perature for 3 hr. The solution was concentrated to dryness under reduced pressure, and the residue was crystallized by trituration with ethanol to give 0.85 g of fairly pure product. This was recrystallized from acetonitrile, affording 0.75 g (58%) of **5a**, mp 206–207°. A mixture melting point with the photochemical product **5a** was 207–208°.

Photochemical Oxidation of 3,4-Dihydro-7-methoxy-1-(*p*-methoxyphenyl)-3-phenyl-2(1*H*)-quinoxalinone.—A solution of 0.79 g (2.20 mmol) of **4a** and 0.26 g (1.07 mmol) of 4,4′-dimethoxyazobenzene (**14a**) in 250 ml of deoxygenated dichloromethane was irradiated for 4 hr at 300 mμ in a quartz vessel in a Rayonet photochemical reactor Model RPR-100 while a stream of helium was passed through the solution. At the end of this time, tlc indicated the presence of **5a** and no **14a** or **4a**. The solution was treated with 2 ml of triethylamine and concentrated to dryness under reduced pressure. The residue was recrystallized from methanol (containing a little triethylamine), affording 0.58 g (74%) of **5a**, mp 203–206°, uv max 368 mμ (ε 19,800). The mother liquors contained *p*-anisidine as shown by vpc.

4,4′-Dimethoxyhydrazobenzene (18).—A solution of 2.42 g of 4,4′-dimethoxyazobenzene (**14a**) in 50 ml of tetrahydrofuran and 50 ml of ether was treated with 0.35 g of lithium aluminum hydride and then with an ether solution of 0.10 g of ferric chloride.[18] The mixture was stirred at room temperature for 2 hr, and then treated successively with 0.35 ml of water, 0.35 ml of 15% sodium hydroxide solution, and 1.05 ml of water. The mixture was filtered, and the filtrate was concentrated to dryness at room temperature under reduced pressure. The residue contained about 15% of the azo compound **14a** (by uv), but could not be purified further. Mild heating, such as attempted recrystallization from ether, effected disproportionation to **14a** and *p*-anisidine: ir (KBr) 3355, 3340 (NH); uv max 353 mμ (ε 4830) and 311 (5650).

(18) G. A. Olah, *J. Amer. Chem. Soc.*, **81**, 3165 (1959).

Anal. Calcd for $C_{14}H_{16}N_2O_2$: C, 68.83; H, 6.60; N, 11.47. Found: C, 68.94; H, 6.56; N, 11.66.

Photochemical Disproportionation of 4,4′-Dimethoxyhydrazobenzene.—A solution of 0.40 g of the above crude 4,4′-dimethoxyhydrazobenzene in 40 ml of dichloromethane was irradiated for 30 min at 300 mμ in a Rayonet photochemical reactor. The solution turned dark, and the ultraviolet spectrum showed an intense peak at 354 mμ due to the azobenzene. (A control solution of **15** in dichloromethane in the dark showed little change in its ultraviolet spectrum after 1 hr at 25°.) The solution was concentrated to dryness under reduced pressure. The residue was extracted with ether and water, leaving a large amount of black insoluble material. The ether layer, concentrated under reduced pressure, afforded 0.14 g of 4,4′-dimethoxyazobenzene, mp 163–164°. Concentration of the aqueous solution gave a residue which was recrystallized from acetonitrile, affording 0.04 g of *p*-anisidine hydrochloride, mp 208–212°, having an infrared spectrum identical with that of an authentic sample.

Registry No.—**4a**, 26596-02-1; **4b**, 26596-03-2; **4c**, 26596-04-3; **5a**, 26596-05-4; **5b**, 26596-06-5; **5c**, 26596-07-6; **7**, 26596-08-7; **9**, 26596-09-8; **10**, 26596-10-1; **11**, 19950-86-8; **18**, 1027-40-3.

Acknowledgment.—The authors wish to express their deep appreciation to Mr. Ernest Schoeb, Mrs. Gloria Cook, and Mrs. Carola Spurlock for their efforts in obtaining the many spectra needed in this work. We also wish to thank Mr. Charles Childs and the staff of our Microanalytical Laboratory and Mr. William Pearlman of our High-Pressure Laboratory for their valuable technical assistance.

The Singlet Oxygen Oxidation of *N*-Phenylpyrroles. Its Application to the Synthesis of a Model Mitomycin

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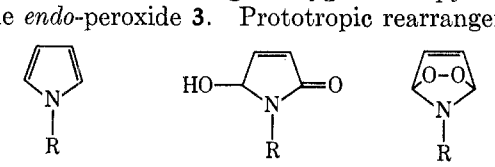
Received June 23, 1970

The photooxygenation of *N*-phenylpyrroles to produce pyrrolinones is described. The conversion of pyrrolinone **14** to a tetracyclic framework **22** related to the aziridine-containing mitomycin antibiotics is elucidated. A tabulation of nmr data for protons on the ring fusion of bicyclic fused aziridines is presented.

The photooxygenation of heterocycles is an area in which a steady level of interest has been maintained through the years.[2] The precedent for our research in pyrrole oxidations was based on the report of De Mayo and Reid,[3] on the photooxidation of pyrrole **1a** and *N*-methylpyrrole **1b** to form the hydroxylactams **2a** and **2b**. A possible mechanism for the reaction invokes the Diels–Alder reaction of singlet oxygen with pyrrole to form the *endo*-peroxide **3**. Prototropic rearrangement



1a, R = H
b, R = CH_3

2a, b

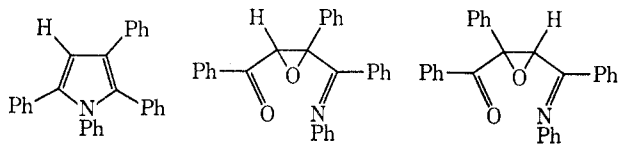
3

(1) (a) Abstracted from the Ph.D. Thesis of J. A., Fordham University, 1970. (b) Supported in part by grants from the National Cancer Institute, CA 11421, and the National Institute of General Medical Sciences, GM 12758. (c) Preliminary reports of portions of this work have appeared: J. Auerbach and R. W. Franck, *Chem. Commun.*, 991 (1969); J. Auerbach and R. W. Franck, Abstracts, 158th National Meeting of the American Chemical Society, New York, N. Y., Sept 1969, ORGN 148. (d) To whom correspondence should be addressed.

(2) S. T. Reid, *Advan. Heterocycl. Chem.*, **11**, 116 (1970).

(3) P. De Mayo and S. T. Reid, *Chem. Ind. (London)*, 1576 (1962).

including O–O bond fission affords **2**. Other oxidations of pyrroles that appear to be reactions with singlet oxygen have been reported.[4,5] In the case of highly substituted pyrroles such as **4**, Wasserman and Miller have isolated photooxidation products **5** and **6** whose formation can be rationalized by postulating rearrangements of an initially formed *endo*-peroxide.



