(O–C, C–C, C–O, etc.) in the symmetrically independent portions of the ring read ag^+aag^-a. This conformation characterizes[10,11] the vast majority[12] of 18C6 adducts. The structural parameters associated with the six-point binding site are summarized in the caption to Figure 1. The angles (θ = 7, 9, 12°) of approach of the C(Me)O vectors to the associated COC planes indicate an almost trigonal geometry (θ = 0°) for the C—H··O hydrogen bonds rather than a tetrahedral one ($\theta \simeq 55°$).

The coronation of an acetonitrile ligand in the [*trans*-Ir(CO)(CH_3CN)(PPh_3)$_2$]$^+$ cation by 18-crown-6 provides an elegant example[13,14] of second-sphere coordination[15] of a transition-metal complex by a crown ether in the solid state.

Acknowledgment. This research was supported by grants from the Science Research Council in the United Kingdom.

Registry No. {[*trans*-Ir(CO)(CH_3CN)(PPh_3)$_2$]$_2^+$·18C6}[PF_6]$_2^-$·2CH_2Cl_2, 80434-43-1; [*trans*-Ir(CO)(CH_3CN)(PPh_3)$_2$]$^+$[PF_6]$^-$, 80434-42-0.

Supplementary Material Available: A table of atomic positional and thermal parameters for {[*trans*-Ir(CO)(CH_3CN)(PPh_3)$_2$]$_2^+$·18-crown-6}[PF_6]$_2^-$·2CH_2Cl_2 (2 pages). Ordering information is given on any current masthead page.

(13) Copper iodide reacts (Hardt, H. D.; Stoll, H.-J. *Z. Anorg. Allg. Chem.* **1978**, *442*, 221) in acetonitrile solution with dibenzo-18-crown-6 (DB18C6) to form a crystalline adduct [(CuI)$_4$(CH_3CN)$_4$·DB18C6] which exhibits fluorescence thermochromism. In addition, the luminescence spectra of the adduct is red shifted at 298 K. This has been interpreted by the authors in terms of an unspecified interaction between the crown and the acetonitrilecopper iodide.

(14) Small rate enhancements in the reaction of [*trans*-Co($H_2NCH_2CH_2NH_2$)$_2$(CH_3CN)(NO_2)]$^{2+}$[ClO_4]$_2^-$ with D_2O at pD 4.4 in the presence of either 18-crown-6 or 15-crown-5 to give [*trans*-Co($H_2NCH_2CH_2NH_2$)$_2$(D_2O)(NO_2)]$^{2+}$[ClO_4]$_2^-$ have been ascribed (Blackmer, G. L.; Nordyke, M. D.; Vickrey, T. M.; Bartsch, R. A.; Holwerda, R. A. *Inorg. Chem.* **1978**, *17*, 3310) to complexation by the crown ethers of the cobalt-bound acetonitrile through the acidic methyl group C–H bonds. It should be recognized, however, that the crown ethers will probably interact (cf. ref 4 and 5) more strongly with (a) the $H_2NCH_2CH_2NH_2$ ligands by N—H··O hydrogen bond formation in the reactant and product complexes and (b) the D_2O ligand by O—D··O hydrogen bond formation in the product complex. In the present investigatiion, we have found that 18C6 promotes the displacement of CH_3CN by Cl^- ion. Thus, on adding excess of solid NaCl to {[*trans*-Ir(CO)(CH_3CN)(PPh_3)$_2$]$_2^+$·18C6}[PF_6]$_2^-$ in CH_2Cl_2, a mixture of [Ir(CO)(CH_3CN)(PPh_3)$_2$]$^+$[PF_6]$^-$, Ir(CO)(PPh_3)$_2$Cl, and (presumably) [Na·18C6]$^+$[PF_6]$^-$ is formed; addition of a further 1 equiv of 18C6 results in complete conversion to Ir(CO)(PPh_3)$_2$Cl. The driving force for this reaction is clearly solubilization of NaCl in CH_2Cl_2 by 18C6 since addition of NaCl to a MeOH solution of [Ir(CO)(CH_3CN)(PPh_3)$_2$]$^+$[PF_6]$^-$ precipitates Ir(CO)(PPh_3)$_2$Cl quantitatively even in the absence of the crown ether.

(15) Bjerrum, J. *Adv. Chem. Ser.* **1967**, *No. 62*, 178.

