Saunders, H. S. Tyagaraj, and B. S. Ramaprasad for microanalysis.

Registry No. 1 (R = OMe) 1-oxide, 61063-01-2; 1 (R = Cl) 1-oxide, 30080-04-7; 1 (R = OMe) 3-oxide, 61063-02-3; 1 (R = OMe) 3-oxide, 61063-00-1; 2 (R = OMe, R′ = OH) 1-oxide, 72916-82-6; 2 (R = Cl, R′ = OH) 1-oxide, 72916-83-7; 2 (R = OMe, R′ = OMe) 1-oxide, 72916-84-8; 2 (R = Cl, R′ = OMe) 1-oxide, 72916-85-9; 2 (R = OMe, R′ = OCH_2Ph) 1-oxide, 72925-72-5; 2 (R = OMe, R′ = OPh) 1-oxide, 72916-86-0; 2 (R = OMe, R′ = NMe_2) 1-oxide, 72916-87-1; 2 (R = Cl, R′ = NMe_2) 1-oxide, 72916-88-2; 2 (R = OMe, R′ = NHPh) 1-oxide, 72916-89-3; 2 (R = Cl, R′ = NHPh) 1-oxide, 72916-90-6; 2 (R = OMe, R′ = OH) 3-oxide, 72916-91-7; 2 (R = Cl, R′ = OH) 3-oxide, 72916-92-8; 2 (R = OMe, R′ = OMe) 3-oxide, 72916-93-9; 2 (R = Cl, R′ = OMe) 3-oxide, 72916-94-0; 2 (R = OMe, R′ = OCH_2Ph) 3-oxide, 72916-95-1; 2 (R = OMe, R′ = OPh) 3-oxide, 72916-96-2; 2 (R = OMe, R′ = NMe_2) 3-oxide, 72916-97-3; 2 (R = Cl, R′ = NMe_2) 3-oxide, 72916-98-4; 2 (R = OMe, R′ = NHPh) 3-oxide, 72916-99-5; 2 (R = Cl, R′ = NHPh) 3-oxide, 72917-00-1; 2 (R = OMe, R′ = dimer) 1,1′-dioxide, 72917-01-2; 3 (R = OMe, R′ = OH), 72917-02-3; 3 (R = Cl, R′ = OH), 72917-03-4; 3 (R = OMe, R′ = OMe), 72917-04-5; 3 (R = Cl, R′ = OMe), 72917-05-6; 3 (R = OMe, R′ = OCH_2Ph), 72917-06-7; 3 (R = OMe, R′ = OPh), 72917-07-8; 3 (R = OMe, R′ = NMe_2), 72917-08-9; 3 (R = Cl, R′ = NMe_2), 72917-09-0; 3 (R = OMe, R′ = NHPh), 72917-10-3; 3 (R = Cl, R′ = NHPh), 72917-11-4; 5, 72917-12-5; 6-methoxyanthranil, 61063-15-8.

Cycloaddition Reactions of *N*-Methyl-1,2-dihydropyridine

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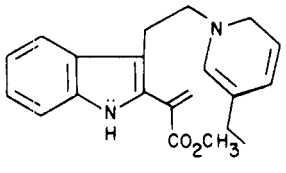
Received November 21, 1979

The reactions of *N*-methyl-1,2-dihydropyridine (**2**) with electron deficient π systems have been studied. This compound is considered as a model for reactive 1,2-dihydropyridines that are not stabilized by electron-withdrawing groups on the ring. Dihydropyridine **2** behaves as an enamine rather than a diene in its primary cycloaddition reactions with methyl acrylate, dimethyl acetylenedicarboxylate, and methyl vinyl ketone. At high temperature the primary [2 + 2] cycloadduct between methyl acrylate and 1,2-dihydropyridine **2** is unstable, and the more thermodynamically stable endo and exo Diels–Alder adducts **4** and **5** are formed. From a comparison of the reactivity and photoelectron spectrum of **2** with an acyclic analogue, it is concluded that the two double bonds of the cyclic dienamine **2** are not in the same plane. *N*-Methyl-1,2-dihydropyridine behaves as both a diene and a dienophile with respect to α-(*N*-methylindol-2-yl)acrylate **13**, giving a 2.3:1 mixture of the aspidosperma and iboga analogues **14** and **15**.

There has been recent interest in the chemistry of dihydropyridines because of their postulation as intermediates in alkaloid biosynthesis.[1] For example, the intramolecular cycloaddition reactions of dihydropyridine **1**

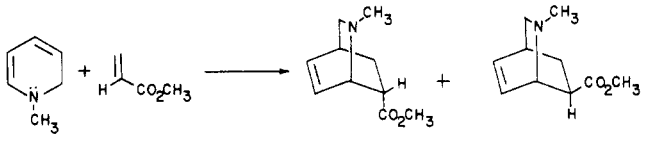


1

have been proposed to play an important role in the biosynthesis of the indole alkaloids.[1a-c] Although dihydropyridine **1** has been frequently discussed in the literature, it has neither been isolated nor synthesized. In spite of the extensive literature on 1,2-dihydropyridine chemistry,[2] the vast majority of 1,2-dihydropyridines known contain an electron-withdrawing group on the ring in conjugation with the nitrogen lone pair of electrons. These substituents have a perturbation on the π system and significantly affect the chemistry of 1,2-dihydropyridines.[3] There are only a few 1,2-dihydropyridines known that could serve as a model for the 1,2-dihydropyridine ring in **1**, and there are no authenticated cycloaddition reactions of unstabilized dihydropyridines with electron-deficient alkenes.

