tallizing in colorless leaflets, m.p. 39°, from aqueous methanol.

Anal. Calcd. for $C_{13}H_{15}N$: C, 84.3; H, 8.2. Found: C, 84.2; H, 8.1.

1-Phenyl-2,3,5-trimethylpyrrole-4-aldehyde (VIII) was prepared in a manner analogous to the lower homolog of the foregoing pyrrole (VI) from 11.5 g. of the foregoing pyrrole, 6.8 g. of dimethylformamide, and 14.5 g. of phosphorus oxychloride in 100 ml. of dry toluene; yield: 11 g. (83.3%) of an aldehyde, crystallizing from methanol in long colorless needles, m.p. 134°.

Anal. Calcd. for $C_{14}H_{15}NO$: C, 78.8; H, 7.1; N, 6.6. Found: C, 78.8; H, 7.1; N, 6.6.

The *semicarbazone* crystallized from ethanol in shiny colorless prisms, m.p. 273°.

Anal. Calcd. for $C_{15}H_{18}N_4O$: N, 20.7. Found: N, 20.7.

1-Phenyl-2,3,4,5-tetramethylpyrrole (X) was prepared in the usual way from 5 g. of the foregoing aldehyde (VIII), 1.7 g. of hydrazine hydrate, and 2 g. of potassium hydroxide. This compound (3.5 g., 70%) was a colorless oil, b.p. 142°/12 mm., which darkened rapidly on exposure to air and light. The same compound was obtained by reduction of dialdehyde V.

Anal. Calcd. for $C_{14}H_{17}N$: C, 84.4; H, 8.6. Found: C, 84.1; H, 8.6.

1,2-Diphenyl-5-methylpyrrole-4-aldehyde (IV) was prepared from 15 g. of 1,2-diphenyl-5-methylpyrrole, 7 g. of dimethylformamide, and 15 g. of phosphorus oxychloride in 150 ml. of dry toluene. Yield: 16.5 g. (98%) of an aldehyde, b.p. 241–242°/13 mm., crystallizing in colorless prisms, m.p. 115–116°, from ethanol. No dialdehyde could be isolated in this reaction.

Anal. Calcd. for $C_{18}H_{15}NO$: C, 82.7; H, 5.8. Found: C, 82.8; H, 5.8.

The *oxime* crystallized from ethanol in fine colorless prisms, m.p. 198°.

Anal. Calcd. for $C_{18}H_{16}N_2O$: N, 10.1. Found: N, 10.1.

The *phenylhydrazone* crystallized from ethanol in silky colorless needles, m.p. 180°.

Anal. Calcd. for $C_{24}H_{21}N_3$: C, 81.8; H, 6.0; N, 12.0. Found: C, 81.7; H, 6.1; N, 12.2.

1,2-Diphenyl-4,5-dimethylpyrrole (VII) was prepared from 10 g. of the foregoing aldehyde (IV), 2.8 g. of hydrazine hydrate, and 3 g. of potassium hydroxide in 100 ml. of diethylene glycol. Yield: 8.2 g. (87%) of a product, b.p. 195°/12 mm., crystallizing from ethanol in colorless prisms, m.p. 79°, giving no coloration with sulfuric acid.

Anal. Calcd. for $C_{18}H_{17}N$: C, 87.4; H, 6.9. Found: C, 87.3; H, 6.9.

1,2-Diphenyl-4,5-dimethylpyrrole-3-aldehyde (IX). When the usual formylation technique was applied to the foregoing pyrrole (VII), no aldehyde was obtained, even after 30 hours' heating. The following procedure, however, furnished the expected aldehyde, in good yield. To a mixture of 5.5 g. of pyrrole VII and 2.4 g. of dimethylformamide, 4 g. of phosphorus oxychloride was added in small portions, and the sticky dark violet mass obtained was heated for 10 hr. on a water bath. After cooling, a 15% aqueous solution of sodium hydroxide was added, and the reaction product worked up in the usual way. Yield: 4.7 g. (77%) of an aldehyde, b.p. 254°/17 mm., crystallizing from cyclohexane in colorless, rhombohedric prisms, m.p. 200°.

Anal. Calcd. for $C_{19}H_{17}NO$: C, 82.9; H, 6.2; O, 5.8. Found: C, 82.9; H, 6.2; O, 5.8.

The *oxime* crystallized from ethanol in shiny colorless prisms, m.p. 238–239°.

Anal. Calcd. for $C_{19}H_{18}N_2O$: N, 9.7. Found: N, 9.7.

1,2-Diphenyl-3,4,5-trimethylpyrrole (XI) was prepared from 6 g. of the foregoing aldehyde (IX), 1.4 g. of hydrazine hydrate, and 1.4 g. of potassium hydroxide in 50 ml. of diethylene glycol. Yield: 4 g. (70%) of a compound crystallizing in shiny colorless needles, m.p. 121°, from cyclohexane or acetic acid.

Anal. Calcd. for $C_{19}H_{19}N$: C, 87.3; H, 7.3. Found: C, 87.3; H, 7.2.

α-Phenyl-β-(1-phenyl-2,5-dimethyl-3-pyrryl)acrylonitrile (XII). A solution of aldehyde III (1 mole) and benzyl cyanide (1 mole) in ethanol was refluxed for 5 min. with a few drops of aqueous sodium hydroxide (5*N*). The precipitate formed on cooling and diluting with water, was washed with water and recrystallized from ethanol, giving silky yellowish needles, m.p. 139°. Yield: 70%. Under the same experimental conditions, no condensation products were obtained with aldehydes VIII and IX.

Anal. Calcd. for $C_{21}H_{17}N_2$: N, 9.4. Found: N, 9.5.

α-Phenyl-β-(1,2-diphenyl-5-methyl-4-pyrryl)acrylonitrile (XIII). Similarly prepared from aldehyde IV and benzyl cyanide, this nitrile crystallized from ethanol in silky yellowish needles, m.p. 145°.

Anal. Calcd. for $C_{26}H_{20}N_2$: N, 7.8. Found: N, 8.1.

bis-*Acrylonitrile* (XIV). This compound, prepared from 1 mole of dialdehyde V with 2 moles of benzyl cyanide, crystallized from ethanol in pale yellow needles, m.p. 171°.

Anal. Calcd. for $C_{30}H_{23}N_3$: N, 9.9. Found: N, 9.9.