4 **5** **6**

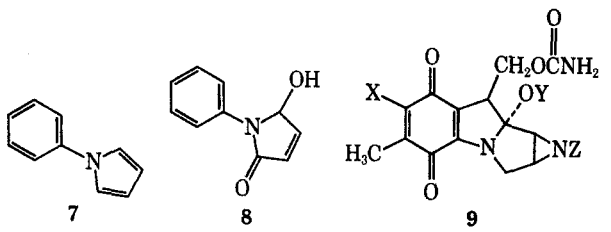
Our research on the singlet oxygen oxidation of *N*-phenylpyrrole (**7**) began because we saw a similarity between the predicted oxidation product **8** and certain features of the mitomycin antibiotics **9**.[6] The double bond

(4) A. R. Katritzky and E. Hoft, *Tetrahedron Lett.*, 2028 (1968).

(5) H. H. Wasserman and A. H. Miller, *Chem. Commun.*, 199 (1969).

(6) (a) J. S. Webb, D. B. Cosulich, J. H. Mowat, J. B. Patrick, R. W. Broschard, W. E. Meyer, R. P. Williams, C. F. Wolf, W. Fulmore, C. Pidacks, and J. E. Lancaster, *J. Amer. Chem. Soc.*, **84**, 3187 (1962); (b) J. B. Patrick, R. P. Williams, W. E. Meyer, W. Fulmor, D. B. Cosulich, R. W. Broschard, and J. S. Webb, *ibid.*, **86**, 1889 (1964).

in **8** was visualized as the aziridine precursor, with the Scheiner aziridine synthesis as the eventual functionalization method.[7] This route requires the cycloaddition of an azide to a double bond to form a triazoline which is converted to an aziridine by subsequent extrusion of nitrogen.

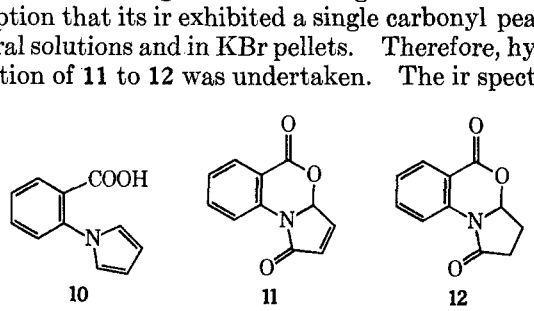


7 8 9

	X	Y	Z
mitomycin A	CH_3O	CH_3	H
mitomycin B	CH_3O	H	CH_3
mitomycin C	NH_2	CH_3	H
porfiromycin	NH_2	CH_3	CH_3

Results and Discussion

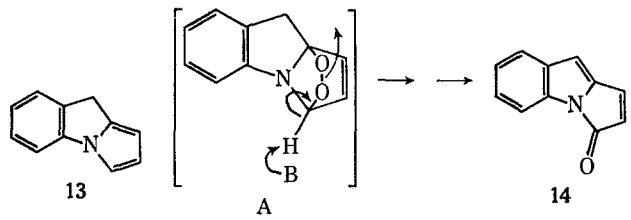
The oxygenation of **7** was performed using several methods of singlet oxygen generation.[8] In every case, low yields of lactam **8** were obtained. The structural assignment was derived from its ir [($CHCl_3$) 3551 (OH), 1705 cm^{-1} (C=O)], nmr [(DMSO) δ 6.05 (m, 1, C-5), 6.23 (d with fine structure, 1, J_{3-4} = 5.5 Hz, C-3), 7.00–7.78 (m, 7, C-4, aromatics, OH)], elemental analysis, and its oxidation with manganese dioxide to form *N*-phenylmaleimide. The yield in this singlet oxygen oxidation route does not compare favorably with a synthesis of 5-hydroxy-Δ^3-pyrrolin-2-ones involving Grignard addition to maleimides.[9] However, the Grignard method cannot be used to prepare the 5-unsubstituted derivatives as in our oxidation. Upon treatment with singlet oxygen, *N*-(2-carboxyphenyl)pyrrole **10** afforded the lactam–lactone **11**, regardless of whether the reaction was performed with the free acid or its sodium salt. The structural assignment was straightforward with the exception that its ir exhibited a single carbonyl peak in several solutions and in KBr pellets. Therefore, hydrogenation of **11** to **12** was undertaken. The ir spectrum



10 11 12

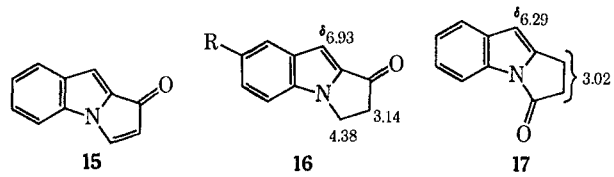
of the resulting dihydro derivative **12** contained two carbonyl bands (1730 and 1710 cm^{-1}).

When the heterocycle **13** was treated with singlet oxygen under a variety of conditions,[10] rapid oxygenation took place and the indole–lactam **14** was isolated. Although the various oxidations seemed "clean," work-up always led to tarry residues and the eventual yield of **14** was low. Our hypothesis was that adduct A was forming, but that an efficient base-catalyzed opening of the *endo*-peroxide was not occurring. Thus, triethylamine



13 A 14

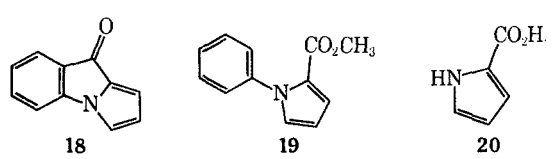
was added to the normal solvent for a photooxidation experiment and it was discovered that no photooxidation took place. Ouannès and Wilson have observed this effect with tertiary amines. They have developed their experiments in an elegant way and demonstrated that tertiary amines quench singlet oxygen.[11] However, added pyridine in aqueous solvents does not act as a quencher, but does serve to improve the yield of **14**, with 70% isolation being routine. The structural assignment for **14** was derived as follows: ir ($CHCl_3$) 1718 cm^{-1} (C=O); uv (ethanol) λ_{max} 208 nm (ϵ 30,000) end absorption, 266 (11,000), 273 (10,000), 355 (11,000); nmr ($CDCl_3$) δ 5.93 (d, 1, J_{1-2} = 5.5 Hz, C-2), 6.31 (s, 1, C-9), 6.90–7.45 (m, 4, H–C_1, H–$C_{6,7,8}$), 7.69 (m, 1, C-5). The formation of an isomeric compound **15** was considered since there is a record of unusual rearrangements in the pyrrolo[1,2-*a*]indole series.[12]



15 16 17

Thus, hydrogenation of **14** was performed to afford **17**. The reported melting point, ir, and uv for **16** (R = H)[13] which would have been the dihydro product from **15**, differ from that of our hydrogenation product **17**. Also, comparison of nmr data obtained for lactam **17** with the published data for **16** (R = benzyloxy) revealed significant differences in the methylene and indolic hydrogen resonances.[12b] Thus, the prediction of structure **14**, based on mechanistic considerations, was shown to be on firm ground.

