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In Situ Vinylindole Synthesis. Diels-Alder Reactions with Maleic Anhydride and Maleic Acid to Give Tetrahydrocarbazoles and Carbazoles[1]

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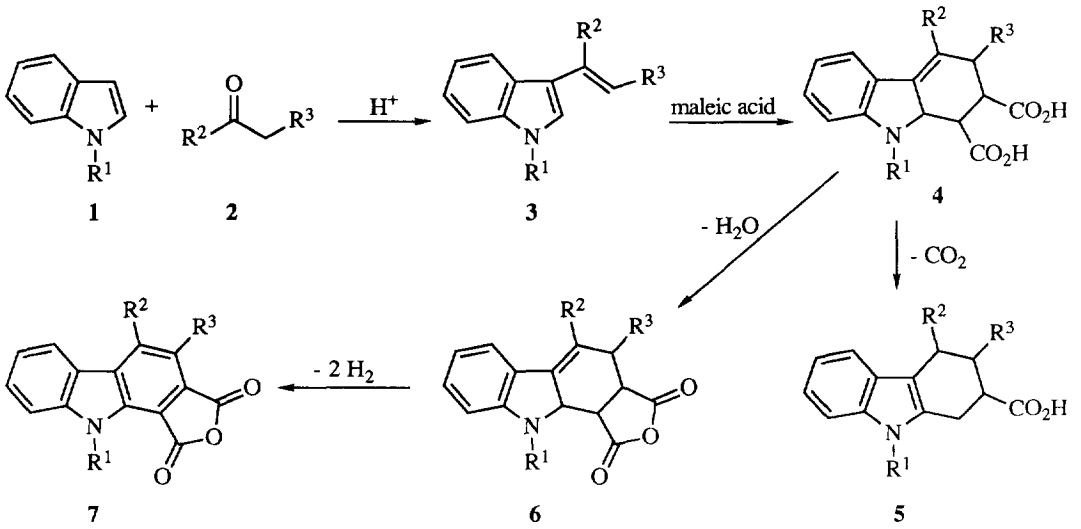
Abstract: Tetrahydrocarbazoles have been prepared in one-flask syntheses from indoles, ketones, and maleic anhydride, with acid catalysis. The reactions involve a condensation of the indole with the ketone or aldehyde, followed by an *in situ* trapping of the vinylindole in a Diels-Alder reaction with maleic anhydride. Depending on which indole is used, this may or may not be followed by a double bond isomerization. If the double bond isomerization doesn't occur, the adduct may or may not be acylated at the nitrogen by maleic anhydride. 1,2,3,4-Tetrahydrocarbazole-1,2-dicarboxylic anhydrides have been hydrolyzed to the 1,2-dicarboxylic acids in good yields. The corresponding 1,2-dicarboxylic acids have been regioselectively decarboxylated at the 1-position in excellent yields. New results with the use of maleic acid as the dienophile in this reaction are also discussed.

Introduction

Synthesis of carbazoles, by using Diels-Alder reactions of vinylindoles, was first developed in our laboratory a number of years ago.[2] Recently, a number of other researchers have expanded upon this methodology.[3] The "*in situ* vinylindole synthesis of carbazoles," also developed in our laboratory, combines the synthesis of the vinylindole and the subsequent Diels-Alder reaction in one flask to produce a variety of substituted and annulated tetrahydrocarbazoles. Thus, 1,2,3,4-tetrahydrocarbazole-2-carboxylic acids (**5**) are produced from indoles (**1**), a methyl or methylene ketone (**2**), and maleic acid[4] (Scheme 1), and 1,2,3,4-tetrahydrocarbazole-1,2-dicarboximides are produced if maleimides and a catalytic amount of hydrochloric acid are used instead of maleic acid.[5] In the above reaction sequences, condensation of the indole with the ketone or aldehyde gives a 3-vinylindole (**3**) which undergoes cycloaddition with the maleic acid or maleimide, followed by double-bond isomerization, and, with the case of maleic acid as the dienophile, regioselective decarboxylation. In the present paper, we describe our results with maleic anhydride (and new results with maleic acid) as the dienophile in this synthesis.

Discussion

The acid-catalyzed condensations of 3-unsubstituted indoles with ketones have been postulated to proceed through 3-vinylindole intermediates (**3**).[4-6] Intermediates **3** can be isolated, in many instances, when the



1	R^1
a	H
b	CH_3

2	R^2	R^3
a	$-(CH_2)_4-$	
b	$-(CH_2)_5-$	
c	$-(CH_2)_8-$	
d	$-(CH_2)_9-$	
e	$-(CH_2)_{10}-$	

3-7	R^1	R^2	R^3
a	H	$-(CH_2)_4-$	
b	CH_3	$-(CH_2)_4-$	
c	H	$-(CH_2)_5-$	
d	CH_3	$-(CH_2)_5-$	
e	H	$-(CH_2)_8-$	
f	CH_3	$-(CH_2)_8-$	

continued in the next column

3-7	R^1	R^2	R^3
g	H	$-(CH_2)_9-$	
h	CH_3	$-(CH_2)_9-$	
i	H	$-(CH_2)_{10}-$	
j	CH_3	$-(CH_2)_{10}-$	

Scheme 1

vinylindoles are sufficiently stable under the reaction conditions.[6] We did not attempt, in this study, to isolate the vinylindole intermediates. Instead, the intermediates were trapped in Diels-Alder reactions with maleic acid or maleic anhydride to give adducts that often underwent further reactions.

Previously, we had reported that 1,2,3,4-tetrahydrocarbazole-2-carboxylic acids (**5**) are produced from indoles (**1**), a methyl or methylene ketone (**2**), and maleic acid in 20-57 % yields.[4] We have now employed this reaction with a series of cyclic ketones (Scheme 1) and have isolated carbazole anhydrides **7**, as well as carboxylic acids **5** and the tetrahydrocarbazole **6**, in low yields from many of these reactions (Table 1). It is interesting to note that carboxylic acids **5** were derived from acyclic ketones and small-ring ketones (5 - 6 carbons), whereas carbazole anhydrides **6** or **7** were derived from medium-ring ketones (7,10, 11, 12 carbons). It is possible that in these reactions rings larger than six atoms cause crowding that forces the carboxylic acid moieties closer together, permitting rapid dehydration. As the rings become even larger, they could be expected

Table 1. Yields of Products **5** - **7** From Indole, Ketones, and Maleic Acid.

indole	ketone	products	yield, %
1a	**2a**	**5a**	2
1b	**2a**	**5b**[a]	3
1a	**2b**	**7c**	1
1b	**2b**	**6d**	3
		7d	1
1a	**2c**	**7e**	1
1b	**2c**	**7f**	6
1a	**2d**	**7g**	2
1b	**2d**	**7h**	5
1a	**2e**	**5i**[a]	7
1b	**2e**	**7j**	4

(a) 2 Isomers which were inseparable by chromatography.

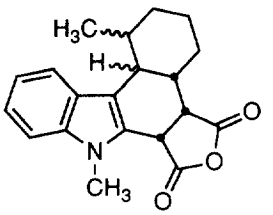


Figure 1. Structure of **8g** with possible epimeric centers.

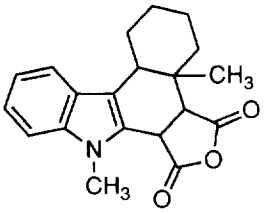
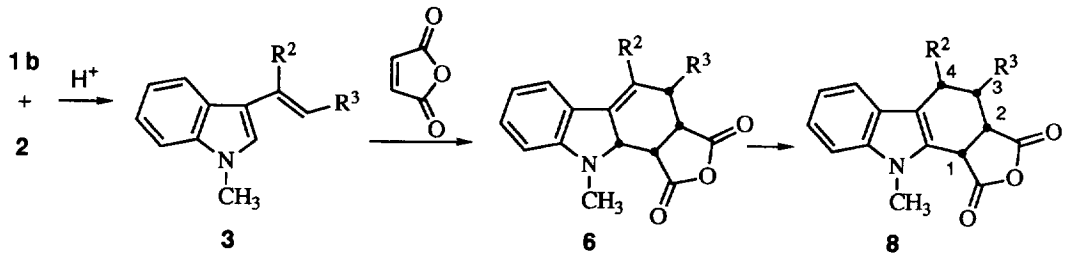


Figure 2. Incorrect structure of **8g**.

to behave more like open chain ketones, giving less crowding of the carboxylic acid moieties. This is a possible explanation for the formation of carboxylic acid **5i** from cyclododecanone. The isolation of anhydride **6d** is evidence that the mechanism for formation of carbazole anhydride **7** involves a closure of dicarboxylic acid **4** to anhydride **6**, immediately after cycloaddition and before double-bond isomerization. Structure **6d** was assigned to this anhydride based on the ^{1}H NMR data and on UV evidence of an *o*-aminostyrene chromophore.

We decided to test the use of maleic anhydride as the dienophile in the "*in situ* vinylindole synthesis of carbazoles." The reaction of 1-methylindole (**1b**) with ketones (**2**), in the presence of a catalytic amount of hydrochloric acid, produced 3-vinylindoles (**3**) which were trapped in Diels-Alder reactions with maleic anhydride (Scheme 2). The intermediate adducts (**6**) then underwent double-bond isomerization to give the 1,2,3,4-tetrahydrocarbazoles (**8**) in 10 - 67 % yields. The results of these reactions are analogous to those that we recently reported for the use of maleimides as the dienophile in this reaction.[5] Aromatized carbazoles were not found in any of these reactions with maleic anhydride in contrast to the use of maleic acid. Since the yields were not quantitative, it is not certain that these were the only related products produced in these reactions, but they are the major products. Only one isomer of each tetrahydrocarbazole **8** was obtained, except for tetrahydrocarbazole **8g**, which was obtained as two isomers. The relatively low coupling constants, $J_{1,2}$ = 7.0 - 9.7 Hz and $J_{2,3}$ = 5.1 - 6.3 Hz, of the tetrahydrocarbazoles **8** are consistent with an assignment of the stereochemistry as 1,2,3-*cis*. The stereochemistry at C-4 was not determined in these studies, but it is assumed (based on our earlier studies[5]) that this hydrogen is *cis* to the hydrogens at C-1, C-2, and C-3 as shown in Scheme 2. We did not determine if the epimeric center for the two isomers of tetrahydrocarbazole **8g** is at C-4 of the carbazole ring system or at the carbon bearing the methyl group (Figure 1). Since the upfield methyl appears as a doublet for both isomers in the ^{1}H NMR spectrum, however, we could rule out the structure shown in



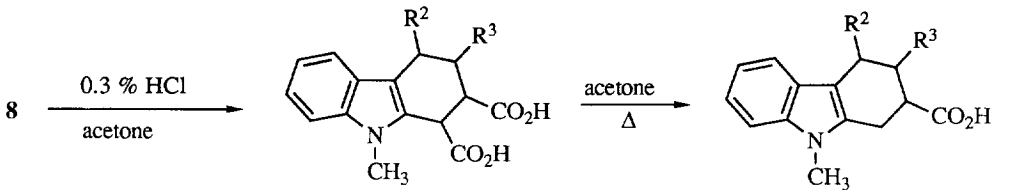
2,3,6,8	R^2	R^3	yield of **8**
a	$-(CH_2)_4-$		18
f	$-(CH_2)_3-$		52
g	$-CH(CH_3)(CH_2)_3-$		22
h	$-CH(CH_2)_2CH-$ $\llcorner\ CH_2\ \lrcorner$		19
i	CH_3	H	62
j	CH_3	CH_3	55
k	CH_3	CH_2CH_3	34
l	CH_2CH_3	CH_3	27
m	CH_3	CH_2Ph	42
n	Ph	H	47
o	Ph	CH_3	60
p	CH_3	Ph	13
q	*p*-CH_3Ph	H	42
r	*p*-CH_3OPh	H	67
s	*m*-CH_3OPh	H	63
t	*p*-BrPh	H	38

continued in the next column

2,3,6,8	R^2	R^3	yield of **8**
u	*p*-ClPh	H	59
v	*p*-FPh	H	39
w	*p*-NO_2Ph	H	53
x	*p*-PhPh	H	50
y	*p*-CH_3COOPh	H	50
z	*p*-$CH_3CONHPh$	H	58
aa	CH_3	$CH_2COC(CH_3)_3$	53
bb	CH_2COCH_3	H	10
cc	$-C{=}C-(CH_2)_2-$ 		33
dd	$-(CH_2)_2-C{=}C-$ 		55
ee	$-C{=}C-OCH_2-$ 		12