PARIS VE, FRANCE

[CONTRIBUTION FROM THE RESEARCH DIVISION, AMERICAN CYANAMID CO., BOUND BROOK LABORATORIES]

Reactions of 2,3-Dichloro-1,4-naphthoquinone with 2-Aminopyridine and Related Amines[1]

WILLIAM L. MOSBY AND RICHARD J. BOYLE

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2,3-Dichloro-1,4-naphthoquinone reacts with 2-aminopyridine to yield a 1:1 and a 1:2 condensation product. The former is shown to have structure I, and the latter is believed to have structure X. Various substitution products of I are described, as are several analogous quinones derived from other heterocyclic amines.

During the preparation of a number of naphtho-[2,3-*b*]pyrrocolinediones *via* the convenient synthesis elaborated by Pratt *et al.*,[2,3] we became interested in the nature of the products which might

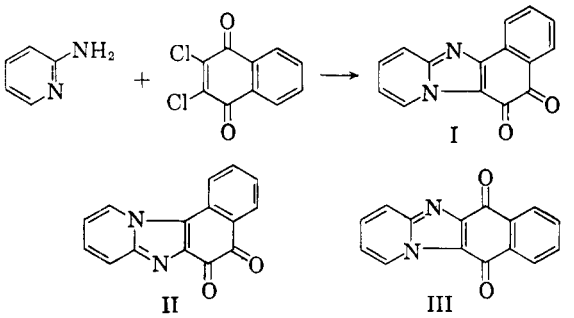
(1) Paper presented at the 133rd National Meeting of the American Chemical Society, San Francisco, Calif., April 13–18, 1958; *Abstracts*, p. 66N.

(2) E. F. Pratt, R. W. Luckenbaugh, and R. L. Erickson, *J. Org. Chem.*, **19**, 176 (1954).

(3) E. F. Pratt, R. G. Rice, and R. W. Luckenbaugh, *J. Am. Chem. Soc.*, **79**, 1212 (1957).

result from the reaction of 2,3-dichloro-1,4-naphthoquinone with 2-aminopyridine in the *absence* of an active methylene compound.

Heating an equimolecular mixture of these two reactants in ethanol was reported[4,5] to afford 3-chloro-2-(2-pyridylamino)-1,4-naphthoquinone (brown, m.p. 276–278° dec.) in 45[4] and 91%[5] yield. Despite numerous attempts, we have been unable to find any evidence for the existence of this product. Repetition of the reported[5] experimental conditions led only to mixtures of products, including 2,3-dichloronaphthoquinone. One of these products, a vattable orange quinone ($C_{15}H_8N_2O_2$, m.p. 301–302°), could be obtained in good yield as the major product of the reaction of 2,3-dichloronaphthoquinone with 2-aminopyridine in ethanol, provided a molar equivalent of sodium bicarbonate or carbonate, or a second molar equivalent of 2-aminopyridine was added initially to the reaction mixture. These reactions were normally heated for from 4–18 hours. However, when the reaction was stopped during the first hour, traces of a vattable reddish brown product ($C_{20}H_{12}N_4O$, m.p. 245.0–245.5°) could be isolated. Upon further heating of the reaction mixture, this product disappeared, and the orange quinone was the sole product isolated. If, however, four (or more) molar equivalents of 2-aminopyridine were employed initially in the reaction with 2,3-dichloronaphthoquinone, the red-brown compound was the major product. The nature of this latter substance will be discussed later (*v.i.*).



I

II

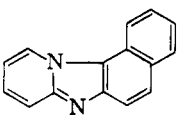
III

The orange quinone $C_{15}H_8N_2O_2$ was obtained pure, in the manner mentioned, in about 47% yield. Structures I, II, and III were considered for this product. Analogy with the naphthopyrrocolinediones[2,3] would suggest the *linear* formula III, but the *angular* structures I and II were included because of the long-known[6] reaction of 2,3-dichloro-1,4-naphthoquinone with *o*-phenylenediamines to yield derivatives of the *angular* benzo[*a*]phenazine. The formation of a phenazine derivative by reaction of the orange quinone with *o*-phenylenediamine eliminated the linear structure III from further consideration.

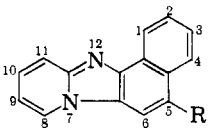
While we were seeking evidence to provide the basis for a choice between structures I and II, Truitt *et al.*[5] described the preparation, by similar reactions, of a quinone to which they assigned structure III. Evidently their failure to obtain a phenazine derivative of the quinone was a major factor in their choice of structure III. Repetition of their directions[5] for the reaction of 2-aminopyridine with dichloronaphthoquinone gave, in our hands, only traces of crude, orange quinone. However, the reaction, as reported,[5] of 2-acetamido-3-chloronaphthoquinone with 2-aminopyridine readily yielded a product identical (in infrared spectrum and other properties) with our orange quinone (I or II). The assignment[5] of structure III is, therefore, incorrect.

2-Acetamidopyridine was reported[5] not to react with 2,3-dichloronaphthoquinone, and we experienced a similar failure when the reaction was run in chlorobenzene solution. However, in methyl Cellosolve solution the reaction afforded the same orange quinone (I or II) otherwise obtained. This piece of evidence tends to support structure I over II, but is hardly conclusive as deacylation of 2-acetamidopyridine under the reaction conditions seems entirely possible. The argument in favor of structure I was strengthened somewhat when the same quinone (I or II) was obtained from the reaction of 2-aminopyridine with 3,4-dichloro-1,2-naphthoquinone.

From the reaction of 1-chloro-2,4-dinitronaphthalene with 2-aminopyridine, Morgan and Stewart[7] obtained after several steps, a product, which could be either IV or V. Without offering



IV



V (R = H)
VI (R = NH_2)

substantial evidence, they preferred structure V. The accuracy of this choice was confirmed later during work upon related compounds by Adams and Pomerantz.[8] However, by its nature, the work of the later workers corroborates that of Morgan and Stewart, and not *vice versa*, as was indicated.[8] Structure I is then merely a quinone of the established ring system V. No information is available concerning derivatives of the nucleus (IV) present in II.

Reduction of V yielded the known[7] tetrahydro compound VII, which was oxidized by chromic acid to the quinone VIII. This substance proved

(4) J. C. Calandra and E. C. Adams, *J. Am. Chem. Soc.*, **72**, 4804 (1950).

