Thermal Transformation of Alkenoylated Aziridines into Ring-Fused Pyrrolidines[1]

David Wenkert,*[2] Stephen B. Ferguson, Barry Porter, and Anders Qvarnstrom

Department of Chemistry, D-006, University of California, San Diego, La Jolla, California 92093

Andrew T. McPhail*

Paul M. Gross Chemical Laboratory, Duke University, Durham, North Carolina 27706

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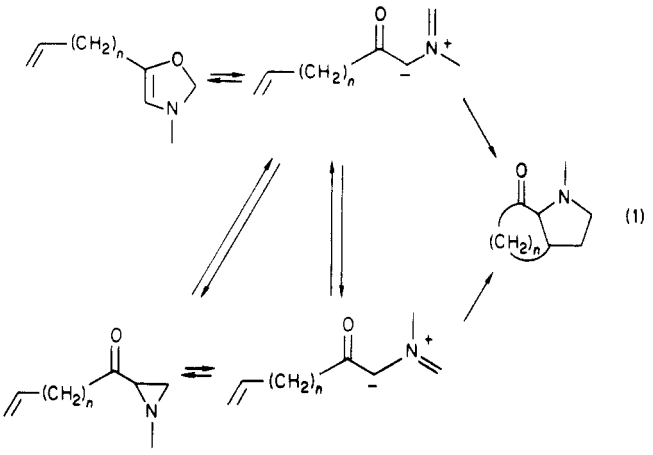
3-Phenyl- and 3-unsubstituted-2-alkenoyl-1-methylaziridines have been synthesized via Grignard reactions with the corresponding 2-cyanoaziridines. The 3-phenylated-2-alkenoylaziridines have been thermally transformed into ring-fused pyrrolidine compounds. The configurations and conformations of the aziridine and pyrrolidine compounds have been determined by ^1H and ^{13}C NMR spectroscopy and X-ray crystallography.

The pyrrolidine ring system is present in many synthetically challenging alkaloids (e.g., dendrobine, mesembrine, lycorine, and erysotrine). Although there has been much recent activity in the development of synthetic routes to these natural products, minor attention has been given to the use of one of the most conceptually simple ways of forming this five-membered ring: a [3 + 2] cycloaddition reaction of an azomethine ylid with an olefin.[3]

As part of a program in alkaloid synthesis, we have been investigating the development of a number of synthetic routes to α-alkenoylazomethine ylids and studying their intramolecular cycloaddition reactions. Among these routes are the utilization of two potential precursors of the ylids: the valence isomeric 4-oxazolines and 2-acylaziridines (eq 1). Some of our studies with the latter are reported here.



(1)

The thermal and photochemical isomerization of aziridines to azomethine ylids and the intermolecular cycloaddition reaction of the latter with deactivated olefins and acetylenes are well studied processes.[4] The intramolecular cycloaddition reaction of aziridine-derived azomethine ylids is a process that is represented by only one literature report.[5] Padwa and Ku found that 1-alkyl-3-(4-biphenylyl)aziridine-2-carboxylates thermally underwent intramolecular cycloaddition when an olefin having an attached deactivating carbomethoxy group was present in the molecule. No intramolecular cycloaddition could be observed in the absence of an attached deactivating group.[6]

In order to investigate the intramolecular cycloaddition reactions of the α-alkenoylazomethine ylids, appropriate 1-methyl-2-alkenoylaziridines and 1-methyl-2-alkenoyl-3-phenylaziridines were desired, the latter to serve as reaction models for these ylids given the well studied intermolecular cycloaddition reactions of 1-alkyl- or 1-aryl-2-acyl-3-arylaziridines.[4] 1-Methyl-2-cyanoaziridine (**1**) and *cis*- and *trans*-2-cyano-1-methyl-3-phenylaziridines (**2** and **3**) proved to be satisfactory starting materials for their synthesis. These nitriles were readily prepared in good yield via bromination of either acrylonitrile or cinnamonitrile, followed by treatment with aqueous methylamine and triethylamine in ethanol.

NMR spectroscopy confirmed the structures of the phenylcyanoaziridines **2** and **3** and allowed conformational assignment. An earlier, exhaustive ^1H NMR spectral analysis of 1-(trideuteriomethyl)-2-cyanoaziridine had yielded chemical shift and coupling data and had shown the compound to exist in solution as two conformers at ambient temperature.[7] The data could now be augmented by the *N*-methyl hydrogen shifts for each conformer (**1a** and **1b**). The configurations of the two cinnamonitrile-derived aziridine stereoisomers **2** and **3** could be assigned from the coupling constants of the aziridine ring hydrogens (see Experimental Section). Neither **2** or **3** appeared in more than one conformational form between room temperature and −40 °C.

Consideration of the ^{13}C NMR spectra data facilitated conformer assignment. [Spectral analysis was aided by the observed loss of the α-cyanomethine signal in the spectra of the 2-deuterio cis compound (**2-*D***), prepared by the base-induced deuteration of 2-cyano-1-methyl-3-phenyl-

(1) Presented May 30, 1984 at "The Latest Trends in Organic Synthesis Symposium" in Blacksburg, VA.

(2) Present address: Department of Chemistry, North Texas State University, Denton, TX 76203-5068.

(3) Studies of the cycloaddition reactions of azomethine ylids include, inter alia: (a) Wang, C.-L. J.; Ripka, W. C.; Confalone, P. N. *Tetrahedron Lett.* **1984**, 4613. (b) Grigg, R.; Thianpatanagul, S. *J. Chem. Soc., Chem. Commun.* **1984**, 180. (c) Grigg, R.; Aly, M. F.; Sridharan, V.; Thianpatanagul, S. *Ibid.* **1984**, 182. (d) Beugelmans, R.; Negron, G.; Roussi, G. *Ibid.* **1983**, 31. (e) Livinghouse, T.; Smith, R. *Ibid.* **1983**, 210. (f) Smith, R.; Livinghouse, T. *J. Org. Chem.* **1983**, *48*, 1554. (g) Vedejs, E.; West, F. G. *Ibid.* **1983**, *48*, 4773. (h) Padwa, A.; Haffmanns, G.; Tomas, M. *Tetrahedron Lett.* **1983**, 4303. (i) Padwa, A.; Chen, Y.-Y. *Ibid.* **1983**, 3447. (j) Kraus, G. A.; Nagy, J. O. *Ibid.* **1983**, 3427. (k) Achiwa, K.; Sekiya, M. *Ibid.* **1982**, 2589. (l) Kraus, G. A.; Nagy, J. O. *Ibid.* **1981**, 2727. (m) Grigg, R.; Jordan, M.; Malone, J. F. *Ibid.* **1979**, 3877. (n) Vedejs, E.; Martinez, G. R. *J. Am. Chem. Soc.* **1980**, *102*, 7993. (o) Reference 4. (p) Reference 5.

(4) (a) Huisgen, R.; Mäder, H. *J. Am. Chem. Soc.* **1971**, *93*, 1777 and references cited therein. (b) Marvell, E. N. "Thermal Electrocyclic Reactions"; Academic Press: New York, 1980; pp 96–105 and references cited therein.

(5) Padwa, A.; Ku, H. *J. Org. Chem.* **1979**, *44*, 255.

