Diels-Alder Reactions of Vinyl Derivatives of Five-Membered Monoheterocyclic Compounds[1a]

Wayland E. Noland*

School of Chemistry, University of Minnesota, Minneapolis, Minnesota 55455

Chang Kiu Lee,[1b] Sun Kun Bae, Bong Yul Chung, and Chi Sun Hahn

Department of Chemistry, Yonsei University, Seoul, Korea

Keun Jae Kim

Department of Chemistry, Soongjun University, Taejon, Korea

Received September 20, 1982

Vinylpyrroles having electron-withdrawing substituents react with dienophiles to give [4 + 2] π adducts while the furan and thiophene analogues do not. The difference in reactivity among the monoheterocycles can be explained in terms of the greater electron-releasing ability of the nitrogen atom in the pyrrole. The s-cis conformation of the (1*H*-pyrrol-2-yl)maleate derivatives appears to be an important factor in their undergoing the cycloaddition reaction.

Vinyl derivatives of five-membered heterocyclic aromatic compounds appear to be attractive substrates as dienes in the Diels-Alder reaction. Thus, the diene system, consisting of the vinyl group and one of the ring double bonds, may give tetrahydrobenzo[*b*]furan, benzo[*b*]-thiophene, or benzo[*b*]pyrrole (indole) derivatives upon Diels-Alder addition with suitable dienophiles. 2-Ethenylfuran (**1a**) or 2-(1-propenyl)furan (**1b**) react with maleic anhydride (MA) to give adducts such as **4a**[2a] (Chart I). 2-Ethenylfuran (**1a**) also reacts with dimethyl acetylenedicarboxylate (DMAD) at room temperature and at 80 °C and with methyl propiolate (MP) at 80 °C in benzene solution to give the corresponding, but fully dehydrogenated, Diels-Alder adducts **5a** and **5b**.[3] At room temperature, but not at 80 °C, **1a** also gave the adduct **6**, which is derived by a competing Diels-Alder reaction across the 2,5-positions of the furan ring.[3] At 80 °C, **1a** also gave a 1:2 adduct (**7**) derived by the ene addition of a second molecule of DMAD to the intermediate 1:1 adduct formed before dehydrogenation.[3] Electron-withdrawing β substituents on the vinyl group of **1a** (such as CHO, COOH, NO_2) prevented the corresponding reactions with MA.[2a,4] We have confirmed the report[4] that (*E*)-3-(2-furanyl)propenal (**1c**), (*E*)-3-(2-furanyl)propenoic acid (**1d**), ethyl (*E*)-3-(2-furanyl)propenoate (**1e**), and (*E*)-2-(2-nitroethenyl)furan (**1h**) do not react with MA. Our attempts to form adducts with the same dienes and other dienophiles such as DMAD and cyclohexene have also been unsuccessful. Hudson and Robinson[5] suggested that the -I effect of the carbonyl group decreases the diene character, and, consequently, reaction does not take place.[2a] In order to reduce this effect, we prepared the diethyl acetal (**1g**) corresponding to **1c** and investigated its reaction with dienophiles. Neither MA nor DMAD gave any adduct in refluxing xylene after 2 days.

2-Ethenylthiophene (**2a**) has also been reported to give a Diels-Alder adduct (**4b**) with MA,[2b] but vinylthiophenes having an electron-withdrawing substituent on the β-carbon appear to show no reactivity with dienophiles. Thus, we observed that 4-(2-thienyl)-3-buten-2-one (**2b**) did not react with DMAD in refluxing xylene for 5 days. The concentration of **2b** was monitored by UV spectroscopy and found not to change even after 7 days.

Table I. Diels-Alder Reaction of Vinylpyrroles

pyrrole[a]	dienophile[b]	product	mp, °C	% yield
3a	MP	9a	154-155	35
	DMAD	9c	114-115	9
3b	MP	9a	154-155	24
		9b	138-139	2
	DMAD	9c	110-113[c]	16
3d	MP	9d	84.5-85	32
	DMAD	9e	164-166	2
3f	DMAD	10	151-152	37
	MA	11	171-172	34
3g	MP	no reaction		
	DMAD	no reaction		
3i	DMAD	8a	155-157[d]	47

[a] E = $COOCH_3$. [b] MP = methyl propiolate; DMAD = dimethyl acetylenedicarboxylate; MA = maleic anhydride. [c] Reference 9. [d] Reference 8.