Results

The simplest 1,2-dihydropyridine, unencumbered by perturbing substituents and suitable for study as a model for **1**, is *N*-methyl-1,2-dihydropyridine (**2**). We have re-



2 **3** **4** **5**

investigated the reaction of *N*-methyl-1,2-dihydropyridine and methyl acrylate and observed that the treatment of *N*-methyl-1,2-dihydropyridine with methyl acrylate (**3**) in refluxing benzene gave a 3.2:1 mixture of Diels–Alder adducts **4** and **5**.[4] These stereoisomers were separated by gas chromatography, and their stereochemistry was assigned on the basis of double-resonance ^1H NMR experiments and by a comparison to suitable model systems.[5] The ^1H NMR spectra of these compounds with proton assignments are shown in Figure 1. The major difference is the chemical shift of the proton at C-7. In the exo isomer **5** this proton occurs at high field due to the shielding effect

(1) (a) Scott, A. I. *Acc. Chem. Res.* **1970**, *3*, 151. (b) *Bioorg. Chem.* **1974**, *3*, 398. (c) Wenkert, E. *J. Am. Chem. Soc.* **1962**, *84*, 78. (d) Leete, E.; Slattery, S. A. *Ibid.* **1976**, *98*, 6326.

(2) (a) Eisner, U.; Kuthan, J.; *Chem. Rev.* **1972**, *72*, 1. (b) Lyle, R. E. "The Chemistry of Heterocyclic Compounds, Pyridine and Its Derivatives"; Abramovitch, R. A., Ed.; Wiley: New York, 1974; Vol. 14, Part 1.

(3) Dihydropyridines without electron-withdrawing groups on the ring are relatively unstable with respect to dimerization and oxidation. Care must be exercised when handling these compounds in the laboratory.

(4) The Diels–Alder reaction of methyl acrylate with *N*-methyl-1,2-dihydropyridine has been reported previously (Wiley, R. A.; Faraj, B. A.; Jantz, A. *J. Med. Chem.* **1972**, *15*, 374). However, our results differ substantially from theirs. Professor Wiley kindly supplied us with his NMR spectra, and we conclude that the data reported are probably due to impurities, such as the 1,2-dihydropyridine dimer.

(5) (a) Morishima, I.; Yoshikawa, K. *J. Am. Chem. Soc.* **1975**, *97*, 2950. (b) Krow, G.; Rodehaugh, R.; Carmosin, R.; Figures, W.; Pannella, H.; DeViccaris, B.; Grippi, M. *Ibid.* **1973**, *95*, 5273.

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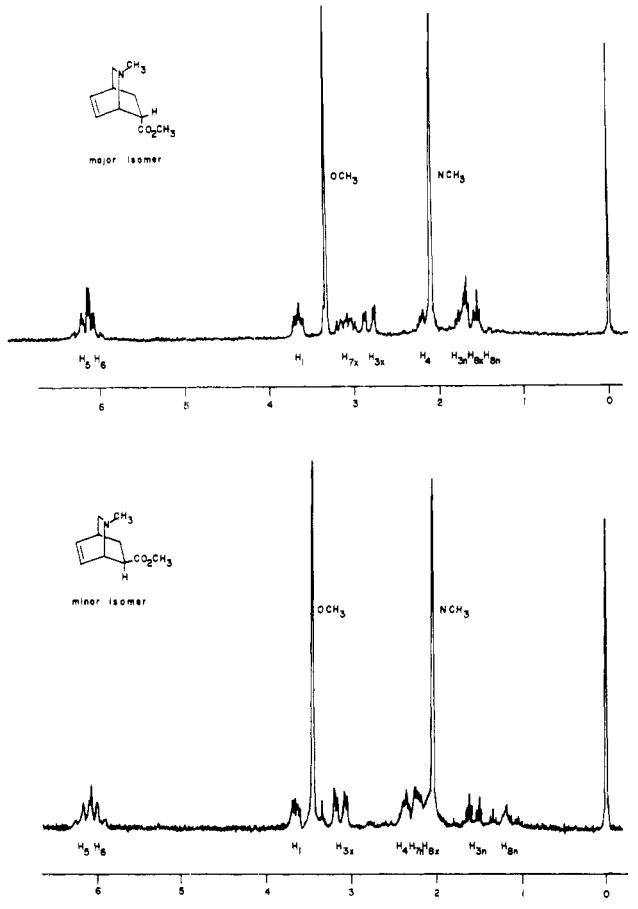
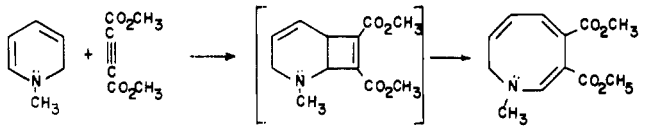


Figure 1. ^{1}H NMR spectra of compounds **4** and **5**.

of the carbon–carbon double bond.