The use of pyridine as a cosolvent for photooxidation did not improve the yields of pyrrolinone products from pyrroles **7**. Our oxidation experiments were extended to the deactivated pyrroles **18**, **19**, and **20**, none of which



18 19 20

consumed oxygen. The main conclusion we draw from our work to date is that nondeactivated *N*-phenylpyrroles react rapidly with singlet oxygen. The control of the subsequent decomposition of the presumed *endo*-peroxide intermediate is not yet fully understood and

(7) (a) P. Scheiner, *J. Org. Chem.*, **30**, 7 (1965); (b) P. Scheiner, *Tetrahedron*, **24**, 2757 (1968).

(8) (a) C. S. Foote, S. Wexler, W. Ando, and R. Higgins, *J. Amer. Chem. Soc.*, **90**, 975 (1968); (b) D. R. Kearns, P. Radlick, P. Hollins, and R. Chambers, *ibid.*, **89**, 5456 (1967); (c) H. H. Wasserman and S. R. Scheffer, *ibid.*, **89**, 3073 (1967).

(9) A. Queen and A. Reipas, *J. Chem. Soc. C*, 2459 (1967).

(10) V. J. Mazzola, K. Bernady, and R. W. Franck, *J. Org. Chem.*, **32**, 486 (1967).

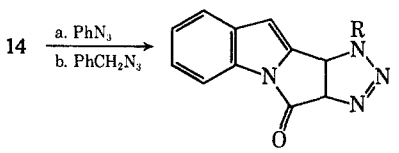
(11) C. Ouannès and T. Wilson, *J. Amer. Chem. Soc.*, **90**, 6527 (1968).

(12) (a) W. A. Remers, *ibid.*, **86**, 4608 (1964); (b) G. R. Allen and M. J. Weiss, *J. Org. Chem.*, **30**, 2904 (1965); (c) E. E. Schweizer and K. K. Light, *ibid.*, **31**, 870, 2912 (1966).

(13) W. A. Remers and M. J. Weiss, *J. Med. Chem.*, **8**, 700 (1965).

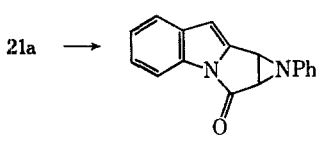
remains the crucial factor in obtaining useful yields of a single product.

The lactam **14**, now readily available, has a double bond in a location appropriate for the fusion of an aziridine ring. Thus, cycloadditions to **14** with benzyl and phenyl azides were attempted, as the first step in the Scheiner aziridine synthesis.[7] Triazolines **21a** and **21b** were formed in good yield. It is not certain that the direction of addition is as depicted, but the assign-



21a, R = Ph
b, R = CH_2Ph

ments are based on the precedents in Huisgen's work on dipolar additions of azides to dipolarophilic double bonds conjugated with carbonyls.[14] Also, the different nmr shifts for the indolic protons in **21a** and **21b** suggest differing shielding effects of the R groups in proximity to the indole proton, rather than the effects of identical N=N linkages. The photochemical elimination of nitrogen was the step remaining for the attainment of a model mitomycin. The phenyltriazoline **21a**, with significant uv absorption above 300 nm, could be photolyzed with a sun lamp and a plate glass filter which effectively excluded light with wavelengths shorter than 310 nm. Nitrogen elimination proceeded smoothly and rapidly to afford aziridine **22** in essentially quantitative yield. Continued irradiation of the photolysate beyond the time required for complete nitrogen evolution resulted in destruction of **22**. The triazoline **21b** had no significant absorption above 300 nm. Thus, the photoextrusion reaction did not take place under the conditions defined for **21a**. Instead, a high-pressure mercury lamp with Corex glass filtering and, in some cases, benzene solvent was used in the photolysis of **21b**. Starting material was consumed; however, no aziridine-like product could be isolated. It was assumed that the desired product had undergone further photochemistry, since the photolability of aziridines conjugated with carbonyl groups has been well established.[15] It could be predicted that the product aziridine would be a good chromophore at wavelengths below 300 nm, based on the extinctions *inter alia* of **17** of 2500 at 293 nm and 2400 at 300 nm. Thus, the failure to isolate an aziridine as the primary photoextrusion product when light of wavelength below 310 nm was used might be rationalized. The structural assignment for **22** was based



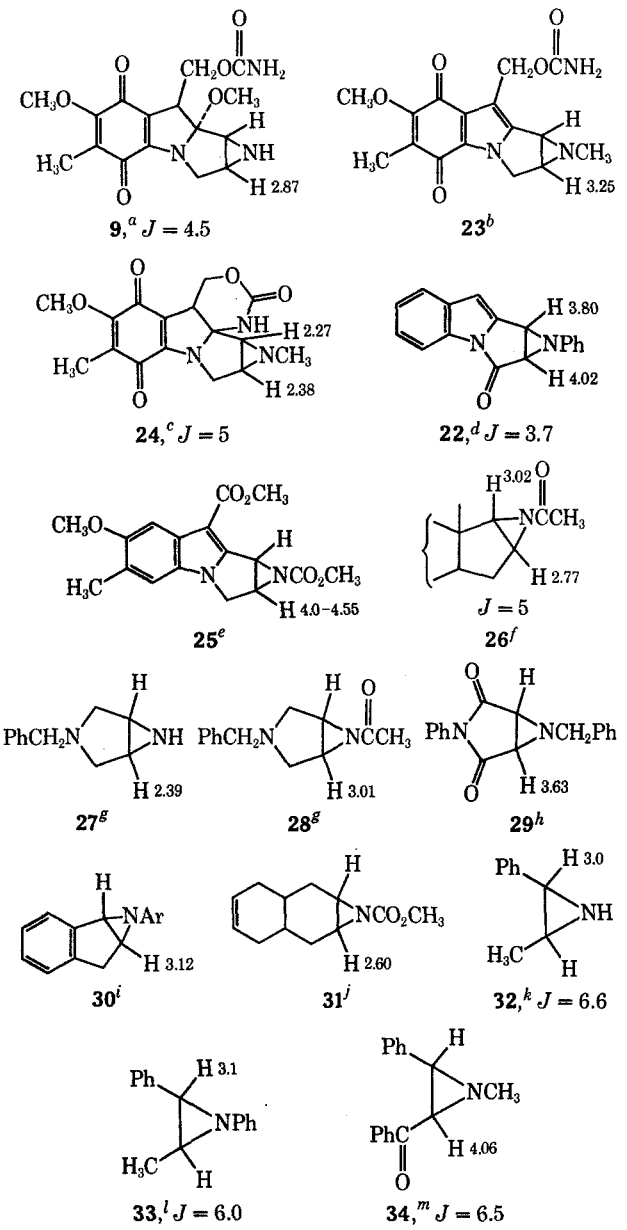
22

on the method of synthesis as well as a consistent ir, uv, nmr, and mass spectral data. Scheme I summarizes nmr data for several aziridine functions including examples of mitomycins and others fused to a five-membered

(14) R. Huisgen, G. Szeimes, and L. Mobius, *Chem. Ber.*, **99**, 475 (1966).
(15) A. Padwa and L. Hamilton, *J. Amer. Chem. Soc.*, **89**, 102 (1967).