A Diels–Alder Route to Pyridone and Piperidone Derivatives

Francy Sainte, Béatrice Serckx-Poncin, Anne-Marie Hesbain-Frisque, and Léon Ghosez*

Laboratoire de Chimie Organique de Synthèse
Université Catholique de Louvain
B-1348 Louvain-La-Neuve, Belgium

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The Diels–Alder reaction is one of the most versatile routes for the construction of carbocycles.[1] Appropriate selection of dienes and dienophiles allows for a wide range of structural and functional variations in the adducts. In this respect, the recent availability of highly functionalized dienes has considerably widened the scope of the reaction.[2]

Relatively few dienophiles incorporating heteroatoms in the conjugated system have found use in synthesis.[3] At the beginning of these studies, we noticed, in particular, that 1- and 2-aza-1,3-dienes had almost not been explored for their reactivity as enophiles.[4-6] We expected significant synthetic potential for 2-aza-1,3-dienes **1** provided that one could force them to interact with the 4π electron system of the diene rather than with the n electrons of the nitrogen. The few available studies on 2-aza-1,3-dienes have indeed shown that they are able to undergo [4 + 2] cycloadditions with conventional electron-poor dienophiles.

Our own studies[5] have been mainly concerned with 2-aza-1,3-dienes bearing a substituted amino group at position 1. This conferred higher reactivity on the diene in its reactions with electrophilic dienophiles. Further, the amino group in the adducts was amenable to elimination. As shown in Scheme I, *conformational factors play a significant role in determining the reaction site for the dienophile.* Thus **1a**, which mainly exists in the s-cis conformation,[7] readily reacts with ethyl propiolate in acetonitrile at 60 °C to give, after spontaneous aromatization, the known pyridine **2** in 50% yield. In the case of **1b**, the s-cis conformation is no longer available,[7] and *no cycloadduct* could be obtained with ethyl propiolate under a variety of experimental conditions. Although the diene quickly disappeared, no characterizable products were obtained.

With these observations in mind, it became obvious that 2-aza-1,3-dienes such as **3** fulfill all structural requirements to react successfully with electrophilic dienophiles. The presence of trialkylsilyloxy group at position 3 should further enhance the reactivity of the π system[8] and permits introduction of a masked lactam function.

The required dienes **3a** and **3b** were conveniently prepared by enol silylation of the readily available imides **4a**[9] and **4b** with *tert*-butyldimethylsilyl triflate[10] in ether containing 2.2 equiv of triethylamine: **3a**, 86%; bp 74 °C (6.10^{-2} torr); NMR ($CDCl_3$)

(1) (a) Sauer, J. *Angew. Chem., Int. Ed. Engl.* **1966**, *5*, 211. (b) *Ibid.* **1967**, *6*, 16. (c) Wollweber, H. "Diels-Alder Reaction"; George Thieme Verlag: Stuttgart, 1972.

(2) For recent notable examples, see: (a) Sonveaux, E.; Ghosez, L. *J. Am. Chem. Soc.* **1973**, *95*, 5417. (b) Corey, E. J. Kozikowski, A. P. *Tetrahedron Lett.* **1975**, 2389. (c) Ibuka, T.; Ito, Y.; Mori, Y.; Aoyama, T.; Inubushi, Y. *Synth. Commun.* **1977**, *7*, 131. (d) Banville, J.; Brassard, P. *J. Chem. Soc., Perkin Trans. 1* **1976**, 1852. (e) Fleming, I.; Percival, A. *J. Chem. Soc., Chem. Commun.* **1978**, 178. (f) Yamamoto, K.; Suzuki, S.; Tsuji, J. *Chem. Lett.* **1978**, 649. (g) Danishefsky, S.; Prisbylla, M. P.; Hiner, S. *J. Am. Chem. Soc.* **1978**, *100*, 2918. (h) Gillard, M.; 'tKint, C.; Sonveaux, E.; Ghosez, L. *Ibid.* **1979**, *101*, 5837. (i) Danishefsky, S.; Kitahara, T.; Yan, C. F.; Morris, J. *Ibid.* **1979**, *101*, 6996. (j) Danishefsky, S.; Yan, C. F.; Singh, R. F.; Gammill, R. B.; McCurry, P. M. Jr.; Fritsch, N.; Clardy, J. *Ibid.* **1979**, *101*, 7001. (k) Chan, T. H.; Brownbridge, P. *Ibid*, **1980**, *102*, 3534. (l) Trost, B. M.; Vladuchick, W. E.; Bridges, A. J. *Ibid.* **1980**, *102*, 3548; **1980**, *102*, 3554. (m) Overman, L. E.; Clizbe, L. A.; Freerks, R. L.; Marlowe, C. K. *Ibid*, **1981**, *103*, 2807. (n) Overman, L. E.; Freerks, R. L.; Bruce Petty, C.; Clizbe, L. A.; Ono, R. K.; Taylor, G. F.; Jessup, P. J. *Ibid.* **1981**, *103*, 2816. (o) Petrzilka, M.; Grayson, J. I. *Synthesis*, **1981**, 753.