Scheme 2

Figure 2 as either isomer. In several of the reactions shown in Scheme 2, the ketone is unsymmetrical and contains α-hydrogens on both sides of the carbonyl. This could have led to more than one 3-vinylindole and given two possible regioisomers for the products. Nevertheless, only one isomer was obtained for each tetrahydrocarbazole. Tetrahydrocarbazoles **8j**, **8k**, **8m**, and **8z** are derived, not unexpectedly, from the vinylindoles with the most-substituted double bonds. Tetrahydrocarbazole **8cc** was derived from a vinylindole that was conjugated to a second aromatic ring, again through the most-stable double bond. Tetrahydrocarbazoles



9 **10**

9	R^2	R^3	yield, %
a	CH_3	H	84
b	CH_3	CH_3	86
c	CH_2CH_3	CH_3	87
d	$-(CH_2)_3-$		96
e	Ph	H	96
f	$-(CH_2)_2-C=C-$		91

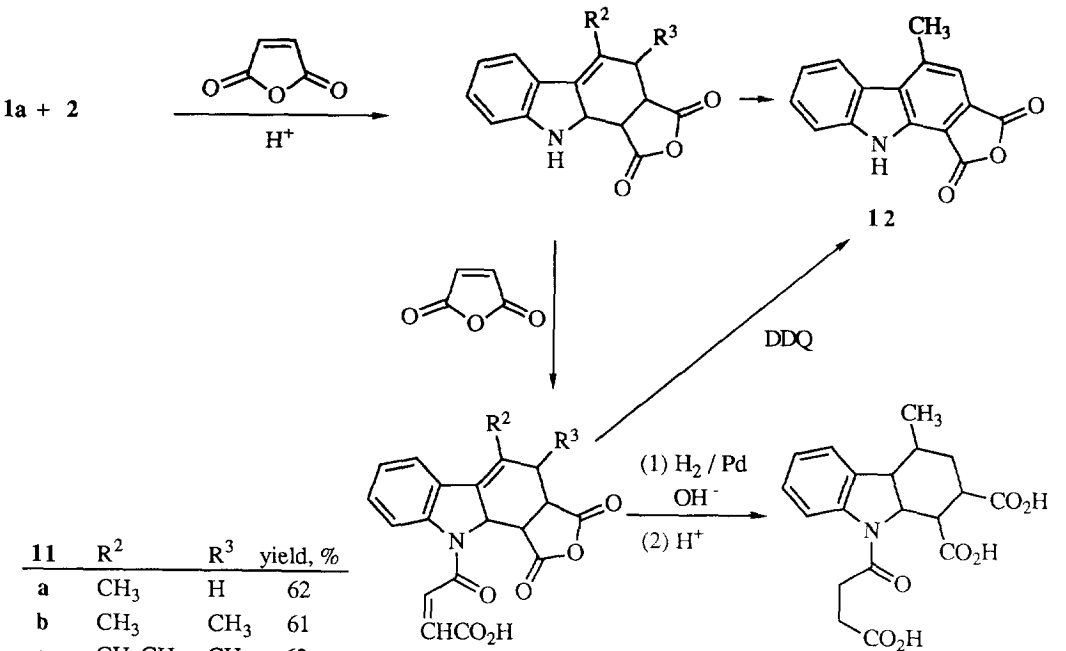
10	R^2	R^3	yield, %
a	CH_3	H	96
b	CH_3	CH_3	82
c	CH_2CH_3	CH_3	99

Scheme 3

8g, **8h**, and **8bb** are derived from vinylindoles with the least-substituted double bonds. This is expected for tetrahydrocarbazole **8h**, since the alternative regioisomer to **8h** would have been derived from a vinylindole that violates Bredt's rule.[7] Tetrahydrocarbazoles **8g** and **8bb**, on the other hand, are derived from vinylindoles with what are expected to be the less stable double bonds. The final product ratio, according to the Curtin-Hammett principle,[8] doesn't represent the stabilities of the intermediates. It is possible that in these cases the irreversibly-formed products come from the less stable intermediates (less-substituted vinylindoles), which are much more reactive for steric and electronic reasons than the more stable intermediates (most-substituted vinylindoles).

Anhydrides **8** were hydrolyzed with 0.3 % hydrochloric acid in acetone at ambient temperature to give 1,2,3,4-tetrahydrocarbazole-1,2-dicarboxylic acids (**9**) in yields of 84 - 96 % (Scheme 3). The relatively low coupling constants, $J_{1,2}$ = 4.4 - 5.5 Hz, of the tetrahydrocarbazoles **9** are consistent with an assignment of a *cis*-stereochemistry, indicating that epimerization of the carboxyl groups did not take place under these mild conditions. The dicarboxylic acids **9** were regiospecifically decarboxylated at the 1-position in excellent yields (82 - 99 %) by heating overnight in refluxing acetone or 2-butanone. Anhydride **8i** was also converted directly to the monocarboxylic acid **10a** in 84 % yield by hydrolyzing it in 0.3 % hydrochloric acid in refluxing acetone.

The reactions of indole (**1a**) with maleic anhydride in the "*in situ* vinylindole synthesis of carbazoles" gave *N*-acylated tetrahydrocarbazoles **11** in yields of 38 - 62 % (Scheme 4) when the hydrochloric acid concentration was kept low (~ 0.025 *M*), the maleic anhydride was used in excess (three equivs), and the reaction solutions were heated. Acylation of indolines has been observed before.[9] The fact that acylated tetrahydrocarbazoles **11** do not contain a double bond isomerized into the indole nucleus is evidence that the isomerization that was previously observed (ref. 4, 5 and Schemes 1 - 2) proceeds through an initial protonation of the double bond which is assisted by a nucleophilic push of the nitrogen. Since the acylated nitrogen of anhydride **11** is less nucleophilic,

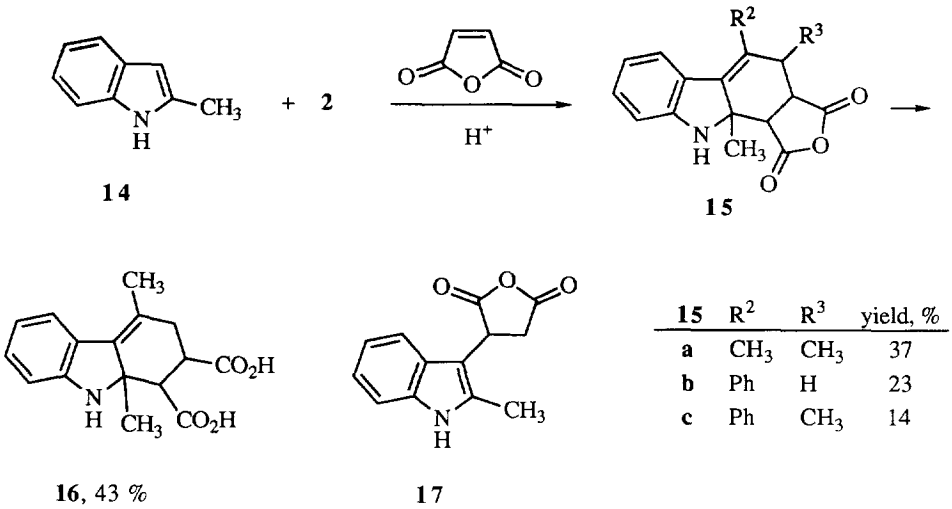


11	R^2	R^3	yield, %
a	CH_3	H	62
b	CH_3	CH_3	61
c	CH_2CH_3	CH_3	62

Scheme 4

protonation of the double bond does not seem to occur, and, consequently, isomerization of the double bond is not observed. Each of the acylated anhydrides **11** was obtained as a pair of isomers. Hydrogenation of tetrahydrocarbazole **11a** gave hexahydrocarbazole **13** in 90 % yield. Hexahydrocarbazole **13** was obtained as only one isomer, indicating that the tetrahydrocarbazoles **11** are mixtures of *cis / trans* double bonds rather than *endo / exo* adducts. The reaction of indole, maleic anhydride, and acetone in the presence of a slightly higher concentration of hydrochloric acid (~ 0.05 *M*) and with only one equiv of the maleic anhydride at room temperature gave only carbazole **12** in low yield (6 %). Tetrahydrocarbazole **11a** was aromatized and deacylated with 2,3-dichloro-5,6-dicyano-1,4-benzoquinone (DDQ) to also give carbazole **12** (38 % yield).

The reactions of 2-methylindole (**14**) with maleic anhydride in the "*in situ* vinylindole synthesis of carbazoles" gave tetrahydrocarbazoles **15** in yields of 14 - 37 % (Scheme 5). Double bond isomerization that had occurred with other tetrahydrocarbazoles could not occur in these tetrahydrocarbazoles because of the methyl group. These tetrahydrocarbazoles did not become acylated either. Presumably, this is because of the steric effects of the angular methyl group. In one case, the reaction of 2-methylindole with acetone, maleic anhydride, and a catalytic amount of hydrochloric acid gave the dicarboxylic acid **16** rather than an anhydride **15**. Decarboxylation did not occur in this reaction. This is not surprising since it is believed that the double bond of the tetrahydro ring must isomerize into the indole nucleus before decarboxylation can easily occur.[4] The reaction of 2-methylindole with acetylacetone, maleic anhydride, and a catalytic amount of hydrochloric acid gave only the previously observed[10] 1,2- or Michael addition product **17** in 10 % yield.



14 **15**

15	R^2	R^3	yield, %
a	CH_3	CH_3	37
b	Ph	H	23
c	Ph	CH_3	14

16, 43 % **17**

Scheme 5

Experimental

General Information. Melting points were determined with a Thomas-Hoover Unimelt apparatus and are uncorrected. The NMR spectra were obtained on Bruker AC-200 and Bruker AC-300 FT NMR spectrometers and were referenced to the solvent (DMSO-d_6, unless otherwise specified). Chemical shifts are given in δ ppm and coupling constants are given in Hz. IR spectra (in cm^{-1}) were obtained using KBr pellets. Electron-impact MS were obtained with a Kratos/AEI MS-30. Microanalyses were performed by M-H-W Laboratories, Phoenix, AZ. Column chromatography was performed on silica gel (Baker, 60 - 200 mesh) with solvent ratios expressed by volume. Thin-layer chromatography (TLC) was performed on silica gel. Petroleum ether used was generally the fraction bp 60 - 70 °C.

General Procedure for the Synthesis of Compounds 5-7. The indole (10 - 23 mmol, 1 equiv) was dissolved in the ketone (5 - 20 ml, 4 - 9 equivs). Solid ketones were first warmed up to their melting points. Maleic acid (10 - 23 mmol, 1 equiv) was added, and the solution was heated to 90 - 120 °C until the indole could no longer be detected by TLC (3 - 18 h). The work-up methods are described individually below.

2,3,4,4a,5,6,7,11c-Octahydro-1*H*-benzo[*c*]carbazole-5-carboxylic Acid (5a). The solution was cooled. The solid that formed was chromatographed (petroleum ether : EtOAc, 4 : 1), giving **5a** as a solid (92 mg, 2 %). Recrystallization from CH_2Cl_2 gave a white powder (mp 245 - 248.5 °C); ^1H NMR 0.97 (m, 1H), 1.19 - 1.36 (m), 1.43 (*pseudo* d, J = 12.5), 1.57 (m), 1.69 (*pseudo* t, area for 1.19 - 1.69 is 7H), 2.34 (m, 1H), 2.75 - 2.96 (m), 3.34 (m, area for 2.75 - 3.34 is 9H, includes H_2O), 6.89 (t, J = 7.5, 1H), 6.98 (t, J = 7.4, 1H), 7.26 (d, J = 7.8, 1H), 7.53 (d, J = 7.9, 1H), 10.77 (s, 1H), 12.44 (broad s, 1H); IR 3404, 3280 - 2440 (broad), 1690; HR MS Calcd. for $C_{17}H_{19}NO_2$ ($M^{\cdot+}$): 269.1411. Found: 269.1396. *Anal.* Calcd.: C, 75.80; H, 7.11; N, 5.20. Found: C, 75.83; H, 6.99; N, 5.13.