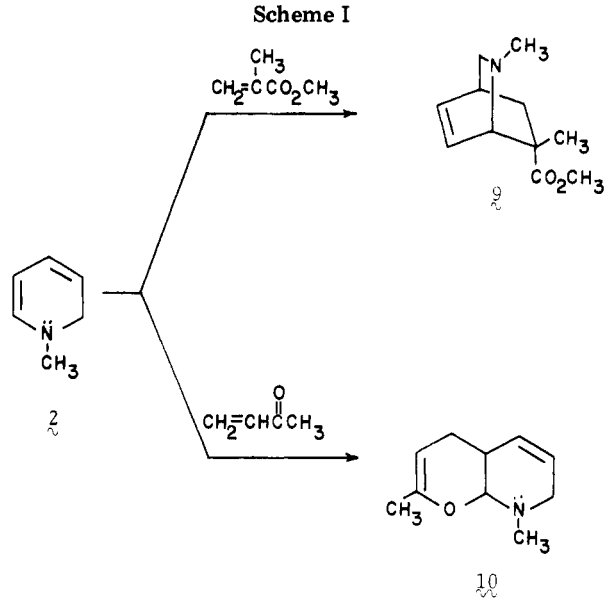
The reaction of dihydropyridine **2** with methyl acrylate (**3**) to give Diels–Alder adducts **4** and **5** was anticipated. Compound **2** should be a reactive diene with respect to the Diels–Alder reaction since the nitrogen lone pair of electrons can activate the π system by electron donation.[6]

However, some 1,2-dihydropyridines are known to react with acetylenic dienophiles such as dimethyl acetylenedicarboxylate to give azocine derivatives rather than Diels–Alder adducts. It is believed that azocine formation involves an initial [2 + 2] cycloaddition reaction between the dihydropyridine and acetylene to give the cyclobutene followed by an electrocyclic ring opening to give the azocine derivative.[7] We have observed that *N*-methyl-1,2-dihydropyridine also reacts with dimethyl acetylenedicarboxylate to give azocine **7**.

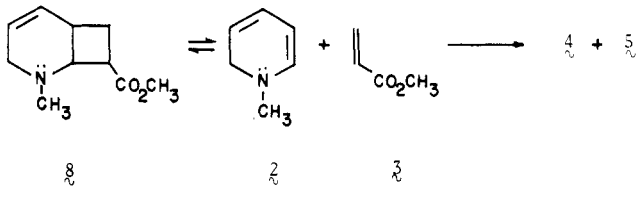


This difference in cycloaddition reactivity of the 1,2-dihydropyridines with respect to electron-deficient acetylenes and alkenes has not been previously explained. We have gained insight into this problem by observing that the major product produced, when *N*-methyl-1,2-dihydropyridine was treated with methyl acrylate at −10 °C, was not either of the Diels–Alder adducts **4** and **5**. We propose the cyclobutane **8** for the structure of this product. This postulation is based on spectral data (see Experimental Section) which show the presence of a 1,2,5,6-tetrahydropyridine ring. Heating the product of this reaction results in decomposition to *N*-methyl-1,2-dihydropyridine and methyl acrylate. This behavior is typical of analogous [2 + 2] cyclobutane adducts formed between enamines containing a β-hydrogen and electron-deficient alkenes.[8]

Scheme I



Our data support the contention that *N*-methyl-1,2-dihydropyridine **2** is behaving as an enamine which reacts with methyl acrylate to give the cyclobutane **8**. This product is in equilibrium with the starting materials which react at a slower rate to give the more thermodynamically stable Diels–Alder adducts **4** and **5**.

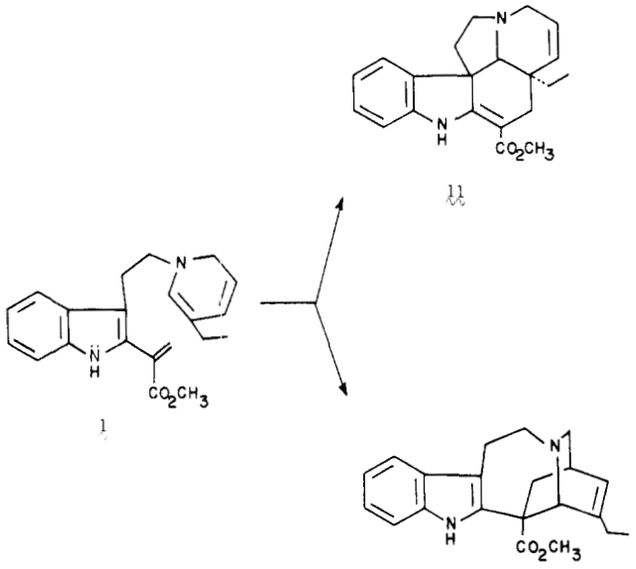


Other electron-deficient dienes such as methyl methacrylate also react with *N*-methyl-1,2-dihydropyridine at high temperature to give Diels–Alder adducts. However, we have observed that the reaction of methyl vinyl ketone with *N*-methyl-1,2-dihydropyridine gave the pyran **10** rather than a Diels–Alder adduct (Scheme I). In this reaction the dihydropyridine is again behaving as an enamine rather than a diene.[9]

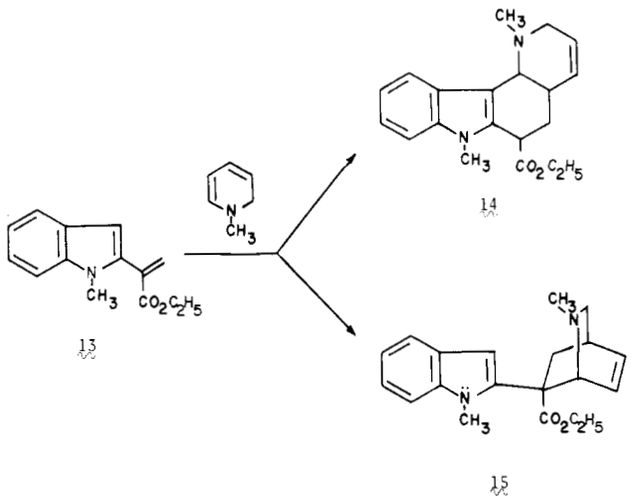
If the enamine reactivity is suppressed by the presence of an electron-withdrawing group on the ring, then reaction as a diene with methyl vinyl ketone is observed. Büchi and co-workers have observed that the reaction of *N*-benzyl-1,2-dihydropyridines with electron-withdrawing groups (C≡N or $CONH_2$) at position 3 or 5 react with methyl vinyl ketone to give the isoquinuclidine derivatives.[10] Also, the reaction of *N*-(ethoxycarbonyl)-1,2-di-

