phy of these esters was accomplished on acid-washed alumina or silica gel eluting with pentane, gradually changing to pentane–ether.

All compounds possessed the expected spectral properties as described in the text.

Alkynes. Methyl stearolate was prepared from oleic acid by a procedure similar to that reported by Butterfield and Dutton.[18] Gunstone and Hornby[19] report a procedure, which may be superior, utilizing liquid ammonia. A small molar excess of liquid bromine was added to methyl oleate in the dark until the red bromine color persisted for 1 hr. Excess bromine was removed on a vacuum evaporator. The dihalide acid was added to 30% KOH in ethylene glycol (6 mol of KOH per mole of acid) and heated at 206° under an atmosphere of nitrogen for 4 hr. Dilution, acidification, and extraction with hexane was followed by esterification in methanol–1% sulfuric acid. Vaccum distillation afforded a clear oil in 70% yield, bp 155° (0.15 mm). Spectroscopic and physical properties of acetylinic esters are rather passive. Retention on a diethylene glycol succinate column was considerably longer than for methyl oleate and a 300-ft butanediol succinate capillary column showed a single unsplit peak. Absorption in the infrared was at 2940, 2845, 1750, 1470, 1445, 1375, 1260, 1200, and 1178 cm^{-1}. The nmr showed no vinylic hydrogens and two overlapping triplets centered around τ 7.9.

Methyl 9-heptadecynoate was synthesized by the method of Ames and Covell.[20] Sodamide (52 g) and 178 g of 1-decyne were dissolved in 4.5 l. of liquid ammonia. After 1 hr, 67 g of 7-bromoheptanoic acid was dissolved in a mixture of tetrahydrofuran and glyme and slowly added. The liquid ammonia was allowed to evaporate, and dilution and acidification was followed by extraction with ether. Esterification was accomplished in methanol–1% sulfuric acid. Vacuum distillation yielded 48 g of a clean oil, bp 114° (0.025 mm). Infrared absorption appeared at 2940, 2845, 1750, 1470, 1445, 1375, 1260, 1200, and 1178 cm^{-1}. The nmr shows no vinylic hydrogens and overlapping triplets at τ 7.9. The mass spectrum shows a parent at m/e 280.

1,2-Dialkylacetylenes.—The lower homologs can be purchased from the Chemical Sample Co., Columbus, Ohio. Other alkynes were synthesized by adding the appropriate alkyl bromide to sodium acetylide in liquid ammonia. After work-up and purification the resultant 1-alkyne was added to 1 equiv of sodamide (50 g per 4 l. of NH_3) in liquid ammonia followed by addition of 1 equiv of the appropriate alkyl bromide. Distillation data is contained in Table I. Yields of the higher molecular weight alkynes are low, 50% for 9-octadecyne based on 1-decyne.

Attempts to synthesize these alkynes from the appropriate Grignard reagent and 1,4-dichloro-2-butyne (Aldrich) proved unsatisfactory.

7-Bromoheptanoic Acid.—One gram-atom of metallic sodium was dissolved in 400 ml of absolute ethanol followed by the addition of 1.05 mol of diethyl malonate. This solution was stirred for 30 min by a strong mechanical stirrer, then added to a freshly prepared solution of 1.25 mol of 1,5-dibromopentane in 100 ml of absolute ethanol. Reaction was exothermic and sodium bromide precipitated. The solution was diluted with a large volume of water and extracted with chloroform. The extract was dried and evaporated. The product was refluxed in 250 ml of acetic acid and 50 ml of sulfuric acid for 1 day, with a warm condenser allowing ethyl acetate to escape. Dilution, extraction, and distillation yielded 7-bromoheptanoic acid in 53% yield, bp 105° (0.08 mm), mp 27–30° [lit.[21] bp 140–142° (1.5 mm), mp 28–29°].

Registry No.—**1c**, 35365-52-7; **1d**, 35365-53-8; **1e**, 1089-40-3; **1f**, 5026-66-4; **1g**, 3220-60-8; **2a**, 1942-45-6; **2b**, 6975-99-1; **2c**, 35216-11-6; **2d**, 19781-86-3; **2e**, 35365-59-4; **2f**, 24471-20-3; **2g**, 1120-32-7; **3b**, 35365-62-9; **3c**, 35365-63-0; **3d**, 35365-64-1; **3e**, 35365-65-2; **3f**, 35365-66-3; **3g**, 30689-71-5; methyl 9-heptadecynoate, 25601-39-2; 3-cyclopropenecarboxylic acid 26209-00-7.

Acknowledgment.—This work was supported in part by Public Health Service Grants ES 00263 and ES 00256 from the Division of Environmental Health Sciences.

(18) R. O. Butterfield and H. J. Dutton, *J. Amer. Oil Chem. Soc.*, **45**, 635 (1968).

(19) F. D. Gunstone and G. M. Hornby, *Chem. Phys. Lipids*, **3**, 91 (1969).

(20) D. E. Ames and A. N. Covell, *J. Chem. Soc.*, 775 (1963).

(21) D. E. Ames, R. E. Bowman, and R. G. Mason, *J. Chem. Soc.*, 174 (1950).

Grignard Reagents from Bromobenzo[*h*]quinolines. 13-Substituted Derivatives of 20-Chloronaphtho[2′,1′:12,13](2,4)pyridinophane[1,2]

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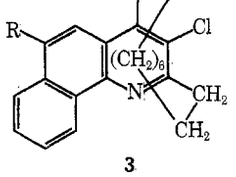
While Grignard reagents are not generally useful intermediates for synthetic conversions in quinoline systems, they are shown to be quite useful in the naphthopyridinophane series (**3**), and to a lesser, but practical extent, useful with 2-alkylbenzo[*h*]quinolines such as **9b**. The stability and utility of such Grignard reagents is not related to decreased acidity of the benzyl bridge methylene groups in **3**, since no metal exchange was noted for the dimethyl analog **9b**. Symmetrical coupling can become the major reaction of Grignard reagents in the benzo[*h*]-quinoline system, as observed for **6**. While the mechanism of this coupling is not known, the lack of coupling parallels steric hindrance at the azomethine linkage. A variety of 13-substituted derivatives of 20-chloronaphtho[2′,1′:12,13][10](2,4)pyridinophane have been prepared and one of these (**3i**) was found to be active (curative at 640 mg/kg) against *Murine Plasmodia–Plasmodium berghei*.

The initial objective of this work was to prepare certain 13-substituted derivatives of 20-chloronaphtho-[2′,1′:12,13][10](2.4)pyridinophane[3] (**3**, Table I),



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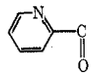
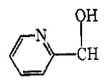
specifically the two diastereomeric[3] racemates corresponding to **3g** and **3i** which were of interest as agents against murine malaria. The replacement of aromatic bromine by functional groups of the type shown in **3g** and **3i** has been studied in detail and is usually accom-

(1) Supported by U.S. Army Medical Research Command, DADA-17-70-C-0008. This paper is contribution no. 1048 from the Army Research Program on Malaria.