There are several reports of vinylpyrroles giving dihydroindoles or indoles; the latter are presumably formed via the intermediacy of dihydroindoles.[6] Recently, Jones and co-workers[6] reported [4 + 2] π addition of 2-ethenyl-1-methyl(or 1-phenyl)-1*H*-pyrrole (**3c** or **3h**) to MA or DMAD, which should give initially tetrahydro adducts **4c** and **4e** or (from DMAD) 3a,6-dihydroindole adducts similar to **8** which isomerized to 6,7-dihydroindoles in the reaction medium. Jones and Arques[7] showed subsequently that with **3c** and DMAD Michael addition at the pyrrole 5-position [to give the corresponding *E* (maleate) and *Z* (fumarate) stereoisomers] competed with Diels-Alder addition (to give the isomerized dimethyl 6,7-dihydro-1-methylindole-4,5-dicarboxylate) at room temperature, but the latter reaction was the exclusive pathway at 80 °C. With **3h** the Diels-Alder addition was the exclusive pathway at 20-80 °C and was 5 times faster.[7] Reactions of these electron-rich vinylpyrroles with electron-deficient dienophiles are not surprising. Vinylpyrroles having electron-withdrawing substituents, however, such as ethyl

(1) (a) Taken in part from the Ph.D. thesis of C.K.L., University of Minnesota, Aug 1976; *Diss. Abstr. Int. B* **1977**, *38*, 1210-1211. (b) Department of Chemistry, Kangwon National University, Chuncheon, Korea.

(2) Onishchenko, A. S. "Diene Synthesis"; Israel Program for Scientific Translations: Jerusalem, 1964: (a) pp 564-566; (b) p 583.

(3) Davidson, W. J.; Elix, J. A. *Aust. J. Chem.* **1973**, *26*, 1059-1067.

(4) Herz, W. *J. Am. Chem. Soc.* **1946**, *68*, 2732.

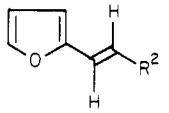
(5) Hudson, B. J. F.; Robinson, R. *J. Chem. Soc.* **1941**, 715-722.

(6) Jones, R. A.; Marriott, M. T. P.; Rosenthal, W. P.; Arques, J. S. *J. Org. Chem.* **1980**, *45*, 4515-4519.

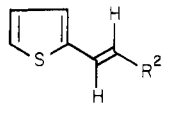
(7) Jones, R. A.; Arques, J. S. *Tetrahedron* **1981**, *37*, 1597-1599.

0022-3263/83/1948-2488$01.50/0

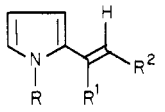
Chart I[a]



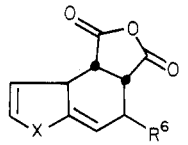
1a, R = H
b, R = CH_3
c, R = CHO
d, R = COOH
e, R = $COOC_2H_5$
f, R = $COCH_3$
g, R = $CH(OC_2H_5)_2$
h, R = NO_2



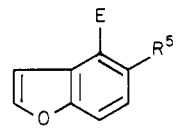
2a, R = H
b, R = $COCH_3$



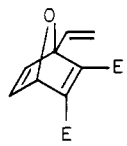
3a, R = H; R^1 = H; R^2 = E
b, R = H; R^1 = R^2 = E
c, R = CH_3; R^1 = R^2 = H
d, R = CH_3; R^1 = H; R^2 = E
e, R = CH_3; R^1 = H; R^2 = $COCH_3$
f, R = CH_3; R^1 = H; R^2 = C_6H_5
g, R = CH_3; R^1 = R^2 = E
h, R = C_6H_5; R^1 = R^2 = H
i, R = 2,6-$(CH_3)_2C_6H_3$; R^1 = R^2 = E



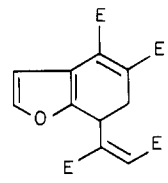
4a, X = O; R^6 = H
b, X = S; R^6 = H
c, X = NCH_3; R^6 = H
d, X = NCH_3; R^6 = C_6H_5
e, X = NC_6H_5; R^6 = H



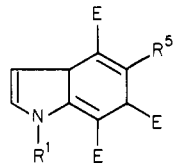
5a, R^5 = $COOCH_3$
b, R^5 = H



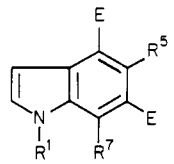
6



7



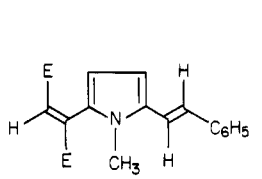
8a, R^1 = 2,6-$(CH_3)_2C_6H_3$; R^5 = E
b, R^1 = H; R^5 = H
c, R^1 = H; R^5 = E



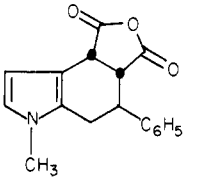
9a, R^1 = H; R^5 = H; R^7 = H
b, R^1 = H; R^5 = H; R^7 = E
c, R^1 = H; R^5 = E; R^7 = H
d, R^1 = CH_3; R^5 = H; R^7 = H
e, R^1 = CH_3; R^5 = E; R^7 = H

[a] In 5–9, E = $COOCH_3$.