SCHEME I

A LISTING OF CHEMICAL SHIFTS (δ) AND COUPLING CONSTANTS (HERTZ) FOR PROTONS ON AZIRIDINES



[a] G. O. Morton, Lederle Laboratories Division, American Cyanamid Co., private communication; δ midpoint of multiplet. [b] Reference 6b. [c] G. O. Morton, G. E. Van Lear, and W. Fulmor, *J. Amer. Chem Soc.*, **92**, 2588 (1970). [d] This work. [e] Reference 17. [f] G. J. Mathews and A. Hassner, *Tetrahedron Lett.*, 1833 (1969). [g] E. Ohki, S. Oida, and H. Saeki, *Ann. Rep. Sankyo Res. Lab.*, **21**, 1 (1969). [h] R. Friary, Fordham University, private communication. [i] P. Walker and W. A. Waters, *J. Chem. Soc.*, 1632 (1962). *Cf.* A. Hassner, G. J. Matthews, and F. W. Fowler, *J. Amer. Chem. Soc.*, **91**, 5046 (1969), for an aziridine of indene which has apparently rearranged. [j] L. A. Paquette, D. E. Kuhla, J. H. Barrett, and R. J. Haluska, *J. Org. Chem.*, **34**, 2866 (1969). [k] S. Brois and L. Beardsley, *Tetrahedron Lett.*, 5116 (1966). [l] J. Deyrup and R. Greenwald, *J. Amer. Chem. Soc.*, **87**, 4538 (1965). [m] A. E. Pohland, R. C. Badger, and N. H. Cromwell, *Tetrahedron Lett.*, 4639 (1965); δ midpoint of AB quartet.

ring. It can be seen that the chemical shifts of hydrogens on aziridine rings are upfield from the usual values of hydrogens adjacent to nitrogen. Also, it should be noted that, when an aziridine is fused to a ring, the J_{vic} of the ring fusion protons is decreased, in a manner anal-

ogous to J_{vic} for epoxides.[16] It is our belief that the mitomycin analog **22** described in this report exhibits nmr shifts and a coupling constant, when substituent and ring fusion effects are taken into account, within the bounds of expectation. We take a note of a recent, revised claim of synthesis of a mitomycin analog **25** which has nmr shifts in a range slightly outside the limits expected. A knowledge of the coupling constant for J_{vic} in **25** would greatly clarify its structural assignment.[17] It is our conclusion that the unambiguous preparation of a tetracyclic molecule with a framework related to the mitomycins has been achieved in our laboratory.

Experimental Section[18]

Synthesis of 5-Hydroxy-1-phenyl-3-pyrrolin-2-one (8).—In a 500-ml gas washing cylinder was placed 500 mg of *N*-phenylpyrrole (**7**) (3.5 mmol) plus 10 mg of methylene blue, 250 ml of THF, 50 ml of pyridine, and 200 ml of distilled water. This vessel was placed in the center of a bank of four General Electric cool-white fluorescent lamps (15 W per tube). The reaction solution was magnetically stirred. The lights were switched on, and oxygen gas, passing through the dispersion disk at the bottom, was bubbled through the solution.

The disappearance of starting material **7** from the reaction solution was followed by tlc. After 45 min, the originally blue solution turned green and no more starting material **7** could be detected. However, photooxygenation was allowed to proceed for another 20 min. Work-up consisted of removal of the THF by vacuum evaporation with warming at 40°. The green pyridine solution was salted out with solid sodium chloride and then extracted into methylene chloride leaving a blue aqueous layer. The methylene chloride was cross-washed with 2 *N* HCl, water and sodium bicarbonate solution, and saturated sodium chloride and dried with anhydrous sodium sulfate. The methylene chloride extract was filtered and taken to dryness, yielding 482 mg of a crude black tar-like product. The crude product was dissolved in methylene chloride and spotted in a 1-cm wide band, the width of a single preparative silica gel coated tlc plate 20 × 20 cm × 0.5 mm thick. Elution with 10% ethyl acetate–ether gave two bands which were observed on the plate by visual inspection. The R_f of the pure compound **8** on a silica gel coated microscope slide was at least 0.5, eluting with either ether or 10% ethyl acetate–ether (v/v). The plate presented a 3-cm wide black band at the bottom and a 15-cm broad band above this which was light yellow. The entire light yellow band was removed and eluted with acetone from the substrate yielding 266 mg of material. This solid was crystallized from benzene yielding 48 mg of **8**, mp 138–140°, and a second crop of compound **8**: 32 mg; mp 136–140°; 14.2% overall yield; uv (ethanol) end absorption 204 nm (ε 14,600), 223 (6750), 280 (2760); ir (chloroform) 3551 (OH, w), 2970 (br, w), 1705 (C=O, s), 1580 cm^{-1} (m); ir (potassium bromide) 3170 (br, m), 1670 (C=O, s), 1610 (m), 1600 (m), 1500 (m), 1480 (w), 1440 (w), 1395 (m), 1320 (w), 1300 (m), 1270 cm^{-1} (w); nmr (DMSO) (DMSO reference) 6.02–6.12 (m, 1, C-5), 6.23 (d, 1, J_{3-4} = 5.5 Hz, C-3), 7.00–7.78 ppm (m, 7, aromatics, OH and C-4).

Anal. Calcd for $C_{10}H_9O_2N$: C, 68.56; H, 5.18; N, 8.00. Found: C, 68.6; H, 5.2; N, 8.0.

Conversion of 8 to *N*-Phenylmaleimide.—A sample of 28 mg of sublimed 5-hydroxy-1-phenyl-3-pyrrolin-2-one (**8**) (0.16 mmol), mp 144–147°, was mixed with 250 mg of activated manganese dioxide. Then 5 ml of benzene was added and the mixture was refluxed 1 hr with stirring. The mixture was filtered and the solvent was evaporated yielding yellow needles, mp 86–87°. A mixture melting point with *N*-phenylmaleimide was undepressed. Also, the ir spectra of *N*-phenylmaleimide and the isolated product were superimposable.