(2) The methylene-bridged aromatic compounds in this study are named using the rules described by B. H. Smith in "Bridged Aromatic Compounds," Academic Press, New York, N. Y., 1964. There does not exist a universally accepted method for the naming of such compounds; *cf.* F. Vogtle and P. Newmann, *Tetrahedron*, **26**, 5847 (1970). *Chemical Abstracts*' name for **3b**, for example, is 15-bromo-20-chloro-3,4,5,6,7,8,9,10,11,12-decahydro-2,13-metheno-13*H*-1-naphtho[1,2-*b*]azacyclopentadecene.

(3) (a) The pyridinophane ring is asymmetric since the methylene bridge cannot flip to the opposite face. *Cf.* W. E. Parham, R. W. Davenport, and J. B. Biasotti, *Tetrahedron Lett.*, 557 (1969); (b) W. E. Parham, R. W. Davenport, and J. K. Rinehart, *J. Org. Chem.*, **35**, 2662 (1970).

TABLE I

3	R	Mp, °C	Composition within 0.3% of calcd value for	Isolated yield	$\nu_{900-760}$, cm^{-1}
a	H	129–131	C, H, N	71% from indole	870 (m), 812 (s), 792 (s), 750 (s)
b	Br	197–198, 200–201.5[a]	C, H, N	To 91%[b] from indole	760 (s)
c	CN	231–232	C, H, N, Cl	82–100% from **3b**	900 (w), 760 (s)
d	$C(=O)CH_3$	212.5–214	C, H, N	57% from **3c** 70% from **3n**	890 (w), 880 (w), 768 (s)
e	$C(=O)CH_2Br$	207–208	C, H, N, Cl, Br	88% from **3d**	770 (m), 760 (s)
f	$C(=O)CH_2N(C_7H_{15})_2$	Unstable		~100%	
g	$CH(OH)CH_2N(C_7H_{15})_2$	(a) 130–131[d] (b) Oil	C, H, N, Cl C, H, N, Cl	~100%[b,d]	(a) 898 (m), 860 (s) (b) 894 (w), 880 (w), 800 (m), 762 (s)
h	$C(=O)CH_2N(C_4H_9)_2$	Unstable		~100%	
i	$CH(OH)CH_2N(C_4H_9)_2$	Mixed racemates, oil	C, H, N	80%	750 (s)
j		147–149	C, H, N	*f*	862 (s), 818 (m), 770 (s), 750 (s)
k		(a) 173–186 (b) 174–176	C, H, N	100%[e]	(a) 830 (w), 770 (m) (b) 828 (w), 785 (w), 760 (s)
l	COOH	280–282	C, H, N, Cl	33–54% from **3c** 82–100% from **3n**	790 (s), 750 (s)
m	C(=O)Cl	202–206	C, H, N	48%[g]	900 (w), 830 (m), 810 (m), 770 (s)
n	–MgBr	Not isolated			
o	$-C(=O)CHBr_2$	164	C, H, N	12%[c]	888 (w), 782 (m), 758 (m), 750 (m)

[a] After sublimation. [b] See Experimental Section. [c] By-product from **3e**. [d] Two racemic diastereomers formed in equal amounts, separated by crystallization. [e] The two diastereomeric racemates were formed in approximately equal amounts. [f] 20% as by-product in formation of **3k** when excess aldehyde is employed with **3n**. [g] From **3l** and $SOCl_2$ in benzene, $\nu_{C=O}$ 1762 cm^{-1}.

plished by a series of reactions corresponding to **3b** → **3c** → **3e** → **3f** → **3g**.[4,5]

Substituted pyridines and quinolines are conveniently prepared by reaction of the appropriate pyrrole[6] or indole[3] with reagents which effect transfer of CCl_2. We have now extended this procedure to benzo[*g*]indoles, and high yields of the benzo[*h*]quinolines **3a** (71%), **3b** (64–90%), **4** (60%), and **9b** (63%), and the related quinoline **5** (41%) were obtained by procedures similar to that shown in Scheme I.

The series of reactions outlined above, starting with **3b** leading to the two diastereomeric racemates **3g** and to the mixed racemates of **3i**, were optimized and were effected in high yields (see Experimental Section). The mixed racemates **3i**[7] was found to be curative in murine malaria at 640 mg/kg; interestingly, neither of the racemic pairs of **3g** showed activity.

In view of the significant activity observed for **3i**, we were interested in developing a shorter synthesis for ketone intermediates of type **3d** in the benzo[*h*]quinoline series and we have, accordingly, studied formation of Grignard reagents from the bromobenzo[*h*]-quinolines **3a**, **9b**, and **6**, and the bromoquinoline **5**.

Although some success has been realized by entrainment procedures for the preparation and subsequent reactions of Grignard reagents in the pyridine series,[8,9-10] Grignard reagents have not been useful intermediates for functional group interchange in the quinoline series.[10,11] This latter result is not surprising since it is known that phenylmagnesium bromide reacts slowly in ether at room temperature[12] and more rapidly[13] in ether–dioxane at room temperature to give 2-phenylquinoline. In addition, Grignard[14] and aryllithium[15] reagents react with 2- and 4-alkylquinolines, as shown in Scheme II.

In our studies with benzo[*h*]quinolines, the heterocycle, magnesium turnings, and tetrahydrofuran were heated at the reflux temperature; then a solution of 1,2-dibromoethane was added slowly over a 2-hr period.[16]

6-Bromobenzo[*h*]quinoline (6).—The quinoline **6** was treated with magnesium as described above, and the mixture was subsequently treated with carbon

(4) K. N. Campbell, C. H. Helbing, and J. F. Kerwin, *J. Amer. Chem. Soc.*, **68**, 1840 (1946).

(5) For alternative schemes see (a) R. E. Lutz, *et al.*, *ibid.*, **68**, 1813 (1946); (b) S. Winstein, *et al.*, *ibid.*, **68**, 1831 (1946); (c) K. N. Campbell and J. F. Kerwin, *ibid.*, **68**, 1837 (1946); (d) K. N. Campbell, *et al.*, *ibid.*, **68**, 1844 (1946).

(6) R. L. Jones and C. W. Rees, *J. Chem. Soc.*, 2249 (1969).

(7) Information received from Walter Reed Army Institute of Research; compound to test animal body weight.

(8) J. Overhoff and W. Proost, *Recl. Trav. Chim. Pays-Bas*, **57**, 179 (1938).

(9) H. Gilman and J. L. Towle, *ibid.*, **69**, 428 (1950).