(*E*)-3-(1-methyl-1*H*-pyrrol-2-yl)propenoate (**3d**), (*E*)-4-(1-methyl-1*H*-pyrrol-2-yl)but-3-en-2-one (**3e**), and (*E*)-1-methyl-2-(2-phenylethenyl)-1*H*-pyrrole (**3f**) were reported not to give similar adducts with MA.[6] On the other hand, dimethyl (*Z*)-[1-(2,6-dimethylphenyl)-1*H*-pyrrol-2-yl]maleate (**3i**) has been found to give a 3a,6-dihydro-1*H*-indole (**8a**) with DMAD.[8] The results of our extensive investigation of the Diels–Alder reaction of electron-deficient vinylpyrroles are listed in Table I. Although the yields were low (2–35%), vinylpyrroles bearing electron-withdrawing substituents did give [4 + 2] π cycloaddition reactions while their furan and thiophene counterparts did not react at all. The products isolated were the indoles **9** which should be derived from dehydrogenation of the initial adducts, 3a,6-dihydro-1*H*-indoles similar to **8**. (*E*)-1-Methyl-2-(2-phenylethenyl)-1*H*-pyrrole (**3f**) gave with DMAD a Michael-type adduct (**10**), instead of a



10, E = $COOCH_3$



11

Diels–Alder adduct, in 37% yield. Apparently, the 2-(2-phenylethenyl) substituent increases the electron density of the 5-carbon of the pyrrole ring so that Michael-type addition is favored. An analogy is the fact that 1-methyl-1*H*-pyrrole undergoes [4 + 2] π addition with DMAD while 2-methyl-1*H*-pyrrole gives Michael-type addition due to enhanced electron density on the 5-carbon.[9] Interestingly, **3f** and MA did give a Diels–Alder adduct (**11**). The difference in the reaction pathways seems to be due to the significant reactivity difference between the two dienophiles. It has been observed that MA reacts about 5000 times faster than DMAD with **3c** to give a Diels–Alder adduct.[6]

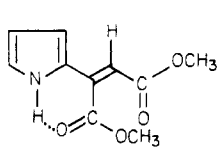
Structure **10** was assigned by spectroscopic methods. In the IR spectrum trans olefinic proton wagging vibrations of **3f** and **10** appear at 950 and 960 cm^{-1}, respectively. In the NMR spectrum of **10**, a singlet at δ 6.94 indicates the presence of a proton in a fumarate derivative.[10] More decisive evidence for structure **10** is the significant bathochromic and hyperchromic shift which occurs in the UV due to the elongation of conjugation. Thus, compound **3f** has λ_{max} at 329 nm (ϵ 25 600) whereas compound **10** has λ_{max} at 393 nm (ϵ 67 600). Structure **11** has also been assigned by examination of spectra. In the IR, the band at 950 cm^{-1} in **3f** is absent in **11**. The UV spectrum of **11** has λ_{max} at 229 nm (ϵ 5900), indicating the relative lack of conjugation.

The [4 + 2] π cycloadditions of **3** may be explained by a stepwise polar addition of the diene acting as an electron donor and the dienophile as an electron acceptor. The greater electron-releasing ability of nitrogen makes the pyrrole better able through resonance or p-orbital overlap to release electrons into the diene system; consistent with this, electrophilic substitution takes place readily at the α-carbon of pyrrole.[11] By the principle of vinylogy, this observation can be extrapolated to explain the observed reactivity of the vinylpyrroles **3a,b,d,f** and the lack of reactivity of the vinylfurans **1c–h**, and vinylthiophene **2b**.