(3) Reviews: (a) Lora-Tamayo, M.; Madronero R. In "1,4-Cycloaddition Reactions"; Hamer, J., Ed.; Academic Press: New York, 1967; Chapter 5, pp 127–142. (b) Lora-Tamayo, M.; Soto, J. L. *Ibid.*; Chapter 7, pp 180–204. (c) Colonge, J.; Descotes, G. *Ibid.*; Chapter 9, pp 217–254. (d) Pfundt, G.; Schenck, G. O. *Ibid.*; Chapter 11, pp 346–418.

(4) Cheng, Y., Fowler, F. W.; Lupo, A. T., Jr. *J. Am. Chem. Soc.* **1981**, *103*, 2090.

(5) Demoulin, A.; Gorissen, H.; Hesbain-Frisque, A. M.; Ghosez, L. *Ibid.* **1975**, *97*, 4409.

(6) (a) Krondrat'eva, G. Ya.; Dols'kaya, Yu. S. *Khim Nauk. Prom.* **1957**, *2*, 666; *Chem. Abstr.* **1958**, *52*, 6345. (b) Kondrat'eva, G. Ya. *Izv. Akad. Nauk. SSSR, Ser. Khim. Nauk.* **1959**, 484; *Chem. Abstr.* **1959** *53*, 21940. (c) Povarov, L. S.; Mikailov, B. M. *Ibid.* **1963**, 955; *Chem. Abstr.* **1963**, *59*, 7489. (d) Kondrat'eva, G. Ya; Dols'kaya, Yu. S. *Zh. Org. Khim.* **1970**, *6*, 2220. (e) Aue, D. M.; thomas, D. *J. Org. Chem.* **1975**, *40*, 1349. (f) Worley S. D.; Taylor, G.; Venugopalan B.; Clark, M. S., Jr. *Tetrahedron* **1978**, *34*, 833. (g) Nomura, Y.; Takeuchi, Y.; Tomoda, S.; Ito, M. M. *Chem. Lett.* **1979**, 187. (h) Gompper, R.; Heinemann U. *Angew. Chem., Int. Ed. Engl.* **1980**, *19*, 217; **1981**, *20*, 296.

(7) Especially noteworthy for configurational assignment is the coupling between C-3 and H-1 in the ^{13}C NMR spectra of **1a** and **1b**. For **1a**, J_{trans} = 11.9 Hz; for **1b**, J_{cis} = 7.8 Hz. E.g., see: Vogeli, U.; von Philipsborn, W. *Org. Magn. Reson.* **1975**, *7*, 617.

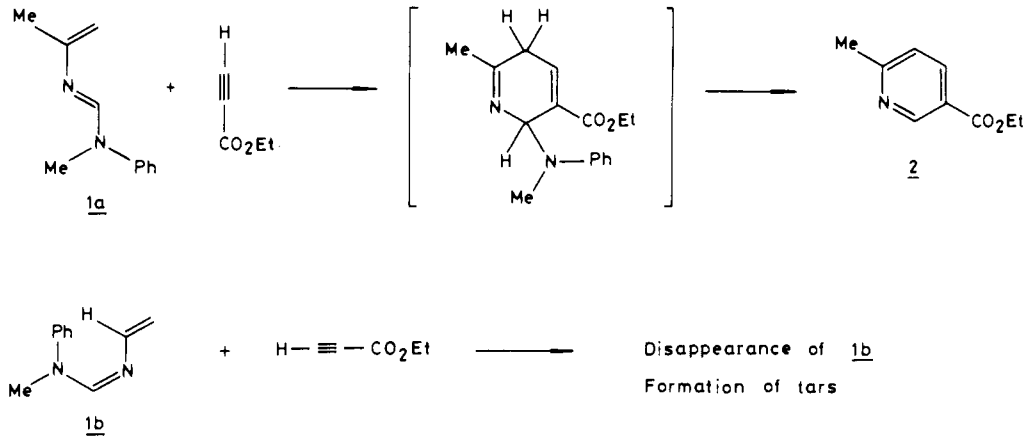
(8) Danishefsky, S.; McKee, R.; Singh, R. K. *J. Org. Chem.* **1976**, *41*, 2934.