(10) (a) J. P. Wibaut and L. G. Heeringa, *ibid.*, **74**, 1003 (1955), obtained a low yield of diphenyl-(2-quinolyl)carbinol from 2-bromoquinoline but concluded that the use of Grignard reagents in the quinoline series was not of preparative value; (b) R. F. Knott, J. Ciric, and J. G. Breckenridge, *Can. J. Chem.*, **31**, 615 (1953).

(11) Quinoline lithium reagents have been successfully used for this purpose. *Cf.* (a) A. Burger and R. N. Pinder, *J. Med. Chem.*, **11**, 267 (1968); (b) C. J. Ohnmacht, A. R. Patel, and R. E. Lutz, *ibid.*, **14**, 926 (1971).

(12) F. W. Bergstrom and S. H. McAllister, *J. Amer. Chem. Soc.*, **52**, 2847 (1930).

(13) H. Gilman and G. C. Gainer, *J. Amer. Chem. Soc.*, **71**, 2327 (1949).

(14) F. W. Bergstrom and S. H. McAllister, *J. Amer. Chem. Soc.*, **52**, 2845 (1930).

(15) K. Ziegler and H. Zeiser, *Justus Liebigs Ann. Chem.*, **485**, 174 (1931).

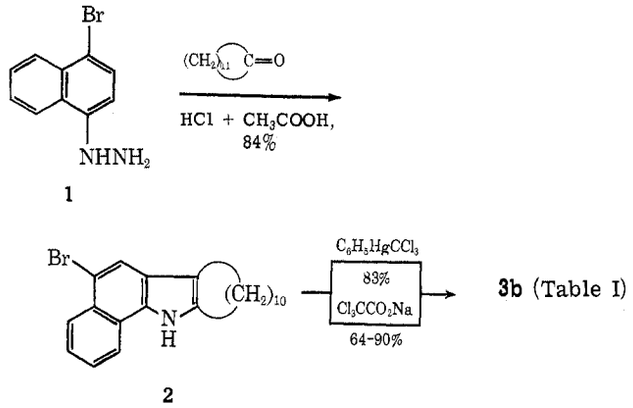
(16) The entraining reagent (1,2-dibromoethane) was not required in all cases; however, higher yields of products were obtained when it was employed, and the procedure was adopted as standard.

TABLE II

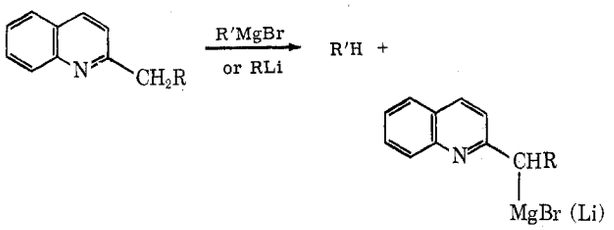
9	R	Mp, °C	Composition, within 0.3% of calcd value for	Yield, %	$\nu_{900-750}$, cm^{-1}
a	H	113–115	C, H, N	*a*	810 (s), 790 (s), 751 (s)
b	Br	224–227	C, H, N	63–77	892 (m), 851 (m), 790 (m), 760 (s)
c	COOH	332–336, dec	C, H, N	42–55[b]	900 (m), 788 (s), 750 (s)
d	D	113–115		56[c]	889 (m), 810 (m), 790 (m), 772 (s), 750 (m)
e	MgBr		Not isolated		

[a] Obtained as a by-product from all reactions of **8e**. [b] Mp 324–327°, 42% (pure) from glacial acetic. [c] 60% deuterium incorporation.

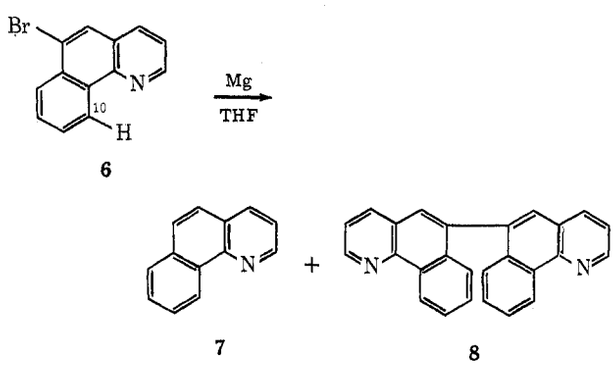
SCHEME I



SCHEME II



SCHEME III

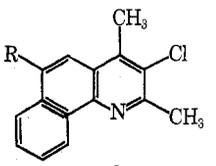


dioxide and benzaldehyde. In neither case was there any evidence (ir) for the formation of carboxylic acid or alcohol. The minor product (13%) was identified as benzo[*h*]quinoline (**7**) and the major product (74%) was a dimer to which structure **8** is assigned (Scheme III). The dimer showed composition, nmr spectrum, and mass spectrum (molecular ion peak at *m/e* 356; second most intense peak at *m/e* 178) consonant with the proposed structure. Assignment of symmetric coupling at the 6 position was based on the infrared spectrum of **8**, which showed no strong peak near 810 cm^{-1}, an absorption which was observed for **7**, **3a**, and **9a**, in which there are two isolated adjacent aromatic hydrogen atoms.

The mechanism for coupling to **8** is not known; however, nucleophilic aromatic displacement of the bromine (which could be catalyzed by a complex between the nitrogen and magnesium bromide) by Grignard reagent was shown not to occur. When **6** was treated with phenylmagnesium bromide, under conditions where coupling to **8** was observed, only unreacted **6** (87% recovery after purification) was isolated. The lack of reactivity of **6** with phenylmagnesium bromide lends further support for the symmetric structure for **8**, since it suggests that addition of Grignard reagents across the azomethine linkage is not a significant side reaction.

6-Bromo-3-chloro-2,4-dimethylbenzo[*h*]quinoline (9b).—5-Bromo-2,3-dimethylbenzo[*g*]indole was prepared (61% yield) from **1** and methyl ethyl ketone (Fisher synthesis) and was converted to **9b** by reaction with phenyl(trichloromethyl)mercury.

Reaction of the Grignard reagent prepared from **9b** with carbon dioxide gave a single acid **9c** (Table II)



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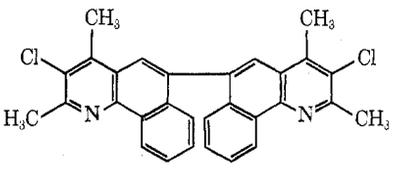
(55% crude, 43% pure), 3-chloro-2,4-dimethylbenzo[*h*]quinoline (**9a**, 6%), and a dimer (~6%) to which structure **10** is assigned.