(6) Wollweber, H. "Methoden der Organische Chemie (Houben-Weyl)", 4th ed.; Georg Thieme Verlag: Stuttgart, Germany, 1970; Vol. 5/1c, pp 997–1210.
(7) Acheson, R. M.; Paglietti, G.; Tasken, P. A. *J. Chem. Soc., Perkin Trans. 1* **1974**, 2496.
(8) Brannock, K. C.; Bell, A.; Burpitt, R. D.; Kelley, C. A. *J. Org. Chem.* **1964**, *29*, 801.
(9) (a) Stork, G.; Brizzolara, A.; Landesman, H.; Szmuszkouicz, J.; Terrell, R. *J. Am. Chem. Soc.* **1963**, *85*, 207. (b) Fleming, I.; Harley-Mason, J. *J. Chem. Soc.* **1964**, 2165.

Scheme II



Scheme III



hydropyridine has recently been observed to give the Diels–Alder adduct.[11]

As mentioned previously, dehydrosecodine (1) has been postulated to play an important role in indole alkaloid biosynthesis. These studies suggested that dehydrosecodine may be a useful intermediate for the efficient synthesis of the indole alkaloids. For example, if the dihydropyridine ring in dehydrosecodine (1) behaves as a diene, then the intramolecular Diels–Alder reaction will give the iboga alkaloid catharanthine (12) (Scheme II). If the dihydropyridine behaves as a dienophile, then the intramolecular Diels–Alder reaction will give the aspidosperma alkaloid tabersonine (11). However, dehydrosecodine (1) has never been isolated or synthesized.

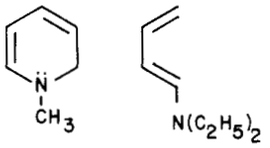
The acrylic ester 13 is of interest since its reaction with *N*-methyl-1,2-dihydropyridine would provide a model for the reactions of the elusive dehydrosecodine (1). The acrylic ester 13 has previously been reported by Ziegler and Spitzner, who used it in their biomimetic synthesis of minovine.[12]

Two modes of Diels–Alder reactivity between the acrylic ester 13 and *N*-methyl-1,2-dihydropyridine are possible. The Diels–Alder reaction of *N*-methyl-1,2-dihydropyridine behaving as a diene with ester 13 would give the iboga[20] analogue 15, whereas the reaction of *N*-methyl-1,2-dihydropyridine behaving as a dienophile would give the aspidosperma[12] analogue 14 (Scheme III).

Treatment of the acrylic ester 13 with an excess of *N*-methyl-1,2-dihydropyridine in chloroform at room temperature led to the disappearance of the acrylic ester within 1.4 h. Thin-layer chromatography of the reaction mixture gave two products in a ratio of 2.3:1. The mass spectra and elemental analyses showed that these compounds were isomeric and 1:1 adducts of the acrylic ester 13 and *N*-methyl-1,2-dihydropyridine. The spectral data of the major and minor isomers were consistent with structures 14 and 15, respectively. This assignment is based primarily on a comparison of the ^{1}H NMR spectra of 14 and 15 with those of 4 and an analogous aspidosperma derivative prepared by Ziegler and Spitzner.[12] In particular, the ^{1}H NMR spectrum of the minor product assigned structure 15 shows an absorption characteristic of 3-unsubstituted indoles at δ 6.84. No other products were isolated from this reaction mixture.

Discussion

To understand the nature of *N*-methyl-1,2-dihydropyridine and its cycloaddition reactions, it is informative to compare its reactivity to the acyclic analogue *N*,*N*-diethyl-1-aminobuta-1,3-diene (16).



A high degree of regiospecificity was observed for both the cyclic and acyclic dienes (2 and 16). High regiospecificity of cycloadditions involving highly perturbed π systems is anticipated and has been rationalized by using frontier molecular orbital theory.[13]

However, the cyclic diene 2 does not show the high stereospecificity that has been reported for the acyclic diene 16.[14] Since a major difference in these dienes is the orientation of the amino group with respect to the π system, the lack of stereospecificity for the cyclic diene could be due to the methyl acrylate having favorable secondary orbital interactions[15] with both the diene and the nitrogen lone pair. The former interaction would lead to the endo product whereas the latter interaction would give the exo product. Because of the trans orientation of the amino group and double bond, secondary orbital interaction of the methyl acrylate with the lone pair of electrons is not as favorable with the acyclic diene during the Diels–Alder reaction.