Hypochlorite–Peroxide Singlet Oxygen Oxygenation of *N*-Phenylpyrrole (7).—A sample of 1.430 g of *N*-phenylpyrrole (**7**) (10 mmol) was dissolved in 35 ml of methanol and 15 ml of *tert*-butyl alcohol. The stirred solution was kept at 15° and then 4 ml of 30% H_2O_2 (35.5 mmol) was added to the reaction mixture. The *N*-phenylpyrrole (**7**) is stable to 30% H_2O_2 solution under these conditions. A total of 50 ml of 0.645 M sodium hypochlorite (32.5 mmol) was added slowly (thus generating 32.2 mmol of O_2 gas) which is a 3.2-fold excess. Work-up yielded 1.373 g of crude product showing a carbonyl band in the ir (1700 cm^{-1}) in chloroform. A small scale column chromatography was performed on the crude product in a 9-in. Pasteur pipet filled with Florisil and eluting with benzene. The crude product was identified as mostly *N*-phenylpyrrole. Column chromatography of 1.287 g of crude product on 40 g of silica gel packed in hexane eluting first with hexane, benzene–hexane, benzene, chloroform, chloroform–ether, and ether yielded 115 mg (6.6%) of material, mp 135°, showing the correct ir of **8**. Also obtained was 288 mg of recovered *N*-phenylpyrrole (**7**). The remaining materials were dark oils and solids of a complex nature. Sublimation of a small amount of material **8** at 0.1 Torr and 115° for 1 hr yielded material, mp 138–140.5°, a slightly yellow product.

Synthesis of 5*H*-Pyrrolo[1,2-*a*][3,1]benzoxazine-1,5(3a*H*)-dione (11).—A solution 500 mg of (1-pyrrolyl)-2-benzoic acid (**10**) (2.67 mmol), mp 106–107°, 10 mg of methylene blue, and 500 ml of methylene chloride was photooxygenated at room temperature as previously described. The reaction was followed by ir. After 45 min, the spectrum displayed a new carbonyl band at 1740 cm^{-1} in chloroform. The split carbonyl band for starting material **10** [1740 (weak), 1695 cm^{-1} (strong)] in chloroform was completely absent. The photooxygenation was terminated after 1 hr and 5 min. The blue reaction solution was evaporated to dryness yielding a green gum. The gum was dissolved in acetone and filtered through a 9-in. Pasteur pipet filled with activity no. II neutral alumina. This procedure removes much of the blue dye and some polar material. The filtrate was chilled and a 97-mg (18%) yield of product **11** was collected, mp 189–193°. A second crop of material was recovered by repeating the process again on the mother liquors and crystallizing a second 59-mg sample of material which had mp 165–166°. Tlc showed the material to be less pure than the 97-mg first crop. A total combined yield of 28.5% was obtained: uv (ethanol) 218 nm (ε 25,400), 242 (7050), 318 (3800); ir (chloroform) 1730 (C=O, s), 1600 (w), 1480 (m), 1460 (w), 1395 (m), 1340 (w), 1165 (w), 1160 (w), 1115 (w), 1075 m), 1043 (w), 1023 (w), 990 (w), 965 (w), 845 cm^{-1} (w); ir (potassium bromide) 3080 (w), 2905 (w), 2840 (w), 1735 (C=O, s), 1600 (m), 1490 (m), 1460 (w), 1395 (m), 1225 (w), 1075 (w), 990 (w), 813 (w), 755 (w) 698 (w), 535 (w), 525 cm^{-1} (w); nmr (dimethyl sulfoxide) (DMSO reference) 6.62 [d, 1, J_{2-3a} = 5 Hz showing apparent (methine) coupling J_{2-3a} < 1 Hz, C-2], 6.68 (s, 1, C-3a), 7.2–8.05 ppm (m, 5, H–$C_{3,6,7,8,9}$). The addition of D_2O did not reveal any exchangeable protons. Material **11** was recrystallized from acetone to afford material softening at 190°, mp 202–205°, to a red liquid.

Anal. Calcd for $C_{11}H_7NO_3$: C, 65.67; H, 3.51; N, 6.96. Found: C, 65.4; H, 3.4; N, 6.8.

Photooxygenation of the Sodium Salt of (1-Pyrrolyl)-2-benzoic Acid (10).—A solution of 500 mg of (1-pyrrolyl)-2-benzoic acid (**10**) (2.66 mmol), 10 mg of eosin dye, 100 ml of THF, 400 ml of distilled water, and 2.6 ml of 1 *N* sodium hydroxide solution was photooxygenated at room temperature in the usual manner. Small portions of solution were withdrawn and acidified with aqueous HCl. The presence of starting material **10** could be followed now by tlc on silica gel coated microscope slides developed in 5% acetic acid–methylene chloride (v/v). After 3 hr, starting material was consumed. The solution was then partially evaporated under vacuum to remove the THF. The aqueous solution remaining was extracted with ethyl acetate in a continuous liquid extractor for 50 hr. The extract was washed with sodium bicarbonate solution, water, and brine, and dried with $MgSO_4$. The solvent was vacuum evaporated, yielding a red tar-like product (107 mg) which was triturated with methanol, at which point 23 mg of product **11** (4.25%) separated. The aqueous

(16) K. Tori, T. Komeno, and T. Nakagawa, *J. Org. Chem.*, **29**, 1137 (1964).

(17) T. Hirata, Y. Yamada, and M. Matsui, *Tetrahedron Lett.*, 4107 (1969).

(18) Commercially available solvents were used as supplied without further purification except as noted. Thin layer chromatograms were performed on silica gel coated microscope slides using iodine to visualize the spots. New compounds were tested for purity by thin layer chromatography in at least two solvents. Melting points were performed on a Fisher–Johns melting point block and are uncorrected. Infrared spectra were recorded on a Perkin-Elmer spectrophotometer Model 137 with sodium chloride optics. Also used was a Perkin-Elmer Model 337 grating spectrophotometer. Nmr spectra were recorded on a Varian Associates Model A-60 or A-60A spectrometer. Spectra were calibrated using tetramethylsilane as internal standard set at δ 0.00 ppm, except where noted, when dimethyl sulfoxide has been used as an internal standard.

layer in the extractor was now acidified to pH 5.5 with 26.6 ml of 0.1 *N* sulfuric acid. The solution was extracted again for 24 hr with ethyl acetate and worked up as above to afford 207 mg of a product which was dissolved in boiling acetone and treated with charcoal and filtered yielding 51 mg (9.5%) of a white product **11**, identified by ir and melting point, softening at 190° and melting at 202–205° to a red liquid.