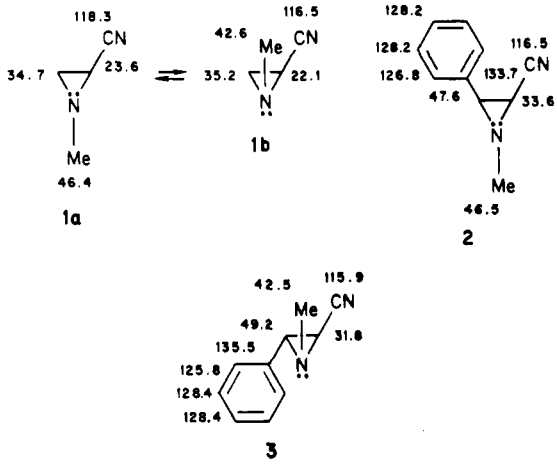
(6) Since the submission of this paper, the editor has brought to the attention of one of the authors (D.W.) a forthcoming publication (DeShong, P.; Kell, D. A.; Sidler, D. R. *J. Org. Chem.* **1985**, 0000) describing the utilization of other aziridine-2-carboxylates in intramolecular and intermolecular azomethine ylid cycloaddition reactions.

(7) Höfner, D.; Tamir, I.; Binsch, G. *Org. Mag. Res.* **1978**, *11*, 172.

0022-3263/85/1950-4114$01.50/0

aziridine (2).] The spectral data of the unphenylated compound (1) reveal the carbon signal of the sterically unencumbered aziridine *N*-methyl group of the trans conformer **1a** and the expected shielded resonances of the *N*-methyl and cyano functions of the minor isomer **1b** where the two groups are in a cis relationship (i.e., γ effect). For the 2,3-cis-disubstituted aziridine (2) the *N*-methyl shift is nearly the same as that of **1a**, while for the trans compound (3) it is nearly the same as that of **1b** (thus showing a *trans*- and a *cis*-methyl–cyano orientation for **2** and **3**, respectively). Comparison of the shift data of the two phenylated compounds (2 and 3) shows the γ-effect of the cyano group on the benzene ipso carbon in the cis isomer (2).

observed conformations

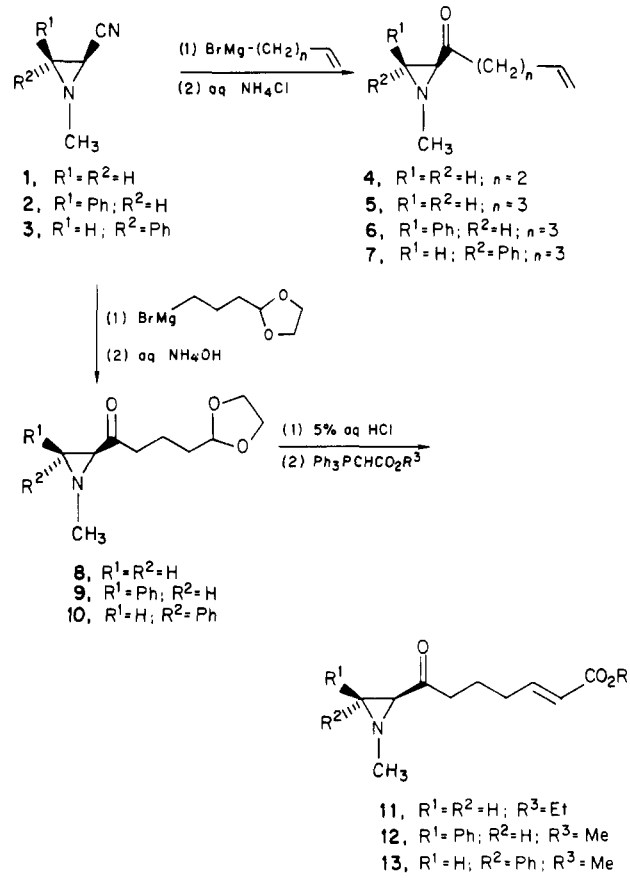


2-Acylaziridines were obtained in reasonable yield (43–77%) via the reaction of nitrile **1**, **2**, or **3** with an appropriate Grignard reagent in ether or THF/ether followed by hydrolytic workup (Scheme I). Thus when the Grignard reagent of 2-(3-bromopropyl)-1,3-dioxolane was used, keto acetals (**8**, **9**, and **10**) were obtained as products (74–77% yields). Careful acid hydrolysis of these, followed by reaction of the resulting keto aldehydes with a (carboalkoxymethylene)triphenylphosphorane gave the 2-alkenoylaziridines (**11**, **12**, and **13**) possessing an acrylic ester function (45–79% yields from the keto acetals).

NMR spectroscopy confirmed that no configurational changes had occurred during the conversion of the nitriles (**1–3**) into the acylaziridines (**4–13**). The stereochemical relationship of H-2 and H-3 was ascertained from the observed coupling constants (see Experimental Section) in concordance with earlier ^{1}H NMR studies of aziridines.[8] In contrast to the solution behavior of the nitriles, among which only the unphenylated compound (1) could be observed as two conformers in the temperature range of −40 °C to room temperature, only the phenylated 2,3-trans compounds (**7**, **10**, and **13**) showed spectrally two conformers in solution.

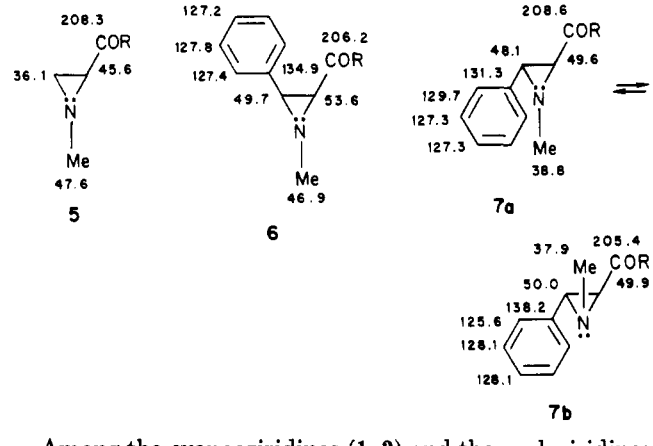
As can be illustrated for aziridines **5–7**, conformer assignments could be determined from consideration of the ^{13}C NMR spectral data,[9] particularly from revealing γ-effects on the chemical shifts of the substituents on the aziridine ring. The *N*-methyl group, at ca. 47 ppm in

Scheme I



compounds in which it faces no cisoid neighbors (**5** and **6**), is shielded on the introduction of either *cis*-phenyl or acyl groups in the two conformers of **7**. Whereas this result does not allow the differentiation of the conformers of **7**, consideration of the γ-effects on the phenyl ipso carbon and the carbonyl carbon does. The phenyl ipso carbon, at ca. 138 ppm in the cis unencumbered ketone **7b**, is shielded in substances **6** and **7a** by the cis carbonyl and methyl groups, respectively. Similarly, the carbonyl group, at ca. 208 ppm in cis unperturbed ketones **5** and **7a**, is shielded in ketones **6** and **7b** by the phenyl and methyl groups, respectively.

observed conformations



Among the cyanoaziridines (**1–3**) and the acylaziridines (**5–7**), only nitrile **1** and ketone **7** could be shown to exist in the two nitrogen inversion forms in the temperature range of −40 °C to room temperature: the nitrile at room temperature and the ketone at 0 °C and below. The **1a**:**1b** nitrile ratio at room temperature was 1.7:1 and the **7a**:**7b**

(8) Booth, H. In "Progress in Nuclear Magnetic Resonance"; Emsley, J. W., Feeney, J., Sutcliffe, L. H., Eds.; Pergamon Press: Oxford, 1969; Vol. 5, 186–194 and references cited therein.