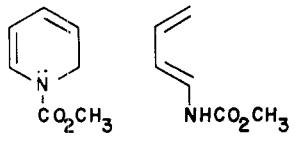
The results reported in this paper demonstrate that the cyclic dienamine 2 reacts as an enamine and not a diene in its initial reaction with electron-deficient π systems. This behavior is in contrast to the acyclic dienamine 16. For example, methyl vinyl ketone is reported to react with

(10) Büchi, G.; Coffen, D. L.; Kocsis, K.; Sonnet, P. E.; Ziegler, F. E. *J. Am. Chem. Soc.* **1966**, *88*, 3099.
(11) Mariano, P. S.; Dunaway-Marino, D.; Huesmann, P. L. *J. Org. Chem.* **1979**, *44*, 124.
(12) Ziegler, F. E.; Spitzner, E. B. *J. Am. Chem. Soc.* **1973**, *95*, 7146.
(13) McAlduff, E. J.; Caramella, P.; Houk, K. N. *J. Am. Chem. Soc.* **1978**, *100*, 105.
(14) Hünig, S.; Kahanek, H. *Chem. Ber.* **1975**, *90*, 238.
(15) Hoffmann, R.; Woodward, R. B. *J. Am. Chem. Soc.* **1965**, *87*, 4388.

the acyclic dienamine **16** to give the Diels–Alder adduct[14] whereas the cyclic dienamine reacted with methyl vinyl ketone to give the cyclic ether.[11] Also, the initial reaction of methyl acrylate with the cyclic dienamine gave the cyclobutane **8**. No analogous product has been reported for the acyclic dienamine **16**.[14]

Qualitatively, the Diels–Alder reaction rate for the cyclic dienamine **2** is less than that for the acyclic analogue **16**. *N*-Methyl-1,2-dihydropyridine (**2**) required heating to 80 °C for 18 h for Diels–Alder adduct formation whereas the reaction of *N,N*-diethyl-1-aminobuta-1,3-diene with methyl acrylate, cooled in a refrigerator, was "complete within a day".[16]

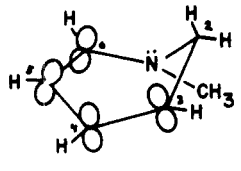
Although the activation of the dienes **17** and **18** with



17 **18**

respect to cycloadditions with methyl acrylate is attenuated by the presence of the methoxycarbonyl substituents, a similar, more quantitative trend has been observed. At 110 °C *N*-(methoxycarbonyl)-1-aminobuta-1,3-diene (**18**) has a half-life of 2 h[17] whereas *N*-(methoxycarbonyl)-1,2-dihydropyridine (**17**) has a half-life of 26 h at the same temperature.

The reactivity of the *N*-methyl-1,2-dihydropyridine **17** can be understood if it is assumed that the 3,4 double bond does not lie in the same plane as the 5,6 double bond of the enamine. This is a reasonable assumption since molecular models indicate this conformation minimizes torsional effects, and it is known that the double bonds in 1,3-cyclohexadiene have a dihedral angle of 18°.[18] If a similar nonplanarity of the two double bonds existed for the 1,2-dihydropyridine ring, then π-electron donation by the nitrogen lone pair of electrons to the 3,4 double bond would be inhibited compared to that for a diene with planar double bonds. Since the acyclic diene **16** does not have the same bond angle constraints, it can attain a more planar conformation, and both double bonds would be activated by the nitrogen lone pair of electrons. The cyclic diene would be less reactive than the acyclic diene with respect to [2 + 4] cycloaddition reactions. However, the nitrogen lone pair of electrons would continue to activate the adjacent 5,6 double bond, facilitating [2 + 2] cycloaddition reactions. That is, the enamine interaction is not inhibited in the heterocycle **2** compared to the acyclic analogue **16**.



2

Photoelectron spectroscopy has proven to be a useful technique for determining the interactions of π systems. It would be anticipated that the more planar π system would have the lower ionization potential because of a greater interaction of the π systems. Consistent with the above discussion is the observation that the first ionization potential of the acyclic diene **16** is 6.95 eV[16] compared to 7.31 eV[17] for the cyclic diene **2**.

We believe that all the observations on the cyclic and acyclic dienes, **2** and **16**, can be interpreted in terms of a greater nonplanarity between the π systems of the enamine and the other double bond for the 1,2-dihydropyridine **2** compared to that of the acyclic analogue **16**.

The reaction of the *N*-methyl-1,2-dihydropyridine with acrylate **13** illustrates that these reactive dihydropyridines may be useful in the total synthesis of indole alkaloids.[20] The dihydropyridine reacted both as a diene and dienophile with respect to acrylate **13**, giving the iboga and aspidosperma analogues **15** and **14**.[21] This reaction also demonstrates that when acrylate **13** is behaving as a dienophile, the indole ring is playing an important role in its reactivity. In contrast to acrylate **13**, which reacts with *N*-methyl-1,2-dihydropyridine within 1.4 h at room temperature, the reaction of methyl methacrylate with *N*-methyl-1,2-dihydropyridine requires refluxing benzene for 5 days for completion.

In summary, we have observed that *N-methyl-1,2-dihydropyridine behaves primarily as an enamine in its cycloaddition reactions with electron-deficient π systems.* The Diels–Alder reactivity of the *N*-methyl-1,2-dihydropyridines is less than that which would be anticipated from studies of the acyclic analogue *N,N*-diethyl-1-aminobuta-1,3-diene. These results are interpreted in terms of a nonplanar diene for the *N*-methyl-1,2-dihydropyridine.

Experimental Section

The proton magnetic resonance spectra were recorded by using a Varian EM-360 or HFT-80 spectrometer. Apparent coupling constants are reported, and the multiplicities are indicated as follows: s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet. Chemical shifts are reported as δ values with tetramethylsilane as an internal standard. The low-resolution mass spectra were recorded with a Hewlett-Packard 5983, and the high-resolution mass spectra were recorded with an AEI MS-30. The spectrometers were operated at an ionization voltage of 70 eV. The infrared spectra were recorded with a Perkin-Elmer 727 spectrometer. The relative intensities are indicated as follows: s = strong, m = medium, w = weak. Microanalyses were performed by Galbraith Laboratories.

