

ponent has been observed in the c.d. spectra (5). For the *R*-pn complexes studied here, the component bands overlap quite strongly and hence assignment to individual transitions is difficult.

### Experimental

*R*-1,2-Propanediamine dihydrochloride was obtained from Frinton Laboratories, Vineland, N.J. ( $[\alpha]_{589} = -34^\circ$  for the free base.) Solutions used in the study were approximately  $3 \times 10^{-2} M$  in copper(II) ion and were prepared as indicated in the text.

Circular dichroism spectra were obtained using a Durrum-Jasco Model ORD/UV-5 recording spectropolarimeter with c.d. attachment. Absorption spectra were determined on a Beckman-DK-1 recording spectrophotometer.

Measurements of *pH* were carried out using a Sargent Model DR *pH* meter equipped with a combination glass-calomel electrode.

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## Reaction of *N*-Acetyl-2,3-diphenylindole with Nitric Acid

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Based on spectroscopic and chemical evidence the 3-hydroxy-6-nitro-2,3-diphenylindolenine structure **8** is assigned to the previously reported *N*-acetyl-2,3-diphenylindole-nitric acid reaction product. The product from the acid-catalyzed rearrangement of **8** is assigned the oxindole structure **12**.

Par des preuves spectrales et chimiques, la structure **8** a été identifiée à l'hydroxy-3 nitro-6 diphenyl-2,3 indolénine, produit issu de la réaction entre le *N*-acétyl diphenyl-2,3 indole et l'acide nitrique. La structure oxindole **12** a été attribuée au produit issu du réarrangement acidocatalysé de **8**.

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In a systematic study of the nitration of indoles, spanning a period of 35 years, Plant and his coworkers treated several indolic compounds with nitric acid (1). One such reaction between *N*-acetyl-2,3-diphenylindole (**1**) and nitric acid in acetic acid yielded a colorless compound, m.p.  $262^\circ$  (dec.), to which Fennell and Plant assigned the phenanthrene nitro alcohol structure **2** (2). There are two characteristic features of **2** which argue against it being the nitration product: an unusual oxidative coupling of the phenyl rings in the 2- and 3-positions, and remarkable stability of the carbinolamine moiety in **2** under the acid conditions used. In view of the doubtful structural assignment for the nitration product, the reaction was reinvestigated.

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When the reaction was carried out according to the published procedure there was indeed obtained a colorless compound, m.p.  $250^\circ$  (dec.), whose i.r. spectrum showed the presence of N—H and/or O—H and nitro group absorption. Mass spectrometry gave the molecular ion peak at 330, confirming Fennell and Plant's molecular formula. However, the u.v. spectrum lacked the absorption due to a dihydrophenanthrene chromophore (3). Since spectroscopic information was not sufficient to establish the structure,<sup>2</sup> chemical means were resorted to.

On treating the nitration product with *m*-chloroperbenzoic acid (*m*-CPBA) there was obtained a lemon yellow compound, m.p.

<sup>2</sup> Insolubility problems made it difficult to get a good integration of the n.m.r. spectrum and no exchangeable protons were apparent.