(9) ^{1}H NMR also permits conformer assignments; e.g., the identity of the $\Delta\delta$ of H-3α between **5** and **6** and the $\Delta\delta$ of H-3β between **5** and **7b** and the nonidentity of these values with the $\Delta\delta$ of H-3β between **5** and **7b** shows conformer **7a** to possess the same methyl–acyl stereochemistry as ketones **5** and **6** (see Experimental Section).

Table I. ^{13}C NMR ($CDCl_3$) of Hydroindoles 14 and 15

carbon	14	15
C(2)	67.8	65.4
C(3)	51.9	38.6
C(3a)	43.6	41.9
C(4)	25.8	26.9
C(5)	23.3	23.8
C(6)	40.4	40.2
C(7)	213.9	214.4
C(7a)	71.3	72.6
N-CH_3	35.8	35.7
C(ipso, C_6H_5)	139.4	144.2
C(ortho, C_6H_5)	127.7	127.2
C(meta, C_6H_5)	128.2	128.1
C(para, C_6H_5)	127.3	126.7
CO_2CH_3	171.6	
CO_2CH_3	51.0	

ketone ratio at −20 °C was 1:1.9.[10] From the obtained data, it appears that the strength of a trans directing effect of a 2- or 3-ring substituent on an aziridine *N*-methyl group is thus phenyl > acyl > cyano.

Thermolytic experiments were performed on the 2-alkenoylaziridines. When degassed benzene-d_6 solutions of the 3-unsubstituted-2-alkenoylaziridines (**4**, **5**, and **11**) in sealed NMR tubes were heated at temperatures up to 200 °C for a few hours, their ^1H NMR spectra were unchanged.[11] In contrast, similarly prepared samples of the 2-alkenoyl-3-phenylaziridines (**6**, **7**, **12**, and **13**) were transformed into bicycloadducts at temperatures as low as 80 °C after a few hours. Both 2-alkenoylaziridines (**12** and **13**) when so treated at 80 °C for 10 h (or at 95 °C for 2.5–3.5 h) were transformed into a single and identical crystalline product (**14**). In like fashion, the 2-alkenoylaziridines (**6** and **7**) provided the bicycloadduct (**15**). [The facility of the reaction process could be observed by following in the ^1H NMR the disappearance of starting material signals and the appearance of product signals. Thus, when thermolyses of equimolar samples of aziridines (**6**, **7**, **12**, and **13**) were run simultaneously at 80 °C, the reactions could be seen, e.g., after 2.5 h, to have proceeded to 63–83% completion.]

The stereochemistry of the air-sensitive hydroindoles **14** and **15** could be derived from their NMR spectra and that of the first bicycle was proved unequivocally by X-ray crystallography. The coupling characteristics of the bridgehead hydrogens (J = 8 and 7 Hz for **14** and **15**, respectively) show the compounds to be cis-bicyclic substances[12] and the anomalously strong shielding of the methoxy group in hydroindole **14** indicate a cis relationship between the carbomethoxy and phenyl groups.[13] The H(3)–H(3a) coupling constant of 11 Hz for the ester (**14**) is consistent with a trans relationship between the ester α-hydrogen and its neighboring bridgehead hydrogen, a result expected on the basis of retention of configuration in the cycloaddition of the *trans*-crotonic ester moiety. A cis–trans–cis hydrogen arrangement around the pyrrolidine ring of **14** is thus suggested. Since the hydroindole **15** exhibited a large H(2)–H(3) coupling constant as one of its two J values (9 and 4 Hz), similar to that of ester **14** (10 Hz), and since the cycloaddition leading to **15** could be expected to follow the same stereochemical route as that

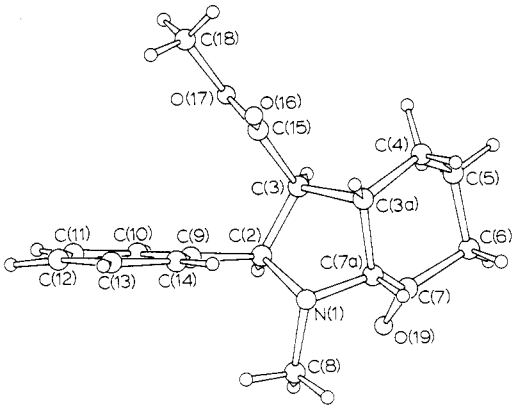
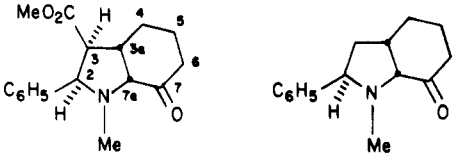


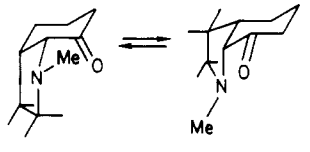
Figure 1. Structure and solid-state conformation of one enantiomer of **14**; small circles denote hydrogen atoms.

terminating in **14**, cycloadduct **15** can be ascribed the shown configuration.



14 **15**

The ^{13}C NMR spectra confirmed the configuration and allowed conformational assignment (Table I). The small variance of the *N*-methyl and cyclohexanone carbon shifts shows the identity of configuration of the two hydroindoles. The chemical shifts of the cyclohexanone α- and β-methylenes reveal the cis relationship of the two rings. Whereas C(6) is shielded only mildly (presumably because of the presence of an equatorial methylamino unit[14]), C(5) is shielded strongly when compared with sterically unencumbered cyclohexanones.[15] This implies a γ-effect by C(3) on C(5), indicates C(3) to be axially oriented in the ketonic ring, and limits the compounds to conformation **16a**. The strong shielding of the ipso carbon of the benzene ring on introduction of a carbomethoxy group onto the pyrrolidine ring shows the cis relationship of the phenyl and ester functions. Whereas such considerations leave ester **14** with two possible structures, one having an all-cis and another the cis–trans–cis pyrrolidine ring hydrogen arrangement, the incompatibility of the former structure with the cyclohexanone carbon shifts leaves only the latter as viable configurations for cycloadducts **14** and **15**.



16a **16b**

The foregoing conclusions were substantiated by the results of an X-ray analysis of racemic **14**, the crystal structure of which was solved by direct methods.[16] Re-

(10) Signal coalescence of the ^1H NMR spectrum of **7** began to occur as the temperature was raised to 75 °C. (Thermochemistry, as described, was observed to occur at higher temperatures.)

(11) Higher temperatures are required to effect cycloadditions (D. Wenkert, unpublished observations).

(12) Inter alia: (a) Eberbach, W.; Brokatzky, J.; Fritz, H. *Angew. Chem., Int. Ed. Engl.* **1980**, *19*, 47. (b) Oppolzer, W.; Keller, K. *Tetrahedron Lett.* **1970**, 1117. (c) Reference 3m. (d) Reference 5.

(13) See, e.g., ref 5.

(14) (a) Eliel, E. L.; Bailey, W. F.; Kopp, L. D.; Willer, R. L.; Grant, D. M.; Bertrand, R.; Christensen, K. A.; Dalling, D. K.; Duch, M. W.; Wenkert, E. *J. Am. Chem. Soc.* **1975**, *97*, 322. (b) Lambert, J. B.; Vagenas, A. R. *Org. Magn. Reson.* **1981**, *17*, 270.