2,3,4,4a,5,6,7,11c-Octahydro-7-methyl-1*H*-benzo[*c*]carbazole-5-carboxylic Acid (5b). The solution was cooled. The solid that formed was chromatographed (petroleum ether : EtOAc, 3 : 1), giving **5b** as white crystals (214 mg, 3 %). Recrystallization from EtOAc gave a mixture of stereoisomers (~ 3 : 2, by

^{1}H NMR) of **5b** as colorless crystals (mp 257 - 262.5 °C); ^{1}H NMR 0.92 (m, 0.6H), 1.03 - 1.83 (m, 6.8H), 2.33 (m, 0.6H), 2.71 - 3.05 (m, 4.4H), 3.28 (m, 0.6H), 3.59 (s, 0.4H), 3.63 (s, 0.6H), 6.93 (t), 6.95 (t, 1H for 6.93- 6.95), 7.04 (t, J = 8.2), 7.07 (t, J = 8.1, 1H for 7.04 - 7.07), 7.54 (overlapping d, J = 7.9), 7.59 (overlapping d, J = 7.9, 1H for 7.54 - 7.59), 12.36 (broad s); IR 3260 - 2500 (broad), 1700; HR MS Calcd. for $C_{18}H_{21}NO_2$ ($M^{\cdot+}$): 283.1567. Found: 283.1567. *Anal.* Calcd.: C, 76.30; H, 7.47; N, 4.94. Found: C, 76.12; H, 7.55; N, 4.88.

6,7,8,13-Tetrahydrocyclohepta[*c*]furo[3,4-*a*]carbazole-1,3(4*H*,5*H*)-dione (7c). Petroleum ether (15 ml) was added to the solution, which was then cooled. The resulting rust-colored precipitate was filtered and recrystallized from CH_2Cl_2, giving **7c** as orange needles (55 mg, 1 %, mp 225.5 - 226.5 °C); ^{1}H NMR 1.66 (m, 2H), 1.79 (m), 1.92 (m, area for 1.79 - 1.92 is 4H), 3.51 (m), 3.60 (m, area for 3.51 - 3.60 is 4H), 7.32 (t, J = 7.6, 1H), 7.58 (t, J = 7.6, 1H), 7.70 (d, J = 7.9, 1H), 8.41 (d, J = 7.9, 1H), 12.40 (s, 1H); IR 3395, 1820, 1740; HR MS Calcd. for $C_{19}H_{15}NO_3$ ($M^{\cdot+}$): 305.1048. Found: 305.1042. *Anal.* Calcd.: C, 74.74; H, 4.95; N, 4.59. Found: C, 74.55; H, 5.11; N, 4.44.

4,5,6,7,8,13,13a,13b-Octahydro-13-methylcyclohepta[*c*]furo[3,4-*a*]carbazole-1,3(3a*H*,3b*H*)-dione (6d) and 6,7,8,13-Tetrahydro-13-methylcyclohepta[*c*]furo[3,4-*a*]carbazole-1,3(4*H*,5*H*)-dione (7d). The solution was cooled, and the resulting precipitate was filtered and rinsed with cycloheptanone, petroleum ether, CH_2Cl_2, and hot EtOAc, consecutively, giving **6d** (0.24 g, 3 %, mp 234 - 236 °C); ^{1}H NMR 1.13 - 1.86 (m, 7H), 1.96 (m, 1H), 2.05 (m, 1H), 2.16 (m, 1H), 3.00 (s, 3H), 3.18 (m, partly buried under H_2O), 3.42 (m, partly buried under H_2O), 3.99 (t, 1H), 4.24 (d, 1H), 6.59 (t), 6.61 (d, area for 6.59 - 6.61 is 2H), 7.08 (t, 1H), 7.43 (d, 1H); IR 1850, 1775; UV (95 % EtOH) λ_{max} (log ε) 345 (3.70), 275 (3.85), 232 (4.24); HR MS Calcd. for $C_{20}H_{21}NO_3$ ($M^{\cdot+}$): 323.1516. Found: 323.1520. *Anal.* Calcd.: C, 74.28; H, 6.54; N, 4.33. Found: C, 74.24; H, 6.58; N, 4.26. The EtOAc filtrate was cooled, giving **7d** as yellow crystals (92 mg, 1 %). Recrystallization from EtOAc gave orange needles (mp 262.5 - 264 °C); ^{1}H NMR 1.66 (m, 2H), 1.80 (m, 2H), 1.94 (m, 2H), 3.58 (m, 2H), 3.65 (m, 2H), 4.37 (s, 3H), 7.40 (t, 1H), 7.68 (t, 1H), 7.78 (d, J = 7.8, 1H), 8.48 (d, J = 7.8, 1H); IR 1820, 1750; HR MS Calcd. for $C_{20}H_{17}NO_3$ ($M^{\cdot+}$): 319.1204. Found: 319.1207. *Anal.* Calcd.: C, 75.22; H, 5.37; N, 4.39. Found: C, 75.13; H, 5.56; N, 4.38.

5,6,7,8,9,10,11,16-Octahydro-1*H*-cyclodeca[*c*]furo[3,4-*a*]carbazole-1,3(4*H*)-dione (7e). The solution was cooled to room temperature and then placed in a freezer for 4 d. The resulting precipitate was filtered, giving **7e** as yellow powder (44 mg, 1 %, mp 272 - 274 °C); ^{1}H NMR 1.24 (m), 1.33 (m), 1.48 (m, area for 1.24 - 1.48 is 8H), 1.98 (m, 4H), 3.28 (m), 3.51 (m, area for 3.28 - 3.51 is 8H, includes H_2O), 7.33 (t, J = 7.6, 1H), 7.56 (t, J = 7.7, 1H), 7.70 (d, J = 8.1, 1H), 8.21 (d, J = 8.1, 1H), 12.39 (s, 1H); IR 3360, 1820, 1740; MS m / z (relative intensity) 347($M^{\cdot+}$, 100), 329 (31), 304 (23), 301 (22); HR MS Calcd. for $C_{22}H_{21}NO_3$ ($M^{\cdot+}$): 347.1516. Found: 347.1512.

5,6,7,8,9,10,11,16-Octahydro-16-methyl-1*H*-cyclodeca[*c*]furo[3,4-*a*]carbazole-1,3(4*H*)-dione (7f). The brown solution was cooled to room temperature, ethanol (15 ml) was added, and then the solution was placed in a freezer for 2 d. The resulting precipitate was filtered, giving **7f** as yellow powder (0.21 g, 6 %, mp 201 - 204 °C); ^{1}H NMR 1.31 (m), 1.38 (m), 1.51 (m, area for 1.31 - 1.51 is 8H), 1.93 (m), 2.00 (m, area for 1.93 - 2.00 is 4H), 3.36 (m), 3.58 (m, area for 3.28 - 3.51 is 13H, includes H_2O), 4.36 (s, 3H), 7.41 (t, 1H), 7.67 (t, 1H), 7.76 (d, J = 8.4, 1H), 8.29 (d, J = 8.3, 1H); IR 1820, 1760; MS m / z (relative intensity) 361($M^{\cdot+}$,100), 291 (41), 279 (25); HR MS Calcd. for $C_{23}H_{23}NO_3$ ($M^{\cdot+}$): 361.1672. Found: 361.1671.

6,7,8,9,10,11,12,17-Octahydrocycloundeca[*c*]furo[3,4-*a*]carbazole-1,3(4*H*,5*H*)-dione (7g). The dark red solution was cooled to room temperature and placed in a freezer. The resulting orange

precipitate was filtered, giving **7g** (71 mg, 2 %). Two recrystallizations from EtOAc gave golden yellow needles (mp 327 - 329 °C); ^{1}H NMR 1.37 - 1.43 (m), 1.55 - 1.73 (m, area for 1.37 - 1.73 is 10H), 1.85 (m, 2H), 3.24 (m), 3.40 (m, area for 3.24 - 3.40 is 63H, includes H_2O), 7.35 (t, 1H), 7.57 (t, 1H), 7.70 (d, 1H), 8.26 (d, 1H), 12.40 (s, 1H); IR 3390, 1815, 1750; HR MS Calcd. for $C_{23}H_{23}NO_3$ ($M^{\cdot+}$): 361.1672. Found: 361.1671. *Anal.* Calcd.: C, 76.43; H, 6.41; N, 3.88. Found: C, 76.33; H, 6.33; N, 3.75.

6,7,8,9,10,11,12,17-Octahydro-17-methylcycloundeca[*c*]furo[3,4-*a*]carbazole-1,3(4*H*, 5*H*)-dione (7h). The dark red solution was cooled to room temperature and placed in a freezer. The resulting orange precipitate was filtered and recrystallized from EtOAc, giving **7h** as yellow flakes (0.20 g, 5 %, mp 230 - 231.5 °C); too insoluble for NMR analysis; IR 1810, 1760; HR MS Calcd. for $C_{24}H_{25}NO_3$ ($M^{\cdot+}$): 375.1828. Found: 375.1836. *Anal.* Calcd.: C, 76.77; H, 6.71; N, 3.73. Found: C, 76.72; H, 6.85; N, 3.76.

2,3,4,5,6,7,8,9,10,10a,11,12,13,17c-Tetradecahydro-1*H*-cyclododeca[*c*]carbazole-11-carboxylic Acid (5i). The solution solidified upon cooling. The solid was chromatographed (petroleum ether; petroleum ether : $CHCl_3$, 1 : 1; $CHCl_3$, $CHCl_3$: CH_2Cl_2, 1 : 1); the latter fraction gave after evaporation of the eluent, **5i** as a white powder (0.60 g, 7 %). Recrystallization from CH_2Cl_2 gave **5i** as a mixture of isomers (~ 4 : 1, by ^{1}H NMR, mp 251 - 253 °C); ^{1}H NMR 1.06 - 1.75 (m), 2.23 - 2.36 (m), 2.45 - 2.57 (m), 2.72 - 2.83 (m), 2.90 - 3.17 (m, area for 1.06 - 3.17 is 25H), 6.87 (overlapping t, J = 7.2 for major isomer, 1H), 6.95 (overlapping t, J = 7.5 for major isomer, 1H), 7.23 (overlapping d, J = 7.8 for major isomer, 1H), 7.32 (d, J = 7.5, 0.2H), 7.56 (d, J = 7.8, 0.8H), 10.63 (s, 0.2H), 10.73 (s, 0.8H), 12.32 (broad s, 1H); IR 3400, 3200 - 2500 (broad), 1695; HR MS Calcd. for $C_{23}H_{31}NO_2$ ($M^{\cdot+}$): 353.2347. Found: 353.2350. *Anal.* Calcd.: C, 78.15; H, 8.84; N, 3.96. Found: C, 78.31; H, 8.90; N, 3.82.

5,6,7,8,9,10,11,12,13,18-Decahydro-18-methyl-1*H*-cyclododeca[*c*]furo[3,4-*a*]-carbazole-1,3(4*H*)-dione (7j). The solution solidified upon cooling. The solid was chromatographed (petroleum ether : EtOAc, 1 : 1), giving, after evaporation of the eluent, **7j** as a yellow powder (344 mg, 4 %). Recrystallization from EtOAc gave a bright yellow powder (mp 237 - 238.5 °C); too insoluble for NMR analysis; IR 1820, 1760; HR MS Calcd. for $C_{25}H_{27}NO_3$ ($M^{\cdot+}$): 389.1984 . Found: 389.1978. *Anal.* Calcd.: C, 77.09; H, 6.99; N, 3.60. Found: C, 76.90; H, 7.01; N, 3.48.

General Procedure for the Synthesis of Compounds 8, 11, 15, and 16. Concentrated HCl (0.01 ml) and maleic anhydride (2.94 g, 30 mmol) were added consecutively to a solution of 1-methylindole (1.31 g, 10 mmol) in the ketone (10 ml) or to a solution of 1-methylindole (1.31 g, 10 mmol) and the ketone (5 g) in CH_3CN (5 ml). The solution was warmed to 60 - 70 °C, except for the solution with acetone (which was heated to reflux), until 1-methylindole could no longer be detected by TLC. If any precipitate (fumaric acid) formed at this point, it was filtered off. The solution was concentrated *in vacuo* in a rotating evaporator, CH_2Cl_2 (10 ml) was added, and the undissolved solid (maleic acid) was filtered off. The filtrate was chromatographed using CH_2Cl_2 as the eluent. The first collected band was concentrated to approximately 10 ml, hexane or petroleum ether was added until cloudy, and the solution was put in a refrigerator for a few h or overnight. The resulting precipitate was collected by filtration. Analytical samples were prepared by recrystallizing several times from CH_2Cl_2 : hexane. Any deviations from this procedure are noted.