Diels–Alder Reaction of *N*-Methyl-1,2-dihydropyridine (2) and Methyl Acrylate. *exo*- and *endo*-2-Methyl-7-(carbomethoxy)-2-azabicyclo[2.2.2]oct-5-enes (4 and 5). To a solution of methyl acrylate (1.7 g) and anhydrous benzene (2.0 mL) was added 700 mg of freshly distilled *N*-methyl-1,2-dihydropyridine–ether solution (75/25). The solution was refluxed for 18 h. The basic products were separated by extraction with 5% HCl, neutralized, extracted into ether, and dried (K_2CO_3). The extract was concentrated in vacuo and distilled (bulb to bulb); yield 712 mg (25%). GC analysis, 3% OV-101 (6 ft × $^1/_8$ in.), showed that the endo and exo isomers were formed in a ratio of

(16) If *N*-methyl-1,2-dihydropyridine and methyl acrylate were kept in the refrigerator for 1 day only the [2 + 2] cycloadduct **10** and the starting materials would be observed. See ref 13.

(17) Overman, L. E.; Taylor, G. F.; Houk, K. N.; Domelsmith, L. N. *J. Am. Chem. Soc.* **1978**, *100*, 3182.

(18) (a) Oberhammer, H.; Bauer, S. H. *J. Am. Chem. Soc.* **1969**, *91*, 10. (b) Butcher, S. S. *J. Chem. Phys.* **1965**, *42*, 1830.

(19) We gratefully acknowledge M. D. Rozeboom and K. N. Houk of Louisiana State University at Baton Rouge for recording this photoelectron spectrum.

(20) R. J. Sundberg and J. D. Bloom have recently developed a synthesis to the iboga alkaloids employing the reaction of *N*-(carbomethoxy)-1,2-dihydropyridine and an analogue of **14** (*Tetrahedron Lett.* **1978**, 5157).

(21) There is interest in efficient syntheses of iboga alkaloids because of the recently discovered coupling of iboga and aspidosperma alkaloids to give the important antineoplastic vinblastine-type dimeric alkaloids. For example, see: (a) Langlois, N.; Gueritte, F.; Langlois, Y.; Potier, P. *J. Am. Chem. Soc.* **1976**, *98*, 7017. (b) Kutney, J. P.; Hibino, T.; Jahngen, E.; Okutani, T.; Radcliffe, A. H.; Treasurywala, A. M.; Wunderly, S. *Helv. Chim. Acta* **1976**, *59*, 2858. Atta-ur-Rahman; Basha, A.; Glazala, M. *Tetrahedron Lett.* **1976**, 2351.

3.2:1. The endo isomer can be obtained in high purity by preparative layer chromatography (70:30 ether–benzene spiked with 1% diisopropylamine). Both isomers can be obtained pure by GC [15% OV-101 Chromsorb W column (5 ft × $^1/_4$ in.) operated at 130 °C]. *endo*-*N*-Methyl-2-aza-7-(carbomethoxy)bicyclo-[2.2.2]oct-5-ene (**4**): ^{1}H NMR ($CDCl_3$, HFT-80) δ 1.63–1.97 (m, 3 H), 2.23 (s, 3 H), 2.43–2.65 (br s, 1 H), 2.88–3.20 (m, 2 H), 3.63 (s, 3 H), 3.63–3.75 (m, 1 H), 6.05–6.53 (m, 2 H); ^{13}C NMR (Me_2CO-d_6, CFT-20) δ 25.87, 31.49, 44.43, 44.62, 51.56, 56.18, 129.73, 134.81, 174.01; mass spectrum (70 eV), *m/e* (relative intensity) 180.9 (8), 94.9 (38), 93.8 (100), 78.6 (6.8); IR (film) 3043 (w), 1737 (s, C=O), 1303 (m), 714 (m) cm^{-1}; high-resolution mass spectrum, *m/e* 181.1095 ($C_{10}H_{15}NO_2$ requires *m/e* 181.1103).

exo-*N*-Methyl-2-aza-7-(carbomethoxy)bicyclo[2.2.2]oct-5-ene (**5**): ^{1}H NMR ($CDCl_3$, HFT-80) δ 1.33–1.56 (m, 1 H), 1.63–1.80 (dt, 1 H, *J* = 9.4, 2.0 Hz), 1.94–2.09 (m, 1 H), 2.11 (s, 3 H), 2.26–2.57 (m, 2 H), 3.04–3.19 (dd, *J* = 3.2, 9.4 Hz), 3.58–3.66 (m, 1 H), 3.70 (s, 3 H), 6.10–6.15 (m, 2 H); ^{13}C NMR (Me_2CO-d_6, CFT-20) δ 26.89, 31.83, 45.21, 45.79, 51.70, 56.44, 57.32, 130.61, 135.49, 174.51; mass spectrum (70 eV), *m/e* (relative intensity) 180.9 (0.8), 94.9 (38), 93.8 (100), 78.8 (6.8); IR (film) 3045 (w), 1738 (s, C=O), 1355 (m), 1200 (s) cm^{-1}; high-resolution mass spectrum, *m/e* 181.1111 ($C_{10}H_{15}NO_2$ requires 181.1103).