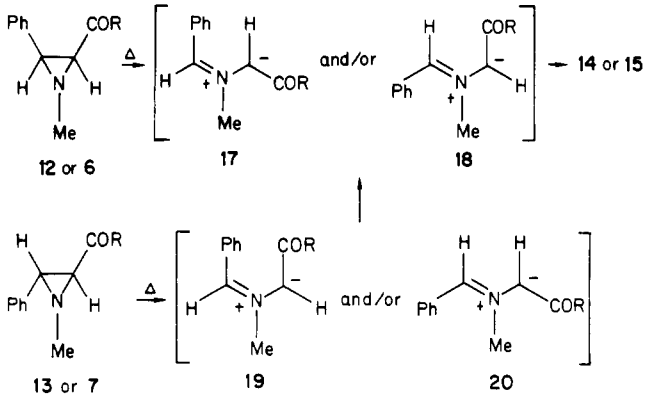
(15) (a) Fringuelli, F.; Pizzo, F.; Taticchi, A.; Halls, T. D. J.; Wenkert, E. *J. Org. Chem.* **1982**, *47*, 5056. (b) Grover, S. H.; Marr, D. H.; Stothers, J. B.; Tan, C. T. *Can. J. Chem.* **1975**, *53*, 1351. (c) Weigert, F. J.; Roberts, J. D. *J. Am. Chem. Soc.* **1970**, *92*, 1347.

(16) Main, P.; Lessinger, L.; Woolfson, M. M.; Germain, G.; Declerq, J.-P. "MULTAN76, A System of Computer Programmes for the Automatic Solution of Crystal Structures"; Universities of York and Louvain, 1976.

finement of atomic positional and thermal parameters converged to $R = 0.054$[17] over 2366 reflections. Final parameters are in Tables II–IV,[18] while bond lengths, bond angles, and torsion angles are in Tables V and VI[18] (supplementary material).

A view of the solid-state conformation of one enantiomer of **14** is provided in Figure 1. The cyclohexanone ring has a chair conformation which is slightly flattened around C(3a) in order to reduce repulsive nonbonded interactions between the methylene at C(3a) and the axial C(5) hydrogen. The pyrrolidine ring has an approximate mirror plane of symmetry passing through C(7a) and the midpoint of the C(2)–C(3) bond, and thus it has an envelope form. Adoption of this conformation results in an eclipsed arrangement around the C(2)–C(3) bond (torsion angle C(9)–C(2)–C(3)–C(15) = 2.2 (2)°) and leads to a highly significant elongation of this bond to 1.577 (2) Å compared with a more normal mean of 1.527 Å for the remaining five $C(sp^3)$–$C(sp^3)$ bonds.

For the described cycloadditions to follow a concerted reaction sequence,[4] the *cis*-acylphenylaziridines (**12** and **6**) would be expected to open to one or both of the two possible *S* azomethine ylid isomers **17** and **18**. The bicyclic products **14** and **15** could then be obtained by a direct cycloaddition reaction of either of these isomeric ylids. A conrotatory ring opening of the *trans*-acylphenylaziridines **13** and **7**, however, would result in an ylid of either a U (**19**), or more likely from steric considerations,[19] a W geometry (**20**). As neither of these can lead via direct cycloaddition to products of the observed stereochemistry, such ylids must isomerize to either of the *S* ylids (**17** or **18**) prior to the intramolecular addition reaction.



Experimental Section

Melting points were determined on a Reichert micro hot-stage melting point apparatus and are uncorrected. ^{1}H NMR spectra were measured at 90 MHz on a Varian EM-390 spectrometer or at 360 MHz on an instrument with a highly modified Varian HR-220 console, an Oxford magnet, and a Nicolet 1180-E computer system. ^{13}C NMR spectra were measured at 50.31 MHz on a Nicolet NT-200, wide-bore, broad-band spectrometer operating with an Oxford magnet in the Fourier transform mode. All NMR spectra were taken of samples in $CDCl_3$ solution and at room temperature, unless otherwise noted. Chemical shifts and coupling constants are reported in parts per million downfield from Me_4Si (internal for ^{1}H NMR and δ (Me_4Si) = δ ($CDCl_3$) + 76.9 ppm for ^{13}C NMR) and Hz, respectively. (The hydrogens and carbons of the 2-alkenoyl substituents of aziridines **4–13** are designated with a prime in their chemical shift assignments.) IR spectra were measured on a Sargent-Welch 3-200 spectrophotometer with polystyrene as external reference. Column chromatography was accomplished with either 70–30 mesh E. Merck, Inc. silica gel or 60–100 mesh Aldrich Chemical Co., Inc. florasil. Medium-pressure chromatography was accomplished with a E. Merck, Inc. Lobar size B LiChroprep Si 60 (silica gel, 40–63 μm) column connected to a Fluid Metering, Inc. pump. Chromatography with a Chromatotron was accomplished with a Model 7924 from Harrison Research, Inc. and glass rotors coated with silica gel PF-254, $CaSO_4 \cdot {}^1/_2\ H_2O$ from E. Merck, Inc.

2-Cyano-1-methylaziridine (1):[20] ^{1}H NMR ($CDCl_3$, 360 MHz) major conformer (**1a**) δ 1.64 (d, 1 H, J = 6 Hz, H-3α), 1.88 (dd, 1 H, J = 3, 6 Hz, H-2), 2.27 (d, 1 H, J = 3 Hz, H-3β), 2.40 (s, 3 H, CH_3); minor conformer (**1b**) δ 1.68 (d, 1 H, J = 3 Hz, H-3β), 2.24 (d, 1 H, J = 6 Hz, H-3α), 2.52 (dd, 1 H, J = 3, 6 Hz, H-2), 2.57 (s, 3 H, CH_3).

***cis*-2-Cyano-1-methyl-3-phenylarizidine (2) and *trans*-2-Cyano-1-methyl-3-phenylaziridine (3).** A solution of bromine (32 mL, 0.62 mmol) in 80 mL of CCl_4 was added dropwise over 40 min to a stirred solution of a cis and trans mixture of cinnamonitrile (79.6 g, 0.616 mol) in 330 mL of CCl_4 at 0 °C. After stirring overnight at room temperature, the reaction was washed with 40 mL of a concentrated aqueous solution of sodium metabisulfite. The aqueous layer was extracted with 40 mL of CCl_4 and the combined CCl_4 layers were dried (K_2CO_3) and evaporated to 163.7 g of 2,3-dibromo-3-phenylpropionitrile.

A 40% aqueous solution of methylamine (66.0 g, 0.850 mol) was added dropwise to a stirred solution of the dibromide in 750 mL of absolute ethanol at 0 °C. This was immediately followed by dropwise addition of triethylamine (158 mL, 1.13 mol). The reaction was stirred at room temperature for 5 days. Most of the ethanol was evaporated from the reaction and the remainder was taken up with 500 mL of 10% K_2CO_3. This was exhaustively extracted with CH_2Cl_2. The CH_2Cl_2 layers were dried (K_2CO_3) and evaporated to 104.5 g.

The crude product was placed on a 245-g silica gel column and eluted with 9:1 hexane–ether, and 700–800-mL fractions were taken. Upon evaporation, fraction 2 yielded 22.13 g of **3** as a liquid and the combined fractions 4–8 yielded 39.37 g of solid **2**, mp 38–57 °C. The 11.66 g obtained from fractions 1 and 3 were used for a second column chromatography on 180 g of silica gel, eluting first with 3 L of 9:1 hexane–ether and then 3 L of 5:1 hexane–ether. Fractions of 500 mL were taken. From this second chromatography, fractions 2–4 provided 7.35 g of **3** and fractions 7–11 provided 1.38 g of **2**, mp 37–56 °C.