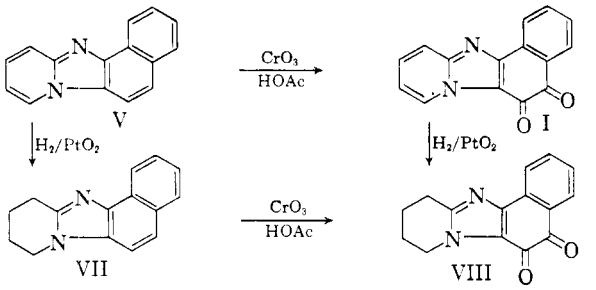
(5) P. Truitt, J. E. Cooper, and F. M. Wood, *J. Am. Chem. Soc.*, **79**, 5708 (1957).

(6) T. Zincke and M. Schmidt, *Ann.*, **286**, 27 (1895).

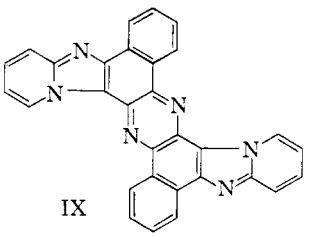
(7) G. Morgan and J. Stewart, *J. Chem. Soc.*, 1057 (1939).

(8) R. Adams and S. H. Pomerantz, *J. Am. Chem. Soc.*, **76**, 705 (1954).

to be identical with the product obtained by hydrogenating the original orange quinone ($C_{15}H_8N_2O_2$). Additional evidence for structure I also was obtained.



Oxidation of V with chromic acid gave, in low yield, a crude orange quinone, the infrared spectrum of which suggests it to be impure I. Oxidation of the amine VI with either chromic acid or lead tetraacetate yielded the phenazine IX as the sole product.



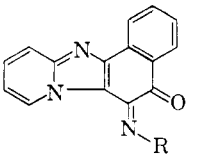
Reductive acetylation of the orange quinone I produced the hydroquinone diacetate, which upon distillation with zinc dust gave a small amount of brown oil. The oil yielded a solid picrate, the infrared spectrum of which was identical with the infrared spectrum of the picrate of V. Furthermore, the ultraviolet spectrum of the hydroquinone diacetate closely resembles that of V. The structure I for the orange quinone is thus established beyond reasonable doubt.

Oxidation of I with peracetic acid produced (at least) four products. Under either mild or vigorous oxidation conditions the major product was 2-aminopyridine (isolated as the picrate). Under mild conditions, a small yield of a substance $C_{13}H_{10}N_2O$ (m.p. 141.5–144.5°) also was obtained. The empirical formula and the presence of a carbonyl absorption at 5.88μ suggest the substance to be 2-phenylimidazo[1,2-*a*]pyridin-3(2*H*)-one. This compound was reportedly prepared by Schmidt and Gründig[9] (who give the melting point as 81.5–82°) from the reaction of 2-aminopyridine with ω-bromo-ω-nitroacetophenone. Our efforts to repeat their synthesis produced only tars. The failure of bromonitroacetophenone to yield a pyrrocoline upon reaction with 2-picoline has been recorded.[10]

Under vigorous conditions (in 40% peracetic acid), in addition to 2-aminopyridine, small amounts of two other substances (m.p. 185–186° and m.p. 226–228.5°) were isolated. The higher-melting product was identified as *N*-(2-pyridyl)-phthalimide, while the other was not identified.

The red-brown $C_{20}H_{12}N_4O$ product. With four molar equivalents of 2-aminopyridine, in either ethanol or chlorobenzene solution, 2,3-dichloronaphthoquinone formed a vattable, reddish brown substance.[10a] The hydrochloride of this substance, mixed with unreacted dichloronaphthoquinone, was formed in a reaction with only *two* equivalents of 2-aminopyridine in *chlorobenzene* solution. The ultraviolet spectrum of the red-brown substance resembled that of the quinone I, and no OH or NH absorption was evident in the infrared spectrum. The red-brown product yielded I and 2-aminopyridine upon acid hydrolysis, but it could not be reconstituted by heating I with 2-aminopyridine in ethanol or acetic acid. Reductive acetylation afforded a colorless diacetyl derivative, the ultraviolet spectrum of which was similar to that of the hydroquinone diacetate from I.

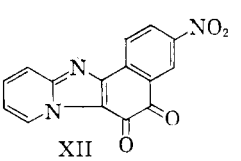
These data, together with the other evidence, suggest that the $C_{20}H_{12}N_4O$ compound is the primary reaction product (which hydrolyzes *in situ*, under appropriate conditions, to form I), and that the pyridylimino group occupies the 6 position as shown in structure X.



X (R = 2-pyridyl)
XI (R = $COCH_3$)

The reaction of 2-acetamido-3-chloronaphthoquinone with two moles of 2-aminopyridine in hydroxylic solvents produced the quinone I. However, in chlorobenzene solution, the orange-brown acetimido compound XI is the sole product.

Related products. By the use of substituted 2-aminopyridines or substituted 2,3-dichloronaphthoquinones, several homologs of I were prepared. From 5 nitro-2,3-dichloronaphthoquinone, two mononitro derivatives of I were obtained, undoubtedly the 1- and 4-nitro compounds. A third mononitro derivative was prepared by the direct nitration of I. As it was different from each of the other



(9) L. Schmidt and K. Gründig, *Monatsh.*, **84**, 491 (1953).

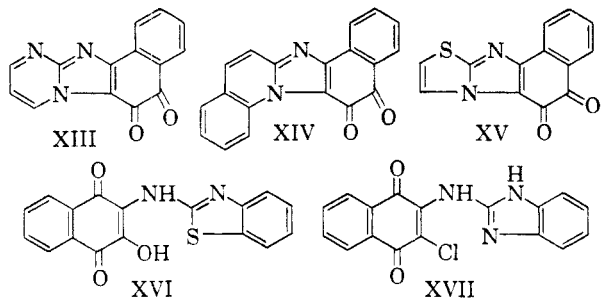
(10) E. T. Borrows, D. O. Holland, and J. Kenyon, *J. Chem. Soc.*, 1077 (1947).

(10a) These conditions were very recently reported[10b] to yield a product (m.p. 223–224°), which, after chromatography, melted at 297–298°, and was assigned structure III. It seems probable that the first substance is actually X, and was hydrolyzed to I (not III) during isolation.

(10b) M. S. Mathur and B. D. Tilak, *J. Sci. Ind. Research (India)*, **17B**, 33 (1958).

two nitro derivatives, it was assigned structure XII. The use of 2,3,5,8-tetrachloronaphthoquinine led to the formation of the 1,4-dichloro derivative of I, and the 8-methyl homolog was obtained from 2-amino-6-methylpyridine.