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In order to determine whether any exchange had occurred of the type shown in Scheme II, the Grignard reagent from **9b** was treated with deuterium oxide and the products were separated by preparative tlc. The deuterium derivative (**9d**) was isolated in 56% yield and dimer **10** was isolated in 6% yield; the position of deuterium was established by spectral evidence. The mass spectrum showed the molecular ion peak of **9d**

(*m/e* 242) as the most intense peak with 60% deuterium incorporation. The nmr spectrum showed no deuterium incorporation in the benzylic methyl groups, but did show incorporation of deuterium in the aromatic region. The ir spectrum of **9d** showed a different absorption pattern from **9a** in the region corresponding to aromatic carbon–hydrogen bending vibrations; **9d** showed absorption at 1185 (s), 889 (m), and 772 (s) cm^{-1}, bands which were not shown by **9a**.

The dimeric product obtained from the D_2O reaction was identical to that obtained from the reaction of **9e** with carbon dioxide, and had spectra consonant with **10**. The mass spectrum showed a parent molecular ion corresponding to **10** (*m/e* 480); the intensity of the P + 2 and P + 4 peaks corresponded to a compound with two chlorine atoms. The nmr spectrum showed only two benzylic methyl peaks (τ 6.63 and 6.80, consistent with symmetric structure). These data, coupled with the fact that the ir spectrum of **10** showed no intense absorption near 810 cm^{-1}, which was observed for all benzo[*h*]quinolines (**7**, **3a**, **8a**) which contained two isolated aromatic hydrogen atoms, are rather convincing evidence that coupling was symmetric, as shown in structure **10**.

13-Bromo-20-chloronaphtho[2′,1′:12,13][10](2,4)pyridinophane (3b).—The Grignard reagent **3n** was treated with carbon dioxide and the acid **3l** was obtained in high yield (~100% crude, 79% after recrystallization). This product was identical to that obtained by hydrolysis of **3c**, which was obtained by reaction of **3b** with cuprous cyanide in dimethylformamide. The yield of pure acid from **3n** was 60 and 83%, respectively, in two subsequent reactions in which the entrainment agent (1,2-dibromoethane) was not employed. The acid **3l**, as other 2-substituted benzo[*h*]quinolines, did not form a hydrochloride salt when its solution (tetrahydrofuran cosolvent) in 5% hydrogen chloride was evaporated.[17]

The simplicity of the Grignard synthesis of **3l** from **3b** provided the model for an improved one-step conversion of **3b** into the ketone intermediate **3d**. This was achieved by inverse addition of **3n** to acetic anhydride in ether at Dry Ice–acetone temperature.[18] A liquid by-product in this synthesis was identified as 4-bromobutyl acetate, which was shown to form rapidly from hot tetrahydrofuran and magnesium bromide, with subsequent reaction with acetic anhydride.

Pyridylmethanols of type **3k** are important intermediates in the preparation of antimalarial drugs and are usually prepared[19] by reaction of the appropriate acid with excess 2-pyridyllithium followed by reduction (metal hydride) of the resulting ketone. Reaction of **3n** with pyridine-2-carboxaldehyde gave a mixture of the two diastereomeric racemates **3k** in quantitative yield, and these were separated into the two racemic pairs by fractional crystallization. This sequence is a superior route for the introduction of such functional groups into systems which form stable Grignard reagents.

While Grignard reagents are not generally considered useful intermediates for synthetic conversions in quinoline systems, these results establish that they are quite useful in the naphthopyridinophane series, and are useful to a lesser, but still practical, extent with 2-alkylbenzo[*h*]quinolines (**9b**). The stability and utility of these reagents is apparently not related to the decreased acidity[20] of α- or γ-alkyl hydrogen atoms in **3**, since no interchange of the type shown in Scheme II was noted for **9b**. Furthermore, studies of the reaction of **5** with magnesium, followed by carbonation, indicate that a rather complex mixture of products is formed.

Coupling can become the major reaction in the naphtho[*h*]quinoline series, as shown for **6**. While the mechanism of coupling is not known, the lack of coupling parallels steric hindrance of the azomethine linkage.

All of the benzo[*h*]quinolines studied showed an aromatic hydrogen absorption (nmr) at low field (τ 0.66 in **6**). This observation is consistent with R. H. Martin[21] and coworkers' assignment of this hydrogen as the one marked 10 in formula **6**.

Experimental Section

Analyses were performed by the M-H-W Laboratory, Garden City, Mich. Infrared spectra were obtained on a Perkin-Elmer Model 257 spectrometer. Ultraviolet spectra were obtained on a Beckman Model DK-A. Nuclear magnetic resonance spectra were obtained on a Varian Associates Model T-60 spectrometer. Melting point data were obtained with a Mel-Temp, and were uncorrected unless otherwise indicated. Petroleum ether is bp 60–70°, unless otherwise noted.

Benzo[*h*]quinolines.—Procedure A, using phenyl(trichloromethyl)mercury, was similar to that reported in ref 3; however, the hydrochloride salts of the resulting quinolines were not employed. Procedure B, using sodium trichloroacetate, was similar to those described in ref 6. Compounds were purified by chromatography [alumina, petroleum ether–benzene (5–50%) as eluent]. Most physical data are reported in Table I and only supporting data as to procedure are reported here.

13-Bromo-20-chloronaphtho[2′,1′:12,13][10](2,4)pyridinophane (3b). Procedure A. From Indole 2 (0.70 g, 1.82 mmol).—Product was purified by chromatography (Alcoa F-20 alumina) using petroleum ether–15% benzene as eluent, and was recrystallized from petroleum ether. **Procedure B.**—It was important to dissolve the sodium trichloroacetate by careful warming prior to adding indole to avoid tar formation. Yield was 91% (from petroleum ether) from 3.0 mmol of indole and 9.0 mmol of salt; yield was 60% when scale of reaction was increased tenfold.

9-Bromo-16-chloronaphtho[2′,1′:8,9][6](2,4)pyridinophane (**4**) was obtained from 5-bromo-7,8,9,10,11,12-hexahydro-13*H*-benzo[*g*]cyclooct[*b*]indole (0.352 g) by procedure A (as for **3b**): yield 0.308 g (77%), mp 187–189°; $uv_{max}^{cyclohexane}$ 218 mμ (log ε 4.40), 266 (4.62), 279 (4.56), 296 (sh, 4.15), 305 (sh, 4.02), 318 (3.94), 353 (3.39), 372 (3.42).

Anal. Calcd for $C_{19}H_{17}BrClN$: C, 60.90; H, 4.57; N, 3.74. Found: C, 60.97; H, 4.40; N, 3.54.

13-Bromo-18-chloro-12,13-benzo[10](2,4)pyridinophane (**5**) was obtained from 2-bromo-5,6,7,8,9,10,11,12,13,14,15-undecahydrocyclododec[*b*]indole (26.5 g, 0.079 mol) by procedure B; yield was 41% (mp 96–98°).