Thus 29.48 g of *trans*-2-cyano-1-methyl-3-phenylaziridine (**3**) was obtained (30.3% from cinnamonitrile): ^{1}H NMR ($CDCl_3$, 360 MHz) δ 2.55 (d, 1 H, J = 3 Hz, H-2), 2.76 (s, 3 H, CH_3), 2.96 (d, 1 H, J = 3 Hz, H-3), 7.20–7.40 (m, 5 H, phenyl); IR (CH_2Cl_2) 2230 cm^{-1}; HRMS, m/e calcd for $C_{10}H_{10}N_2$ 158.0844, found 158.0844.

The 40.75 g (41.9% from cinnamonitrile) of *cis*-2-cyano-1-methyl-3-phenylaziridine (**2**) obtained was recrystallized from Et_2O–hexanes to provide 35.63 g (36.6% from cinnamonitrile): mp 56–58 °C; ^{1}H NMR ($CDCl_3$, 360 MHz) δ 2.30 (d, 1 H, J = 6 Hz, H-2), 2.60 (s, 3 H, CH_3), 2.84 (d, 1 H, J = 6 Hz, H-3), 7.35–7.48 (m, 5 H, phenyl); IR (CH_2Cl_2) 2245 cm^{-1}. Anal. Calcd for $C_{10}H_{10}N_2$: C, 75.92; H, 6.37. Found: C, 75.80; H, 6.22.

2-Deuterated *cis*-2-Cyano-1-methyl-3-phenylaziridine (2-*D*). Sodium (10 mg, 0.4 mmol) was added to 4 mL of CH_3CH_2OD and stirred until all the sodium had reacted. Compound **2** (200 mg, 1.26 mmol) was added and the resulting solution was stirred at 30 °C overnight. Heating of the solution was discontinued and a few milliliters of D_2O were added. The contents were then exhaustively extracted with diethyl ether. The ether was evaporated and the residue was chromatographed on a Chromatotron with a 2-mm silica gel plate with 1:1 diethyl ether–hexane as eluant to give after solvent evaporation 147 mg of 2-deuterated *cis*-2-cyano-1-methyl-3-phenylaziridine (**2-*D***), mp 46–53 °C (73.1%). Recrystallization from Et_2O–hexane provided 123 mg (61.1%): mp 54–58 °C (mp of **2** 56–58 °C; mixed mp 56–58 °C); ^{1}H NMR ($CDCl_3$) δ 2.56 (s, 3 H), 2.80 (s, 1 H), 7.32 (s, 5 H); ^{13}C NMR ($CDCl_3$) δ 46.6 (CH_3), 47.7 (C-3), 116.5 (CN), 126.9 (C-*o*-C_6H_5), 128.3 (C-*m*- and -*p*-C_6H_5), 133.7 (C-*i*-C_6H_5).

2-(3-Bromopropyl)-1,3-dioxolane. A solution of 4-bromobutanal[21] (59.1 g, 391 mmol), ethylene glycol (170 g, 2.74 mol),

(17) $R = \sum||F_o| - |F_c||/\sum|F_o|$.
(18) See paragraph at end of paper regarding supplementary material.
(19) Huisgen, R.; Mäder, H. *Angew. Chem., Int. Ed. Engl.* **1969**, *8*, 604.
(20) Gundermann, K.-D.; Burzin, K.; Sprenger, F.-J.; Schulze, H. *Chem. Ber.* **1972**, *105*, 312.

and *p*-toluenesulfonic acid (2.50 g, 13.1 mmol) in 1.3 L of benzene was refluxed with an attached Dean–Stark trap. After having been refluxed 2.75 h, 9.5 mL of water had been collected. The reaction solution was allowed to cool and K_2CO_3 (10 g) added. After stirring 10 min, the contents were washed with 10% K_2CO_3. The aqueous layer was extracted with benzene (3 × 200 mL) and the combined organic layers dried (K_2CO_3) and evaporated to 82.44 g. This was distilled ((0.025 mmHg) 45–51 °C) to provide 69.1 g of 2-(3-bromopropyl)-1,3-dioxolane (90.5%): ^{1}H NMR ($CDCl_3$, 90 MHz) 1.65–2.15 (m, 4 H, $BrCH_2CH_2CH_2$), 3.43 (t, 2 H, J = 6 Hz, CH_2Br), 3.75–4.00 (m, 4 H, OCH_2CH_2O), 4.88 (t, 1 H, J = 4 Hz, O_2CH); HRMS, m/e calcd for $C_6H_{11}O_2Br$ 193.9943, found [M^+ – H] 192.9864.

Grignard Addition. Procedure A. A solution of 1.20 equiv of the 1-bromoalkene in dry Et_2O (4 mL/mmol of nitrile) stirred and refluxed under a dry nitrogen atmosphere with 1.40 equiv of magnesium turnings for 1.5 h. The resulting Grignard solution was added over 15 min via cannula to a 0 °C stirred solution of 1 equiv of the nitrile in dry Et_2O (6 mL/mmol of nitrile). After stirring 12 h at room temperature, the reaction was washed with saturated aqueous ammonium chloride solution and the aqueous layer was then exhaustively extracted with Et_2O. The combined Et_2O layers were dried (K_2CO_3) and evaporated.

Procedure B. A solution of 1.35 equiv of 2-(3-bromopropyl)-1,3-dioxolane in dry THF (0.5 mL/mmol of nitrile) was stirred under a dry nitrogen atmosphere together with 1.50 equiv of crushed magnesium turnings for 3 h at room temperature. [An ice bath was used periodically for the first 1.5 h to cool the reaction to prevent excessive warming.[22]] Dry Et_2O (1.5 mL/mmol of nitrile) was added. The Grignard solution was added over 40 min via cannula to a 0 °C stirred solution of 1 equiv of the nitrile in dry Et_2O (2 mL/mmol of nitrile). After stirring 12 h at room temperature, the reaction was washed with 10% aqueous ammonium hydroxide solution and the aqueous layer was then exhaustively extracted with Et_2O. The Et_2O layers were dried (K_2CO_3) and evaporated.

2-(4-Pentenoyl)-1-methylaziridine (4) was prepared according to procedure A (2-cyano-1-methylaziridine (1) and 1-bromo-3-butene as the nitrile and bromoalkene, respectively). Bulb-to-bulb distillation ((1.0 mmHg) oven temperature 75–85 °C) gave **4** in 62% yield: ^{1}H NMR ($CDCl_3$, 90 MHz) δ 1.53 (dd, 1 H, J = 6, 2 Hz, H-3α), 1.95–2.10 (m, 2 H, H-2, H-3β), 2.20–2.80 (m, 4 H, 2 H-2′, 2 H-3′), 2.38 (s, 3 H, CH_3), 4.85–5.15 (m, 2 H, 2 H-5′), 5.50–6.00 (m, 1 H, H-4′); IR (CH_2Cl_2) 1720, 1645 cm^{-1}; HRMS, m/e calcd for $C_8H_{13}NO$ 139.0997, found 139.0977.