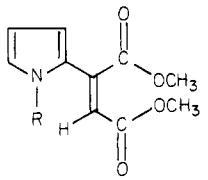
We have reported that (*N*-alkyl(or aryl)pyrrol-2-yl)maleates or -fumarates do not undergo [4 + 2] π cycloaddition except for dimethyl [*N*-(2,6-dimethylphenyl)-1*H*-pyrrol-2-yl]maleate (**3i**), which reacted with DMAD to give **8a**.[8] The conformation of the diene system seems to be as critical a factor as the electron-releasing power of the heteroatoms for [4 + 2] π cycloaddition. Of the possible conformations of **3**, s-cis and s-trans, only the s-cis should undergo cycloaddition. Steric interaction between the *N*-alkyl (or aryl) and α-ester groups (as in **3g**) inhibits the s-cis conformation and favors the s-trans conformation; consequently, N-substituted (1*H*-pyrrol-2-yl)maleates do

(8) Noland, W. E.; Kim, K. J.; Lee, C. K.; Bae, S. K.; Hahn, C. S. *J. Org. Chem.* **1980**, *45*, 4582–4584.

(9) Noland, W. E.; Lee, C. K. *J. Org. Chem.* **1980**, *45*, 4573–4582.
(10) Noland, W. E.; Lee, C. K. *J. Chem. Eng. Data* **1981**, *26*, 91–98.
(11) Joule, J. A.; Smith, G. F. "Heterocyclic Chemistry", 2nd ed.; Van Nostrand-Reinhold: New York, 1978; p 186.



s-cis-3b

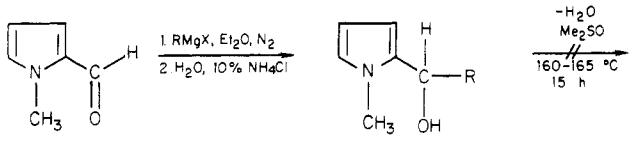


s-trans (such as 3g)

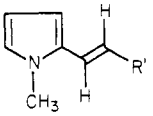
not undergo the cycloaddition reaction. The exception with **3i** is possible because steric interaction between the *o*-methyl groups of the phenyl ring and the C_2 or C_5 substituents on the pyrrole ring should cause the pyrrole and phenyl rings to lie out of plane with respect to each other. This arrangement should decrease steric interactions between the phenyl and α-ester groups, permitting attainment of the s-cis conformation. When there is no substituent on the nitrogen, as in **3b**, the s-cis conformation is probably favored not only because of lack of steric hindrance but also because hydrogen bonding is possible between the NH and the α-carbonyl oxygen atom. Therefore, [4 + 2] π cycloaddition is possible, as is observed with **3b**.

The loss of the 7-methoxycarbonyl group from the intermediate, trimethyl 3a,6-dihydro-1*H*-indole-4,6,7-tricarboxylate (**8b**), was observed in the course of formation of **9a** from the reaction of **3b** and MP. A similar elimination of the 7-methoxycarbonyl group has been reported previously from the intermediate tetramethyl 3a,6-dihydro-1*H*-indole-4,5,6,7-tetracarboxylate (**8c**).[5] Compounds **9a** and **9c** were converted to **9d** (72%) and **9e** (56%) by N-methylation with methyl iodide in a solution of dimethyl sulfoxide (Me_2SO) containing potassium hydroxide.

We also investigated an alternative synthetic method of preparing vinylpyrroles (**13**) using Grignard reagents on



12a, R = CH_3
b, R = C_2H_5
c, R = $CH(CH_3)_2$
d, R = $CH_2C_6H_5$



13

1-methylpyrrole-2-carboxaldehyde. The purified yields of 1-methyl-1*H*-pyrrol-2-ylcarbinols (**12a–d**) were 35–38%, but attempted dehydration by heating **12** in Me_2SO at 160–165 °C for 15 h gave only polymeric material. The carbinols are colorless oils, but they seem to be unstable in air or at room temperature and turn to jelly-like yellow resins within 2 days.

Experimental Section

Melting points were determined on a Thomas-Hoover capillary melting point apparatus and are uncorrected. Infrared spectra were recorded on Beckman IR-18 or Perkin-Elmer Model 257 spectrophotometers. Ultraviolet and visible spectra were recorded on Cary Model 11 or Shimadzu double-beam spectrophotometers. NMR spectra were recorded on a Varian Associates T-60 spectrometer. Mass spectra were obtained on an AEI MS-30 spectrometer at 70 eV and 200 °C by Dr. Roger A. Upham and his associates at the University of Minnesota. Elemental analyses were performed by M-H-W Laboratories, Phoenix, AZ. Column chromatography was performed as previously reported.[9]

Starting Materials. Compounds **1c**,[12] **1d**,[13] **1e**,[14] **1f**,[15] **1g**,[12] **1h**,[16] **2b**,[17] **3a**,[18] **3b**,[9] **3f**,[19] and **3g**[9] were prepared by literature methods. Commercial dimethyl acetylenedicarboxylate (DMAD) and methyl propiolate (MP) were distilled prior to use.