3b,4,5,6,7,7a,12,12b-Octahydro-12-methyl-1*H*-benzo[*c*]furo[3,4-*a*]carbazole-1,3(3a*H*)-dione (8a). Yellow powder (0.55 g, 18 %, mp 259 - 262 °C). Four recrystallizations gave white crystals (mp 262 - 263 °C); ^{1}H NMR 1.00 - 1.81 (m, 7H), 2.36 - 2.42 (m, 1H), 2.81 - 2.86 (*pseudo* d, 1H), 3.23 - 3.34 (m, 1H), 3.79 - 3.83 (m), 3.83 (s, area for 3.79 - 3.83 is 4H), 5.06 (d, J = 7.3, 1H), 7.05 (t, J = 7.5, 1H), 7.18 (t, J = 7.6, 1H), 7.48 (d, J = 8.2, 1H), 7.68 (d, J = 7.9, 1H); IR 1865, 1760; HR MS

Calcd. for $C_{19}H_{19}NO_3$ ($M^{\cdot+}$): 309.1360. Found: 309.1365. *Anal.* Calcd.: C, 73.77; H, 6.19; N, 4.53. Found: C, 73.43; H, 6.14; N, 4.54.

4,5,6,6a,11,11b-Hexahydro-11-methylcyclopenta[*c*]furo[3,4-*a*]carbazole-1,3(3a*H*, 3b*H*)-dione (8f). Yellow powder (1.52 g, 52 %, mp 228 - 230 °C). Four recrystallizations gave white crystals (mp 230 - 231 °C); ^{1}H NMR 1.19 - 1.41 (m, 1H), 1.62 - 1.74 (m, 3H), 2.23 (m, 1H), 2.36 (m, 1H), 2.77 (m, 1H), 3.50 (dd, *J* = 7.0, 6.3, 1H), 3.66 (dd, *J* = 8.5, 5.7, 1H), 3.85 (s, 3H), 4.26 (d, *J* = 8.6, 1H), 7.13 (t, *J* = 7.4, 1H), 7.28 (t, *J* = 7.2, 1H), 7.36 (d, *J* = 8.1, 1H), 7.61 (d, *J* = 7.9, 1H); IR 1870, 1790; HR MS Calcd. for $C_{18}H_{17}NO_3$ ($M^{\cdot+}$): 295.1204. Found: 295.1227. *Anal.* Calcd.: C, 73.20; H, 5.80; N, 4.74. Found: C, 73.12; H, 5.95; N, 4.73.

3b,4,5,6,7,7a,12,12b-Octahydro-7,12-dimethyl-1*H*-benzo[*c*]furo[3,4-*a*]carbazole-1, 3(3a*H*)-dione (8g). 8g, a mixture of isomers (~ 2 : 1, by ^{1}H NMR), was obtained as mixture of white crystals and white powder (0.72 g, 22 %, mp 179 - 194 °C). The isomers could not be separated by chromatography or by fractional crystallization. ^{1}H NMR 0.63 (d, *J* = 7.1, major isomer), 0.72 (d, *J* = 7.3, minor isomer, area for 0.63 - 0.72 is 3H), 1.10 - 3.60 (complex m, 10H, includes DMSO), 3.83 (s), 3.86 (s, area for 3.83 - 3.86 is 3H), 3.90 - 3.99 m, 1H), 4.86 (d, *J* = 8.2, major isomer), 4.98 (d, *J* = 9.9, minor isomer, area for 4.86 - 4.98 is 1H), 7.03 (t, *J* = 7.5, 1H), 7.18 (t, *J* = 7.2, 1H), 7.43 (d, *J* = 8.3), 7.46 (d, *J* = 8.3, area for 7.43 - 7.46 is 1H), 7.58 (d, *J* = 7.9, minor isomer), 7.65 (d, *J* = 8.0, major isomer, area for 7.58 - 7.65 is 1H); IR 1860, 1780; HR MS Calcd. for $C_{20}H_{21}NO_3$ ($M^{\cdot+}$): 323.1516. Found: 323.1522. *Anal.* Calcd.: C, 74.28; H, 6.54; N, 4.33. Found: C, 74.41; H, 6.30; N, 4.30.

3b,4,5,6,7,7a,12,12b-Octahydro-4,7-methano-12-methyl-1*H*-benzo[*c*]furo[3,4-*a*]-carbazole-1,3(3a*H*)-dione (8h). Yellow powder (0.62 g, 19 %, mp 267 - 270 °C). Two recrystallizations gave white needles (mp 269 - 271 °C); ^{1}H NMR 0.98 (d, *J* = 9.0, 1H), 1.15(d, *J* = 9.1, 1H), 1.38 - 1.63 (m, 4H), 2.24 (m, 1H), 2.33 - 2.41 (m, 2H), 2.98 (d, *J* = 8.4, 1H), 3.60 (dd, *J* = 8.4, 5.7, 1H), 3.79 (s, 3H), 4.96 (d, *J* = 8.4, 1H), 7.07 (t, *J* = 7.4, 1H), 7.20 (t, *J* = 7.6, 1H), 7.45 (d, *J* = 8.2, 1H), 7.53 (d, *J* = 7.4, 1H); IR 1870, 1790; HR MS Calcd. for $C_{20}H_{19}NO_3$ ($M^{\cdot+}$): 321.1360. Found: 321.1361. *Anal.* Calcd.: C, 74.75; H, 5.96; N, 4.36. Found: C, 74.57; H, 5.86; N, 4.36.

4,5,10,10b-Tetrahydro-5,10-dimethyl-1*H*-furo[3,4-*a*]carbazole-1,3(3a*H*)-dione (8i). Light yellow powder (1.68 g, 62 %, mp 198 - 201 °C). Three recrystallizations gave white needles (mp 200 - 201.5 °C); ^{1}H NMR 1.39 (d, *J* = 7.1, 3H), 2.13 (m, 1H), 2.27 (m, 1H), 3.31 (m, 1H), 3.56 (m, 1H), 3.88 (s, 3H), 4.42 (d, *J* = 9.0, 1H), 7.14 (t, *J* = 7.4, 1H), 7.28 (t, *J* = 6.9, 1H), 7.35 (d, *J* = 8.3, 1H), 7.61 (d, *J* = 7.9, 1H); IR 1870, 1800; HR MS Calcd. for $C_{16}H_{15}NO_3$ ($M^{\cdot+}$): 269.1048. Found: 269.1053. *Anal.* Calcd.: C, 71.36; H, 5.61; N, 5.20. Found: C, 71.21; H, 5.72; N, 5.21.

4,5,10,10b-Tetrahydro-4,5,10-trimethyl-1*H*-furo[3,4-*a*]carbazole-1,3(3a*H*)-dione (8j). Light yellow powder (1.66 g, 55 %, mp 182 - 184 °C). Four recrystallizations gave white needles (mp 191 - 192.5 °C); ^{1}H NMR 1.31 (d, *J* = 7.2), 1.39 (d, *J* = 7.2, area for 1.31 - 1.39 is 6H), 2.37 - 2.48 (m, 1H), 3.21 - 3.27 (m, 1H), 3.51 (dd, *J* = 9.4, 5.6, 1H), 3.89 (s, 3H), 4.42 (d, *J* = 9.3, 1H), 7.14 (t, *J* = 7.4, 1H), 7.28 (t, *J* = 7.6, 1H), 7.35 (d, *J* = 8.2, 1H), 7.60 (d, *J* = 7.9, 1H); IR 1860, 1760; MS *m* / *z* (relative intensity) 283 ($M^{\cdot+}$, 87), 196 (100), 181 (32); HR MS Calcd. for $C_{17}H_{17}NO_3$ ($M^{\cdot+}$): 283.1204. Found: 283.1207.

4-Ethyl-4,5,10,10b-tetrahydro-5,10-dimethyl-1*H*-furo[3,4-*a*]carbazole-1,3(3a*H*)-dione (8k). White solid (1.00 g, 34 %, mp 149 - 153 °C). Four recrystallizations gave white crystals (mp 157 - 159 °C); ^{1}H NMR 1.12 (t, *J* = 7.1), 1.17 (d, *J* = 7.3, area for 1.12 - 1.17 is 6H), 2.02 - 2.17 (m, 3H), 3.30 (m, 1H), 3.63 (dd, *J* = 9.0, 5.1, 1H), 3.91 (s, 3H), 4.53 (d, *J* = 9.7, 1H), 7.14 (dd, *J* = 7.9, 6.8, 1H), 7.28 (dd, *J* = 8.3, 7.0, 1H), 7.34 (d, *J* = 8.2, 1H), 7.53 (d, *J* = 7.9, 1H); IR 1855, 1760; HR MS Calcd. for

$C_{18}H_{19}NO_3$ ($M^{\cdot+}$): 297.1360. Found: 297.1373. *Anal.* Calcd.: C, 72.71; H, 6.44; N, 4.71. Found: C, 72.75; H, 6.44; N, 4.61.

5-Ethyl-4,5,10,10b-tetrahydro-4,10-dimethyl-1*H*-furo[3,4-*a*]carbazole-1,3(3a*H*)-dione (8l). The collected yellow and orange precipitates were washed with hot cyclohexane, leaving **8l** as a white solid (0.81 g, 27 %, mp 150 - 152 °C). Three recrystallizations gave white crystals (mp 151 - 152.5 °C); ^{1}H NMR 1.02 - 1.93 (m, 8H), 2.44 (m, 1H), 2.93 (m, 1H), 3.34 (dd, J = 9.5, 6.3, 1H), 3.90 (s, 3H), 4.59 (d, J = 9.7, 1H), 7.12 (dd, J = 7.8, 7.1, 1H), 7.25 (dd, J = 8.1, 7.1, 1H), 7.34 (d, J = 8.2, 1H), 7.59 (d, J = 7.8, 1H); IR 1855, 1780; HR MS Calcd. for $C_{18}H_{19}NO_3$ ($M^{\cdot+}$): 297.1360. Found: 297.1376. *Anal.* Calcd.: C, 72.71; H, 6.44; N, 4.71. Found: C, 72.53; H, 6.32; N, 4.67.

4,5,10,10b-Tetrahydro-5,10-dimethyl-4-phenylmethyl-1*H*-furo[3,4-*a*]carbazole-1,3(3a*H*)-dione (8m). White solid (1.53 g, 42 %, mp 221 - 223 °C). Two recrystallizations gave white needles (mp 223 - 224 °C); ^{1}H NMR 1.31 (d, J = 7.3, 3H), 2.50 (m, 1H), 3.11 (dd, J = 13.6, 5.5, 1H), 3.35 (dd, J = 7.2, 4.6), 3.41 (dd, J = 9.6, 5.5, area for 3.35 - 3.41 is 2H), 3.63 (dd, J = 13.6, 10.8, 1H), 3.87 (s, 3H), 4.35 (d, J = 9.6, 1H), 7.11 - 7.52 (m, 9H); IR 1860, 1780; HR MS Calcd. for $C_{23}H_{21}NO_3$ ($M^{\cdot+}$): 359.1516. Found: 359.1522. *Anal.* Calcd.: C, 76.86; H, 5.89; N, 3.90. Found: C, 76.69; H, 5.84; N, 3.75.

4,5,10,10b-Tetrahydro-10-methyl-5-phenyl-1*H*-furo[3,4-*a*]carbazole-1,3(3a*H*)-dione (8n). Light yellow powder (1.58 g, 47 %, mp 185 - 190 °C). Two recrystallizations gave white crystals (mp 189 - 190 °C); ^{1}H NMR 2.18 - 2.34 (m, 1H), 2.55 (m, 1H), 3.55 (m, 1H), 3.94 (s, 3H), 4.38 (m, 1H), 4.43 (d, J = 8.8, 1H), 6.88 (d, J = 7.8, 1H), 6.95 (dd, J = 7.8, 7.0, 1H), 7.11 - 7.30 (m, 6H), 7.38 (d, J = 8.3, 1H); IR 1860, 1780; HR MS Calcd. for $C_{21}H_{17}NO_3$ ($M^{\cdot+}$): 331.1204. Found: 331.1206. *Anal.* Calcd.: C, 76.12; H, 5.17; N, 4.23. Found: C, 76.16; H, 5.13; N, 4.21.