(9) Kantlehner, W.; Fischer, P.; Kugel, W.; Möhring, E., Bredereck, H. *Liebigs Ann. Chem.* **1978**, 512.

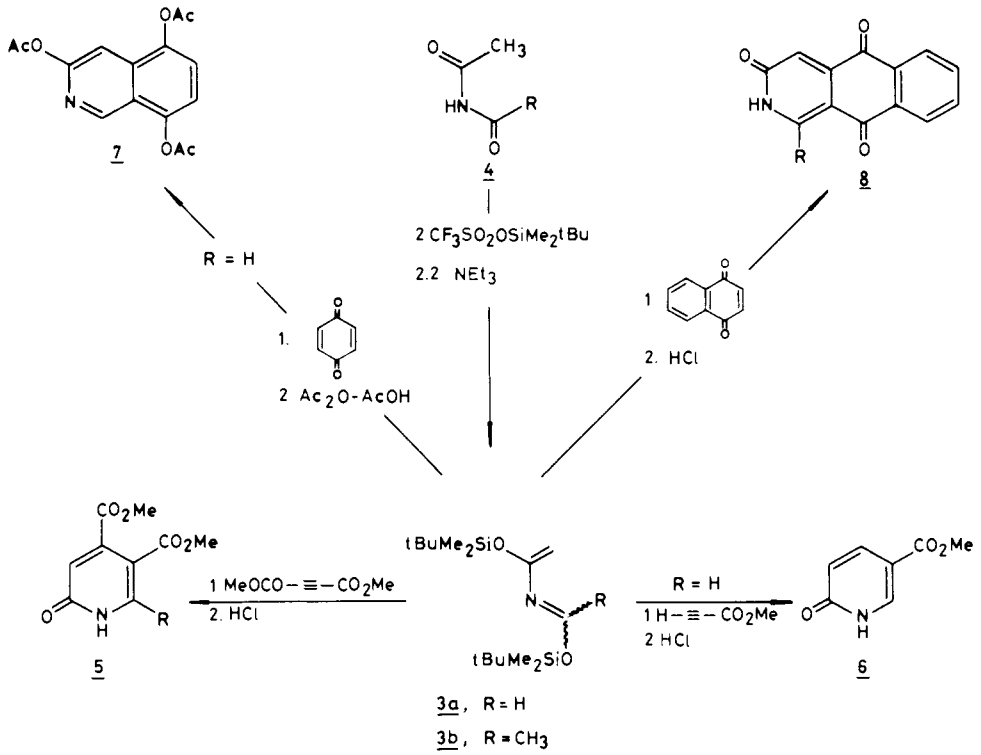
(10) Corey, E. J.; Cho, H.; Rücker, C.; Hua, D. H. *Tetrahedron Lett.* **1981**, 3455.

0002-7863/82/1504-1428$01.25/0

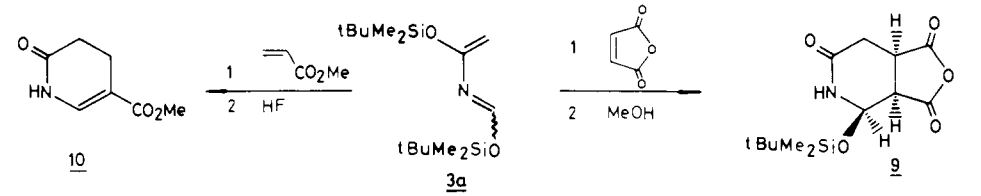
Scheme I



Scheme II



Scheme III



singlets at δ 0.2 (6 H), 0.28 (6 H), 0.98 (18 h), 3.75 (1 H), 3.96 (1 H), 7.8 (1 H). **3b**, 81%; bp 69 °C (4.10^{-2} torr); NMR ($CDCl_3$) singlets at δ 0.13 (6 H), 0.28 (6 H) 0.97 (18 H), 2.03 (3 H), 3.42 (br, 1 H), 3.67 (br, 1 H). The less expensive trimethylsilyl ethers derived from **4a** and **4b** were also readily obtained but decomposed extensively upon distillation.