Dimethyl 1*H*-Indole-4,6-dicarboxylate (9a). A mixture of **3a** (0.45 g, 3.00 mmol) and MP (0.91 g, 10.8 mmol) was refluxed for 24 h. The black, tarry solution was left at room temperature for 2 days, during which a yellow precipitate formed. The precipitate was collected by filtration, washed with ether, and recrystallized from methanol, giving **9a** as pale yellow prisms: 0.24 g (35%); mp 154–155 °C; IR (KBr) 3350 (ms, NH), 1706 (s) and 1693 (s, C=O), 1605 (m), 1580 (mw), and 1505 (m, C=C) cm^{-1}; NMR ($CDCl_3$) δ 3.97 (s, 6 H, $COOCH_3$), 7.17 (m, 1 H, 3-H), 7.38 (m, 1 H, 2-H), 7.83 (s, 2 H, 5- and 7-H), 10.0 (br s, 1 H, NH); UV (CH_3OH) λ_{max} 234 nm (log ϵ 4.40), 266 (diffuse sh, 2.93), 292 (sh, 3.26), 337 (4.02); mass spectrum, *m/e* (relative intensity > 10%, M* indicates ^{13}C peak) 234 (13, M*), 233 (100, M), 202 (46, M – CH_3O), 201 (80, M – CH_3OH), 174 (10), 143 (36, M – CH_3O – CH_3OCO), 142 (23), 115 (11). Anal. Calcd for $C_{12}H_{11}NO_4$ (mol wt 233.23): C, 61.80; H, 4.75; N, 6.00. Found: C, 61.63; H, 4.63; N, 5.90.

9a and Trimethyl 1*H*-Indole-4,6,7-tricarboxylate (9b). A solution of **3b** (0.30 g, 1.40 mmol) and MP (0.60 g, 7.14 mmol) was heated at 90–95 °C for 24 h. The tarry solution was distilled under aspirator pressure to remove unreacted MP, and the residual solid mass was suspended in cold methanol (2 mL). The pale yellow solid was collected by filtration and crystallized from methanol, giving **9a** as colorless needles: 78 mg (24 %); mp and mmp 154–155 °C; IR (KBr) and NMR ($CDCl_3$) spectra identical with those of the sample from **3a** described above. The filtrate was chromatographed on a preparative TLC plate of silica gel (20 × 20 cm × 1 mm), eluting with benzene to give two bands: (1) R_f 0.30–0.36; (2) R_f 0.19–0.24. Each band was extracted with chloroform by using a Soxhlet extractor. Band 1 gave a trace of **9a** (mp 153–155 °C), and band 2 gave **9b** as a pale yellow powder, which was crystallized from methanol, giving colorless needles: 10 mg (2%); mp 138–139 °C; IR (KBr) 3390 (ms, NH), 1730 (s), 1719 (s), and 1698 (s, C=O), 1604 (vw), 1576 (w), 1503 (m), and 1495 (mw, C=C) cm^{-1}; NMR ($CDCl_3$) δ 3.93 (s), 3.97 (s), and 4.00 (s, total 9 H, $COOCH_3$), 7.20 (m, 1 H, 3-H), 7.49 (m, 1 H, 2-H), 8.10 (s, 1 H, 5-H), 9.67 (br s, 1 H, NH); UV (CH_3OH) λ_{max} 222 nm (log ϵ 4.21), 253 (4.40), 334 (3.97); mass spectrum, *m/e* (relative intensity ≥ 10%, M* indicates ^{13}C peak) 292 (10, M*), 291 (60, M), 261 (12, M* – CH_3O), 260 (65, M – CH_3O), 259 (49, M – CH_3OH), 202 (13), 173 (29, M – $2CH_3OCO$), 142 (18), 114 (10). Anal. Calcd for $C_{14}H_{13}NO_6$ (mol wt 291.26): C, 57.53; H, 4.50; N, 4.81. Found: C, 57.43; H, 4.56; N, 4.71.