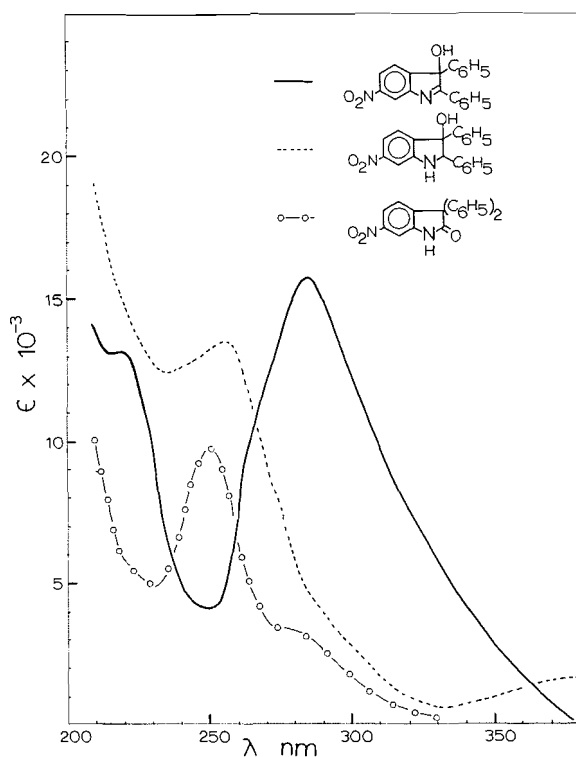


FIG. 1. The u.v. spectra of the nitro alcohol, its reduction product, and its rearrangement product.

192°, whose i.r. spectrum showed the presence of two carbonyl groups, one of which was likely due to an amide, suggesting possible cleavage of a double bond in the pyrrole ring during the peracid reaction. A literature search revealed that the two known nitro indoles **3** and **4** on oxidation gave the ring cleavage products **5** and **6** which were also yellow and had melting points close to that of the lemon yellow compound described above (4, 5).<sup>3</sup> Comparison of the lemon yellow compound from the peracid reaction on the nitration product with authentic samples (Scheme 1) of **5** (**4**) and **6** (**5**) showed it to be identical with **5**. The peracid reaction thus proved the presence of an indole or indolenine double bond and established that the nitro group was in the 6-position.

It was tempting to assume that the nitration product was *N*-hydroxy-6-nitro-2,3-diphenylindole (**7**). However, this possibility was dis-

<sup>3</sup>Compounds formed by the double bond cleavage of 4- and 5-nitro-2,3-diphenylindole are colorless (**4**).

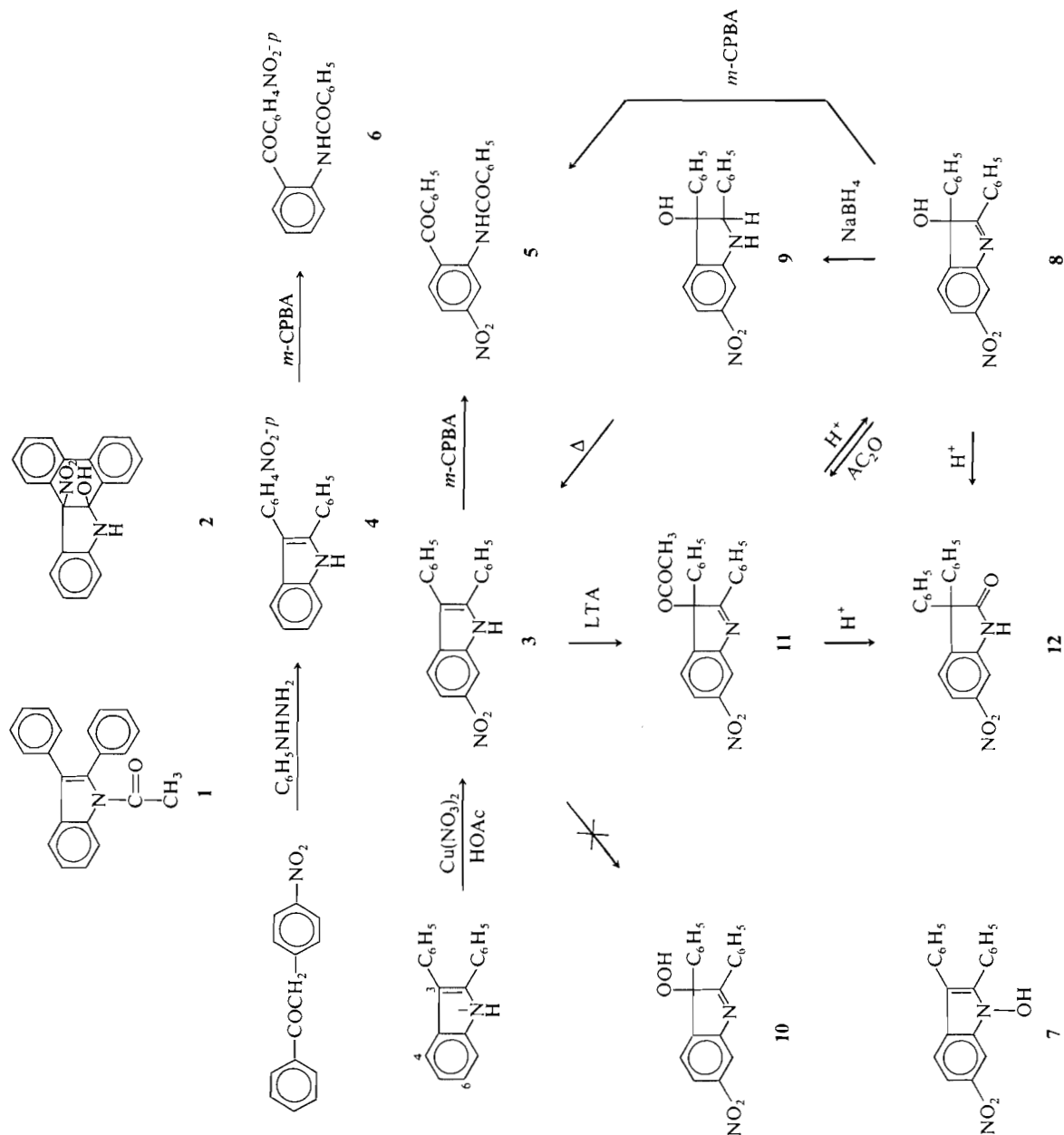
counted for the following reasons: (a) since 6-nitro-2,3-diphenylindole is orange in color, the *N*-hydroxy derivative would be expected to be colored, while the nitration product is colorless; (b) the compound did not give a positive ferric chloride test (8, 9), and (c) it lacked the characteristic bathochromic shift for *N*-hydroxy indoles in its u.v. spectrum in the presence of base (9).