2-(5-Hexenoyl)-1-methylaziridine (5) was prepared according to procedure A (2-cyano-1-methylaziridine (1) and 1-bromo-4-pentene as the nitrile and bromoalkene, respectively). Two bulb-to-bulb distillations ((0.025 mmHg) oven temperature 75–98 °C) provided **5** in 43% yield: ^{1}H NMR ($CDCl_3$, 360 MHz) δ 1.56 (d, 1 H, J = 7 Hz, H-3α), 1.60–170 (m, 2 H, 2 H-3′), 2.05 (dd, 1 H, J = 7, 3 Hz, H-2), 2.09 (d, 1 H, J = 3 Hz, H-3β), 2.00–2.10 (m, 2 H, 2 H-4′), 2.28 (ddd, 1 H, J = 17, 7, 7 Hz, 1 H-2′), 2.39 (s, 3 H, CH_3), 2.45 (ddd, 1 H, J = 17, 7, 7 Hz, 1 H-2′), 4.95–5.05 (m, 2 H, 2 H-6′), 5.70–5.85 (m, 1 H, H-5′); ^{13}C NMR ($CDCl_3$) additional δ 22.0 (C-3′), 32.8 (C-4′), 36.9 (C-2′), 114.9 (C-6′), 137.7 (C-5′); IR (CH_2Cl_2) 1695, 1640 cm^{-1}; HRMS, m/e calcd for $C_9H_{15}NO$ 153.1154, found 153.1132.

***cis*-2-(5-Hexenoyl)-1-methyl-3-phenylaziridine (6)** was prepared according to procedure A (*cis*-2-cyano-1-methyl-3-phenylaziridine (2) and 1-bromo-4-pentene as the nitrile and bromoalkene, respectively). Medium pressure chromatography with 1:3 Et_2O–hexane as eluent provided **6** in 49% yield: ^{1}H NMR ($CDCl_3$, 360 MHz) δ 1.25–1.50 (m, 2 H, 2 H-3′), 1.75 (dt, 2 H, J = 7, 7 Hz, 2 H-4′), 1.94 (ddd, 1 H, J = 17, 8, 6 Hz, 1 H-2′), 2.21 (ddd, 1 H, J = 17, 8, 6 Hz, 1 H-2′), 2.48 (d, 1 H, J = 7 Hz, H-2), 2.59 (s, 3 H, NCH_3), 2.92 (d, 1 H, J = 7 Hz, H-3), 4.80–4.90 (m, 2 H, 2 H-6′), 5.50–5.65 (m, 1 H, H-5′), 7.20–7.40 (m, 5 H, phenyl); ^{13}C NMR ($CDCl_3$) additional δ 21.8 (C-3′), 32.5 (C-4′), 39.9 (C-2′), 114.6 (C-6′), 137.7 (C-5′); IR (CH_2Cl_2) 1703, 1648 cm^{-1}; HRMS, m/e calcd for $C_{15}H_{17}NO$ (M^+ – 2H) 227.1310, found 227.1310.

***trans*-2-(5-Hexenoyl)-1-methyl-3-phenylaziridine (7)** was prepared according to procedure A (*trans*-2-cyano-1-methyl-3-phenylaziridine (3) and 1-bromo-4-pentene as the nitrile and bromoalkene, respectively). Medium pressure chromatography with 1:3 Et_2O–hexane as eluant provided **7** in 71% yield: ^{1}H NMR ($CDCl_3$, 360 MHz, –20 °C) minor conformer (**7a**) δ 1.70–1.80 (m, 2 H, 2 H-3′), 2.05–2.15 (m, 2 H, 2 H-4′), 2.18 (s, 3 H, CH_3), 2.48 (ddd, 1 H, J = 16, 7, 7 Hz, 1 H-2′), 2.63 (ddd, 1 H, J = 16, 7, 7 Hz, 1 H-2′), 2.75 (d, 1 H, J = 3 Hz, H-2), 3.53 (d, 1 H, J = 3 Hz, H-3), 4.95–5.10 (m, 2 H, 2 H-6′), 5.70–5.85 (m, 1 H, H-5′), 7.20–7.40 (m, 5 H, phenyl); major conformer (**7b**) δ 1.70–1.80 (m, 2 H, 2 H-3′), 2.05–2.15 (m, 2 H, 2 H-4′), 2.65–2.70 (m, 2 H, 2 H-2′), 2.69 (s, 3 H, CH_3), 2.94 (d, 1 H, J = 3 Hz, H-2), 3.13 (d, 1 H, J = 3 Hz, H-3), 4.95–5.10 (m, 2 H, 2 H-6′), 5.70–5.85 (m, 1 H, H-5′), 7.20–7.40 (m, 5 H, phenyl); ^{13}C NMR ($CDCl_3$, –20 °C) minor conformer (**7a**) additional δ 21.9 (C-3′), 32.8 (C-4′), 37.8 (C-2′), 115.1 (C-6′), 137.7 (C-5′); major conformer (**7b**) additional δ 22.0 (C-3′), 32.7 (C-4′), 44.1 (C-2′), 115.3 (C-6′), 137.5 (C-5′); IR (CH_2Cl_2) 1700, 1643 cm^{-1}; HRMS, m/e calcd for $C_{15}H_{19}NO$ 229.1467, found 229.1460.

2-[4-[2-(1,3-Dioxolanyl)]butanoyl]-1-methylaziridine (8) was prepared according to procedure B (2-cyano-1-methylaziridine (1) as the nitrile). Medium-pressure chromatography with Et_2O as eluant provided **8** in 77% yield: ^{1}H NMR ($CDCl_3$, 90 MHz) 1.50–1.75 (m, 5 H, 2 H-3′, 2 H-4′, H-3α), 1.95–2.10 (m, 2 H, H-2, H-3β), 2.25–2.55 (m, 2 H, 2 H-2′) 2.36 (s, 3 H, CH_3), 3.75–4.00 (m, 4 H, OCH_2CH_2O), 4.81 (bt, 1 H, J = 4 Hz, H-5′); IR (CH_2Cl_2) 1695 cm^{-1}; HRMS, m/e calcd for $C_{10}H_{17}NO_3$ 199.1208, found 199.1179.

***cis*-2-[4-[2-(1,3-Dioxolanyl)]butanoyl]-1-methyl-3-phenylaziridine (9)** was prepared according to procedure B (*cis*-2-cyano-1-methyl-3-phenylaziridine (2) as the nitrile). Medium-pressure chromatography with 1:3 Et_2O–hexane as eluant provided **9** in 74% yield: ^{1}H NMR ($CDCl_3$, 90 MHz) δ 1.20–1.50 (m, 4 H, 2 H-3′, 2 H-4′), 1.70–2.30 (m, 2 H, 2 H-2′), 2.44 (d, 1 H, J = 7 Hz, H-2), 2.58 (s, 3 H, CH_3), 2.90 (d, 1 H, J = 7 Hz, H-3), 3.70–4.00 (m, 4 H, OCH_2CH_2O), 4.64 (t, 1 H, J = 4 Hz, H-5′), 7.00–7.60 (m, 5 H, phenyl); IR (CH_2Cl_2) 1691 cm^{-1}; HRMS, m/e calcd for $C_{16}H_{21}NO_3$ 275.1521, found 275.1495.