4,5,10,10b-Tetrahydro-4,10-dimethyl-5-phenyl-1*H*-furo[3,4-*a*]carbazole-1,3(3a*H*)-dione (8o). Yellow crystals (2.06 g, 60 %, mp 204 - 207 °C). Four recrystallizations gave white crystals (mp 208 - 210 °C); ^{1}H NMR 1.14 (d, J = 7.2, 3H), 2.67 (m, 1H), 3.58 (dd, J = 9.4, 5.3, 1H), 3.96 (s, 3H), 4.43 (m, 2H), 6.91 - 7.39 (m, 9H); IR 1870, 1790; MS m/z (relative intensity) 345 ($M^{\cdot+}$, 79), 274 (23), 273 (100), 272 (23), 258 (60), 196 (57), 181 (26). *Anal.* Calcd. for $C_{22}H_{19}NO_3$: C, 76.50; H, 5.54; N, 4.06. Found: C, 76.43; H, 5.69; N, 4.07.

4,5,10,10b-Tetrahydro-5,10-dimethyl-4-phenyl-1*H*-furo[3,4-*a*]carbazole-1,3(3a*H*)-dione (8p). Yellow solid (0.45 g, 13 %, mp 228 - 231 °C). Four recrystallizations gave white needles (mp 231 - 232 °C); ^{1}H NMR 1.47 (d, J = 6.7, 3H), 3.63 - 3.71 (m, 2H), 3.89 (m), 3.91 (s, area for 3.89 - 3.91 is 4H), 4.35 (d, J = 8.6, 1H), 7.12 - 7.25 (m, 6H), 7.32 (dd, J = 8.3, 7.1, 1H), 7.44 (d, J = 8.0, 1H), 7.77 (d, J = 8.0, 1H); IR 1865, 1785; HR MS Calcd. for $C_{22}H_{19}NO_3$ ($M^{\cdot+}$): 345.1360. Found: 345.1345. *Anal.* Calcd. for $C_{22}H_{19}NO_3$: C, 76.50; H, 5.54; N, 4.06. Found: C, 76.32; H, 5.51; N, 4.04.

4,5,10,10b-Tetrahydro-10-methyl-5-(4-methylphenyl)-1*H*-furo[3,4-*a*]carbazole-1,3(3a*H*)-dione (8q). Light yellow solid (1.47 g, 42 %, mp 184 - 186 °C). Four recrystallizations gave white crystals (mp 196 - 198 °C); ^{1}H NMR 2.17 - 2.34 (complex m with s at 2.32, 4H), 2.52 (m, 1H), 3.53 - 3.71 (m, 1H), 3.94 (s, 3H), 4.34 (dd, J = 6.4, 5.7, 1H), 4.46 (d, J = 8.8, 1H), 6.88 - 6.94 (m, 2H), 6.99 (d, J = 8.1, 2H), 7.07 (d, J = 8.1, 2H), 7.23 (t, J = 6.9, 1H), 7.37 (d, J = 8.0, 1H); IR 1870, 1850, 1770; HR MS Calcd. for $C_{22}H_{19}NO_3$ ($M^{\cdot+}$): 345.1360. Found: 345.1372. *Anal.* Calcd. for $C_{22}H_{19}NO_3$: C, 76.50; H, 5.54; N, 4.06. Found: C, 76.30; H, 5.59; N, 4.05.

4,5,10,10b-Tetrahydro-5-(4-methoxyphenyl)-10-methyl-1*H*-furo[3,4-*a*]carbazole-1,3(3a*H*)-dione (8r). Yellow solid (2.41 g, 67 %, mp 180 - 184 °C). Four recrystallizations gave white crystals (mp 184 - 185 °C); ^{1}H NMR 2.28 (m, 1H), 2.52 (m, 1H), 3.57 (m, 1H), 3.77 (s, 3H), 3.94 (s, 3H), 4.33 (m, 1H), 4.46 (d, *J* = 8.4, 1H), 6.78 - 7.03 (m, 6H), 7.24 (dd, *J* = 6.4, 1.7, 1H), 7.37 (d, *J* = 8.2, 1H); IR 1870, 1850, 1780; HR MS Calcd. for $C_{22}H_{19}NO_4$ ($M^{\cdot+}$): 361.1309. Found: 361.1318. *Anal.* Calcd. for $C_{22}H_{19}NO_3$: C, 73.12; H, 5.30; N, 3.88. Found: C, 72.91; H, 5.41; N, 3.87.

4,5,10,10b-Tetrahydro-5-(3-methoxyphenyl)-10-methyl-1*H*-furo[3,4-*a*]carbazole-1,3(3a*H*)-dione (8s). Yellow solid (2.29 g, 63 %, mp 159 - 162 °C). Four recrystallizations (two with activated charcoal) gave off-white crystals (mp 162 - 163 °C); ^{1}H NMR 2.31 (m, 1H), 2.53 (m, 1H), 3.55 (m, 1H), 3.71 (s, 3H), 3.93 (s, 3H), 4.34 (t, *J* = 6.4, 1H), 4.44 (d, *J* = 8.6, 1H), 6.66 - 6.98 (m, 5H), 7.16 - 7.25 (m, 2H), 7.36 (d, *J* = 8.3, 1H); IR 1870, 1780; MS *m* / *z* (relative intensity) 361 ($M^{\cdot+}$, 46), 290 (66), 182 (100). *Anal.* Calcd. for $C_{22}H_{19}NO_4$: C, 73.12; H, 5.30; N, 3.88. Found: C, 72.94; H, 5.24; N, 3.90.

5-(4-Bromophenyl)-4,5,10,10b-tetrahydro-10-methyl-1*H*-furo[3,4-*a*]carbazole-1,3(3a*H*)-dione (8t). Light yellow solid (1.54 g, 38 %, mp 210 - 213 °C). Four recrystallizations gave white crystals (mp 214 - 215 °C); ^{1}H NMR 2.20 (m, 1H), 2.53 (m, 1H), 3.58 (m, 1H), 3.94 (s, 3H), 4.27 (t, *J* = 6.3, 1H), 4.46 (d, *J* = 8.7, 1H), 6.86 (d, *J* = 8.7, 1H), 6.93 - 7.00 (m, 3H), 7.24 (dd, *J* = 8.3, 7.0, 1H), 7.38 (d, *J* = 8.3, 3H); IR 1870, 1780; HR MS Calcd. for $C_{21}H_{16}{}^{81}BrNO_3$ ($M^{\cdot+}$): 411.0289. Found: 411.0288. *Anal.* Calcd.: C, 61.48; H, 3.93; N, 3.41; Br, 19.48. Found: C, 61.59; H, 3.93; N, 3.41; Br, 19.66.

5-(4-Chlorophenyl)-4,5,10,10b-tetrahydro-10-methyl-1*H*-furo[3,4-*a*]carbazole-1,3(3a*H*)-dione (8u). Light yellow solid (2.15 g, 59 %, mp 209 - 212 °C). Two recrystallizations gave white crystals (mp 212 - 213 °C); ^{1}H NMR 2.26 (m, 1H), 2.53 (m, 1H), 3.61 (m, 1H), 3.94 (s, 3H), 4.35 (dd, *J* = 6.4, 5.9, 1H), 4.44 (d, *J* = 8.7, 1H), 6.87 (d, *J* = 7.9, 1H), 6.97 (t, *J* = 7.4, 1H), 7.05 (d, *J* = 8.4, 2H), 7.25 (m, 3H), 7.38 (d, *J* = 8.3, 1H); IR 1865, 1790; HR MS Calcd. for $C_{21}H_{16}{}^{35}ClNO_3$ ($M^{\cdot+}$): 365.0815. Found: 365.0793. *Anal.* Calcd.: C, 68.93; H, 4.41; N, 3.83; Cl, 9.71. Found: C, 68.97; H, 4.39; N, 3.91; Cl, 9.63.

5-(4-Fluorophenyl)-4,5,10,10b-tetrahydro-10-methyl-1*H*-furo[3,4-*a*]carbazole-1,3(3a*H*)-dione (8v). Light yellow solid (1.35 g, 39 %, mp 182 - 184 °C). Three recrystallizations gave white crystals (mp 186 - 188 °C); ^{1}H NMR 2.29 (m, 1H), 2.53 (m, 1H), 3.58 (m, 1H), 3.94 (s, 3H), 4.37 (dd, *J* = 6.3, 5.8, 1H), 4.44 (d, *J* = 8.7, 1H), 6.87 (d, *J* = 7.0, 1H), 6.92 - 7.10 (m, 5H), 7.23 (dd, *J* = 8.3, 6.9, 1H), 7.38 (d, *J* = 8.3, 1H); IR 1860, 1780; HR MS Calcd. for $C_{21}H_{16}FNO_3$ ($M^{\cdot+}$): 349.1110. Found: 349.1117. *Anal.* Calcd.: C, 72.20; H, 4.62; N, 4.01; F, 5.44. Found: C, 72.27; H, 4.75; N, 4.01; F, 5.51.

4,5,10,10b-Tetrahydro-10-methyl-5-(4-nitrophenyl)-1*H*-furo[3,4-*a*]carbazole-1,3(3a*H*)-dione (8w). Light yellow solid (2.00 g, 53 %, mp 117 - 119 °C). Four recrystallizations gave white needles (mp 121 - 122 °C); ^{1}H NMR 2.36 (m, 1H), 2.49 (m, 1H), 3.73 (m, 1H), 3.92 (s, 3H), 4.54 (t, *J* = 5.9, 1H), 4.77 (d, *J* = 8.9, 1H), 6.79 (d, *J* = 7.9, 1H), 6.89 (dd, *J* = 7.8, 7.1, 1H), 7.19 (t, *J* = 7.6, 1H), 7.30 (d, *J* = 8.4, 2H), 7.43 (d, *J* = 8.3, 1H), 8.06 (d, *J* = 8.6, 2H); IR 1870, 1790; MS *m* / *z* (relative intensity) 376 ($M^{\cdot+}$, 4), 182 (13), 44 (100). *Anal.* Calcd. for $C_{21}H_{16}N_2O_5$: C, 67.02; H, 4.28; N, 7.44. Found: C, 66.91; H, 4.40; N, 7.48.

5-(4-Biphenylyl)-4,5,10,10b-tetrahydro-10-methyl-1*H*-furo[3,4-*a*]carbazole-1,3(3a*H*)-dione (8x). Light yellow solid (2.05 g, 50 %, mp 194 - 197 °C). Three recrystallizations gave white needles (mp 198 - 200 °C); ^{1}H NMR 2.30 (m, 1H), 2.59 (m, 1H), 3.59 (m, 1H), 3.95 (s, 3H), 4.40 (dd, *J* = 7.4, 5.3, 1H), 4.46 (dd, *J* = 7.7, 1.2, 1H), 6.91 - 7.61 (m, 13H); IR 1870, 1790; MS *m* / *z* (relative intensity) 407

($M^{\cdot+}$, 48), 335 (68), 334 (21), 182 (100), 167 (36). *Anal.* Calcd. for $C_{27}H_{21}NO_3$: C, 79.59; H, 5.19; N, 3.44. Found: C, 79.60; H, 5.30; N, 3.52.

Methyl 4-[4,5,10,10b-Tetrahydro-10-methyl-1,3(3a*H*)-dioxo-1*H*-furo[3,4-*a*]carbazol-5-yl]benzoate (8y). Yellow solid (1.93 g, 50 %, mp 215 - 217 °C). Three recrystallizations gave white crystals (mp 220 - 222 °C); ^{1}H NMR 2.26 (m), 2.27 (s, area for 2.26 - 2.27 is 4H), 2.55 (m, 1H), 3.58 (m, 1H), 3.94 (s, 3H), 4.36 (dd, *J* = 6.8, 5.3, 1H), 4.48 (dd, *J* = 8.7, 1.2, 1H), 6.87 (d, *J* = 7.9, 1H), 6.95 (t, *J* = 7.5, 1H), 6.99 (dd, *J* = 6.6, 2.1, 2H), 7.12 (d, *J* = 8.6, 2H), 7.23 (dd, *J* = 8.3, 6.7, 1H), 7.37 (d, *J* = 8.3, 1H); IR 1870, 1855, 1780; MS *m* / *z* (relative intensity) 389 ($M^{\cdot+}$, 24), 318 (28), 317 (100), 275 (21), 182 (52). *Anal.* Calcd. for $C_{23}H_{19}NO_5$: C, 70.94; H, 4.92; N, 3.60. Found: C, 70.83; H, 5.16; N, 3.54.