Anal. Calcd for $C_{19}H_{23}NBrCl$: C, 59.91; H, 6.09; N, 3.68. Found: C, 60.13; H, 6.22; N, 3.54.

20-Chloronaphtho[2′,1′:12,13][10](2,4)pyridinophane (**3a**) was obtained from 7,8,9,10,11,12,13,14,15,16-decahydro-17*H*-benzo-

(17) R. E. Lutz, *et al.*, *J. Amer. Chem. Soc.*, **68**, 1813 (1946), reported that 2,8-disubstituted quinolines do not lead to stable hydrobromides, presumably for steric reasons.

(18) M. S. Newman and A. S. Smith, *J. Org. Chem.*, **13**, 592 (1948).

(19) D. W. Boykin, Jr., A. R. Patel, and R. E. Lutz, *J. Med. Chem.*, **11**, 273 (1968).

(20) It has been shown (ref 3) that substituents on the α-methylene carbon atom in the pyridinophane structure are resistant to SN1 and SN2 reactions, and it has been suggested that steric factors do not favor stabilization of a developing carbonium ion (sp^2 carbon) at this center. Similarly, one would not expect carbanions to be easily formed at this position. D. J. Cram and L. A. Singer, *J. Amer. Chem. Soc.*, **85**, 1084 (1963), have shown that, as the ring size in paracyclophanes is decreased, the acidity of benzylic methylene is decreased.

(21) R. H. Martin, N. Defay, F. Geerts-Evrard, and D. Bogaert-Verhoogen, *Tetrahedron, Suppl. 8*, Part I, 181 (1966).

[g]cyclododec[b]indole (1.00 g) by procedure A: yield 0.82 g (71%); mp 129–131°; $uv_{max}^{cyclohexane}$ 214 mμ (log ε 4.43) 221 (4.38), 242 (sh, 4.59), 247 (4.63), 253 (sh, 4.57), 273 (4.47), 285 (sh, 4.20), 304 (3.87), 322 (3.38), 337 (3.68), 353 (3.81).

Anal. Calcd for $C_{23}H_{26}ClN$: C, 78.50; H, 7.45; N, 3.98. Found: C, 78.61; H, 7.52; N, 3.92.

6-Bromobenzo[h]quinoline (6) was prepared from 4-bromo-α-naphthylamine using a general procedure for the Skraup synthesis reported by Manske, *et al.*[22] The pale green crystals (11.00 g, 43% yield, mp 112–113°) gave light yellow needles (mp 117–119°, lit.[23] 115–116.5°) when recrystallized from petroleum ether.

6-Bromo-3-chloro-2,4-dimethylbenzo[h]quinoline (**9b**, **Table II**) was obtained from 5-bromo-2,3-dimethylbenzo[g]indole (3.00 g, 0.11 mol) by procedure A. The precipitate contained phenylmercuric chloride and some **9b**. Combined precipitate and solid, obtained by removal of benzene, was chromatographed over 235 g of alumina using petroleum ether–benzene (to 25%) as eluent to give **9b** as white crystals: 2.69 g, 77% yield, mp 223–227°; yield 63%, mp 224–227° from petroleum ether; $uv_{max}^{cyclohexane}$ 212 mμ (log ε 4.32), 225 (sh, 4.33), 231 (4.36), 247 (sh, 4.59), 252 (4.69), 262 (sh, 4.43), 272 (4.50), 282 (sh, 4.22), 292 (4.05), 304 (4.10), 322 (3.48), 332 (sh, 3.30), 337 (3.81), 348 (sh, 3.30), 354 (3.91).

4-Bromo-α-naphthylhydrazine (**1**).—4-Bromo-α-naphthylamine (25.0 g) was converted to **1** by a modification of the procedure reported by Plant and Tomlinson.[24] The diazonium salt was reduced with stannous chloride as described in ref 24. The mixture was cooled; the solid was collected and crystallized from water–20% ethanol to give the hydrochloride of **1** as silver needles. This procedure is simpler than that previously reported. The free base is unstable to air and was stored as the hydrochloride. The hydrazine **1** was generated as needed by treating the salt with aqueous sodium acetate. The solid was crystallized from ethanol to give orange needles (66% overall yield, mp 134–136° dec, lit.[24] mp 138–139°).

Indoles.—Buu-Hoï, *et al.*,[25] reported the preparation of analogous indoles by treating the corresponding hydrazones with glacial acetic acid saturated with hydrogen chloride. When these conditions were employed, only black tars were isolated; much better results were obtained when only 1 equiv of hydrogen chloride was used.

5-Bromo-7,8,9,10,11,12-hexahydro-13*H*-benzo[g]cyclooct[b]indole (Precursor to 4).—The hydrazine **1** (0.85 g, 3.6 mmol) was added to a 125-ml flask along with 5 ml of ethanol and five drops of glacial acetic acid. Cyclooctanone (0.455 g, 3.6 mmol) was added and the mixture was heated for 45 min. The red oil obtained by removal of solvent was added to 15 ml of glacial acetic acid. One milliliter of glacial acetic acid saturated with hydrogen chloride was added and the mixture was heated at reflux for 2 hr. The product was poured into water and the mixture was extracted with benzene. The benzene was washed (aqueous Na_2CO_3), dried (Na_2SO_4), filtered from charcoal, and concentrated. The red oil was crystallized from petroleum ether and from ethanol–water to give the indole as light yellow needles [0.70 g, 59% yield, mp 112–114°; ν_{N-H} 3410 cm^{-1}].

Anal. Calcd for $C_{18}H_{18}BrN$: C, 65.85; H, 5.53; N, 4.27. Found: C, 65.79; H, 5.45; N, 4.18.

5-Bromo-7,8,9,10,11,12,13,14,15,16-decahydro-17*H*-benzo[g]cyclododec[b]indole (2) (Precursor to 3b).—The procedure was essentially identical to that described above but cyclododecanone was employed. An acetic acid solution of hydrazone and hydrogen chloride (1 equiv) was heated at the reflux temperature for 75 min; then the solution was quenched with ice water and the solid product was filtered and crystallized from ethanol–20% benzene to give white needles [10.15 g, 71%, yield, decomposition starts at 145°; ν_{N-H} 3420 (s) cm^{-1}].

Anal. Calcd for $C_{22}H_{26}BrN$: C, 68.75; H, 6.82; N, 3.65; Br, 20.78. Found: C, 68.73; H, 6.67; N, 3.53; Br, 21.09.

7,8,9,10,11,12,13,14,15,16-Decahydro-17*H*-benzo[g]cyclododec[b]indole (Precursor to 3a).—The procedure was that described above using α-naphthylhydrazine[26] and cyclododecanone. The crude product was chromatographed (alumina; eluent, petroleum ether–50% benzene) and the indole was obtained as a yellow oil which was crystallized from petroleum ether to give the indole as yellow clusters [2.17 g, 72% yield, mp 102–106°; ν_{N-H} 3460 (s) cm^{-1}]. Recrystallization from ethanol–water yielded white clusters (mp 105–106.5°).