The only structure left which could account for the available information was 3-hydroxy-6-nitro-2,3-diphenylindolenine (**8**). Support for this structure was provided by the following two observations. Firstly, sodium borohydride reduction of the carbon—nitrogen double bond in **8** gave the hydroxyindoline **9** as an orange-red solid.<sup>4</sup> The n.m.r. spectrum of this compound showed the presence of a methine proton at  $\delta$  5.1 and the i.r. spectrum showed absorption at 3340 and 3510  $\text{cm}^{-1}$  due to NH and OH. The dihydro compound **9** on heating above the melting point gave 6-nitro-2,3-diphenylindole (**3**) as the only product. Secondly, reaction of the "nitro alcohol" with acetic anhydride in pyridine gave a colorless *O*-acetate. The u.v. spectrum of this compound was identical with that of the nitration product and hence the acetate was tentatively assigned the nitroacetoxyindolenine structure **11**.

Attempts to prepare the hydroperoxide **10** from the nitro indole **3** for reduction to **8** were unsuccessful. However, Taylor and his co-workers had treated several indole alkaloids with lead tetraacetate in methylene chloride to obtain 3-acetoxyindolenines (**10**). This reaction on 6-nitro-2,3-diphenylindole (**3**) gave a colorless compound which was identical with the *O*-acetate obtained from the nitro alcohol—acetic anhydride reaction, thus establishing the 3-acetoxyindolenine structure **11** for the latter and the 3-hydroxy-6-nitro-2,3-diphenylindolenine structure (**8**) for the nitration product.

Fennell and Plant had treated their nitration product with refluxing acetic acid and obtained an isomeric red compound, m.p. 227°, to which no structure was assigned. Repetition of the reaction gave a red-orange compound, m.p. 227–229°, whose i.r. spectrum showed the presence of a carbonyl group at 1720  $\text{cm}^{-1}$ . Mass spectrom-

<sup>4</sup>The orange-red color of this dihydro compound is not surprising, since *N*-methyl and *N*-ethyl-*m*-nitroaniline are reddish-yellow in color.