***N*-Phenyl-4-[4,5,10,10b-tetrahydro-10-methyl-1,3(3a*H*)-dioxo-1*H*-furo[3,4-*a*]-carbazol-5-yl]benzamide (8z).** After 1-methylindole could no longer be detected in the reaction mixture, the black solution was cooled, giving a white precipitate (mp 250 - 255 °C), which was collected by filtration. The solvent was evaporated from the filtrate, CH_2Cl_2 (10 ml) was added to the residue, and the remaining white solid (mp 245 - 255 °C) was filtered and added to the first crop of solid. One recrystallization gave **8z** as white crystals (2.26 g, 58 %, mp 268 - 270 °C). Four additional recrystallizations gave white crystals (mp 271 - 273 °C); ^{1}H NMR 2.02 (s, 3H), 2.30 (m, 2H), 3.83 dd, *J* = 8.6, 7.5, 1H), 3.91 (s, 3H), 4.34 (t, *J* = 5.6, 1H), 5.03 (d, *J* = 8.8, 1H), 6.79 (d, *J* = 7.8, 1H), 6.87 (t, *J* = 7.3, 1H), 6.98 (d, *J* = 8.4, 2H), 7.15 (dd, *J* = 8.4, 7.0, 1H), 7.44 (d, *J* = 8.4, 2H), 7.49 (d, *J* = 8.3, 1H), 9.90 (s, 1H); IR 3360, 1850, 1765; MS *m* / *z* (relative intensity) 388 ($M^{\cdot+}$, 65), 316 (88), 182 (100). *Anal.* Calcd. for $C_{23}H_{20}N_2O_4$: C, 71.12; H, 5.19; N, 7.21. Found: C, 71.13; H, 5.32; N, 7.28.

4,5,10,10b-Tetrahydro-5,10-dimethyl-4-(3,3-dimethyl-2-oxobutyl)-1*H*-furo[3,4-*a*]-carbazole-1,3(3a*H*)-dione (8aa). White solid (1.96 g, 53 %, mp 220 - 223 °C). Three recrystallizations gave white crystals (mp 228 - 229 °C); ^{1}H NMR 1.20 (d, *J* = 7.3), 1.25 (s, area for 1.20 - 1.25 is 12H), 2.79 (m, 2H), 3.21 (m, 1H), 3.81 (dd, *J* = 18.4, 10.2, 1H), 3.91 (s, 3H), 3.97 (dd, *J* = 9.8, 6.7, 1H), 4.60 (d, *J* = 9.7, 1H), 7.13 (t, 1H), 7.27 (m, 1H), 7.34 (d, *J* = 8.2, 1H), 7.49 (d, *J* = 7.8, 1H); IR 1855, 1775, 1695; HR MS Calcd. for $C_{22}H_{25}NO_4$ ($M^{\cdot+}$): 367.1777. Found: 367.1775. *Anal.* Calcd.: C, 71.91; H, 6.86; N, 3.81. Found: C, 71.98; H, 6.86; N, 3.84.

4,5,10,10b-Tetrahydro-10-methyl-5-(2-oxopropyl)-1*H*-furo[3,4-*a*]carbazole-1,3(3a*H*)-dione (8bb). Yellow solid (0.30 g, 10 %, mp 220 - 222 °C). Four recrystallizations gave white needles (mp 224 - 226 °C); ^{1}H NMR 2.08 (s), 2.08 - 2.23 (m, 5H), 2.48 (m, 1H), 2.92 (dd, *J* = 17.7, 4.8, 1H), 3.60 (dd, *J* = 9.5, 4.7, 1H), 3.86 (s), 3.89 (m, area for 3.86 - 3.89 is 4H), 4.93 (d, *J* = 9.1, 1H), 7.05 (t, *J* = 7.5, 1H), 7.20 (dd, *J* = 8.2, 7.1, 1H), 7.46 (d, *J* = 8.2, 1H), 7.54 (d, *J* = 7.8, 1H); IR 1870, 1790, 1720; HR MS Calcd. for $C_{18}H_{17}NO_4$ ($M^{\cdot+}$): 311.1153. Found: 311.1183. *Anal.* Calcd.: C, 69.44; H, 5.50; N, 4.50. Found: C, 69.30; H, 5.52; N, 4.43.

6,6a,10,14c-Tetrahydro-10-methyl-5*H*-furo[3,4-*a*]naphtho[2,1-*c*]carbazole-7,9(6b*H*,9a*H*)-dione (8cc). After 1-methylindole could no longer be detected in the reaction mixture, the solution was cooled, giving a white precipitate (mp 252 - 255 °C), which was collected by filtration. After being cooled in a refrigerator, the filtrate gave a second crop of precipitate (mp 250 - 255 °C) which was collected by filtration and added to the first crop. One recrystallization gave **8cc** as white crystals (1.18 g, 33 %, mp 256 - 258 °C). Four additional recrystallizations gave white crystals (mp 258 - 259 °C); ^{1}H NMR 1.80 - 2.10 (m, 2H), 2.68 (m, 1H), 2.77 - 2.82 (m, 2H), 3.88 (s, 3H), 3.99 (dd, *J* = 8.7, 5.7, 1H), 4.30 (d, *J* = 4.0, 1H), 5.02 (d, *J* = 8.8, 1H), 6.89 (t, *J* = 7.4, 1H), 7.12 - 7.21 (m, 6H), 7.47 (d, *J* = 8.1, 1H); IR 1865, 1785, 1720; HR MS Calcd. for $C_{23}H_{19}NO_3$ ($M^{\cdot+}$): 357.1360. Found: 357.1339. *Anal.* Calcd.: C, 77.29; H, 5.36; N, 3.92. Found: C, 77.29; H, 5.44; N, 3.88.

4b,4c,8,12c,13,14-Hexahydro-8-methyl-5*H*-furo[3,4-*a*]naphtho[1,2-*c*]carbazole-5,7 (7a*H*)-dione (8dd). Yellow solid (1.95 g, 55 %, mp 219 - 222 °C). Four recrystallizations gave white crystals (mp 223 - 224 °C); ^{1}H NMR 1.44 (m, 1H), 2.22 (*pseudo* d, 1H), 2.87 (dd, *J* = 17.2, 5.2, 1H), 3.09 (m, 1H), 3.37 (*pseudo* d, 1H), 3.49 (t, *J* = 5.9, 1H), 3.91 (s, 3H), 4.35 (dd, *J* = 9.0, 6.6, 1H), 4.95 (d, *J* = 9.1, 1H), 7.09 (t, *J* = 7.5, 1H), 7.19 - 7.25 (m, 4H), 7.35 (d, 1H), 7.48 (d, *J* = 8.2, 1H), 7.62 (d, *J* = 7.8, 1H); IR 1860, 1780; HR MS Calcd. for $C_{23}H_{19}NO_3$ ($M^{\cdot+}$): 357.1360. Found: 357.1360. *Anal.* Calcd.: C, 77.29; H, 5.36; N, 3.92. Found: C, 77.02; H, 5.14; N, 3.94.

6,6a,10,14c-Tetrahydro-10-methylchromeno[3,4-*c*]furo[3,4-*a*]carbazole-7,9(6b*H*,9a*H*)-dione (8ee). Yellow solid (0.44 g, 12 %, mp 288 - 291 °C). Two recrystallizations from acetone : hexane gave yellow crystals (mp 291 - 293 °C); ^{1}H NMR 2.94 (m, 1H), 3.05 (dd, *J* = 10.9, 8.5, 1H), 3.86 (s, 3H), 4.35 - 4.52 (m, 2H), 4.64 (d, *J* = 4.6, 1H), 5.11 (d, *J* = 8.4, 1H), 6.73 - 7.68 (m, 8H); IR 1855, 1780; MS *m* / *z* (relative intensity) 359 ($M^{\cdot+}$, 40), 92 (50), 49 (100). *Anal.* Calcd. for $C_{22}H_{17}NO_4$ ($M^{\cdot+}$): C, 73.53; H, 4.77; N, 3.90. Found: C, 73.64; H, 4.94; N, 3.66.

***Z*- and *E*-4-[4,10,10a,10b-Tetrahydro-5-methyl-1,3(3a*H*)-dioxo-1*H*-furo[3,4-*a*]-carbazol-10-yl]-4-oxo-2-butenoic Acid (11a).** After indole could no longer be detected in the reaction mixture, the solution was cooled. The golden yellow precipitate was collected by filtration and washed with CH_2Cl_2, giving **11a** as an ~ 1 : 1 pair of isomers (2.19 g, 62 %, mp 190 - 192 °C). Two recrystallizations from acetone gave yellow crystals (mp 192 - 194 °C); ^{1}H NMR 2.10 (s), 2.13 (s, area for 2.10 - 2.13 is 3H), 2.57 - 2.62 (m, 2H), 3.66 (m, 1H), 4.07 (dd, *J* = 9.1, 7.6, 0.5H), 4.48 (dd, *J* = 9.4, 7.3, 0.5H), 4.88 (m, 1H), 6.25 (dd, *J* = 11.8, 5.6, 1H), 6.89 (d, *J* = 10.9, 0.5H), 7.07 - 7.37 (m, 3H), 7.96 (d, *J* = 7.7, 1H), 8.28 (d, *J* = 8.1, 0.5H), 12.82 (s, 1H); IR 3400 - 2500 (broad), 1850, 1775, 1705; HR MS Calcd. for $C_{19}H_{15}NO_6$ ($M^{\cdot+}$): 353.0895. Found: 353.0886. *Anal.* Calcd.: C, 64.59; H, 4.28; N, 3.96. Found: C, 64.82; H, 4.50; N, 4.04.

***Z*- and *E*-4-[4,10,10a,10b-Tetrahydro-4,5-dimethyl-1,3(3a*H*)-dioxo-1*H*-furo[3,4-*a*]-carbazol-10-yl]-4-oxo-2-butenoic Acid (11b).** After indole could no longer be detected in the reaction mixture, the solution was cooled. The golden yellow precipitate was collected by filtration and washed with CH_2Cl_2, giving 11b as an ~ 1 : 1 pair of isomers (2.25 g, 61 %, mp 185 - 187 °C). Two recrystallizations from acetone gave yellow crystals (mp 202 - 204 °C); ^{1}H NMR 1.48 (dd, *J* = 7.0, 4.3, 3H), 2.07 (s, 3H), 2.68 (m, 1H), 3.50 (m, 1H), 4.04 (dd, *J* = 8.6, 7.7, 0.5H), 4.45 (dd, *J* = 8.9, 7.4, 0.5H), 4.91 (m, 1H), 6.26 (m, 1H), 6.89 (d, *J* = 11.8, 0.5H), 7.07 - 7.62 (m, 3H), 7.67 (d, *J* = 7.7, 1H), 8.29 (d, *J* = 8.1, 0.5H), 12.82 (s, 1H); IR 3400 - 2500 (broad), 1850, 1775, 1705; MS *m* / *z* (relative intensity) 269 ($M^{\cdot+}$ - maleic anhydride, 5), 171 (100), 170 (22), 156 (40). *Anal.* Calcd. for $C_{20}H_{17}NO_6$ ($M^{\cdot+}$): C, 65.39; H, 4.66; N, 3.81. Found: C, 65.16; H, 4.80; N, 3.79.

***Z*- and *E*-4-[5-Ethyl-4,10,10a,10b-tetrahydro-4-methyl-1,3(3a*H*)-dioxo-1*H*-furo[3,4-*a*]-carbazol-10-yl]-4-oxo-2-butenoic Acid (11c).** After indole could no longer be detected in the reaction mixture, the solution was cooled. The golden yellow precipitate was collected by filtration and washed with CH_2Cl_2, giving 11c as an ~ 1 : 1 pair of isomers (2.35 g, 38 %, mp 202 - 206 °C dec). The filtrate and washes were combined, concentrated to a few ml, and cooled to room temperature. The resulting solid was triturated with CH_2Cl_2 and filtered, giving a second crop (total: 62 %). Two recrystallizations from acetone gave yellow crystals (mp 206 - 208 °C dec); ^{1}H NMR 1.01 (m, 3H), 1.50 (m, 3H), 2.50 (m, 3H, includes DMSO), 2.71 (m, 1H), 3.49 (d, *J* = 5.9, 1H), 4.06 (t, *J* = 8.0, 0.5H), 4.47 (t, *J* = 8.0, 0.5H), 4.90 (d, *J* = 6.8, 1H), 6.26 (dd, *J* = 11.5, 4.5, 1H), 6.89 (d, *J* = 11.9, 0.5H), 7.09 - 7.40 (m, 3H), 7.57 (d, *J* = 7.3, 1H), 8.32 (d, *J* = 7.9, 0.5H), 12.86 (s, 1H); IR 3400 - 2500 (broad), 1860, 1790, 1735; MS *m* / *z* (relative intensity) 381

($M^{\cdot+}$, 7), 283 (27), 185 (100). *Anal.* Calcd. for $C_{21}H_{19}NO_6$: C, 66.14; H, 5.02; N, 3.67. Found: C, 66.28; H, 5.20; N, 3.80.