Anal. Calcd for $C_{22}H_{27}N$: C, 86.50; H, 8.91; N, 4.59. Found: C, 86.33; H, 9.01; N, 4.44.

3-Bromo-5,6,7,8,9,10,11,12,13,14,15-undecahydrocyclododec[b]indole (Precursor of 5).—Prepared from 4-bromophenylhydrazine (22.3 g, 0.1 mol) and cyclododecanone (18.2 g, 0.1 mol) by general procedure of Buu-Hoï, *et al.*[25] Product was purified by recrystallization from petroleum ether (97% yield, mp 93–95°).

Anal. Calcd for $C_{18}H_{24}BrN$: C, 64.69; H, 7.18; N, 4.19; Br, 23.9. Found: C, 64.50; H, 7.36; N, 4.06; Br, 23.84.

5-Bromo-2,3-dimethylbenzo[g]indole (Precursor to 9b).—The procedure described above did not provide this indole; a modification of the procedure reported by Atkinson, *et al.*,[27] using boron trifluoride etherate in acetic acid was employed. The black oil gave the indole [5.65 g, 61% yield, mp 92° dec; ν_{N-H} 3405 (s) cm^{-1}] as tan needles subsequent to chromatography (alumina, petroleum ether–diethyl ether as eluent) and recrystallization.

Anal. Calcd for $C_{14}H_{12}BrN$: C, 61.32; H, 4.42; N, 5.11. Found: C, 61.54; H, 4.49; N, 5.03.

Solutions of the indole in CCl_4 or $CHCl_3$ rapidly turned to a purple dye when exposed to air.

20-Chloronaphtho[2′,1′:12,13][10](2,4)pyridinophane-13-nitrile (3c) was prepared from **3b** (2.15 g, 0.005 mol) and cuprous cyanide in dimethylformamide (6 hr at 155–160°) by the procedure described by Friedman and Schechter.[28] The yellowish-white crude nitrile [yield 1.78 g (100%), mp 229–230°] was recrystallized from benzene–petroleum ether to give colorless crystals (1.54 g, 86% yield, mp 231–232°; ν_{CN} 2208 cm^{-1}).

20-Chloronaphtho[2′,1′:12,13][10](2,4)pyridinophane-13-carboxylic Acid (3l). (1) **From 3c.**—The nitrile **3c** (1.25 g) was hydrolyzed with potassium hydroxide in glycerol (180°, 15 hr) by the procedure described by Campbell, *et al.*[4,5] The crude product was purified by chromatography (silica gel with chloroform and chloroform–methanol as eluent) to give **3c** (36% recovery) and **3l** (54% yield crude; 0.44 g, 33% from ethanol, mp 280–282°).

(2) **General Grignard Procedure.**—A mixture of quinoline **3b** (4.00 g, 9.29 mmol), magnesium turnings, (0.544 g, 0.0224 g-atom, 20% excess), and dry tetrahydrofuran (50 ml distilled from $LiAlH_4$) was heated in a glass apparatus (flame dried under nitrogen) at the reflux temperature under an atmosphere of nitrogen. 1,2-Dibromoethane (1.74 g, 9.2 mmol in 17 ml of tetrahydrofuran) was added dropwise over a 2-hr period while maintaining the reaction solution at the reflux temperature. The solution was then maintained at the temperature for an additional 30 min. After cooling the reaction solution to room temperature, dry carbon dioxide (Matheson) was bubbled through the solution for 2.5 hr and then 5% aqueous hydrochloric acid (15 ml) was added. The solvent was evaporated and the resulting crude solid was washed with 5% hydrochloric acid and water. After drying (vacuum desiccator), the product was crystallized from ethyl acetate to small white needles (2.92 g, 79% yield, mp 280–284°) which showed an undepressed mixture melting point when admixed with **3l** obtained from nitrile.

20-Chloronaphtho[2′,1′:12,13][10](2,4)pyridinophan-13-yl Methyl Ketone (3d). (1) **From 3c.**—The ketone was prepared by reaction of **3c** (0.753 g) with methylmagnesium iodide by the general procedure of Callen, *et al.*[29] The product was purified by chromatography [silica gel, benzene–petroleum ether (30%) as eluent] to give **3c** (0.24 g) and **3d** (57% yield, mp 207–208° from benzene–petroleum ether; $\nu_{C=O}$ 1690 cm^{-1}).

(2) **From 3n.**—The Grignard reagent prepared as described for **3l** was slowly added to a diethyl ether solution of acetic anhydride at ~−70° by the general procedure described by Newman and Smith,[18] and was purified by chromatography as described above; the methyl ketone (**3d**) from the column was washed with petroleum ether and dried (mp 210–211°, 70% yield). The petroleum ether washings were concentrated to the 4-bromobutyl acetate by-product.

(22) R. H. F. Manske, Leo Marion, and F. Leger, *Can. J. Res. Sect. B*, **20**, 133 (1942).

(23) W. P. Utermohlen, Jr., and C. S. Hamilton, *J. Amer. Chem. Soc.*, **63**, 156 (1941).

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(25) Ng. Ph. Buu-Hoï, P. Jacquignon, and T. B. Loc, *ibid.*, 738 (1958).

(26) E. Fischer, *Justus Liebigs Ann. Chem.*, **232**, 236 (1886).

(27) C. M. Atkinson, J. C. E. Simpson, and A. Taylor, *J. Chem. Soc.*, 165 (1954).

(28) L. Friedman and H. Shechter, *J. Org. Chem.*, **26**, 2522 (1961).

(29) J. E. Callen, C. A. Dornfeld, and G. H. Colerman, *Org. Syn.*, Coll. Vol. **3**, 26 (1964).

(3) **From 3l.**—A solution of **3l** (0.70 g) in tetrahydrofuran was treated with methyllithium (4 equiv) at room temperature. The solution was stirred for 30 min and then quenched with water. The solvent was evaporated and the crude product was chromatographed (silica gel, eluent, petroleum ether–to 50% benzene) to give **3d** (32% yield, mp 212.5–214°) subsequent to crystallization from petroleum ether.

(4) **From 3e.**—Attempts to prepare the corresponding bromohydrin by reduction of **3e** by the general procedure of Winstein, *et al.*,[30] (Meerwein–Ponndorf reduction) gave primarily ketone **3d**.