Synthesis of 3,3a-Dihydro-5*H*-pyrrolo[1,2-*a*][3,1]benzoxazine-1,5(2*H*)-dione (12).—A mixture of 18 mg of 5*H*-pyrrolo[1,2-*a*]-[3,1]benzoxazine-1,5(3a*H*)-dione (**11**), mp 204–206° (0.0895 mmol), dissolved in 25 ml of acetone and 10 mg of 10% palladium on carbon was hydrogenated at atmospheric pressure for 20 min. The catalyst was filtered off yielding a 16-mg (88%) yield of a white solid **12**, mp 206–208°, melting to a clear liquid. The material was crystallized from acetone: mp 206–208°; uv (ethanol) 223 nm (ε 23,000), 248 (8600), 307 (3110); ir (potassium bromide) 2910 (w), 2840 w), 1730 (C=O, s), 1710 C=O, s), 1590 (m), 1480 (s), 1460 (m), 1395 (s), 1240 (m), 1218 (m), 1088 (m), 773 cm^{-1} (m); ir (chloroform) 1730 (C=O, sh, s), 1720 (C=O, s), 1590 (m), 1470 (m), 1460 (m), 1395 (s), 1320 (m), 1290 (m), 1070 (m), 1020 cm^{-1} (w); nmr (dimethyl sulfoxide-d_6) 3.25 (s, 4, $W_{1/2}$ = 1 Hz, CH_2CH_2), 6.02–6.29 (m, 1, C-3a), 7.20–8.13 ppm (m, 4, H-$C_{6,7,8,9}$).

Anal. Calcd for $C_{11}H_9NO_3$: C, 65.02; H, 4.46; N, 6.89. Found: C, 64.9; H, 4.5; N, 6.8.

In a separate experiment, the starting material **11** was allowed to stir in acetone in the presence of the catalyst under an atmosphere of either oxygen or nitrogen. No reaction of the starting material **11** was apparent from observation of the ir of this material for times exceeding the time of the hydrogenation experiment.

Synthesis of 3*H*-Pyrrolo[1,2-*a*]indol-3-one (14).—In a 500-ml gas washing bottle, 500 mg of pure 9*H*-pyrrolo[1,2*a*]indole (**13**) (3.2 mmol) and 10 mg of methylene blue was dissolved in 250 ml of THF, 50 ml of pyridine, and 200 ml of distilled water. The contents of the cylinder were cooled to 0–5° in an ice–water bath. This was photooxygenated as previously described. It proceeded for 1.25 hr and was shown to be completed by the disappearance of the starting material **13** by silica gel tlc, eluting with benzene. This photooxygenation was repeated twice to give 1000 ml of reaction solution. The THF was evaporated under reduced pressure. The aqueous pyridine solution remaining was cooled and extracted with ether (200 ml per extraction) three times. The ether was washed twice with water, then with 2 *N* HCl (200 ml), and then with a solution of aqueous acidified 1 *N* ferrous sulfate. The ether was then washed with water, aqueous sodium bicarbonate, water, and brine. The ether was dried with anhydrous sodium sulfate and then filtered. Five drops of pyridine were added to the etherate which was then evaporated, leaving a crude material which was dark and crystalline. The solid was dissolved in methylene chloride and 5 g of activity no. II neutral alumina was added. The solvent was removed with the vacuum evaporator, leaving the crude product adsorbed on the alumina. Dry column chromatography (on 160 g of no. II neutral alumina eluting with methylene chloride, according to the method of Loev and Goodman)[19] was performed. An intense yellow band moved down the column near the solvent front which, after full development, was 3 in. wide. The rest of the column was quite clear except for green material remaining on the alumina at the top of the column. The R_f value on an alumina coated microscope slide was 0.95. The yellow band was cut out and the product eluted from it with benzene. The benzene solution evaporated to dryness and yielded 793 mg of material **14** (71.5%): mp 86–89°; ir (chloroform) 1718 (C=O, s), 1608 (m), 1575 (m), 1464 (w), 1443 (w), 1383 (m), 1374 (m), 1337 (s), 1328 (s), 1289 (m), 1152 (m), 1068 (m), 963 cm^{-1} (w); uv (ethanol) end absorption 208 nm (ε 30,300), 266 (11,400), 273 (10,300), 355 (10,800); nmr (deuteriochloroform) 5.93 upfield half of AB quartet (d, 1, J_{1-2} = 5.5 Hz, C-2), 6.31 (s, 1, C-9), 6.90–7.45 (m, 4, H-$C_{1,6,7,8}$), 7.6–7.75 ppm (m, 1, C-5). A spin decoupling experiment was performed; irradiation at −1.15 ppm downfield from the doublet centered at δ 5.95 caused it to collapse to a singlet. This demonstrates that C-2 is coupled to C-1. The corollary experiment of irradiating at 5.93 ppm with a spin decoupling field caused an alteration of the aromatic region of the spectrum but did not unequivocally identify C-2. However, the signal for C-2 should be centered at δ 7.08. An analytical sample of **14** was prepared by repeated sublimation at 35° (0.10 Torr) yielding material **14**, mp 94–95°.

Anal. Calcd for $C_{11}H_7NO$: C, 78.09; H, 4.17; N, 8.28. Found: C, 78.1; H, 4.2; N, 8.2.

Synthesis of 14. Photooxygenation in Methylene Chloride.—A solution of 250 mg of 9*H*-pyrrolo[1,2-*a*]indole (**13**) (1.6 mmol), 5 mg of methylene blue, and 250 ml of methylene chloride was photooxygenated at room temperature as described previously. After 1 hr, no more starting material **13** could be detected by tlc. The solution was green. Work-up consisted of washing the methylene chloride solution with water, aqueous sodium carbonate solution, and saturated sodium chloride. The solution was dried with anhydrous magnesium sulfate and evaporated to dryness yielding a green tar-like product. The crude product was column chromatographed on 30 g of silica gel eluting with hexane–benzene, benzene, and chloroform yielding 43 mg (15.8%) of yellow amide **14**, mp <70°. However, tlc showed the material **14** to be quite pure. Comparison of the ir with previously characterized **14** showed it to be of good quality.

A Quenching Experiment.—A mixture of 250 mg of **13** (1.6 mmol) with 10 mg of methylene blue, 0.25 ml of triethylamine, and 250 ml of methylene chloride was charged in the oxygenation apparatus. The mixture was photooxygenated at room temperature for 1 hr. The reaction solution turned green. However, the starting material **13** was not consumed as judged by tlc and its recovery by the usual work-up procedure.