4,10,10a,10b-Tetrahydro-4,5,10a-trimethyl-1*H*-furo[3,4-*a*]carbazole-1,3(3a*H*)-dione (15a). Off-white plates (mp 187 - 191 °C dec). The column was further eluted with CH_2Cl_2 : acetone (1 : 1). This band was treated identically to the first and additional **15a** was obtained (total: 0.74 g, 37 %, mp 188 - 191 °C dec). Three recrystallizations gave white crystals (mp 191 - 193 °C dec); ^{1}H NMR ($CDCl_3$) 1.36 (s, 3H), 1.60 (d, *J* = 7.4, 3H), 2.13 (s, 3H), 2.85 (m, 1H), 3.26 (dd, *J* = 8.9, 5.0, 1H), 3.47 (d, *J* = 8.8, 1H), 4.05 (s, 1H), 6.66 (d, *J* = 7.9, 1H), 6.75 (t, *J* = 7.6, 1H), 7.07 (t, *J* = 7.6, 1H), 7.46 (d, *J* = 7.7, 1H); IR 3400, 1860, 1780; HR MS Calcd. for $C_{17}H_{17}NO_3$ ($M^{\cdot+}$): 283.1204. Found: 283.1213. *Anal.* Calcd.: C, 72.07; H, 6.05; N, 4.94. Found: C, 72.23; H, 6.19; N, 4.91.

4,10,10a,10b-Tetrahydro-10a-methyl-5-phenyl-1*H*-furo[3,4-*a*]carbazole-1,3(3a*H*)-dione (15b). Yellow crystals (0.76 g, 23 %, mp 212 - 214 °C dec). Two recrystallizations gave yellow crystals (mp 213.5 - 214 °C dec); ^{1}H NMR ($CDCl_3$) 1.50 (s, 3H), 2.93 (dd, *J* = 16.9, 5.6, 1H), 3.12 (dd, *J* = 16.9, 1.9, 1H), 3.54 (m, 1H), 3.62 (d, *J* =9.5, 1H), 4.53 (s, 1H), 6.43 (t, *J* = 7.5, 1H), 6.62 (d, *J* = 7.2, 1H), 6.67 (d, *J* = 7.9, 1H), 7.03 (t, *J* = 7.5, 1H), 7.25 - 7.45 (m, 5H); IR 3380, 1730, 1680; HR MS Calcd. for $C_{21}H_{17}NO_3$ ($M^{\cdot+}$): 331.1204. Found: 331.1212. *Anal.* Calcd.: C, 76.12; H, 5.17; N, 4.23. Found: C, 76.11; H, 5.06; N, 4.17.

4,10,10a,10b-Tetrahydro-4,10a-dimethyl-5-phenyl-1*H*-furo[3,4-*a*]carbazole-1,3(3a*H*)-dione (15c). Off-white crystals (0.49 g, 14 %, mp 202 - 204 °C dec). Three recrystallizations gave white crystals (mp 210 - 210.5 °C dec); ^{1}H NMR ($CDCl_3$) 1.28 (s, 3H), 1.53 (s, 3H), 3.14 (m, 1H), 3.40 (dd, *J* = 8.9, 4.1, 1H), 3.61 (d, *J* = 8.8, 1H), 4.38 (s, 1H), 5.96 (d, *J* = 7.7, 1H), 6.38 (t, *J* = 7.6, 1H), 6.63 (d, *J* = 7.9, 1H), 6.99 (t, *J* = 7.6, 1H), 7.07 (d, *J* = 6.7, 1H), 7.19 (d, *J* = 7.2, 1H), 7.36 - 7.48 (m, 3H); IR 3400, 1760, 1680; HR MS Calcd. for $C_{22}H_{19}NO_3$ ($M^{\cdot+}$): 345.1360. Found: 345.1378. *Anal.* Calcd.: C, 76.50; H, 5.54; N, 4.06. Found: C, 76.57; H, 5.63; N, 3.96.

2,3,9,9a-Tetrahydro-4,9a-dimethyl-1*H*-carbazole-1,2-dicarboxylic Acid (16). The column was first eluted with CH_2Cl_2, giving, after evaporation of the eluent, maleic acid, and then with EtOAc : petroleum ether. The second fraction was concentrated, petroleum ether was added to the point of cloudiness, and the solution was put in a refrigerator. The resulting precipitate was collected by filtration, giving **16** as a white solid (1.22 g, 43 %, mp 202 - 205 °C dec). Three recrystallizations gave yellow plates (mp 206 - 208 °C dec); ^{1}H NMR 1.28 (s, 3H), 1.89 (s, 3H), 2.40 (m, 1H), 2.62 (m, 1H), 3.04 - 3.20 (m, 2H), 5.95 (s, 1H), 6.67 (t, *J* = 7.7, 2H),6.99 (t, *J* = 7.6, 1H), 7.32 (d, *J* = 7.5, 1H), 12.30 (s, 2H); IR 3600 - 2300 (broad), 1730, 1680; HR MS Calcd. for $C_{16}H_{17}NO_4$ ($M^{\cdot+}$): 287.1153. Found: 287.1154. *Anal.* Calcd.: C, 66.89; H, 5.96; N, 4.88. Found: C, 66.69; H, 6.21; N, 4.58.

General Procedure for the Synthesis of Compounds 9. HCl (1 ml, 10 %) was added to a solution of anhydride **8** (0.5 g) in acetone (30 ml). The solution was stirred at room temperature until **8** could no longer be detected by TLC. Hexane was slowly added until phases formed, anhydrous Na_2SO_4 was added, and the dry solution was decanted. The solution was further diluted with hexane to approximately 100 ml, put in a refrigerator overnight, and the resulting precipitate was collected by filtration.

2,3,4,9-Tetrahydro-4,9-dimethyl-1*H*-carbazole-1,2-dicarboxylic Acid (9a). Light yellow solid (0.45 g, 84 %, mp 217 - 219 °C dec); ^{1}H NMR 1.40 (d, *J* = 6.6, 3H), 2.01 (m, 1H), 2.41 (m, 1H), 2.82 (m, 1H), 3.02 (m, 1H), 3.74 (s, 3H), 4.26 (d, *J* = 4.4, 1H), 7.02 (t, *J* = 7.5, 1H), 7.15 (t, *J* = 7.5, 1H), 7.41 (d, *J* = 8.1, 1H), 7.61 (d, *J* = 7.8, 1H), 12.60 (s, 2H); IR 3400 - 2300 (broad), 1700; MS *m* / *z* (relative

intensity) 287 ($M^{\cdot+}$, 4), 243 (52), 228 (100), 182 (30). *Anal.* Calcd. for $C_{16}H_{17}NO_4$: C, 66.89; H, 5.96; N, 4.88. Found: C, 66.71; H, 5.94; N, 4.94.

2,3,4,9-Tetrahydro-3,4,9-trimethyl-1*H*-carbazole-1,2-dicarboxylic Acid (9b). Light yellow solid (0.46 g, 86 %, mp 220 - 223 °C dec). Three recrystallizations gave a light yellow solid (mp 223 - 225 °C dec); ^{1}H NMR 0.93 (d, *J* = 6.9, 3H), 1.43 (d, *J* = 6.9, 3H), 2.43 (m, 1H), 2.99 (d, *J* = 5.4, 1H), 3.14 (t, *J* = 6.3, 1H), 3.65 (s, 3H), 4.35 (d, *J* = 5.5, 1H), 6.99 (t, *J* = 7.5, 1H), 7.12 (dd, *J* = 8.1, 7.1, 1H), 7.40 (d, *J* = 8.2, 1H), 7.64 (d, *J* = 8.0, 1H), 12.65 (s, 2H); IR 3400 - 2300 (broad), 1700; MS *m* / *z* (relative intensity) 283 ($M^{\cdot+}$ - H_2O, 6), 242 (21), 197 (23), 171 (37). *Anal.* Calcd. for $C_{17}H_{19}NO_4$: C, 67.76; H, 6.35; N, 4.65. Found: 67.68; H, 6.33; N, 4.76.

4-Ethyl-2,3,4,9-tetrahydro-3,9-dimethyl-1*H*-carbazole-1,2-dicarboxylic Acid (9c). Light yellow solid (0.46 g, 87 %, mp 244 - 248 °C dec). Three recrystallizations gave a light yellow solid (mp 245 - 248 °C dec); ^{1}H NMR 0.91 (d, *J* = 6.8, 3H), 1.06 (m, 3H), 1.47 (m, 1H), 2.59 (m, 2H), 2.87 (m, 2H), 3.64 (s, 3H), 4.35 (d, *J* = 5.5, 1H), 6.97 (t, *J* = 7.6, 1H), 7.11 (dd, *J* = 8.0, 7.1, 1H), 7.39 (d, *J* = 8.2, 1H), 7.67 (d, *J* = 8.0, 1H), 12.54 (s, 2H); IR 3400 - 2300 (broad), 1700; MS *m* / *z* (relative intensity) 315 ($M^{\cdot+}$, 2), 297 (43), 271 (43), 268 (37), 242 (100), 196 (45). *Anal.* Calcd. for $C_{18}H_{21}NO_4$: C, 68.55; H, 6.71; N, 4.44. Found: 68.83; H, 6.68; N, 4.59.

1,2,3,3a,4,5,6,10c-Octahydro-6-methylcyclopenta[*c*]carbazole-4,5-dicarboxylic Acid (9d). Light yellow solid (0.51 g, 96 %, mp 233 - 236 °C dec). Two recrystallizations gave a white solid (mp 234 - 236 °C dec); ^{1}H NMR 1.47 - 1.60 (m, 3H), 1.81 - 1.90 (m, 2H), 2.12 (m, 1H), 2.71 (m, 1H), 3.16 (m, 1H), 3.40 (t, *J* = 7.5, 1H), 3.67 (d, *J* = 2.5, 3H), 4.38 (d, *J* = 5.2, 1H), 7.01 (dt, *J* = 7.4, 1.8, 1H), 7.14 (dt, *J* = 6.8, 1.5, 1H), 7.39 (d, *J* = 8.1, 1H), 7.46 (d, *J* = 8.0, 1H), 12.50 (s, 2H); IR 3500 - 2300 (broad), 1710; MS *m* / *z* (relative intensity) 295 ($M^{\cdot+}$ - H_2O, 15), 269 (85), 240 (24), 224 (91), 223 (34), 197 (420), 196 (28), 195 (26), 194 (75), 180 (22), 167 (29). *Anal.* Calcd. for $C_{18}H_{19}NO_4$: C, 69.00; H, 6.11; N, 4.47. Found: 69.22; H, 6.37; N, 4.39.

2,3,4,9-Tetrahydro-9-methyl-4-phenyl-1*H*-carbazole-1,2-dicarboxylic Acid (9e). Light yellow solid (0.50 g, 96 %, mp 134 - 137 °C dec). Two recrystallizations gave a white solid (mp 136 - 137 °C dec); ^{1}H NMR 2.31 (m, 1H), 2.49 (m, 1H), 3.03 (dd, *J* = 9.7, 3.4, 1H), 3.79 (s, 3H), 4.15 (m, 1H), 4.37 (d, *J* = 4.6, 1H), 6.54 (d, *J* = 7.8, 1H), 6.74 (t, *J* = 7.5, 1H), 7.05 (t, *J* = 7.6, 1H), 7.20 - 7.32 (m, 5H), 7.39 (d, *J* = 8.2, 1H), 12.69 (s, 2H); IR 3500 - 2300 (broad), 1690; MS *m* / *z* (relative intensity) 305 ($M^{\cdot+}$ - CO_2, 100), 233 (45), 232 (73), 228 (67). *Anal.* Calcd. for $C_{21}H_{19}NO_4$: C, 72.19; H, 5.48; N, 4.01. Found: C, 72.01; H, 5.47; N, 4.03.