Replacement of 2-aminopyridine with 2-aminopyrimidine in the reaction with dichloronaphthoquinone, yielded a golden yellow quinone. Like I, it formed a phenazine, and it was assigned structure XIII. Products obtained similarly from 2-aminoquinoline and 2-aminothiazole were formulated as XIV and XV, respectively, although no proof of these structures has been attempted. The reaction of dichloronaphthoquinone (in the presence of

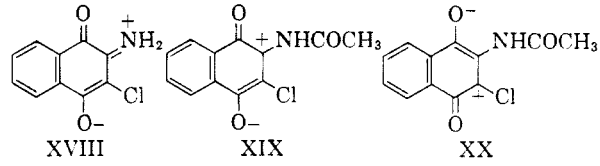


sodium carbonate and ethanol) with 2-amino benzothiazole and with 2-aminobenzimidazole gave only products thought to have structures XVI and XVII, respectively.

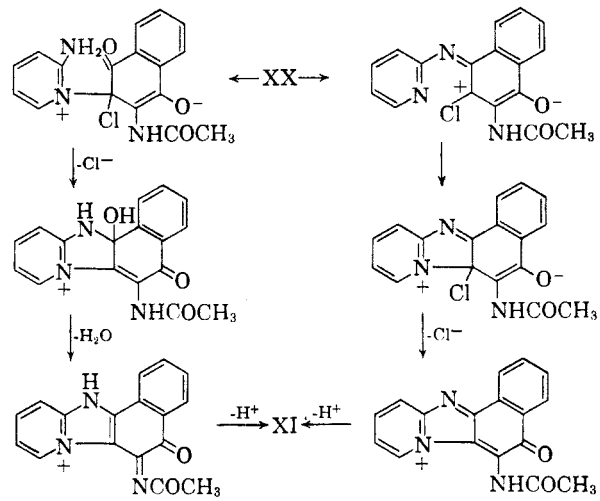
Reaction mechanism. Insomuch as the available evidence indicates the quinoneimine X to be the precursor of the quinone I, and to form the latter by simple hydrolysis, we need consider only the mode of formation of X. The initial reaction of 2-aminopyridine with 2,3-dichloro-1,4-naphthoquinone could involve, *a priori*, attack by either the amino group or by the ring nitrogen of the pyridine, and either 1,2 or 1,4- addition to the naphthoquinone system. Evidently a complex series of reactions is required to produce X.

The failure of 2-acetamidopyridine to react (in *chlorobenzene* solution) with either 2,3-dichloro- or 2-acetamido-3-chloro-1,4-naphthoquinone seems to indicate involvement of the amino group of 2-aminopyridine in the initial reaction step. Now in nucleophilic displacement reactions of 2-aminopyridine upon α-haloesters, α-haloketones *etc.*, it is the ring nitrogen which is usually involved. Thus one is led to favor a 1,2- or 1,4- addition reaction to the naphthoquinone as the initial step. In this connection some related reactions in the older literature are particularly revealing.

Aniline, in ethanolic solution, reacts with 1,4-naphthoquinone to yield 2-anilino-1,4-naphthoquinone,[11] and with 2-chloronaphthoquinone to form 3-anilino-2-chloronaphthoquinone,[12] while no reaction at all occurs with 2-chloro-3-methyl-naphthoquinone.[13] These data imply 1,4- addition to the naphthoquinone. Similarly, the reaction of 2,3-dichloronaphthoquinone with ammonia (or simple amines) produces 2-amino-3-chloronaphthoquinone.[14] Further treatment of this compound with amines, even 2-aminopyridine, is without effect. A probable explanation for this lack of reactivity is the large contribution made by forms such as XVIII to the resonance hybrid. On the other hand, it is well recognized[15-18] that acylation of the amino group activates the chlorine to nucleophilic displacement. Normal amide resonance ($-CONH_2 \longleftrightarrow {}^{-}O-C=\overset{+}{N}H_2$) suppresses contributions from forms such as XIX, but permits forms of type XX, and consequently reaction occurs with displacement of chlorine.



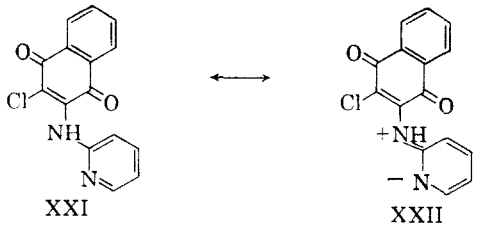
The reaction of XX with 2-aminopyridine may involve 1,2 addition of the amino group, or 1,4-addition of the ring nitrogen as follows:



Each of these sequences is capable of several variations, which, for want of evidence, it is pointless to discuss, and for the same reason a choice between the two mechanisms cannot now be made.

The formation of X may be considered to involve 1,4- addition of 2-aminopyridine to dichloronaphthoquinone, followed by loss of hydrogen chloride to produce XXI.

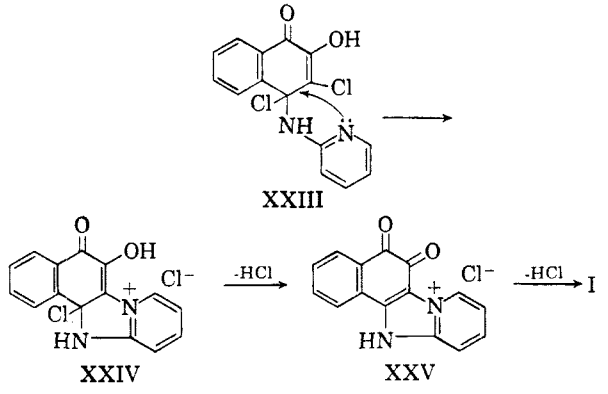
(11) T. Zincke, *Ber.*, **12**, 1641 (1879).
(12) T. Zincke, *Ber.*, **21**, 1027 (1888).
(13) K. Fries and W. Lohmann, *Ber.*, **54**, 2912 (1921).
(14) K. Fries and P. Ochwat, *Ber.*, **56**, 1291 (1923).
(15) K. Fries and K. Billig, *Ber.*, **58**, 1128 (1925).
(16) L. F. Fieser and E. L. Martin, *J. Am. Chem. Soc.*, **57**, 1844 (1935).
(17) J. R. Hoover and A. R. Day, *J. Am. Chem. Soc.*, **76**, 4148 (1954).
(18) R. Neef and O. Bayer, *Chem. Ber.*, **90**, 1137 (1957).