N-Methyl-2,3-[bis(carbomethoxy)]-1,8-dihydroazocine (7). A solution of 10 mL of anhydrous ether and dimethyl acetylenedicarboxylate (1.04 g), maintained under an inert atmosphere, was cooled in an ice–H_2O bath. Then, *N*-methyl-1,2-dihydropyridine (875 mg, 80% ether solution) in 5 mL of anhydrous ether was added dropwise. The ice bath was removed, and the solution was stirred for an additional 1.5 h at room temperature. The reaction mixture was concentrated in vacuo and then chromatographed on silica gel. Elution with CH_2Cl_2–$CH_3CO_2C_2H_5$ (80:20) gave pure azocine **7** (1.32 g, 89%) as orange flakes from ether–pentane: mp 93–94 °C; ^{1}H NMR (benzene-d_6, HFT-80) δ 2.01 (s, 3 H, NCH_3), 3.51 (s, 3 H), 3.58 (s, 3 H), 3.58–3.65 (m, 2 H), 5.74–6.29 (m, 2 H), 6.84 (d, *J* = 3.0 Hz), 7.65 (s, 1 H); mass spectrum (70 eV), *m/e* (relative intensity) 239.1 (7), 237.1 (38.9), 178.1 (88.8), 118.0 (100); IR (KBr) 3035 (w), 1713 (s), 1686 (s), 1585 (s), 1432 (s), 1240 (s), 872 (m) cm^{-1}.

Anal. Calcd for $C_{12}H_{15}NO_4$: C, 60.75; H, 6.37. Found: C, 60.88; H, 6.60.

Low-Temperature Condensation of Methyl Acrylate and *N*-Methyl-1,2-dihydropyridine (2). 2-Methyl-8-(carbomethoxy)-2-azabicyclo[4.2.0]oct-5-ene (8). To a freshly distilled ice-cooled ether solution of *N*-methyl-1,2-dihydropyridine (1.34 g, 55% ether solution) maintained under an inert atmosphere (N_2) was added methyl acrylate (2.00 g). The solution was then placed in a refrigerator (ca. −10 °C) for 4 days. The volume was reduced in vacuo, and the product was distilled (bulb to bulb), giving 412 mg (35%) of **8** as a pale yellow oil: ^{1}H NMR ($CDCl_3$, HFT-80) δ 2.35 (s, 3 H, NCH_3), 3.66 (5, 3 H, OCH_3) 5.70–5.80 (br d, 2 H, vinyl); ^{13}C NMR (Me_2CO-d_6, CFT-20) δ 27.34, 33.59, 41.99, 49.17, 51.54, 62.10, 125.00, 127.93, 175.48; mass spectrum (70 eV), *m/e* (relative intensity) 181.0 (0.4), 95.0 (32.8), 93.9 (100), 77.9 (5.2), 54.9 (12.1); IR (film) 3035 (w), 1732 (s, C=O), 1449 (m), 1110 (m), 693 (m) cm^{-1}; high-resolution mass spectrum, *m/e* 181.1111 ($C_{10}H_{15}NO_2$ requires *m/e* 181.1103).

Thermal Decomposition of 8. A solution of 110 mg of **8** in 390 μL of benzene-d_6 was degassed by a series of freeze–thaw cycles. The tube was then sealed under vacuum and heated to 150 °C. ^{1}H NMR analysis after 15 min showed the presence of methyl acrylate and *N*-methyl-1,2-dihydropyridine. Heating for an additional 1 h gave a dark solution which upon GC analysis (OV1, 140 °C) showed two products in a 3.2:1 ratio which were identified as Diels–Alder adducts **4** and **5**.

Diels–Alder Reaction of *N*-Methyl-1,2-dihydropyridine (2) and Methyl Methacrylate. 2,7-Dimethyl-7-(carbomethoxy)-2-azabicyclo[2.2.2]oct-5-ene (9). To a refluxing solution of freshly distilled methyl methacrylate (0.7 g) in 3 mL of anhydrous benzene was added 800 mg of a 60% ether solution of *N*-methyl-1,2-dihydropyridine. The solution was refluxed for 5 days under an inert atmosphere. The basic products were separated by extraction with 5% HCl followed by neutralization and back-extraction into ether. The solution was dried (K_2CO_3) and concentrated in vacuo to give 28.4 mg of **9** (34%). The product was further purified by GC [15% OV-101 on a Chromosorb W column (5 ft × $^1/_4$ in.) operated at 140 °C]. Analysis of the ^{1}H NMR spectrum revealed two isomeric products (0.67:1.0): ^{1}H NMR ($CDCl_3$, HFT-80) δ 1.01 (s, CH_3), 1.42 (s, CH_3), 2.07 (s, NCH_3), 2.21 (s, NCH_3), 3.61 (s, OCH_3), 3.69 (s, OCH_3), 6.04–6.51 (vinyl); mass spectrum (70 eV), *m/e* (relative intensity) 164.1 (1.4), 95.1 (44.3), 94.1 (100); IR (film) 3035 (w), 1732 (s, C=O), 1449 (m), 1110 (m) cm^{-1}; high-resolution mass spectrum, *m/e* 195.1279 (minor isomer), 195.1264 (major isomer) ($C_{11}H_{17}NO_2$ requires *m/e* 195.1259).