SCHEME 1

etry gave the molecular ion peak at 330, corresponding to Fennell and Plant's molecular formula. Treatment of 3-acetoxy-6-nitro-2,3-diphenylindolenine (**11**) with hydrochloric acid, Taylor's general method for preparation of oxindole alkaloids (10), gave the same red compound which is therefore 3,3-diphenyl-6-nitrooxindole (**12**). From the acid reaction on 3-acetoxyindolenine **11** there was also obtained, albeit in only 3% yield, Fennell and Plant's nitration product **8**, presumably by acid hydrolysis of the acetate group, confirming the 3-hydroxyindolenine structure **8** for the nitration product.

Formation of 3-hydroxy-6-nitro-2,3-diphenylindolenine (**8**) under the nitration conditions used is understandable. The initial product of the reaction probably is 3,6-dinitro-2,3-diphenylindolenine which on hydrolysis in aqueous acid would give the 3-hydroxyindolenine **8**.<sup>5</sup> One possible mechanism (13) for the peracid reaction of indolenine **8** would involve formation of an oxaziridine followed by cleavage to give **5**.

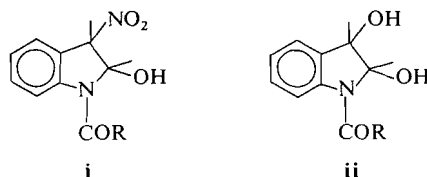
In view of the present findings, the structures of products from other reactions between nitric acid and *N*-acetyl-2,3-diphenylindole under different conditions for which the basic phenanthrene skeleton have been assumed (2) should be considered suspect.

### Experimental<sup>6</sup>

#### Reaction of *N*-Acetyl-2,3-diphenylindole with Nitric Acid

The reaction was carried out by the method of Fennell and Plant (2) to give the nitro alcohol **8** as colorless needles

<sup>5</sup>Precedent for such ready hydrolysis of a C-nitro group is known from the work of Plant (11) and Taylor (12) who treated *N*-acetyl and *N*-benzoyl-2,3-dimethylindole with nitric acid and isolated what was presumably the nitro alcohol **i** which on hydrolysis gave the diol **ii**.



<sup>6</sup>For general experimental methods see ref. 14. Unless otherwise stated i.r. spectra were taken with chloroform solutions, u.v. spectra with methanol, and n.m.r. spectra with deuteriochloroform solutions containing tetramethylsilane as internal standard.

(23%), m.p. 250° (dec., sealed capillary) (lit. (2) 262° (dec.));  $\nu_{\max}$  (Nujol) 3100 (OH) and 1500  $\text{cm}^{-1}$  ( $\text{NO}_2$ );  $\nu_{\max}$  (THF) 3280 (OH) and 1520  $\text{cm}^{-1}$  ( $\text{NO}_2$ );  $\lambda_{\max}$  220 (12 900) and 285 nm (15 600);  $m/e$  330 (molecular ion).

Anal. Calcd. for  $\text{C}_{20}\text{H}_{14}\text{N}_2\text{O}_3$  (330.3): C, 72.72; H, 4.27; N, 8.48. Found: C, 72.62; H, 4.42; N, 8.05.

#### Reaction of Nitro Alcohol **8** with Peracid

To a stirred solution of nitro alcohol **8** (100 mg) in chloroform (40 ml) was added a solution of *m*-chloroperbenzoic acid (200 mg) in chloroform (2.0 ml). After the pale yellow solution was stirred for 1 h at room temperature, it was first washed with 10% aqueous  $\text{Na}_2\text{SO}_3$  and then with 5%  $\text{NaHCO}_3$  solution. The organic layer was washed to neutrality, dried, and concentrated giving a yellow solid. Three recrystallizations from chloroform-petroleum ether gave lemon-yellow needles of **5** (70 mg), m.p. 190–192°;  $\nu_{\max}$  3310 (NH), 1680, 1640 ( $\text{C}=\text{O}$ ), and 1530  $\text{cm}^{-1}$  ( $\text{NO}_2$ );  $\lambda_{\max}$  255 (10 100) and 272 nm (8900);  $m/e$  346 (molecular ion).