XXI XXII

Unlike simple 2-amino-3-chloronaphthoquinones, however, XXI may enjoy contributions from resonance forms such as XXII and thus, for the same reasons indicated for the acetamido compound XX, it contains an active chlorine and reacts rapidly with a second molecule of 2-aminopyridine. The formation of X may then occur *via* either of the two routes shown for the formation of XI.

The formation of I from 3,4-dichloro-1,2-naphthoquinone appears to be the simplest reaction of this group. Aniline is known to react with 1,2-naphthoquinone[19] and with its 3-chloro[20] or 3-nitro[21] derivatives by 1,4- addition, with the 3-substituent intact. In the present case, therefore, one may postulate an initial adduct such as XXIII, and its conversion, *via* XXIV and XXV, into I.



XXIII XXIV XXV

In view of these conclusions, it is rather surprising that the linear quinone III was not formed by the internal cyclization of XXI. Further study of these complex reactions is required for complete elucidation of the mechanisms involved.

EXPERIMENTAL[22]

5H,6H-Benzo[e]pyrido[a]benzimidazole-5,6-dione (I).[23] (*a*) A mixture of 68.1 g. (0.30 mole) of 2,3-dichloro-1,4-naphthoquinone, 56.4 g. (0.60 mole) of 2-aminopyridine, and 500 ml. of ethanol was stirred and boiled under reflux for 8 hr. The cooled reaction mixture was filtered, washed well with ethanol, and dried. The yield of crude product was 60.6 g. (81.5%). Crystallization from *o*-dichlorobenzene gave 35.3 g. (47.4% yield) of orange quinone, m.p. 298.5–300.5°. A sample recrystallized from *o*-dichlorobenzene melted at 301–302.2°. Further recrystallization from various solvents or vacuum sublimation did not raise the melting point. λ_{max} 241, 261, 272–278, 295, 305–309 and 390 mμ (log ε 4.58, 4.36, 4.30, 4.21, 4.13, and 3.77).

Anal. Calcd. for $C_{15}H_8N_2O_2$: C, 72.57; H, 3.25; N, 11.29. Found: C, 72.20; H, 3.29; N, 11.60.

(*b*) A modification of the above method consists in substituting 0.30 mole of sodium carbonate for 0.30 mole of the (0.60 mole total of the) 2-aminopyridine, and heating the mixture for 18 hr. A 55.6% yield of crude product was thereby obtained, and crystallization from chlorobenzene gave a 46% yield of pure I, m.p. 299.5–301.5°.

(*c*) The reaction of 2-acetamido-3-chloro-1,4-naphthoquinone with 2-aminopyridine in the manner described by Truitt *et al.*[5] gave a 67.3% yield of crude orange product, which, after three recrystallizations from acetic acid, melted at 300–301.5° and possessed an infrared spectrum identical with that of I.

(*d*) The same quinone (I) also was obtained from the reaction of 1.70 g. (0.0075*M*) of 3,4-dichloro-1,2-naphthoquinone[20] with 1.41 g. (0.015*M*) of 2-aminopyridine in 25 ml. of ethanol. The purified product melted at 301–302°, and had an infrared spectrum identical with those of the samples otherwise prepared.

(*e*) A mixture of 2.27 g. (0.01 mole) 2,3-dichloro-1,4-naphthoquinone, 1.36 g. (0.01 mole) 2-acetamidopyridine, and 10 ml. of methyl Cellosolve was stirred and boiled under reflux for 24 hr. The crude product (1.31 g.) was crystallized from *o*-dichlorobenzene and recrystallized from chlorobenzene, after which it melted at 298.5–301° and was identical (by infrared spectrum) with I. In chlorobenzene, however, 2-acetamidopyridine failed to react with either 2,3-dichloro- or 2-acetamido-3-chloro-1,4-naphthoquinone.

The *hydroquinone diacetate* was obtained from I by reductive acetylation. Crystallization from benzene gave fluffy, white acicular clusters, m.p. 233–234° (lit.[5] 194°); λ_{max} 248,* 255, 276, 281,* 299, 316, 330, 340,* 355, and 370* mμ. (log ε 4.63, 4.67, 4.35, 4.30, 3.99, 3.94, 4.08, 3.96, 3.93, and 3.77).

Anal. Calcd. for $C_{19}H_{14}N_2O_4$: C, 68.30; H, 4.19; N, 8.39. Found: C, 68.20; H, 4.17; N, 8.19.

The *phenazine* of I was obtained by heating the quinone with a molar equivalent of *o*-phenylenediamine in acetic acid for 2 hr. The crude phenazine (92.2% yield) was recrystallized twice from chlorobenzene and once from methyl Cellosolve, giving a 50% yield of bright yellow crystals, m.p. 294.1–295.0°.

Anal. Calcd. for $C_{21}H_{12}N_4$: C, 78.73; H, 3.78; N, 17.49. Found: C, 78.90; H, 3.83; N, 17.40.

Benzo[e]pyrido[a]benzimidazole (V) was prepared by essentially the same method described by Morgan and Stewart.[7] It formed pale yellow plates, m.p. 193–195° (lit.[7] 187°), but chromatography of a benzene solution upon alumina gave very pale yellow crystals, m.p. 195.2–196.2°; λ_{max} 242–244.5, 252, 257,* 276.5, 299, 313, 326.5, 344–350, 358, and 370–372.5 mμ. (log ε 4.57, 4.66, 4.60, 4.37, 3.99, 3.85, 3.95, 3.94, 4.01, and 3.80).

The *picrate* was prepared in methanol and crystallized from methyl Cellosolve as fluffy yellow crystals, m.p. 258–261° dec.

Anal. Calcd. for $C_{21}H_{13}N_5O_7$: C, 56.37; H, 2.91; N, 15.66 Found: C, 56.32; H, 3.18; N, 15.64.

A mixture of 0.50 g. of the hydroquinone diacetate of I and 12.0 g. of zinc dust was distilled. The combined oily distillates from two such runs were dissolved in 0.5 ml. of methanol and treated with an excess of saturated methanolic picric acid. The resulting yellow picrate (70 mg.) was crystallized twice from methyl Cellosolve. The infrared spectrum of this material was identical with that of the picrate (*v.s.*) prepared from V.

(19) T. Zincke, *Ber.*, **14**, 1493 (1881).
(20) T. Zincke, *Ber.*, **19**, 2493 (1886).
(21) F. Brauns, *Ber.*, **17**, 1133 (1884).
(22) All melting points were taken in Pyrex capillaries using a Hershberg melting point apparatus and Anschütz thermometers. The ultraviolet spectra were measured in ethanol using a Cary recording automatic spectrophotometer and points of interest are indicated by asterisks. The infrared spectra were determined from Nujol mulls, using a Perkin-Elmer Model 321 recording spectrophotometer.
(23) This compound was first prepared in these laboratories by Dr. O. G. Birsten.