Dimethyl 1-Methyl-1*H*-indole-4,6-dicarboxylate (9d). A solution of **3d** (1.65 g, 10.0 mmol) and MP (1.68 g, 20.0 mmol) was refluxed for 20 h. The black solution was distilled at 0.10 mm: (1) 0.48 g, bp 105–145 °C; (2) 0.95 g, bp 150–200 °C. Distillate 1 was unchanged **3d** (29% recovery). Distillate 2 solidified immediately and was recrystallized from methanol, giving **9d** as a pale yellowish white powder: 0.79 g (32%); mp 84.5–85 °C; IR (KBr) 1711 (vs, C=O), 1591 (m) and 1518 (m, C=C) cm^{-1}; NMR ($CDCl_3$) δ 3.85 (s, 3 H, NCH_3), 3.98 (s, 6 H, $COOCH_3$), 7.18 (s, 2 H, 5- and 7-H), AB pattern (J = 8 Hz) at 7.55 and 7.87 (2 H, 2- and 3-H); UV (CH_3OH) λ_{max} 237 nm (log ϵ 4.41), 331 (3.90); mass spectrum, *m/e* (relative intensity ≥ 9%, M* indicates ^{13}C peak) 248 (15, M*), 247 (100, M), 217 (10, M* – CH_3O), 216 (69, M – CH_3O), 214 (15), 189 (9), 188 (11), 187 (9), 156 (11), 128 (9).

(12) Rallings, R. J.; Smith, J. C. *J. Chem. Soc.* **1953**, 618–622.
(13) Johnson, J. R. In "Organic Syntheses"; Horning, E. C., Ed.; Wiley: New York, 1955; Collect. Vol. III, pp 426–427.
(14) Hughes, E. C.; Johnson, J. R. *J. Am. Chem. Soc.* **1931**, *53*, 737–746.
(15) Leuck, G. J.; Cejka, L. In "Organic Syntheses", 2nd ed.; Gilman, H.; Blatt, A. H., Eds.; Wiley: New York, 1941; Collect. Vol. I, pp 283-284.
(16) Thiele, J.; Landers, H. *Justus Liebigs Ann. Chem.* **1909**, *369*, 300–310.
(17) Keskin, H.; Miller, R. E.; Nord, F. F. *J. Org. Chem.* **1951**, *16*, 199–206.
(18) Badar, Y.; Lockley, W. J. S.; Toube, T. P.; Weedon, B. C. L.; Valadon, L. R. G. *J. Chem. Soc., Perkin Trans. 1* **1973**, 1416–1424.
(19) Jones, R. A.; Lindner, J. A. *Aust. J. Chem.* **1965**, *18*, 875–885.

Anal. Calcd for $C_{13}H_{13}NO_4$ (mol wt 247.25): C, 63.15; H, 5.30; N, 5.66. Found: C, 63.28; H, 5.40; N, 5.58.

Trimethyl 1*H*-Indole-4,5,6-tricarboxylate (9c). A solution of **3a** (0.45 g, 3.00 mmol) and DMAD (0.85 g, 6.00 mmol) in xylene (5 mL) was refluxed for 16 h. The black, tarry solution was chromatographed on a column of silica gel (1.5 × 30 cm) by eluting with the following: petroleum ether (bp 30–60 °C)/benzene (1) 2:3, 0.40 L; (2) 2:3, 0.45 L; (3) 2:1, 0.45 L; benzene (4) 0.50 L; benzene–chloroform (5) 2:1, 1.00 L; (6) 1:1, 1.50 L; chloroform (7) 1.00 L. Fractions 1 and 7 gave no organic material. Fractions 2–4 gave unchanged **3a** (0.17 g, 38%). Fraction 5 gave a trace amount of black gummy material. Fraction 6 gave **9c** as a pale yellow powder: 0.07 g (9%); mp and mmp 114–115 °C; IR (KBr) and NMR ($CDCl_3$) spectra identical with those of the sample previously prepared.[9]

Trimethyl 1-Methyl-1*H*-indole-4,5,6-tricarboxylate (9e). A solution of **3d** (1.70 g, 10.3 mmol) and DMAD (2.85 g, 20.0 mmol) in xylene (20 mL) was refluxed for 65 h. The black, tarry solution was distilled under aspirator pressure to remove the xylene and then distilled at 0.15 mm: (1) 0.24 g, bp 138–140 °C; (2) 0.25 g, bp 140–200 °C; (3) 0.30 g, bp 205–250 °C. Distillates 1 and 2 were unchanged **3d** (29% recovery). Distillate 3 was triturated with ether, leaving a white powder, which was recrystallized from methanol to give **9e** as white needles: 50 mg (2%); mp 164–166 °C; IR (KBr) 1750 (vs) and 1735 (vs, C=O), 1621 (m) and 1568 (mw, C=C) cm^{-1}; NMR (acetone-d_6) δ 3.87 (s, 6 H) and 3.93 (s, 3 H, all $COOCH_3$), 4.00 (s, 3 H, NCH_3), 6.93 (d, $J_{3,2}$ = 3 Hz, 1 H, 3-H), 7.65 (d, $J_{2,3}$ = 3 Hz, 1 H, 2-H), 8.23 (s, 1 H, 7-H); UV (CH_3OH) λ_{max} 258 nm (log ϵ 4.52), 316 (sh, 3.73), 332 (3.80); mass spectrum, *m/e* (relative intensity ≥ 5%, M* indicates ^{13}C peak) 306 (8, M*), 305 (46, M), 275 (16, M* –CH_3O), 274 (100, M – CH_3O), 216 (7, M – CH_3OCO – CH_2O), 173 (5), 157 (13, M – $2CH_3OCO$ – CH_2O), 156 (5), 130 (5), 129 (10), 128 (6). Anal. Calcd for $C_{15}H_{15}NO_6$ (mol wt 305.29): C, 59.01; H, 4.95; N, 4.59. Found: C, 59.00; H, 5.06; N, 4.32.