***trans*-2-[4-[2-(1,3-Dioxolanyl)]butanoyl]-1-methyl-3-phenylaziridine (10)** was prepared according to procedure B (*trans*-2-cyano-1-methyl-3-phenylaziridine (3) as the nitrile). Medium-pressure chromatography with 1:3 ethyl acetate–hexane as eluant provided **10** in 76% yield: ^{1}H NMR ($CDCl_3$, 360 MHz, –20 °C) minor conformer (**10a**) δ 1.70–1.80 (m, 4 H, 2 H-3′, 2 H-4′), 2.17 (s, 3 H, CH_3), 2.54 (ddd, 1 H, J = 18, 7, 7 Hz, 1 H-2′), 2.68 (ddd, 1 H, J = 18, 7, 7 Hz, 1 H-2′), 2.77 (d, 1 H, J = 3 Hz, H-2), 3.53 (d, 1 H, J = 3 Hz, H-3), 3.80–4.00 (m, 4 H, OCH_2CH_2O), 4.86 (t, 1 H, J = 4 Hz, O_2CH), 7.20–7.40 (m, 5 H, phenyl); major conformer (**10b**) δ 1.70–1.80 (m, 4 H, 2 H-3′, 2 H-4′), 2.68 (s, 3 H, CH_3), 2.75 (dt, 2 H, J = 7, 7 Hz, 2 H-2′), 2.93 (d, 1 H, J = 3 Hz, H-2), 3.12 (d, 1 H, J = 3 Hz, H-3), 3.80–4.00 (m, 4 H, OCH_2CH_2O), 4.86 (t, 1 H, J = 4 Hz, O_2CH), 7.20–7.40 (m, 5 H, phenyl); IR (CH_2Cl_2) 1695 cm^{-1}; HRMS, m/e calcd for $C_{16}H_{21}NO_3$ 275.1521, found 275.1514.

Acetal Hydrolysis–Wittig Reaction Procedure. A solution of 1 equiv of the acetal in Et_2O (0.5 mL/mol of acetal) was shaken with ice-cold 5% HCl (15 mL/mol of acetal). After sitting 25 min, the phases were added dropwise during 2 min to 20% K_2CO_3 (15 mL/mol of acetal) maintained at 0 °C. This was exhaustively extracted with CH_2Cl_2. The combined organic layers were dried (K_2CO_3) and evaporated.

A solution of the aldehyde product and 1.15 equiv of the (carboalkoxymethylene)triphenylphosphorane in dry benzene (30 mL/mol of acetal) was stirred at room temperature for 24 h. The benzene was evaporated from the reaction. For the removal of some of the triphenylphosphine oxide, the residue was extracted with a minimal quantity of Et_2O and the extract, containing the desired product, was evaporated.

2-[6-Carbethoxy-(*E*)-5-hexenoyl]-1-methylaziridine (11) was prepared according to the above acetal hydrolysis–Wittig reaction procedure (2-{5-[2-(1,3-dioxolanyl)]pentanoyl}-1-methylaziridine (8) and (carbethoxymethylene)triphenylphosphorane as the acetal and the Wittig reagent, respectively). Silica gel column chromatography with 1:1 ethyl acetate–hexane as eluant followed by bulb-to-bulb distillation ((0.050 mmHg) oven

(21) Vedejs, E.; Arnost, M. J.; Hagen, J. P. *J. Org. Chem.* **1979**, *44*, 3230.

(22) For precautions employed in preparation of the Grignard reagent derived from the related 2-(3-chloropropyl)-1,3-dioxolane see: Forbes, C. P.; Wenteler, G. L.; Wiechers A. *J. Chem. Soc., Perkin Trans. 1* **1977**, 2353.

temperature 110–120 °C) provided **11** in 67% yield: ^{1}H NMR ($CDCl_3$, 360 MHz) δ 1.29 (t, 3 H, J = 7 Hz, CH_3), 1.57 (d, 1 H, J = 7 Hz, H-3α), 1.70–1.80 (m, 2 H, 2 H-3′), 2.05 (dd, 1 H, J = 3, 7 Hz, H-2), 2.09 (d, 1 H, J = 3 Hz, H-3β), 2.20 (dt, 2 H, J = 7, 7 Hz, 2 H-4′), 2.28 (ddd, 1 H, J = 17, 7, 7 Hz, 1 H-2′), 2.39 (s, 3 H, NCH_3), 2.48 (ddd, 1 H, J = 17, 7, 7 Hz, 1 H-2′), 4.18 (q, 2 H, J = 7 Hz, OCH_2), 5.81 (d, 1 H, J = 16 Hz, H-6′), 6.91 (dt, 1 H, J = 7, 16 Hz, H-5′); IR (CH_2Cl_2) 1700, 1650 cm^{-1}; HRMS, m/e calcd for $C_{12}H_{19}NO_3$ 225.1365, found 225.1362.

***cis*-2-[6-Carbomethoxy-(*E*)-5-hexenoyl]-1-methyl-3-phenylaziridine (12)** was prepared according to the above acetal hydrolysis–Wittig reaction procedure (*cis*-2-[5-[2-(1,3-dioxolanyl)]pentanoyl]-1-methyl-3-phenylaziridine (**9**) and (carbomethoxymethylene)triphenylphosphorane as the acetal and the Wittig reagent, respectively). Silica gel column chromatography with 1:3 Et_2O–hexane as eluant provided **12** in 79% yield: ^{1}H NMR ($CDCl_3$, 360 MHz) 1.30–1.55 (m, 2 H, 2 H-3′), 1.83 (dt, 2 H, J = 7, 7 Hz, 2 H-4′), 1.93 (ddd, 1 H, J = 17, 8, 8 Hz, 1 H-2′), 2.23 (ddd, 1 H, J = 17, 8, 8 Hz, 1 H-2′), 2.48 (d, 1 H, J = 8 Hz, H-2), 2.58 (s, 3 H, NCH_3), 2.94 (d, 1 H, J = 8 Hz, H-3), 3.71 (s, 3 H, OCH_3), 5.63 (d, 1 H, J = 16 Hz, H-6′), 6.72 (dt, 1 H, J = 16, 7 Hz, H-5′), 7.20–7.35 (m, 5 H, phenyl); HRMS, m/e calcd for $C_{17}H_{21}NO_3$ 287.1521, found 287.1520.

***trans*-2-[6-Carbomethoxy-(*E*)-5-hexenoyl]-1-methyl-3-phenylaziridine (13)** was prepared according to the above acetal hydrolysis–Wittig reaction procedure (*trans*-2-[5-[2-(1,3-dioxolanyl)]pentanoyl]-1-methyl-3-phenylaziridine (**10**) and (carbomethoxymethylene)triphenylphosphorane as the acetal and the Wittig reagent, respectively). Silica gel column chromatography with 1:3 Et_2O–hexane provided **13** in 45% yield: ^{1}H NMR ($CDCl_3$, 90 MHz) δ 1.77 (quin, 2 H, J = 7, 2 H-3′), 2.01 (s, 3 H, NCH_3 of minor conformer), 2.23 (dt, 2 H, J = 7, 7 Hz, 2 H-4′), 2.40–2.90 (bm, 3 H, H-2, 2 H-2′), 2.70 (s, 3 H, NCH_3 of major conformer), 3.00–3.40 (bm, 1 H, H-3), 3.70 (s, 3 H, OCH_3), 5.80 (d, 1 H, J = 16 Hz, H-6′), 6.93 (dt, 1 H, J = 16, 7 Hz, H-5′); IR (CH_2Cl_2) 1704, 1655 cm^{-1}; HRMS, m/e calcd for $C_{17}H_{21}NO_3$ 287.1521, found 287.1520.