8,9,10,11-Tetrahydrobenzo[e]pyrido[a]benzimidazole (VII). To 100 mg. of benzo[e]pyrido[a]benzimidazole (V) in 25 ml. of ethanol was added 50 mg. of Adams' catalyst, and the mixture was hydrogenated at 30 p.s.i. (gage pressure) for 3 hr. The catalyst was filtered and the filtrate was stripped of ethanol to give 100 mg. of viscous oil. Trituration with cyclohexane caused crystallization, and recrystallization from cyclohexane and then from benzene gave white granular crystals, m.p. 161.5–162.5° (lit.[7] 157–158°); λ_{max} 223, 238, 256, 284.5, 308, 314.5, 322, and 328 mμ. (log ε 4.54, 4.68, 4.31, 3.73, 3.16, 3.68, 3.59, and 3.78).

Anal. Calcd. for $C_{15}H_{14}N_2$: C, 81.05; H, 6.30; N, 12.62. Found: C, 80.82; H, 6.20; N, 12.40.

The *picrate* was prepared in methanol and after crystallization from methyl Cellosolve melted at 233.5–235.2°.

Anal. Calcd. for $C_{21}H_{17}N_5O_7$: C, 55.87; H, 3.77; N, 15.53; O, 24.80. Found: C, 55.71; H, 3.70; N, 15.73; O, 24.78.

5,6,8,9,10,11-Hexahydrobenzo[e]pyrido[a]benzimidazole-5,6-dione (VIII). To a boiling solution of 0.60 g. of VII in 5 ml. of glacial acetic acid, was added dropwise a solution of 0.70 g. of chromic acid in 1 ml. of water. The mixture was cooled, diluted with water, and filtered. The crude orange quinone was crystallized twice from benzene, giving 0.50 g. of bright orange needles, m.p. 233.3–234.7°; λ_{max} 246–254,* 259.5, 266, and 305 mμ. (log ε 4.36, 4.42, 4.40, and 3.84).

Anal. Calcd. for $C_{15}H_{12}N_2O_2$: C, 71.43; H, 4.76; N, 11.10. Found: C, 71.65; H, 4.74; N, 11.22.

A slurry of 0.40 g. of the quinone I, 0.10 g. of Adams' catalyst, 50 ml. of ethanol, and a few small glass beads was shaken at 50° under hydrogen at 30 p.s.i. for several hours. The beads and catalyst were removed by filtration and the colorless filtrate was allowed to evaporate, yielding 0.32 g. of brownish orange solid. This was dissolved in benzene and chromatographed upon alumina, giving 0.11 g. of bright orange crystals, m.p. 232–233°, identical in infrared spectrum with the product (VIII) described above.

Oxidation of VI to IX was effected in boiling acetic acid by the action of either chromic acid or lead tetraacetate. The precipitated orange phenazine was boiled with acetic acid and then with methanol. Crystallization from 1-chloronaphthalene did not appear to improve the product. The use of lead tetraacetate gave a purer product. The orange phenazine melted above 360°.

Anal. Calcd. for $C_{30}H_{16}N_6$: C, 78.25; H, 3.48; N, 18.25. Found: C, 78.20; H, 3.70; N, 18.15.

Oxidation of I with peracetic acid was attempted under mild and vigorous conditions. When 10.0 g. of I were refluxed for 4.5 hr. with 90 ml. of acetic acid and 110 ml. of 6% hydrogen peroxide solution, neutralization of the resulting solution with 5% sodium carbonate solution gave 0.75 g. of crude solid. Three crystallizations from aqueous ethanol and from ethyl acetate–methyl cyclohexane gave a pale yellow substance, m.p. 141.5–144.5°, having a carbonyl absorption at 5.88 μ.

Anal. Calcd. for $C_{13}H_{10}N_2O$: C, 74.27; H, 4.79; N, 13.33. Found: C, 73.90; H, 4.84; N, 12.71.

The *picrate*, prepared in aqueous methanol, melted at 162.5–167.5°. Lack of material prevented purification.

Anal. Calcd. for $C_{19}N_{15}N_5O_7$: C, 53.65; H, 3.55; N, 16.47. Found: C, 53.00; H, 3.24; N, 16.20.

From the original, neutralized, reaction mother liquor, 2-aminopyridine was readily isolated as the picrate (m.p. 224–225°). Under more vigorous conditions, 2-aminopyridine, again isolated as the picrate, was the major degradation product.

When 1.00 g. of I was added to 4.0 ml. of 40% peracetic acid, after a minute or two a vigorous reaction ensued and the residual orange oily liquid was diluted with water and allowed to stand. The resulting pale yellow precipitate was filtered, crystallized from methanol, and then fractionally crystallized from acetonitrile. The more soluble of the two products formed colorless crystals, m.p. 226.0–228.5°, and was identified by comparison of the infrared spectrum with that of an authentic sample (m.p. 230.5–233.0°; lit.[24] 227°) of *N*-(2-pyridyl)phthalimide prepared from 2-aminopyridine and phthalic anhydride.

The less-soluble product formed white granules, m.p. 185.2–186.0°, and showed strong absorption at 3.10 and 5.85μ in the infrared spectrum. No satisfactory structure could be deduced from the spectra and microanalyses.

Anal. Found: C, 60.55; H, 3.59; N, 10.02; O, 24.96.

3-Phenyl-imidazo[1,2-a]pyridine-2(3H)-one. A solution of 2.15 g. of α-bromophenylacetic acid[25] in chloroform was converted into the acid chloride by treatment with thionyl chloride, and this was treated with a solution of 2.0 g. of 2-aminopyridine in chloroform. The solvent was allowed to evaporate and the oily residue was triturated with water. The aqueous extract was basified with ammonia, then adjusted to maximum turbidity by the addition of a few drops of acetic acid. Upon standing, the solution deposited a small quantity of yellow knobby crystals. Four recrystallizations from glycol diacetate gave 0.18 g. of pale straw-colored needles, m.p. *ca.* 246–248° dec. The melting point appears to vary somewhat with the temperature of the bath upon immersion of the sample. The carbonyl absorption at 5.80μ was visible in acetonitrile solution, but not in a nujol mull.

Anal. Calcd. for $C_{13}H_{10}N_2O$: C, 74.28; H, 4.76; N, 13.33; O, 7.62. Found: C, 74.24; H, 4.86; N, 13.00; O, 7.71.