Anal. Calcd. for  $\text{C}_{20}\text{H}_{14}\text{N}_2\text{O}_4$  (346.3): C, 69.36; H, 4.07; N, 8.09. Found: C, 69.35; H, 4.03; N, 7.44.

The compound was identical in all respects with the authentic sample of the keto amide **5** (see below).

#### Reaction of 6-Nitro-2,3-diphenylindole (**3**) with Peracid

To a stirred solution of 6-nitro-2,3-diphenylindole (**5**) (50 mg) in chloroform (4.0 ml) was added a solution of *m*-chloroperbenzoic acid (100 mg) in chloroform (0.5 ml). After the pale yellow solution was stirred at room temperature for 0.5 h, it was worked-up as above to give a yellow solid (52 mg). Two recrystallizations from chloroform-petroleum ether gave the keto amide **5** as lemon-yellow needles (42 mg), m.p. 190–192° (lit. (4) 192–193°).

#### Reaction of 2-Phenyl-3-(4'-nitrophenyl)indole (**4**) with Peracid

A solution of the nitroindole **4** (**5**, **6**) (30 mg), *m*-chloroperbenzoic acid (60 mg), and chloroform (5.0 ml) was refluxed for 0.5 h. After cooling, the solution was worked-up as above giving a yellow solid. Three recrystallizations from chloroform-petroleum ether gave the keto amide **6** as yellow needles (26 mg), m.p. 185–188° (lit. (5) 187–189°). The mixed m.p. of this compound with the nitro alcohol-peracid product **5** was depressed to 163–185° and the two compounds had different  $R_f$  on t.l.c.;  $\nu_{\max}$  3280 (NH), 1670, 1630 ( $\text{C}=\text{O}$ ), and 1500  $\text{cm}^{-1}$  ( $\text{NO}_2$ );  $\lambda_{\max}$  257 (5500) and 272 nm (4500);  $m/e$  346 (molecular ion).

#### Reaction of the Nitro Alcohol **8** with Sodium Borohydride

To a stirred colorless solution of the nitro alcohol (100 mg) in methanol (2.5 ml) and tetrahydrofuran (2.5 ml) was added sodium borohydride (200 mg) over a period of 5 min. The solution which immediately became yellow-orange was stirred at room temperature for 20 min, diluted with ether, washed with water, dried, and concentrated to give an orange colored solid (98 mg). The crude material was put on a silica gel preparative layer plate and developed with benzene-ether (90:10). The orange band at  $R_f$  0.48 gave an orange-red solid (86 mg). Two recrystallizations from chloroform-petroleum ether gave the hydroxyindoline **9** as reddish-orange plates (64 mg), m.p. 158–204° (dec.)

(see below);  $\nu_{\max}$  3510 and 3340  $\text{cm}^{-1}$  (NH and OH);  $\lambda_{\max}$  255 (13 570) and 385 nm (1590);  $\delta$  5.1 (1H, N—CHPh); highest peak in the mass spectrum was at 314 corresponding to 6-nitro-2,3-diphenylindole.

Anal. Calcd. for  $\text{C}_{20}\text{H}_{16}\text{N}_2\text{O}_3$  (332.4): C, 72.28; H, 4.85; N, 8.43. Found: C, 72.48; H, 4.71; N, 7.78.

The sodium borohydride product (15 mg) was sealed in a glass tube and heated at 180° for 2 h. After cooling, the material was recrystallized twice from chloroform–methanol–petroleum ether giving orange crystals (9 mg), m.p. 229–231°, identical in all respects with the authentic sample of 6-nitro-2,3-diphenylindole (3).