3-Carbomethoxy-1-methyl-2-phenyl-2α,3α,3aβ,4,5,7aβ-hexahydro-7(6*H*)-indolone (14). Two ampules, each containing a degassed (via freeze–thaw under vacuum) solution of *cis*-2-[6-carbomethoxy-(*E*)-5-hexenoyl]-1-methyl-3-phenylaziridine (**12**) (267 mg/ampule, 0.930 mmol/ampule) in 2.5 mL of dry benzene, were sealed and then heated at 95 °C for 3 h. The ampules were opened, the contents combined, and the benzene evaporated, leaving 531 mg of crystalline product, mp 72–114 °C. Recrystallization from Et_2O–hexane provided 200 mg of **14**, mp 118–125 °C. The mother liquor was evaporated and used for a similar recrystallization to give 86 mg more of **14**, mp 125–129 °C. The mother liquor from the latter recrystallization was used similarly for a third recrystallization to give an additional 31 mg of **14**, mp 118–125 °C. Thus a total of 310 mg (58%) of **14** was obtained from the three recrystallizations: ^{1}H NMR ($CDCl_3$, 360 MHz) δ 1.50–1.60 (m, 1 H), 1.75–1.85 (m, 1 H) and 1.90–2.10 (m, 2 H) (2 H-4, 2 H-5), 2.30 (ddd, 1 H, J = 13, 5, 1 Hz, 1 H-6), 2.39 (ddd, 1 H, J = 13, 11, 6 Hz, 1 H-6), 2.50 (s, 3 H, NCH_3), 3.12 (s, 3 H, OCH_3), 3.15 (dd, 1 H, J = 10.1, 11.4 Hz, H-3), 3.40–3.50 (m, 1 H, H-3a), 3.81 (d, 1 H, J = 8.1 Hz, H-7a), 4.42 (d, 1 H, J = 10.1 Hz, H-2), 7.15–7.30 (m, 5 H, phenyl); IR (CH_2Cl_2) 1720 cm^{-1}. Anal. (sample recrystallized from Et_2O–hexanes, mp 124–128 °C). Calcd for $C_{17}H_{21}NO_3$: C, 71.06; H, 7.37; N, 4.87. Found: C, 71.20; H, 7.42; N, 4.86.

3-Carbomethoxy-1-methyl-2-phenyl-2α,3α,3aβ,4,5,7aβ-hexahydro-7(6*H*)-indolone (14). A degassed (via freeze–thaw under vacuum) solution of *trans*-2-[6-carbomethoxy-(*E*)-5-hexenoyl]-1-methyl-3-phenylaziridine (**13**) (35.0 mg, 0.122 mmol) in 1.0 mL of dry benzene-d_6 in a sealed NMR tube was heated at 95 °C for 2.5 h. The tube was opened and the solvent evaporated, leaving 35 mg of crystalline product, mp 95–121 °C. Recrystallization from Et_2O–hexane provided 16.3 mg of **14**, mp 118–122 °C (mixed mp with the second crop of crystals from the previously described preparation, mp 118–121 °C). The mother liquor was evaporated and used for a similar recrystallization to give 2.7 mg more of **14**, mp 113–118 °C. Thus a total of 19.0 mg (54%) of **14** was obtained from the two recrystallizations.

1-Methyl-2-phenyl-2α,3,3aβ,4,5,7aβ-hexahydro-7(6*H*)-indolone (15). A degassed (via freeze–thaw under vacuum) solution of *cis*-2-(5-hexenoyl)-1-methyl-3-phenylaziridine (**6**) (37.7 mg, 0.166 mmol) in 0.65 mL of dry benzene-d_6 in a sealed NMR tube was heated at 80 °C for 10.75 h. The tube was opened and the solvent evaporated. The residue was placed on a 1.0-g florasil column and eluted with degassed $CHCl_3$, providing 25.2 mg (67%) of product **15**: ^{1}H NMR ($CDCl_3$, 360 MHz) δ 1.60–1.75 (m, 1 H) and 1.80–2.00 (m, 3 H) (2 H-4, 2 H-5), 1.84 (ddd, 1 H, J = 13, 8, 4 Hz, 1 H-3), 2.09 (ddd, 1 H, J = 13, 9, 9 Hz, 1 H-3), 2.30–2.45 (m, 2 H, 2 H-6), 2.42 (s, 3 H, CH_3), 2.95–3.05 (m, 1 H, H-3a), 3.63 (d, 1 H, J = 7.1 Hz, H-7a), 4.13 (dd, 1 H, J = 9.4, 4.4 Hz, H-2), 7.20–7.40 (m, 5 H, phenyl); IR (CH_2Cl_2) 1705 cm^{-1}; HRMS, m/e calcd for $C_{15}H_{19}NO$ 229.1467, found 229.1465.

1-Methyl-2-phenyl-2α,3,3aβ,4,5,7aβ-hexahydro-7(6*H*)-indolone (15). *trans*-2-(5-Hexenoyl)-1-methyl-3-phenylaziridine (**7**) was used in an identical procedure as the previous preparation of **15** to provide 22.0 mg (58%) of product **15**.

X-ray Analysis of Compound 14. Crystal Data. $C_{17}H_{21}NO_3$ (**14**), M_r 287.36, triclinic, a = 9.888 (4) Å, b = 10.210 (4) Å, c = 8.413 (4) Å, α = 84.16 (1)°, β = 114.10 (1)°, γ = 103.84 (1)°, V = 752.8 Å^3, Z = 2, D_{calcd} = 1.268 g cm^{-3}, Cu Kα radiation (Ni filter, λ = 1.5418 Å), μ = 6.6 cm^{-1}. Space group $P1(C_1^1)$ or $P\bar{1}(C_i^1)$ from Laue symmetry; shown to be the latter by structure solution and refinement. Sample dimensions: ca. 0.24 × 0.38 × 0.70 mm.

Crystallographic Measurements. Preliminary unit-cell parameters and space group information were obtained from oscillation, Weissenberg, and precession photographs. Intensity data were recorded on an Enraf-Nonius CAD-3 automated diffractometer ($\theta - 2\theta$ scans, θ_{max} = 67°) as described elsewhere.[23] From a total of 2695 independent measurements, those 2366 with $I > 2.0\sigma(I)$ were retained for the structure analysis and corrected for the usual Lorentz and polarization effects. Refined unit cell parameters were derived by least-squares treatment of the diffractometer setting angles for 40 high-order reflections widely separated in reciprocal space.

Structure Analysis. The centrosymmetric space group $P\bar{1}$ was assumed to be the correct choice at the outset, and the structure was solved by direct methods.[14] Full-matrix least-squares adjustment of non-hydrogen atom positional and anisotropic thermal parameters, with hydrogen atom positional and isotropic thermal parameters included as variables in the later iterations, converged to R = 0.054.[15] Final atomic positional and thermal parameters are in Tables II–IV.[16]

For all structure-factor calculations, atomic scattering factors for carbon and oxygen were taken from ref 24, and for hydrogen from ref 25. In the least-squares iterations (performed using a locally modified version of the Gantzel, Sparks, Trueblood ULCA least-squares program), $\sum w\Delta^2$ ($\Delta = ||F_o| - |F_c||$) was minimized with weights, w, assigned according to the scheme: $w^{1/2} = 1$ for $|F_o| \leq 7.0$, and $w^{1/2} = 7.0/|F_o|$ for $|F_o| > 7.0$.

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Supplementary Material Available: Tables of fractional atomic coordinates (Tables II and IV), anisotropic thermal parameters (Table III), bond lengths and angles (Table V), and torsion angles (Table VI) for racemic **14** (6 pages). Ordering information is given on any current masthead page.

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