5,6-Dihydro-5-oxo-6-(2-pyridylimino)-benzo[e]pyrido[a]-benzimidazole (X). A mixture of 22.7 g. (0.10 mole) of 2,3-dichloro-1,4-naphthoquinone, 37.6 g. (0.40 mole) of 2-aminopyridine, and 500 ml. of ethanol was stirred under reflux for 4 hr. The cooled reaction mixture was filtered and the solid was washed with ethanol, giving 22.2 g. (68.5% yield) of crude reddish brown product. A sample crystallized twice from chlorobenzene melted at 239.5–241.5°. The infrared spectrum showed a carbonyl absorption at 5.94μ, but no absorption characteristic of OH or NH stretching; λ_{max} 227, 248, 267, 308, 320.5, and 388 mμ (log ε 4.45, 4.54, 4.48, 4.20, 4.18, and 3.65).

Anal. Calcd. for $C_{20}H_{12}N_4O$: C, 74.06; H, 3.73; N, 17.28. Found: C, 74.12; H, 3.96; N, 17.14.

This product also was formed from the reaction of dichloronaphthoquinone with 4 moles of 2-aminopyridine in chlorobenzene solution. The crude product (72% yield) was crystallized from acetonitrile to give reddish brown lozenges, m.p. 245.0–245.5°.

Hydrolysis of X by heating with dilute sulfuric acid produced the quinone I, identified by melting point and infrared spectrum.

Reductive acetylation of X yielded *5-acetoxy-6-[N-(2-pyridyl)-acetamido]-benzo[e]pyrido[a]benzimidazole*, which crystallized from benzene in white granules having an instantaneous melting point of 280° dec.; if put into the melting point bath at a lower temperature the sample decomposes over a range. λ_{max} 248.5, 254, 271, 290,* 303, 320–325, 333–340, 355, and 370 mμ (log ε 4.30, 4.33, 4.01, 3.68, 3.62, 2.56, 3.67, 3.67, and 2.48).

Anal. Calcd. for $C_{24}H_{18}N_4O_3$: C, 70.25; H, 4.39; N, 13.66. Found: C, 70.41; H, 4.30; N, 13.24.

6-Acetimido-5,6-dihydro-5-oxo-benzo[e]pyrido[a]benzimidazole (XI). A mixture of 1.00 g. (0.004 mole) of 2-acetamido-3-chloro-1,4-naphthoquinone, 0.70 g. (0.008 mole) of 2-amidopyridine, and 10 ml. of dry chlorobenzene was stirred and boiled under reflux for an hour, then cooled and filtered. The resulting solid (0.81 g., 70% yield, m.p. 265–267°) was crystallized from glycol diacetate, giving 0.68 g. of orange needles, m.p. 271.5–272.5° dec.; λ_{max} 246, 265, 306, 320, and 390 mμ (log ε 4.51, 4.38, 3.13, 3.10, and 3.56).

Anal. Calcd. for $C_{17}H_{11}N_3O_2$: C, 70.58; H, 3.81; N, 14.53. Found: C, 70.43; H, 3.74; N, 14.32.

Hydrolysis of XI with hot dilute hydrochloric acid yielded

(24) E. Koenigs and H. Greiner, *Ber.*, **64**, 1049 (1931).

(25) J. M. Bruce and F. K. Sutcliffe, *J. Chem. Soc.*, 4789 (1957).

the quinone I, identified by infrared spectrum and melting point.

5,6-Dihydro-3-nitro-5,6-dioxo-benzo[e]pyrido[a]benzimidazole (XII). To a solution of 2.48 g. of I in 50 ml. of concentrated sulfuric acid was added 1.0 ml. of concentrated nitric acid. The solution was heated to 125° over a 45-min. period, then an additional 1.0 ml. of nitric acid was added and the solution was kept at 125° for an hour. The cooled solution was drowned, and the solid was filtered, washed, and dried. The crude product (2.22 g., 78.5% yield) was crystallized thrice from *o*-dichlorobenzene, giving orange crystals, m. >360° dec. The compound dyes cotton a weak green from an orange-red vat.

Anal. Calcd. for $C_{15}H_7N_3O_4$: C, 61.44; H, 2.41; N, 14.33. Found: C, 61.30; H, 2.64; N, 14.30.

5,6-Dihydro-1- and 4-nitro-5,6-dioxobenz[e]pyrido[a]benzimidazoles. A mixture of 5.98 g. (0.022 mole) of 2,3-dichloro-5-nitro-1,4-naphthoquinone (m.p. 174–175.5°), 4.14 g. (0.044 mole) of 2-aminopyridine, and 75 ml. of ethanol was stirred and boiled under reflux for 4 hr., then cooled and filtered. The yield of crude product was 3.90 g. (60.5%). Extraction with hot *o*-dichlorobenzene removed the more soluble component (1.70 g.) and recrystallization from the same solvent gave orange-red crystals, m.p. 292.5–293.5° dec., which dyed cotton a bluish red shade from a yellowish red vat.

Anal. Calcd. for $C_{15}H_7N_3O_4$. C, 61.44; H, 2.41; N, 14.33. Found: C, 61.30; H, 2.52; N, 14.20.

The fraction insoluble in *o*-dichlorobenzene (0.80 g.) was crystallized from nitrobenzene. The orange product melted at 322–324° dec., and dyed cotton a very pale pink from a brownish red vat.

Anal. Calcd. for $C_{15}H_7N_3O_4$: C, 61.44; H, 2.41; N, 14.33. Found: C, 61.40; H, 2.49; N, 14.20.

5,6-Dihydro-8-methyl-5,6-dioxobenzo[e]pyrido[a]benzimidazole, was obtained crude (m.p. 266–275°) in 20% yield from 2-amino-6-methylpyridine by procedure (*b*) described under the preparation of I. Crystallization from toluene gave yellow needles, m.p. 280.8–283.0°.

Anal. Calcd. for $C_{16}H_{10}N_2O_2$: C, 73.27; H, 3.84; N, 10.69; O, 12.20. Found: C, 73.19; H, 3.74; N, 10.56; O, 12.51.

1,4-Dichloro-5,6-dihydro-5,6-dioxobenzo[e]pyrido[a]benzimidazole, was prepared from 2,3,5,8-tetrachloro-1,4-naphthoquinone (m.p. 251–252°, prepared by Bruck's method[26]) by procedure (*a*) described under the synthesis of I, except that the heating period was reduced to 4 hr. An 83.1% yield of crude product resulted, and crystallization from *o*-dichlorobenzene afforded a 50.1% yield of the orange quinone, m.p. 319.0–320.7°.