20-Chloronaphtho[2′,1′:12,13][10](2,4)pyridinophan-13-yl Bromomethyl Ketone (3e).—A variety of conditions[4,5] were explored with yields of **3e** varying from 0[31] to 88%. Bromine (2.4 g, 0.015 mol) in acetic acid (30 ml) was added dropwise over a 1.5-hr period to a boiling solution of **3d** (5.90 g, 0.015 mol) in glacial acetic acid (210 ml). The solid, obtained by cooling the mixture and dilution with water, was extracted with chloroform and the extract was washed (aqueous sodium bicarbonate, water) and dried. The solid (7.83 g, mp 200–205°) obtained by evaporation of chloroform was purified by chromatography (silica gel, 400 g). The first product, eluted with benzene–petroleum ether, was dibromide **3o** (1.0 g, 12% yield, mp 161–162°; mp 164° from petroleum ether; $\nu_{C=O}$ 1692 cm^{-1}). The second fraction, eluted with benzene was **monobromide 3e** (6.19 g, 88% yield, mp 207–208° from chloroform–petroleum ether; $\nu_{C=O}$ 1700 cm^{-1}). The third fraction also eluted with benzene was recovered **3d** (3.4%).

Attempts to **reduce 3e to the epoxide** with sodium borohydride in methanol[32a] gave recovered **3e** (85%); reduction with sodium borohydride in diglyme[32b] gave a mixture of five products (tlc).

20-Chloro-α-(di-*n*-heptylaminomethyl)naphtho[2′,1′:12,13]-[10](2,4)pyridinophane-13-methanol (3g).—Di-*n*-heptylamine (0.266, 1.25 mmol) in dry benzene (20 ml) was added over a period of 1 hr to a solution of **3e** (0.236 g, 0.50 mmol) in dry benzene (30 ml) at 30° under nitrogen. The mixture was stirred for 24 hr and concentrated (rotatory evaporator); dry diethyl ether was added and di-*n*-heptylamine hybromide (135.5 mg, 94.4%) was filtered. The filtrate (which was kept at 30°), containing excess amine and **ketone 3f** ($\nu_{C=O}$ 1680 cm^{-1}), was added dropwise to a stirred suspension of $LiAlH_4$ (80 mg, 0.002 mol) in dry diethyl ether (20 ml) maintained at gentle reflux. The mixture was heated for an additional 40 min and was then cooled, filtered, and concentrated to an oil [di-*n*-heptylamine and **3g** (~100% yield)]. The mixture was chromatographed over silica gel. Elution with 2% methanol in benzene gave **one racemic isomer** (154 mg, 52% yield, mp 130–131° from petroleum ether). Further elution of the column with the same eluent gave the second diastereomer contaminated with some di-*n*-heptylamine. This product was rechromatographed (same conditions) to give the **second racemic isomer** as an oil with composition calculated for $C_{38}H_{59}ClN_2O$. Differences in R_f values and ir spectra suggested that the second isomer was free of the first.

20-Chloro-α-(di-*n*-butylaminomethyl)naphtho[2′,1′:12,13][10]-(2,4)pyridinophane-13-methanol (3i) was prepared from **3e** and di-*n*-butylamine as described for **3g**. The intermediate ketone **3h** ($\nu_{C=O}$ 1675 cm^{-1}) was unstable. The diastereomeric racemates (**3i**) were obtained as an oil (0.24 g, 82% yield) and no resolution was achieved by chromatography as described for **3g**.

20-Chloro-α-(2-pyridyl)naphtho[2′,1′:12,13][10](2,4)pyridinophane-13-methanol (3k).—The Grignard reagent **3n** (from 4.00 g, 9.27 mmol of **3b**) was prepared as described in the preparation of **3l**, and was treated with freshly distilled 2-pyridinecarboxyaldehyde (0.99 g, 9.27 mmol) at ice bath temperature; the mixture was allowed to warm to 30° before quenching with water. The dry oil obtained subsequent to neutralization (aqueous NH_4Cl) and extraction (diethyl ether) was chromatographed (silica gel; eluent, petroleum ether to diethyl ether), and 4.35 g (100% crude yield, mp 152–166°) of a mixture of the two diastereomeric racemates of **3k** was obtained. The mixture contained approximately 50% of each racemate (determined by nmr, the aromatic 12H proton absorbs at τ 2.00 for isomer A and at τ 2.14 for isomer B).

The mixture was crystallized from 95% ethanol and then 20% chloroform in petroleum ether to give isomer A as white crystals (mp 173–186°) in 40% yield (pure by nmr spectroscopy at τ 2.00). Several recrystallizations of a sample with the composition calculated for $C_{29}H_{31}ClN_2O$ did not sharpen the broad melting range.

The mother liquors from the above purification were concentrated and the resulting material was crystallized (20% $CHCl_3$ in petroleum ether) to give isomer B as white crystals (mp 174–176°) in 18% yield (pure by nmr spectroscopy at τ 2.14). The two diastereomers showed similar but not identical spectra and a mixture melting point of the two was depressed (mmp 157–179°).

When a 50% molar excess of 2-pyridinecarboxyaldehyde was used and the mixture was heated at the reflux temperature for 30 min, a **third component (3j)** was formed and isolated in 20% yield ($\nu_{C=O}$ 1672 cm^{-1}). The crude reaction mixture was separated by column chromatography (silica gel; eluent, petroleum ether to 80% diethyl ether) to give **3a** in 8%, **3j** in 20%, and **3k** in 61% yield.

Reaction of 6 with Magnesium.—6-Bromobenzo[*h*]quinoline (**6**) (2.40 g) was reacted with magnesium as described for the preparation of **3l** and carbon dioxide was introduced (2 hr) followed by the addition of 5% aqueous hydrochloric acid (15 ml). The solvent (THF) was removed and **dimer 8** was collected as a tan solid (74% yield, mp 325–330°). The dimer was most readily purified by sublimation (little loss) at 250° (0.005 mm): mp 342–345°; $\lambda_{max}^{95\%}$ 225 mμ (sh, log ε 4.75), 235 (4.86), 270 (4.70), 297 (sh, 4.19), 316 (371), 331 (3.76), 347 (3.78); nmr (12% in trifluoroacetic acid, areas relative to 16 protons) τ 0.48–0.89 (m, 5.5), 1.39–2.36 (m, 10.5); mass spectrum, base peak 356 (molecular ion), 178 (monomer), 29% of base peak.

Anal. Calcd for $C_{26}H_{16}N_2$: C, 87.61; H, 4.52; N, 7.86. Found: C, 87.53; H, 4.71; N, 7.70.