#### Reaction of 6-Nitro-2,3-diphenylindole with Lead Tetraacetate

The method of Taylor *et al.* (10) was slightly modified. To a refluxing solution of 6-nitro-2,3-diphenylindole (106 mg) in methylene chloride (10 ml) was added lead tetraacetate (270 mg). After the solution was refluxed for 3.5 h, it was cooled, filtered, and concentrated to give an oily solid. The material was put on two alumina preparative layer plates and developed with benzene–ether (87:13). The band at  $R_f$  0.41 gave a colorless solid (83 mg). Three recrystallizations from chloroform–petroleum ether gave the nitro acetoxyindolenine **11** as a colorless solid (60 mg), m.p. 210° (dec.);  $\nu_{\max}$  1770 (sh), 1755 (—CO), and 1520  $\text{cm}^{-1}$  ( $\text{NO}_2$ );  $\lambda_{\max}$  285 nm (20 100);  $m/e$  372 (molecular ion).

Anal. Calcd. for  $\text{C}_{22}\text{H}_{16}\text{N}_2\text{O}_4$  (372.4): C, 70.96; H, 4.33; N, 7.52. Found: C, 70.39; H, 4.18; N, 6.87.

The faintly yellow band from the above plates at  $R_f$  0.70 gave a pale yellow oil (18 mg) which failed to crystallize and was not further investigated.

#### Reaction of Nitro Alcohol 8 with Acetic Anhydride

A solution of nitro alcohol **8** (40 mg), pyridine (1.0 ml), and acetic anhydride (0.5 ml) was stirred at room temperature for 12 days. After the addition of chloroform, the reaction mixture was washed first with water and then with 5%  $\text{NaHCO}_3$  solution. The organic layer was washed, dried, and concentrated giving a faintly yellow solid. Two recrystallizations from chloroform–petroleum ether gave the acetoxy compound **11** as colorless crystals (29 mg), identical in all respects with the authentic sample of 6-nitro-3-acetoxy-2,3-diphenylindolenine (**11**).

#### Reaction of the Nitro Alcohol 8 with Acetic Acid

The reaction was carried out in essentially the same way as reported by Fennell and Plant (2). The crude product was recrystallized from methanol–petroleum ether to give orange-red needles, m.p. 227–230° (lit. (2) 227°);  $\nu_{\max}$  3410 (NH), 1720, 1700 (sh) (—C=O), and 1510  $\text{cm}^{-1}$  ( $\text{NO}_2$ );  $\lambda_{\max}$  250 (9700), 280 (3200), and 460 nm (860);  $m/e$  330 (molecular ion). This compound was identical in all respects with the authentic sample of 3,3-diphenyl-6-nitrooxindole (see below).

#### Reaction of 3-Acetoxy-6-nitro-2,3-diphenylindolenine (**11**) with Hydrochloric Acid

The method of Taylor and his coworkers (10) was used. To the refluxing solution of 6-nitro-3-acetoxy-2,3-diphenylindolenine (**11**) (50 mg) in methanol (10 ml) and chloroform (5 ml) was added concentrated HCl (0.5 ml). After the solution was refluxed for 13 h, the solvents were evaporated on the rotary evaporator. The residual orange solid was dissolved in chloroform and washed with water. The organic layer was dried and concentrated to give an orange solid (51 mg). The material was put on a silica gel preparative plate and developed with benzene–ether (95:5). The band at  $R_f$  0.77 gave an orange solid (27 mg). Two recrystallizations from chloroform–petroleum ether gave 3,3-diphenyl-6-nitrooxindole (**12**) as orange-red needles (12 mg), m.p. 228–230°.

The band at  $R_f$  0.42 gave a colorless compound (8 mg). Two recrystallizations from acetone–petroleum ether gave colorless needles (1.5 mg) identical in all respects with the nitro alcohol **8**.

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