Synthesis of 14. Demonstration of the Necessity of Pyridine.—A solution of 500 mg of **13** (3.2 mmol), 10 mg of methylene blue, 250 ml of water, and 250 ml of commercial THF was photooxygenated between 0–10° as described previously. After 1 hr, no more starting material **13** could be detected by tlc on silica gel. The greenish-blue photooxygenation solution was vacuum evaporated to remove all the THF. Work-up afforded an organic extract showing one spot on tlc plate. The solution was evaporated (Roto-Vac) to dryness at room temperature whereupon it blackened. The ir spectrum of the crude product was different from the spectrum seen in a reaction performed with added pyridine. There was a notable OH band at 3546 cm^{-1}. This product was absorbed on a small amount of silica gel and eluted with benzene to yield a benzene soluble extract of a product which, after solvent evaporation, yielded 444 mg of a black tar-like product. The crude product was worked up by preparative tlc on silica gel using three plates 20 × 20 cm × 0.5 mm thick, eluting with benzene. A recovery of 46 mg of crystalline material was obtained which was sublimed at 90° (0.1 Torr). This produced 31 mg of a yellow solid **14** (5.6%), mp 78–81°, which was crystalline and showed one spot on tlc. When the above experiment was performed a second time, 24 mg of **14** was recovered (4.45%) after sublimation at 90° (0.1 Torr), mp 80–83°.

Synthesis of 14 *via* Hypochlorite–Hydrogen Peroxide Oxygenation.—In a 100-ml three-neck round-bottom reaction flask was placed 775 mg of **13** (5 mmol), 25 ml of DMF, and 3 ml of 30% hydrogen peroxide (18 mmol). The pyrrolo[1,2-*a*]indole (**13**) was shown to be stable to hydrogen peroxide in the cold. In a buret was placed 0.645 M sodium hypochlorite (Clorox) solution. The entire system was sealed and the gases generated were led to a eudiometer. The slow dropwise addition of 10 ml of hypochlorite solution to the mixture generated 5 ml of O_2 (0.225 mmol). After 15 ml of sodium hypochlorite (Clorox) was added, material appeared to crystallize from solution; 10 ml of additional DMF was added to affect resolution of this material. After 25 ml of Clorox (16 ml of O_2 generated) was added, tlc revealed no more **13**.

Work-up yielded 2.005 g of black crude product which was chromatographed on 43 g of Florisil eluting with hexane, hexane–benzene, and chloroform. After combining fractions with the appropriate carbonyl band (1718 cm^{-1}) and sublimation at 30–35° (0.1 Torr), 18 mg of yellow product (**14**), mp 75–81 (2.14%), was recovered.

Synthesis of 14. Singlet Oxygen Generated *via* the Thermal Decomposition of 9,10-Diphenylanthracene *endo*-Peroxide.—In a 50-ml reaction flask was placed 155 mg of **13** (1 mmol), 724 mg of 9,10-DPA-O_2 (2 mmol), and 15 ml of benzene. The solution was kept under nitrogen and refluxed for 71 hr. The reaction was followed by tlc and ir. After 25 hr, a carbonyl band appeared in the ir. The reaction mixture was evaporated to dryness and column chromatographed on 30 g of silica gel. The column was eluted with benzene yielding 26 mg of amide which, after sublimation, yielded 18 mg of pure amide **14**, mp 90–91° (10.6%).

Synthesis of 1,2-Dihydro-3*H*-pyrrolo[1,2-*a*]indol-3-one (17).—A mixture of 169 mg of 3*H*-pyrrolo[1,2-*a*]indol-3-one (**14**) (1 mmol), mp 90–93°, dissolved in 25 ml of absolute ethanol, and 40 mg of 10% palladium on carbon was hydrogenated at room temperature

and atmospheric pressure for 1 hr. The reaction mixture was then filtered yielding 156 mg (92%) of a white crystalline solid **17**, mp 150–151°, melting to a clear liqud. The material was recrystallized from methanol, mp 153–154°, and showed one spot on tlc: ir (chloroform) 1730 (C=O, s), 1570 (w), 1440 (m), 1380 (s), 1340 (m), 1310 (m), 1290 cm^{-1} (m); ir (potassium bromide) 2960 (w), 2940 (w), 2845 (w), 1735 (C=O, s), 1580 (m), 1470 (m), 1452 (s), 1390 (s), 1370 (m), 1330 (m), 1315 (m), 1290 (m), 1172 (m), 1158 (m), 1109 (m), 1055 (m), 820 (m), 785 (m), 760 (s), 750 cm^{-1} (m); uv (absolute ethanol) 238 nm (ϵ 25,400), 258 sh (11,900), 293 (2550), 300 (2350); nmr (deuteriochloroform) 3.02 (s, 4, CH_2CH_2), 6.29 (b s, 1, $W_{1/2}$ = 3 Hz, C-9), 7.23–7.70 (m, 3, H–$C_{6,7,8}$), 8.05–8.30 ppm (m, 1, C-5).

Anal. Calcd for $C_{11}H_9NO$: C, 77.17; H, 5.30; N, 8.18. Found: C, 77.4; H, 5.3; H, 8.1.

Synthesis of 1-Benzyl-3a,10b-dihydro-*v*-triazolo[4′,5:3,4]pyrrolo[1,2-*a*]indol-4(1*H*)-one (21b).—In a 100-ml round-bottom reaction flask fitted with a water-cooled condenser was placed 349 mg of 3*H*-pyrrolo[1,2-*a*]indol-3-one (**14**) (2.06 mmol), mp 93–94°, 700 mg of benzyl azide (5.25 mmol), and 4 ml of benzene. The reaction was stirred under a nitrogen atmosphere at reflux temperature. After 24 hr, a precipitate was noted and an additional 1 ml of benzene was added. After 60 hr, the reaction was terminated and cooled, and hexane was added to the dark crude mixture. Additional precipitate formed. The mixture was filtered yielding a dark product. The product was crystallized twice from benzene yielding 331 mg (53.5%) of a crystalline white solid (**21b**) decomposing at 184–186° with apparent gas evolution, and then the material turned to a red liquid on the melting point block. The pure material **21b** showed one spot on a tlc plate: uv (ethanol) 217 nm (ϵ 26,600), 265 (9900), 290 sh (5200); ir (chloroform) 1748 (C=O, s), 1595 (w), 1445 (m), 1380 (m), 1351 (m), 1320 (m), 1166 (w), 1060 cm^{-1} (m); nmr (dimethyl sulfoxide) (DMSO reference) first half of AB quartet 4.91 (d, 1, J_{AB} = 16 Hz, benzyl CH_2), second half of AB quartet 5.08 (d, 1, J_{AB} = 16 Hz, benzyl CH_2), 5.05 (d, 1, J_{10b-3a} = 10 Hz showing additional apparent coupling $J_{10-10b} < 1$ Hz, C-10b), 5.98 (d, 1, J_{10b-3a} = 10 Hz, C-3a), 6.47 (b s, 1, $W_{1/2}$ = 2 Hz, $J_{10-10b} < 1$ Hz), 7.25–7.73 (m, 8, H–$C_{7,8,9}$ + 5 phenyl protons), 7.45 (b s, 5 phenyl protons), 7.85–8.05 ppm (m, 1, C-6). The analytical sample, prepared *via* benzene recrystallization, consisted of white needles which turn red at 175° and decomposed at 185° with apparent gas evolution.