The reaction of **3a** with dimethyl acetylenedicarboxylate (2 equiv) in refluxing chloroform was accompanied by aromatization of the 1,4 adduct[11] to give 64% of **5a** (mp 151 °C) after hydrolysis with a minimum amount of concentrated HCl. The 1,1-disubstituted azadiene **3b** reacted similarly to give **5b** (61%, mp 156.7 °C). The regioselectivity of the cycloaddition was demonstrated by the formation of a *single* aromatized adduct **6** (64%, mp 163 °C, lit.[12] 164 °C) when **3a** and methyl propiolate were refluxed in benzene for 14 h and the resulting mixture was hydrolyzed with 1 N HCl.

Azadienes **3** could also be used for a one-step synthesis of polycyclic heteroaromatics (Scheme II). Treatment of **3a** with *p*-benzoquinone in chloroform at 20 °C yielded a 1:1 adduct which was acylated without isolation (Ac_2O–AcOH, 70 °C, overnight) to give **7**, a polyoxygenated derivative of isoquinoline, in 56% yield. Both **3a** and **3b** also reacted with 1,4-naphthoquinone in refluxing

(11) All products were fully characterized by infrared, nuclear magnetic resonance, and mass spectral analysis. These data will be presented in the full paper to follow for all compounds.

chloroform to yield, after hydrolysis, tricyclic heteroaromatics **8a** (72%, mp 285.5 °C) and **8b** (44%, mp 280 °C), respectively. These preliminary data indicate the potential of these new azadienes for direct synthesis of highly functionalized aromatic nitrogen heterocycles.

The utility of compounds **3a** and **3b** for the synthesis of nonaromatic heterocycles is demonstrated in the examples shown in Scheme III. Diene **3a** and maleic anhydride form a 1:1 adduct after 1 h in chloroform at room temperature. Addition of methanol to the crude adduct resulted in the regeneration of the lactam function by monodesilylation. The crystalline piperidone **9** is obtained in 82% yield; mp 249.5 °C; ν_{max} (KBr) 3320, 1830, 1780, 1765, 1675 cm^{-1}. The configuration of **9** follows from a detailed analysis[13] of the NMR spectrum at 200 MHz and decoupling experiments.

The reaction of **3a** with methyl acrylate further illustrates the potential for direct synthesis of functionalized piperidines. The adduct, upon hydrolysis with aqueous hydrogen fluoride,[14] gave a 65% yield of **10**, mp, 93.6 °C. The regiochemical assignment for **10** was confirmed by the presence of a doublet at δ 7.29 corresponding to one olefinic proton couplet (J = 4.7 Mz) with the proton of the NH group.

We believe that these readily prepared[15] reactive azadienes should find a place on the chemist's panoply. Further applications of the use of this methodology for natural product synthesis are currently under way.

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Registry No. 1a, 80658-26-0; **2**, 21684-59-3; **3a**, 80658-27-1; **3b**, 80658-28-2; **4a**, 21163-79-1; **4b**, 625-77-4; **5a**, 80658-29-3; **5b**, 29341-16-0; **6**, 66171-50-4; **7**, 80662-18-6; **8a**, 80658-30-6; **8b**, 80658-31-7; **9**, 80658-32-8; **10**, 80658-33-9; ethyl propiolate, 623-47-2; dimethyl acetylene dicarboxylate, 762-42-5; methyl propiolate, 922-67-8; *p*-benzoquinone, 106-51-4; 1,4-napthoquinone, 130-15-4; maleic anhydride, 108-31-6; methyl acrylate, 96-33-3.

(12) Meyer, H. *Monatsh. Chem.* **1902**, *22*, 440.

(13) NMR (Me_2SO-d_6) δ 0.025 and 0.04 (2s, 6 H), 0.76 (s, 9 H), 2.42–2.72 (m, 2 H), 3.56 (dd, 1 H), 4.06–4.22 (m, 1 H), 5.22 (dd, 1 H), 8.94 (d, 1 H).

(14) Newton, R. F.; Reynolds, D. P.; Finch, M. A. W.; Kelly D. R.; Roberts, S. W. *Tetrahedron Lett.* **1979**, 3981.

(15) Azadienes of type **3** can also be conveniently prepared from imidates by acylation followed by enol silylation.