Anal. Calcd. for $C_{15}H_6Cl_2N_2O_2$: C, 56.81; H, 1.91; Cl, 22.36; N, 8.83. Found: C, 56.60; H, 2.09; Cl, 22.40; N, 8.89.

The *phenazine* was obtained from the quinone by refluxing it with *o*-phenylenediamine in methyl Cellosolve for 16 hr. Two crystallizations from methyl Cellosolve and one from chlorobenzene gave golden crystals, m.p. 313–314.2°.

Anal. Calcd. for $C_{21}H_{10}Cl_2N_4$: C, 64.80; H, 2.59; Cl, 18.22; N, 14.39. Found: C, 64.80; H, 2.63; Cl, 18.1; N, 14.00.

5,6-Dihydro-5,6-dioxobenzo[e]pyrimido[1,2-a]benzimidazole (XIII).[27] A solution of 11.35 g. (0.05 mole) of 2,3-dichloro-1,4-naphthoquinone and 9.50 g. (0.10 mole) of 2-aminopyrimidine in 100 ml. of methyl Cellosolve was stirred and boiled under reflux for 22 hr. The cooled reaction mixture was filtered and the solid was washed well with ethanol and hot water and was dried. The yield of crude brown quinone was 6.41 g. (51.3%). Crystallization from glycol diacetate, followed by recrystallization from *o*-dichlorobenzene gave felted microneedles of the golden yellow quinone, m.p. 343.5–345.0° dec.; λ_{max} 240–248, 259.5–262, 280.5–284, 288, 300,* 315–318,* and 355–370* mμ (log ε 4.53, 4.36, 4.41, 4.46, 4.24, 4.13, and 3.71).

Anal. Calcd. for $C_{14}H_7N_3O_2$: C, 67.47; H, 2.83; N, 16.86; O, 12.84. Found: C, 67.40; H, 2.84; N, 16.76; O, 12.91.

The *phenazine* was obtained from this quinone in the usual manner. Two crystallizations from chlorobenzene gave a product melting at 343.5–346.5°.

Anal. Calcd. for $C_{20}H_{11}N_5$: C, 74.75; H, 3.43; N, 21.80. Found: C, 74.51; H, 3.54; N, 21.70.

Reductive acetylation gave the *hydroquinone diacetate.* Crystallization from chlorobenzene afforded bright yellow crystals melting at about 270° dec. (the melting point varies with the temperature of the bath upon immersion of the sample, which decomposes over a range).

Anal. Calcd. for $C_{18}H_{13}N_3O_4$: C, 64.50; H, 3.88; N, 12.54. Found: C, 64.47; H, 3.92; N, 12.49.

12,13-Dihydro-12,13-dioxobenzo[e]quinolo[1,2-a]benzimidazole (XIV), was prepared from 2-aminoquinoline by method (*b*) used to make I. The yield of crude quinone was 39.3%, and crystallization from chlorobenzene gave dull orange needles, m.p. 327.5–328.5°; λ_{max} 249, 284–290, 297, 306–308° and 328 mμ (log ε 4.46, 4.33, 4.42, 4.35, and 4.11).

Anal. Calcd. for $C_{19}H_{10}N_2O_2$: C, 76.50; H, 3.38; N, 9.39. Found: C, 76.37; H, 3.17; N, 9.31.

Reductive acetylation of the quinone gave *12,13-diacetoxybenzo[e]quinolo[1,2-a]benzimidazole* as bright greenish yellow crystals (from acetic anhydride), m.p. 217.5–218.5°; λ_{max} 236–239, 280–289, 293, 326, 341, 357, and 385 mμ (log ε 4.47, 4.57, 4.62, 3.85, 3.76, 3.86, and 3.79).

Anal. Calcd. for $C_{23}H_{16}N_2O_4$: C, 71.87; H, 4.16; N, 7.29; O, 16.66. Found: C, 71.69; H, 4.16; N, 7.55; O, 16.86.

5,6-Dihydro-5,6-dioxobenzo[e]thiazolo[3,2-a]benzimidazole (XV), was obtained from 2-aminothiazole by the method used to prepare XIII. The cooled reaction mixture was diluted with ethanol, and the precipitate was washed well with alcohol and dried. The crude quinone (33% yield) was purified by solution in *o*-dichlorobenzene and precipitation with methylcyclohexane, after which it decomposed at 273–275° when introduced into the bath at 263°.

Anal. Calcd. for $C_{13}H_6N_2O_2S$: C, 61.41; H, 2.38; N, 11.02. Found: C, 60.6; H, 2.71; N, 11.0.

2-(2-Benzothiazolylamino)-3-hydroxy-1,4-naphthoquinone (XVI), was obtained crude in 22% yield when a mixture of 11.40 g. (0.05 mole) of 2,3-dichloronaphthoquinone, 7.50 g. (0.05 mole) of 2-aminobenzothiazole, 6.0 g. of sodium carbonate, and 100 ml. of ethanol was stirred and boiled under reflux for 16 hr. Crystallization of the crude product from chlorobenzene-methylcyclohexane gave the dull violet quinone, m.p. 231.5–233.5°.

Anal. Calcd. for $C_{17}H_{10}N_2O_3S$: C, 63.34; H, 3.13; N, 8.69; O, 14.89; S, 9.95. Found: C, 63.75; H, 2.62; N, 9.24; O, 14.71; S, 10.49.

2-(2-Benzimidazolylamino)-3-chloro-1,4-naphthoquinone (XVII), was obtained by exactly the same procedure described for the preceding compound with the exception that 0.05 mole of 2-aminobenzimidazole was substituted for the aminobenzothiazole. Extraction of the crude product (29.4% yield) with boiling *o*-dichlorobenzene afforded bright violet crystals, m.p. 266.3–266.7°.

Anal. Calcd. for $C_{17}H_{10}ClN_3O_2$: C, 63.07; H, 3.11; Cl, 10.95; N, 12.98; O, 9.89. Found: C, 63.27; H, 3.27; Cl, 11.01; N, 13.26; O, 10.20.

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(26) W. Bruck, I. G. Farbenindustrie, A. G. in PB Report No. 70341, p. 13632.

(27) A product (m.p. 323–324°) prepared similarly, recently was assigned[10b] the structure of the linear isomer of XIII. No evidence for this structure was offered, and it is probable that the product is identical with XIII.