine **14a** (2 g) was refluxed in toluene (70 mL) for 5 h to give a mixture of **12a** (49%), **14a** (35%), and **13a** (16%). Fractional crystallization from ether allowed separation of **12a** (0.50 g) and **14a** (0.3 g). **12a:** mp 95 °C (ether). Anal. Found: C, 62.70; H, 4.42; N, 12.09. All attempts to isolate or characterize 4-isoxazolines failed even at low temperature. For instance, in CCl_4 solutions (20%) at 0 °C (R = CN; Y = COC_6H_5) or at −20 °C (R = CO_2CH_3; Y = COC_6H_5), only the signals of the starting materials and the aziridines were observed on the NMR spectra.

Aziridines 11b–14b. To 3 g (30 mmol) of the distilled mixture of nitronic esters **1** and **2** (R = CN) in CCl_4 (5 mL) was added butynone (6.2 g, 100 mmol). After 10 days at room temperature, the solvent and the excess alkyne were distilled under vacuum. The NMR spectrum showed quantitative formation of **11b–14b.** Addition of ether (5 mL) gave 1.80 g of **11b.** The other isomers were not separated. **11b:** 1.80 g (36% yield), mp 79 °C (ether). Anal. Calcd for $C_7H_8N_2O_3$: C, 50.00; H, 4.76; N, 16.66. Found: C, 50.00; H, 4.84; N, 16.64.

The reaction was carried out in the same way using 3 g of **2** (R = CN). The NMR spectrum showed the formation of **13b** (20%) and **14b** (80%). Distillation gave a mixture of **12b** (12%) + **13b** (18%) and **14b** (70%): bp 110 °C (0.1 mm), 3.85 g (76% yield). Anal. Found: C, 49.81; H, 4.70; N, 16.50.

Aziridines 11c–14c. To the mixture (2.66 g, 20 mmol) of nitronic esters **1** and **2** (R = CO_2CH_3, 60% **1**) in CCl_4 (10 mL) was added portionwise benzoylacetylene (2.6 g, 1 equiv). After 7 days at room temperature, the solvent was evaporated and a quantitative amount (NMR) of the four aziridines **11c–14c** was formed.

The nitronic ester **2** (R = CO_2CH_3) treated under the same conditions gave quantitatively **13c** (36%) and **14c** (64%). Various attempts to separate these aziridines failed.

Aziridines 11d–14d. To 2 g (15 mmol) of the mixture of nitronic esters **1** and **2** (R = CO_2CH_3) in CCl_4 (5 ml) was added butynone (3.1 g, 45 mmol). After 7 days at room temperatures, the solvent and the excess alkyne were vacuum distilled. The NMR spectrum of the crude reaction mixture showed a quantitative formation of **11d–14d.** In the same way, nitronic ester **2** (R = CO_2CH_3) led to a mixture of **13d** (38%) and **14d** (62%).

Aziridines 11e–14e. To the crude mixture of nitronic esters **1** and **2** (R = CO_2CH_3, 1 g, 7.5 mmol) was added at room temperature methyl propiolate (3.15 g, 37.5 mmol). After 10 days, the excess alkyne was removed under vacuum. The NMR spectrum indicated quantitative formation of the mixture of aziridines **11e–14e.**

In the same way, nitronic ester **2** (R = CO_2CH_3) led quantitatively to **13e** (45%) and **14e** (55%).

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(14) It has not been possible to distinguish the nitrogen inversion phenomena from the cis–trans isomerization for these aziridines, even by working at lower temperature (boiling benzene). It may be noted (a) that the formation of the three aziridines is observed at the beginning of the reaction, **11a** being always present in the mixture; (b) that the same observation is made starting from the other isomers and led to the same thermodynamic mixture; (c) that a photochemical irradiation led to the same result.
(15) We also note that, for all these aziridines, the protons which are cis with respect to the nitrogen lone pair and trans with respect to the OCH_3 group are always more shielded than the corresponding protons of the other invertomer. The same result is observed in the case of *N*-chloroaziridines[11b].
(16) The signals for these protons are masked by the signals of the ester groups.
(17) INDO calculations for these alkynes **8** show that the carbon atom bearing the hydrogen has the largest coefficients both in the HOMO and in the LUMO. A treatment similar to that described for the addition to monoactivated olefins[4a] allows the orientation to be correctly predicted in all cases.
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Mechanism of the Reaction of Hexachloroacetone with Enamines. A New, Convenient Synthesis of α-Chloro Ketones, β-Chloro Enamines, and Allylic Chloro Enamines[1]

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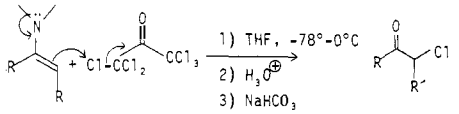
Abstract: A new, convenient preparation of α-chloro ketones by the reaction of hexachloroacetone with enamines is reported. The mechanism of this reaction has been examined and found to follow three pathways. The reaction with enamines that do not have axial α' substituents has been shown to generate solely allylic chloro enamines while the reaction with enamines containing axial α' substituents has been shown to generate β-chloroimmonium-pentachloroacetonide ion pairs. These ion pairs can be hydrolyzed directly or permitted to react at higher temperatures to generate β-chloro enamines. The regioselectivity and stereochemistry of this reaction are also discussed.

We have recently reported that hexachloroacetone (HCA) acts as a source of positive chlorine in its reactions with enamines giving, after acid hydrolysis, good yields of α-chloro ketones.[2] HCA reacts rapidly with enamines at temperatures between −78 and 0 °C while being inert toward enol ethers, alkenes, and thioethers at room temperature.[3] This mild



chlorination reaction results in regioselective α-chlorination of ketones owing to the availability of either α- or α'-enamines, thus making routes to 6-chloro-2-alkyl- or 6-chloro-3-alkylcyclohexanones quite feasible.

Enamines of cyclohexanone derivatives have been halogenated with halogens[4a,b] or *N*-halosuccinimide. While α-halo ketones do result from these procedures they are not always the methods of choice. The reaction of cyclhexanone enamines with *N*-chlorosuccinimide has been reported to give substantial amounts of dichlorinated product.[5] Published procedures for the preparation of 6-halo-2-methylcyclohexanones have, in general, not been satisfactory. Direct chlorination of 2-methylcyclohexanone with chlorine provides 2-chloro-2-methylcyclohexanone as the major isomer, *cis*- and *trans*-6-chloro-2-methylcyclohexanone, and substantial amounts of 2,6-dichloro-2-methylcyclohexanone.[6] The pyrrolidine enamines of 2-methylcyclohexanone (90% 6-methyl-1-pyrrolidino-1-cyclohexene[7]) react with bromine, sulfuryl chloride, *N*-bromosuccinimide, or *N*-chlorosuccinimide to give primarily the

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