Anal. Calcd for $C_{18}H_{14}N_4O$: C, 71.51; H, 4.67; N, 18.53. Found: C, 71.4; H, 4.8; N, 18.5.

Synthesis of 1-Phenyl-3a,10b-dihydro-*v*-triazolo[4′5′:3,4]pyrrolo[1,2-*a*]indol-4(1*H*)-one (21a).—In a 50-ml round-bottom flask under a nitrogen atmosphere was placed 507 mg of **14** (3 mmol), 714 mg of phenyl azide (6 mmol), and 5 ml of acetone. The stirred reaction mixture was kept at reflux for 24 hr. An ir spectrum indicated only small conversion to the triazoline **21a**. The solvent was blown off with a nitrogen stream, and then an additional 714 mg of phenyl azide (6 mmol) was added plus 1 ml of acetone. The mixture was held at 65–70° for an additional 12 hr and a precipitate was formed. The reaction mixture was evaporated under vacuum to dryness and washed with small portions of benzene, yielding 484 mg (56% yield) of slightly tan solid decomposing at 171–175° with apparent gas evolution and turning to red liquid. The material was recrystallized from THF–hexane yielding 464 mg (53.8%) of **21a**. In a separate experiment, 500 mg (2.96 mmol) of 3*H*-pyrrolo[1,2-*a*]indol-3-one (**14**) was mixed with 1.5 g of phenyl azide (13.4 mmol) and 1 ml of benzene, stirred under nitrogen between 70 and 75° for 24 hr yielding 871 mg (68% yield) of the phenyl triazolone **21a** crystallized from THF–hexane (we thank Mr. Robert Kempton for this result): uv (ethanol) end absorption 207 nm (ϵ 24,600), 238 (24,600), 290 (8800); ir (chloroform) 1745 (C=O, s), 1590 (m), 1440 (m), 1380 (s), 1340 (m), 1320 (m), 1170 (w), 1120 (w), 1055 cm^{-1} (m); ir (potassium bromide) 1740 cm^{-1} (C=O, s); nmr (deuteriochloroform) 5.63 and 6.02 (AB quartet, J_{10b-3a} = 10 Hz, C-10b, C-3a), 6.64 (b s, 1, $W_{1/2}$ = 2 Hz, C-10 showing apparent additional coupling to C-10b), 7.3–7.65 (m, 8, 5 phenyl protons +H–$C_{7,8,9}$), 7.5 (s, 5, phenyl protons of *N*-phenylaziridine), 8.0–8.33 ppm (m, 1, unique aromatic proton C-6). An analytical sample of **21a** was prepared by crystallizing from chloroform yielding a white solid which decomposed at 173–175° with apparent gas evolution.

Anal. Calcd for $C_{17}H_{12}N_4O$: C, 70.82; H, 4.20; N, 19.43. Found: C, 70.8; H, 4.3; N, 19.5.

Synthesis of 1a,8b-Dihydro-1-phenylazirino[2′,3′:3,4]pyrrolo-[1,2-*a*]indol-2(1*H*)-one (22).—In a 500-ml photochemical reaction vessel was placed 50 mg of 1-phenyl-3a,10b-dihydro-*v*-triazolo[4′,5′:3,4]pyrrolo[1,2-*a*]indol-4(1*H*)-one (0.174 mmol) and 300 ml of benzene. With a water-cooled immersion well inserted into the reaction vessel, the solution was purged with nitrogen gas for 10 min and the vessel was covered in the back with reflective foil. The stirred solution was irradiated (with a Sears Roebuck sun lamp no. 7081 held 1 in. from the reaction vessel) through two thicknesses of plate glass for 15 min. The solution color changed from clear to slight yellow. The solution was evaporated to dryness yielding a slightly yellow solid crude product **22**, mp 126–128°. The crude reaction mixture appeared to be quite pure by ir and tlc. The material was dissolved in benzene and filtered rapidly through a 9-in. Pasteur pipet packed with activity grade no. II neutral alumina to remove polar impurities, recovering after solvent removal 45 mg of material **22** (99.5%), which was crystallized from cyclohexane, mp 133–135°, to yield a white solid exhibiting one spot on tlc: ir (potassium bromide) 1739 cm^{-1} (C=O, s); ir (chloroform) 1739 (C=O, s), 1592 (m), 1445 (m), 1374 (m), 1318 (m), 1152 (w), 1075 (w), 1052 cm^{-1} (w); uv (ethanol) end absorption 206 nm (ϵ 22,000), 250 (22,000), 305 (5300); nmr (deuteriochloroform) 3.82, 4.02 (AB quartet, J_{8b-1a} = 3.7 Hz, C-8b, C-1a), 6.64 (s, 1, $W_{1/2}$ = 1.5 Hz, C-8), 6.95–7.61 (m, 8, H–$C_{-5,6,7}$ + 5 phenyl protons), 7.75–8.0 ppm (m, 1, C-4); *m/e* 260 (molecular ion), 232 (M − CO), 169 (M − PhN<), 155 (M − PhNCH + H), 129 (?), 115 [M − Ph(C_3H_4N)C=O]. An analytical sample was obtained from material recrystallized from cyclohexane, mp 136–137°.[19]

Anal. Calcd for $C_{17}H_{12}N_2O$: C, 78.44; H, 4.65; N, 10.76. Found: C, 78.6; H, 4.8; N, 10.7.

Photolysis of Triazoline 21b.—In a quartz well photolysis apparatus with a water-cooled outer jacket was placed 100 mg of benzyltriazoline **21b** and 300 mg of benzene solvent. The benzene solution was purged for 15 min with dry N_2 gas. Photolysis of the stirred solution with a Hanovia No. 608A high-pressure mercury arc lamp (140 W) using a 2 mm 2800A cut-off filter proceeded for 85 min. Work-up of the reaction consisted of evaporation of the solvent *in vacuo* followed by preparative tlc using 10% ether chloroform as eluent. Two crystalline materials were isolated: 2 mg of material whose ir suggested it to be an imine, and 30 mg of starting benzyltriazoline **21b**. The remaining material on the plate was very complex in nature.

Registry No.—**8**, 26709-62-6; **11**, 26697-46-1; **12**, 26709-63-7; **14**, 24009-76-5; **17**, 26709-65-9; **21a**, 24009-77-6; **21b**, 26709-66-0; **22**, 24009-78-7.

(19) We thank Dr. Van Lear of Lederle Laboratories for the mass spectrum.