Dimethyl [(*E*)-1-Methyl-5-(*E*)-(2-phenylethenyl)-1*H*-pyrrol-2-yl]-2-butenedioate (10). A solution of **3f** (1.83 g, 10.0 mmol) and DMAD (2.84 g, 20.0 mmol) in anhydrous ether (20 mL) was refluxed for 21 h and cooled, causing separation of an orange powder. The powder was collected by filtration and recrystallized from methanol, giving **10** as orange needles: 1.20 g (37%); mp 151–152 °C; IR (KBr) 1710 (s, C=O), 1580 (s, C=C), 960 (m, *trans*-HC=CH) cm^{-1}; NMR ($CDCl_3$) δ 3.66 (s), 3.76 (s), and 3.92 (s, 3 H each, $2COOCH_3$, NCH_3), 5.94 (d, $J_{4,3}$ = 3.5 Hz, 1 H, 4-H), 6.51 (m, 2 H, 3-H and HC=CHC_6H_5), 6.94 (s, 1 H, HCE=CE), 7.10–7.60 (m, 6 H, HC=CHC_6H_5); UV (CH_3OH) λ_{max} 393 nm (log ϵ 4.83); mass spectrum, *m/e* (relative intensity ≥ 10%, M* indicates ^{13}C peak) 325 (100, M), 267 (12, M* – $COOCH_3$), 266 (56, M – $COOCH_3$), 251 (11), 207 (23, M – $2COOCH_3$), 206 (32, M – $COOCH_3$ – $HCOOCH_3$), 191 (10), 91 (20); calcd for $C_{19}H_{19}NO_4$ (M^+) *m/e* 325.1311, found *m/e* 325.1311.

4,5,6,7-Tetrahydro-1-methyl-6-phenyl-1*H*-indole-4,5-*cis*-dicarboxylic Anhydride (11). A solution of maleic anhydride (1.96 g, 20.0 mmol) and **3f** (1.83 g, 10.0 mmol) in anhydrous ether (10 mL) was refluxed for 40 h. When the mixture cooled, a pale yellow powder formed, was collected by filtration, and recrystallized from benzene, giving **11** as colorless needles: 0.95 g (34%); mp 171–172 °C; IR (KBr) 1840 (s), 1750 (s, anhydride) cm^{-1}; NMR (Me_2SO-d_6) δ 2.82 (d, $J_{7,6}$ = 5.5 Hz, 2 H, 7-H), 3.43 (s, NCH_3) overlapping 3.59 (m, total 4 H, 6-H), 3.91 (apparent t, $J_{5,4}$ = 8.0 Hz, 1 H, 5-H), 4.32 (apparent d, $J_{4,5}$ = 8.0 Hz, 1 H, 4-H), 6.01 (d, $J_{3,2}$ = 2.5 Hz, 1 H, 3-H), 6.67 (d, $J_{2,3}$ = 2.5 Hz, 1 H, 2-H), 7.24 (s, 5 H, C_6H_5); UV (CH_3OH) λ_{max} 229 nm (log ϵ 3.77); mass spectrum, *m/e* (relative intensity ≥ 15%) 281 (45, M), 209 (100, M – COOCO), 208 (85, M – COOCO – H), 193 (16, M – COOCO – CH_4), 151 (17), 132 (69, M – COOCO – C_6H_5), 131 (27), 130 (15), 118 (17), 117 (21), 91 (24), 51 (16), 44 (22), 42 (17); calcd for $C_{17}H_{15}NO_3$ (M^+) *m/e* 281.1050, found 281.1053.