Reaction of *N*-Methyl-1,2-dihydropyridine with Methyl Vinyl Ketone. To an ice-cooled solution of 9 mL of anhydrous ether and 1.40 g of purified methyl vinyl ketone, under an inert atmosphere (N_2), was added dropwise 3.01 g (55% ether solution) of freshly distilled *N*-methyl-1,2-dihydropyridine in 15 mL of anhydrous ether. The cooling bath was removed and the mixture stirred for 2 days. Concentration in vacuo followed by bulb to bulb distillation gave 2.44 g (100%) of **10**: ^{1}H NMR ($CDCl_3$, HFT-80) δ 1.63–1.69 (m, 3 H), 1.85–2.16 (m, 3 H), 2.54 (s, 3 H, NCH_3), 3.08–3.21 (m, 2 H), 4.19–4.29 (m, 1 H), 4.62–4.69 (m, 1 H), 5.25–5.81 (m, 2 H, vinyl); ^{13}C NMR (acetone-d_6) δ 19.62, 27.24, 33.98, 42.04, 49.12, 87.69, 91.84, 126.21, 127.43, 159.28; IR (film) 3044 (w), 1680 (s), 1175 (s), 1073 (s), 825 (s) cm^{-1}; high-resolution mass spectrum, *m/e* 165.1150 ($C_{10}H_{15}NO$ requires *m/e* 165.1154).

Ethyl α-(*N*-methylindol-2-yl)acrylate (13) was prepared according to the procedure reported by Ziegler and Spitzner for the methyl ester.[12] The spectral properties of **13** are as follows: IR (film) 3020 (s), 1720 (s, C=O), 1640 (m), 1260 (s), 800 (s) cm^{-1}; ^{1}H NMR ($CDCl_3$) δ 6.85–7.70 (m, 4 H), 6.56 (d, 1 H, *J* = 2 Hz), 6.47 (s, 1 H), 5.93 (d, 1 H, *J* = 2 Hz), 4.26 (q, 2 H, *J* = 7 Hz), 3.59 (s, 3 H), 1.28 (t, 3 H, *J* = 7 Hz); UV λ_{max} (MeOH) 295 nm (ε 23448), 283 (24827), 275 (26207), 223 (100689).

Reaction of *N*-Methyl-1,2-dihydropyridine (2) and Ethyl α-(*N*-Methylindol-2-yl)acrylate (13). A 5-mm NMR tube was fitted with a rubber septum and flushed several times with dry nitrogen. To this tube was added a solution of **13** (69 mg) in 0.5 mL of $CDCl_3$ followed by 113 mg of *N*-methyl-1,2-dihydropyridine. The mixture remained at room temperature, and ^{1}H NMR analysis revealed that the conversion was complete within 1.4 h. The solvent and excess *N*-methyl-1,2-dihydropyridine were removed by a stream of dry nitrogen. The residue (173 mg) was purified by preparative layer chromatography on silica gel. Elution with $CHCl_3$–CH_3OH (90:10) gave 36 mg (37%) of the two products **14** and **15** in a relative ratio of 2.3:1. Recrystallization of the major product (R_f 0.51) from ether–pentane provided colorless crystals of **14**: mp 111.5–112 °C; IR (KBr) 3030 (m), 2955 (m), 2780 (s), 1725 (s, C=O), 1180 (s), 740 (s), 705 (m) cm^{-1}; ^{1}H NMR (benzene-d_6, HFT-80) 6.93–7.83 (m, 4 H), 5.58–5.78 (m, 2 H), 3.85 (q, 2 H, *J* = 7 Hz), 3.51–3.70 (m, 2 H), 3.06 (s, 3 H), 2.68–2.98 (m, 4 H), 2.36 (s, 3 H), 1.98–2.28 (m, 1 H), 0.83 (t, 3 H, *J* = 7 Hz); UV (CH_3OH) λ_{max} 275 nm (ε 3933), 225 (11800); mass spectrum (70 eV), *m/e* (relative intensity) 324 (11), 323 (14), 293 (29), 221 (27), 220 (100), 219 (12), 205 (25), 204 (14), 194 (40), 182 (14), 181 (14), 180 (13), 167 (16), 94 (8).

Anal. Calcd for $C_{20}H_{24}N_2O_2$: C, 74.07; H, 7.40. Found: C, 74.29; H, 7.65.

Recrystallization of the minor product (R_f 0.75) from ether–pentane provided colorless crystals of **15**: mp 144–145 °C; IR (KBr) 3040 (m), 2920 (m), 2800 (4), 1720 (s, C=O), 1202 (s), 840 (m), 740 (s), 705 (m) cm^{-1}; ^{1}H NMR (benzene-d_6, HFT-80) 6.92–7.92 (m, 4 H), 6.84 (d, 1 H, *J* = 0.75 Hz), 6.05–6.35 (m, 2 H), 4.27 (dd, 1 H, *J* = 10, 1.75 Hz), 3.49–4.07 (m, 3 H), 3.42 (s, 3 H), 2.67–3.02 (m, 2 H), 2.20 (s, 3 H), 1.42–1.85 (m, 2 H), 0.76 (t, 2 H, *J* = 7 Hz); UV (CH_3OH) λ_{max} 287 nm (ε 33116), 226 (114935); mass spectrum (70 eV) *m/e* (relative intensity) 324 (10), 95 (68), 94 (100).

Anal. Calcd for $C_{20}H_{24}N_2O_2$: C, 74.07; H, 7.40. Found: C, 74.41; H, 7.56.

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Registry No. 2, 33707-38-9; **4**, 72984-23-7; **3**, 96-33-3; **5**, 73035-80-0; **7**, 72938-62-6; **8**, 72938-63-7; **9** (isomer 1), 72938-64-8; **9** (isomer 2), 72984-24-8; **10**, 72938-65-9; **13**, 72938-66-0; **14**, 72938-67-1; **15**, 72938-68-2; dimethyl acetylenedicarboxylate, 762-42-5; methyl vinyl ketone, 78-94-4.