4b,6,7,11c,12,13-Hexahydro-7-methyl-5*H*-naphtho[1,2-*c*]carbazole-5,6-dicarboxylic Acid (9f). Light yellow solid (0.48 g, 91 %, mp 302 - 305 °C dec). Two recrystallizations gave a white solid (mp 308 - 310 °C dec); ^{1}H NMR was not obtained due to insolubility; IR 3200 - 2300 (broad), 1690; MS *m* / *z* (relative intensity) 357 ($M^{\cdot+}$ - H_2O, 6), 331 (100), 286 (49), 201 (48), 157 (22), 144 (31). *Anal.* Calcd. for $C_{23}H_{21}NO_4$: C, 73.58; H, 5.64; N, 3.73. Found: C, 73.48; H, 5.77; N, 3.67.

General Procedure for Synthesis of Compounds 10. A solution of the dicarboxylic acid **9** in acetone or 2-butanone was refluxed overnight. The solvent was evaporated off under reduced pressure, leaving **10** as a pale yellow solid. Analytical samples were obtained by recrystallization from acetone : hexane.

2,3,4,9-Tetrahydro-4,9-dimethyl-1*H*-carbazole-2-carboxylic Acid (10a). 0.43 g, 96 %, mp 217 - 220 °C dec. Three recrystallizations gave a yellow solid (mp 219 - 222 °C dec); ^{1}H NMR 1.33 - 1.45 (m, 4H), 2.29 (m, 1H), 2.71 - 2.84 (m, 2H), 3.00 (m, 2H), 3.62 (s, 3H), 6.97 (t, *J* = 7.4, 1H), 7.08 (t,

J = 7.6, 1H), 7.37 (d, *J* = 8.1, 1H), 7.55 (d, *J* = 7.9, 1H), 12.45 (s, 1H); IR 3400 - 2300 (broad), 1695; MS *m / z* (relative intensity) 243 ($M^{\cdot+}$, 48), 228 (100), 182 (29). *Anal.* Calcd. for $C_{15}H_{17}NO_2$: C, 74.05; H, 7.04; N, 5.76. Found: C, 73.78; H, 7.15; N, 5.74.

2,3,4,9-Tetrahydro-3,4,9-trimethyl-1*H*-carbazole-2-carboxylic Acid (10b). 0.37 g, 82 %, mp 219 - 232 °C dec. Three recrystallizations gave a white solid (mp 230 - 232 °C dec); ^1H NMR 0.74 (d, *J* = 6.9, 3H), 1.42 (d, *J* = 7.1, 3H), 2.43 (dd, *J* = 6.7, 5.3, 1H), 2.85 (m, 3H), 3.24 (dd, *J* = 6.5, 5.4, 1H), 3.62 (s, 3H), 6.93 (t, *J* = 7.5, 1H), 7.07 (dd, *J* = 8.1, 7.1, 1H), 7.36 (d, *J* = 8.1, 1H), 7.57 (d, *J* = 7.9, 1H), 12.43 (s, 1H); IR 3400 - 2300 (broad), 1690; MS *m / z* (relative intensity) 257 ($M^{\cdot+}$, 38), 242 (61), 196 (30), 182 (30), 171 (100). *Anal.* Calcd. for $C_{16}H_{19}NO_2$: C, 74.68; H, 7.44; N, 5.44. Found: C, 74.55; H, 7.31; N, 5.51.

4-Ethyl-2,3,4,9-tetrahydro-3,9-dimethyl-1*H*-carbazole-2-carboxylic Acid (10c). 0.45 g, 99 %, mp 242 - 244 °C dec. Three recrystallizations gave a white solid (mp 244 - 245 °C dec); ^1H NMR 0.70 (d, *J* = 6.8, 3H), 1.07 (t, *J* = 7.2, 3H), 1.40 (m, 1H), 2.60 (m, 2H), 2.83 (m, 3H), 3.02 (m, 1H), 3.62 (s, 3H), 6.94 (t, *J* = 7.5, 1H), 7.05 (dd, *J* = 8.2, 7.3, 1H), 7.35 (d, *J* = 8.1, 1H), 7.59 (d, *J* = 8.0, 1H), 12.47 (s, 1H); IR 3300 - 2300 (broad), 1695; MS *m / z* (relative intensity) 271 ($M^{\cdot+}$, 20), 242 (100), 196 (42), 182 (27). *Anal.* Calcd. for $C_{17}H_{21}NO_2$: C, 75.25; H, 7.80; N, 5.16. Found: C, 75.12; H, 7.70; N, 5.12.

9-(3-Carboxy-1-oxo-1-propyl)-2,3,4,4a,9,9a-hexahydro-4-methyl-1*H*-carbazole-1,2-dicarboxylic Acid (13). Tetrahydrocarbazole **11a** (1.00 g, 2.83 mmol) was dissolved in 5 % NaOH, and 10 % Pd on activated charcoal (30 mg) was added. A balloon was attached and H_2 was added to the system until the balloon had expanded considerably. The solution was stirred for 30 h, then 10 % HCl was added to pH 1. Benzene was added and the H_2O was removed by azeotropic distillation. The distillation was stopped when the solution began to appear cloudy. The solution was cooled in an ice-bath, and the precipitate was collected by filtration, giving **13** as a white solid. The filtrate was placed in a refrigerator overnight, and a second crop was recovered (total: 0.96 g, 90 %). Recrystallization from acetone : hexane, followed by recrystallization from methanol, gave a white solid (mp 214 - 216 °C); ^1H NMR 1.45 (d, *J* = 5.1, 3H), 1.82 (d, *J* = 8.9, 1H), 2.09 (m, 2H), 2.57 - 2.74 (m, 4H), 3.06 (m, 1H), 3.32 (m, 1H), 3.58 (m, 1H), 4.87 (t, *J* = 7.5, 1H), 6.91 (t, *J* = 7.5, 1H), 7.08 (t, *J* = 7.6, 1H), 7.36 (d, *J* = 7.4, 1H), 7.93 (d, *J* = 7.9, 1H), 12.04 (s, 3H); IR 3400 - 2300 (broad), 1700; MS *m / z* (relative intensity) 339 ($M^{\cdot+}$ - 2 H_2O, 5), 257 (42), 157 (30), 144 (100), 117 (31). *Anal.* Calcd. for $C_{19}H_{21}NO_7$: C, 60.79; H, 5.64; N, 3.73. Found: C, 60.90; H, 5.34; N, 3.72.

5-Methyl-1*H*-furo[3,4-*c*]carbazole-1,3(10*H*)-dione (12) A. From Indole, Acetone, and Maleic Anhydride. Concentrated HCl (~ 0.5 ml) and then maleic anhydride (4.19 g, 42.8 mmol) were added to a solution of indole (5.05 g, 43.2 mmol) in acetone (100.4 g). The solution was stirred at room temperature for 50 h. The excess acetone was removed under reduced pressure, giving a dark red tar. The tar was triturated with CH_2Cl_2 and filtered, giving a yellow solid. The solid was recrystallized from toluene : pyridine, giving **12** as a yellow powder (0.21 g, 6 %, mp 371 - 373 °C sublimed); ^1H NMR 2.99 (s, 3H), 7.34 (t, *J* = 7.5, 1H), 7.60 (t, *J* = 7.4,), 7.63 (s, area for 7.60 - 7.63 is 2H), 7.72 (d, *J* = 8.0, 1H), 8.28 (d, *J* = 7.9, 1H), 12.57 (s, 1H); IR 3385, 1823, 1750; HR MS Calcd. for $C_{15}H_9NO_3$ ($M^{\cdot+}$): 251.0580. Found: 251.0566. *Anal.* Calcd.: C, 71.71; H, 3.61; N, 5.58. Found: C, 71.54; H, 3.79; N, 5.72.

B. From Tetrahydrocarbazole 11a. Tetrahydrocarbazole **11a** (303 mg, 0.86 mmol) was suspended in 1,4-dioxane (30 ml) with stirring. 2,3-Dichloro-5,6-dicyano-1,4-benzoquinone (390 mg, 1.72 mmol) was added, and the solution was heated to reflux (by which time the solids had completely dissolved) and maintained there for 4.5 h. The solvent was removed by evaporation under reduced pressure, and the resulting solid was

triturated with MeOH and filtered, giving **12** as a yellow solid (81.8 mg, 0.33 mmol, 38%, mp 368 - 370 °C sublimed).

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References

1. Portions of this paper are from two Ph. D. Theses: (a) Guang-Ming Xia, *In Situ Vinylindole Synthesis of Carbazoles*, Ph. D. Thesis, University of Minnesota, Minneapolis, MN August 1987; *Diss. Abstr. Int. B* **1988**, *49*, 756. (b) Mary J. Condoluci (now Wahlstrom), *The in situ Vinylindole Synthesis of Carbazoles. Use of 2-D NMR and Mass Spectrometry to Determine Regio- and Stereochemistry*, Ph. D. Thesis, University of Minnesota, Minneapolis, MN May 1988; *Diss. Abstr. Int. B* **1989**, *49*, 3759 - 3760.
2. (a) Noland, W. E.; Kuryla, W. C.; Lange, R. F. *J. Am. Chem. Soc.* **1959**, *81*, 6010 - 6017. (b) Noland, W. E.; Sundberg, R. J. *J. Org. Chem.* **1963**, *28*, 884 - 885.
3. Reviews of Diels-Alder reactions of vinylindoles: (a) Pindur, U. *Chimia* **1990**, *44*, 406 - 412. (b) Pindur, U. *Heterocycles* **1988**, *27*, 1253 - 1268. (c) Pindur, U.; Pfeuffer, L. *Chem.-Ztg.* **1986**, *110*, 95 - 99.
4. Noland, W. E.; Wann, S. R. *J. Org. Chem.* **1979**, *44*, 4402 - 4412.
5. Noland, W. E.; Wahlstrom, M. J.; Konkel, M. J.; Brigham, M. E.; Trowbridge, A. G.; Konkel, L. M. C.; Gourneau, R. P.; Scholten, C. A.; Lee, N. H.; Condoluci, J. J.; Gac, T. S.; Mostafaei Pour, M.; Radford, P. M. *J. Heterocycl. Chem.* **1993**, *30*, 81 - 91.
6. (a) Noland, W. E.; Venkiteswaran, M. R.; Richards, C. G. *J. Org. Chem.* **1961**, *26*, 4241 - 4248. (b) Noland, W. E.; Venkiteswaran, M. R.; Lovald, R. A. *J. Org. Chem.* **1961**, *26*, 4249 - 4254. (c) Noland, W. E.; Venkiteswaran, M. R.; Richards, C. G.; Desai, H. S. *J. Org. Chem.* **1961**, *26*, 4263 - 4269. (d) Freter, K. *J. Org. Chem.* **1975**, *40*, 2525 - 2529.
7. For a review of Bredt's rule see: Shea, K. J. *Tetrahedron* **1980**, *36*, 1683 - 1715.
8. Bassindale, A. *The Third Dimension in Organic Chemistry;* Boschke, F. L.; Fresenius, W.; Huber, J. F. K.; Pungor, E.; Rechnitz, G. A.; Simon, W.; West, T. S. Eds., John Wiley and Sons, Inc.: New York, 1984; p 164.
9. (a) Diels, O.; Alder, K.; Lubbert, W. *Justus Liebigs Ann. Chem.* **1931**, *490*, 277 - 294; (b) Sauer, G. L. *The Reaction of Indole and Dienophiles. Maleic Anhydride*, M.S. Thesis, University of Minnesota, Minneapolis, MN June 1955; (c) Noland, W. E.; Hammer, C. F. *J. Org. Chem.* **1960**, *25*, 1525 - 1535; (d) Campbell, R. W. *Reactions of Dimethyl (3-Indole)fumarate with Dienophiles*, Ph. D. Thesis, University of Minnesota, Minneapolis, MN August 1961; *Diss. Abstr.* **1962**, *22*, 3851; (e) Acheson, R. M.; Feinberg, R. S.; Hands, A. R. *J. Chem. Soc.* **1964**, 526 - 528.
10. Lange, R. F. *The Reactions of Indoles with Dienophiles*, Ph. D. Thesis, University of Minnesota, Minneapolis, MN June 1958; *Diss. Abstr.* **1959**, *20*, 1172.

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