1-Methyl-1*H*-pyrrol-2-ylcarbinols. Illustrative Procedure: 1-(1-Methyl-1*H*-pyrrol-2-yl)ethanol (12a). 1-Methyl-1*H*-pyrrole-2-carboxaldehyde (10.8 g, 100 mmol) was added dropwise to a Grignard reagent prepared from magnesium (2.64 g, 110 mmol) and methyl iodide (10 mL) in anhydrous ether (50 mL) under nitrogen. The solution was stirred for 1 h, and then aqueous 10% ammonium chloride solution (40 mL) was added. The ethereal layer was separated and distilled under vacuum, giving **12a** as a colorless liquid: 4.40 g (36%); bp 64–65 °C (1 mm); IR (neat) 3600–3200 (br s, OH); NMR (CCl_4) δ 1.47 (d, J = 7.0 Hz, 3 H, CCH_3), 3.08 (s, 3 H, NCH_3), 3.95 (q, J = 7.0 Hz, 1 H, $HOCHCH_3$), 5.54 (m, 2 H, 3′- and 4′-H), 6.29 (m, 1 H, 5′-H); UV (CH_3OH) λ_{max} 222 nm (log ϵ 3.87).

1-(1-Methyl-1*H*-pyrrol-2-yl)propanol (12b): colorless liquid; 38%; bp 90–92 °C (2 mm); IR (neat) 3600–3200 (br s, OH) cm^{-1}; NMR (CCl_4) δ 0.96 (t, J = 7.0 Hz, 3 H, CH_2CH_3), 1.72 (apparent quintet, J = 7.0 Hz, 2 H, $CHCH_2CH_3$), 3.65 (s, 3 H, NCH_3), 4.00 (t, J = 7.0 Hz, 1 H, $HOCHCH_2$), 5.85 (m, 2 H, 3′- and 4′-H), 6.42 (m, 1 H, 5′-H); UV (CH_3OH) λ_{max} 222 nm (log ϵ 3.94).

2-Methyl-1-(1-ethyl-1*H*-pyrrol-2-yl)propanol (12c): colorless liquid; 37%; bp 89–90 °C (3 mm); IR (neat) 3600–3200 (br s, OH) cm^{-1}; NMR (CCl_4) δ 0.98 (d, J = 7.0 Hz, 6 H, $CH(CH_3)_2$), 1.85 (m, 1 H, $CH(CH_3)_2$), 3.54 (s, 3 H, NCH_3), 4.03 (d, J = 7.0 Hz, 1 H, HOCHCH), 5.82 (m, 2 H, 3′- and 4′-H), 6.33 (m, 1 H, 5′-H); UV (CH_3OH) λ_{max} 222 nm (log ϵ 3.98).

1-(1-Methyl-1*H*-pyrrol-2-yl)-2-phenylethanol (12d): pale yellow liquid; 35%; bp 149–150 °C (3 mm); IR (neat) 3600–3200 (br s, OH), 1600 (m) and 1500 (s, C=C) cm^{-1}; NMR ($CDCl_3$) δ 3.16 (d, J = 7.0 Hz, 2 H, $CHCH_2$), 3.54 (s, 3 H, NCH_3), 3.85 (t, J = 7.0 Hz, 1 H, $HOCHCH_2$), 6.31 (m, 2 H, 3′- and 4′-H), 6.62 (m, 1 H, 5′-H), 7.32 (m, 5 H, C_6H_5); UV (CH_3OH) λ_{max} 237 nm (log ϵ 3.77).

Acknowledgment. We are indebted to the University of Minnesota for a Graduate Teaching Assistantship to C.K.L. during the years 1972–1976. We gratefully acknowledge summer fellowships to C.K.L. from the 3M Co., the Eastman Kodak Co. (1973), the General Mills Foundation (1974), and the Camille and Henry Dreyfus Foundation, Inc., (1975) and partial support of the expenses of this research, including a summer fellowship to C.K.L. (1973), from Hoffman-La Roche Inc. We gratefully acknowledge a research grant from the Korean Science and Engineering Foundation to C.K.L. in 1979.

Registry No. **3a**, 32585-91-4; **3b**, 66653-24-5; **3d**, 69917-84-6; **3f**, 2761-79-7; **3g**, 74985-91-4; **3i**, 74965-13-2; **8a**, 86012-89-7; **9a**, 86012-83-1; **9b**, 86012-84-2; **9c**, 74986-27-9; **9d**, 86012-85-3; **9e**, 86012-86-4; **10**, 86012-87-5; **11**, 86012-88-6; **12a**, 56423-58-6; **12b**, 86012-90-0; **12c**, 86012-91-1; **12d**, 86012-92-2; MP, 922-67-8; DMAD, 762-42-5; MA, 108-31-6.