New Methods for Alkaloid Synthesis: α-Acylamino Radical Cyclizations

David J. Hart* and Yeun-Min Tsai

Department of Chemistry, The Ohio State University Columbus, Ohio 43210

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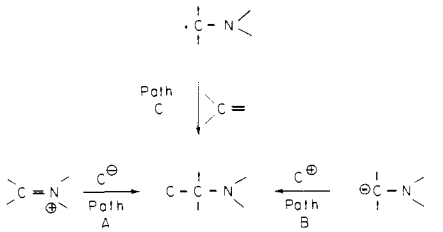
Construction of carbon–carbon bonds adjacent to nitrogen plays a central role in alkaloid chemistry (Scheme I). Both biosynthetic and laboratory pathways to these natural products rely heavily on variants of the Mannich reaction (path A) for construction of these bonds.[1] Recently, methods which couple α-aminocarbanion equivalents with electrophiles have been developed to accomplish the same task (path B).[2] The use of α-amino and α-acylamino radicals for assembling these bonds, however, has been largely ignored (path C).[3] We report here a new approach

Scheme I



Scheme II

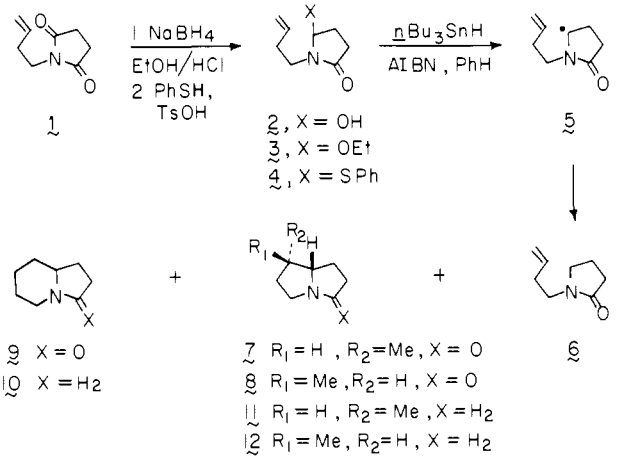


Table I. Treatment of α-Thiophenoxylactams with Tri-*n*-butyltin Hydride[a]

entry	thiophenoxylactam	products (% yield; ratio)[b]
1	13a	14a (12), 17 + 18 (70; 3.7:1)[c,e]
2	13b	14b (13), 15 + 16 + 19 (69; 7:61:33)[d]
3	13c	14c (25), 15 + 16 + 19 (56; 12:81:7)[d]

[a] A mixture of *n*-Bu_3SnH (1.1–1.5 mmol) and AIBN (0.05 mmol) in 10 mL of benzene was added dropwise to 13a-c (1.0 mmol) in 12 mL of benzene at reflux over a 2–4 h period followed by heating for an additional 2–4 h. [b] Reduction products 14a-c were separated from cyclization products by column chromatography. The ratios of cyclization products are based on VPC and 300-MHz ^{1}H–NMR data collected on purified mixtures of cyclization products. [c] A pure sample of 17 was obtained by preparative VPC. [d] A pure sample of 19 was obtained by VPC and by independent synthesis. Lactams 15 and 16 were analyzed as a pure mixture of stereoisomers. The stereochemical assignments for 15 and 16 are tentative and based in part on analogy with results obtained in the cyclizations of 4 and 24. Similarities between ^{1}H NMR spectra of 15 and 16 and those of 8 and 7, respectively, support this assignment. [e] The stereochemistry of the major and minor indolizidinones was not determined. The ratio may be the reverse of that shown here.

to the synthesis of indolizidines and pyrrolizidines, important substructures found in many alkaloids, via α-acylamino radical cyclizations.

We began our studies by developing a site-specific method for generating α-acylamino radicals as outlined in Scheme II.[4] Thus

(1) Dalton, D. R. "The Alkaloids"; Marcel Dekker: New York, 1979.

(2) Seebach, D. *Angew. Chem. Int. Ed. Engl.* **1979**, *18*, 239 and references cited therein.

(3) For a relevant synthesis of (±)-coniine see: Urry, W. H.; Juveland, O. O.; Stacey, F. W. *J. Am. Chem. Soc.* **1952**, *74*, 6155. Urry, W. H.; Juveland, O. O. *Ibid.* **1958**, *80*, 3322. For other brief accounts see: Julia, M.; Maumy, M. *Bull. Soc. Chim. Fr.* **1968**, 1603. Julia, M. *Pure Appl. Chem.* **1967**, *15*, 167.

(4) For other methods of generating α-acylamino radicals see; Friedman, L.; Shechter, H. *Tetrahedron Lett.* **1961**, 238. Nikishin, G. I.; Mustafaev, R. I. *Dokl. Akad. Nauk SSSR* **1964**, *158*, 1127. Elad, D.; Sinnreich, J. *Tetrahedron* **1968**, *24*, 4509.

0002-7863/82/1504-1430$01.25/0