The acid filtrate from above was evaporated to dryness and extracted with chloroform (no carboxylic acid in extract). The residue, after removal of chloroform, was dissolved in water, made basic, and extracted with ether. The oil obtained from the ether extract was chromatographed [Alcoa F-20, petroleum ether–diethyl ether (to 25%)] to give benzo[*h*]quinoline (**7**) (13.3%, mp 49–52°, lit.[33] 52°; ir spectrum identical with that published).[34]

Reactions of 9b with Magnesium. (1) **Isolation of Acid 9c, Quinoline 9a, and Dimer 10.**—The reaction of **9b** (1.00 g, 3.12 mmol) with magnesium and carbon dioxide was effected as described for **6**. The reaction was quenched with 5% hydrochloric acid (6 ml), and after the mixture was stirred for 1 hr, the solvent was removed (rotatory evaporator) to a gray solid. A portion (0.329 g) of the gray solid thus obtained (0.817 g) was heated with benzene (25 ml, 4 hr). **Acid 9c** [$\nu_{C=O}$ 1684 (s) cm^{-1}] was insoluble in benzene; the extract contained **9a** (~6%) and dimer **10** (~6%), which were separated by preparative tlc (25 g of silica gel PF_{254} on 20 × 20 cm plate using petroleum ether–50% benzene). **The band** with R_f **0.60 was 9a** (0.018 g, 6% yield, mp 113–115° from pentane): nmr (5% w/v $CDCl_3$) τ 0.56–0.75 (m, 1 ArH at 10 position), 2.04–2.40 (m, 5.0, ArH), 7.12 (s, 3.0, CH_3), 7.25 (s, 3.0, CH_3).

Anal. Calcd for $C_{15}H_{12}ClN$: C, 74.52; H, 5.00; N, 5.79. Found: C, 74.33; H, 5.14; N, 5.72.

The band with R_f **0.37 was dimer 10** (0.10 g, 6% yield, mp 330–334°): ir 3040 (w), 2900 (m), 2840 (w), 1580 (m), 1505 (m), 1438 (s), 1382 (s), 1010 (s), 865 (m), 768 (s), 750 (w), 740 (m), 730 (m) cm^{-1}; mass spectrum, molecular ion (*m/e* 480, base peak), intensity of P + 2 (66% of parent peak) and P + 4 (14% of parent peak) corresponding to 2 chlorines.

(2) **Isolation of 9d.**—The reagent **9e** was formed from **9b** (0.316 g) as described above and treated with deuterium oxide (2 ml); solvent was removed and the residue was extracted with chloroform. The solid obtained from the extract was purified by preparative tlc as described above. The derivative **9d** was obtained in 56% yield: mp and mmp (with **9a**) 114–115.5°; ir showed additional bands at 1185 (w), 889 (m), 772 (s) cm^{-}; nmr (10% in $CDCl_3$) (areas relative to 11.4 protons) τ 0.60–0.88 (m, 1.0, ArH at 10 position), 2.05–2.44 (m, 4.4, ArH), 7.16 (s, 3.0, CH_3), 7.33 (s, 3.0, CH_3); mass spectrum showed molecular ion peak (*m/e* 242) as base peak and 60% deuterium incorporation. The **dimer 10** (0.015 g, 6% yield, mp 323–325°)

(30) (a) S. Winstein, T. L. Jacobs, R. B. Henderson, and W. H. Florsheim, *J. Org. Chem.*, **11**, 150 (1946); (b) S. Winstein, *et al.*, *J. Amer. Chem. Soc.*, **68**, 1831 (1946).

(31) E. May and E. Mosettig, *J. Org. Chem.*, **11**, 10 (1946).

(32) (a) S. W. Chaikin and W. G. Brown, *J. Amer. Chem. Soc.*, **71**, 122 (1949); (b) E. T. McBee and T. M. Burton, *ibid.*, **74**, 3022 (1952).

(33) E. Bamberger and L. Stettenheimer, *Ber.*, **24**, 2473 (1891).

(34) "Sadtler Index of Infrared Spectra," Sadtler Research Laboratories, Philadelphia, Pa., 1967, No. 8691K.

was also isolated from the preparative tlc plate [ir spectrum identical to that obtained as described in (1), above].

Registry No.—**1**, 35158-78-2; **2**, 35158-79-3; **3a**, 35158-80-6; **3a** (precursor to), 13226-05-6; **3b**, 35158-82-8; **3c**, 35158-83-9; **3d**, 35158-84-0; **3e**, 35158-85-1; **3g** (one racemic isomer), 35158-86-2; **3g** (second racemic isomer), 35158-87-3; **3i** (one racemic isomer), 35158-88-4; **3i** (second racemic isomer), 35158-89-5; **3j**, 35158-90-8; **3k** (one racemic isomer), 35158-91-9; **3k** (second racemic isomer), 35158-92-0; **3l**, 35158-93-1; **3m**, 35158-94-2; **3o**, 35191-47-0; **4**, 35158-95-3; **4** (precursor to), 35158-96-4; **5**, 35158-97-5; **5** (precursor to), 35158-98-6; **8**, 35158-99-7; **9a**, 35159-00-3; **9b**, 35159-01-4; **9b** (precursor to), 35159-02-5; **9c**, 35159-03-6; **9d**, 35159-04-7; **10**, 35159-05-8.

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Medium-Sized Cyclophanes. XIII. A Highly Selective Cycloisomerization Reaction of [2.2]Metacyclophanes to 1,2,3,3a,4,5-Hexahydropyrenes Induced by Iodine[1]

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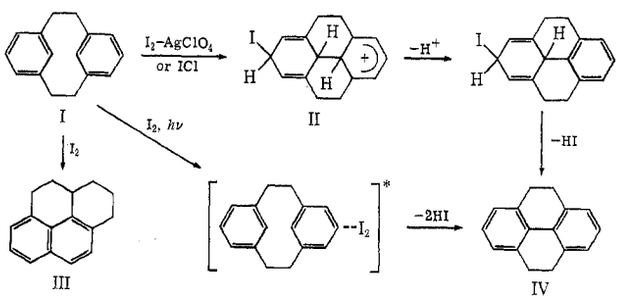
[2.2]Metacyclophane (I) underwent an iodine-induced cycloisomerization reaction to give 1,2,3,3a,4,5-hexahydropyrene (III) with remarkable ease and in high yield. The generality of the isomerization has been established using several alkyl derivatives (V–VII), which gave the corresponding hexahydropyrenes (VIII–XII), and efficacious reaction conditions have been broadly examined. Cross experiments using [2.2]metacyclophane-*8,16-d*$_2$ indicate the reaction might to involve intermolecular hydrogen transfer. Competitive experiments between I and alkyl derivatives suggest that a π-complex mechanism might apply.

Owing to electronic interactions between two benzene rings, the proximity of 8,16 positions, and the considerable strain energy, [2.2]metacyclophane (I) is prone to give transannular reaction products.[2] These are mostly explained by the initial formation of a dehydrogenation product, 4,5,9,10-tetrahydropyrene (IV) (Scheme I). It has been isolated under electrophilic,[3-6] radical,[7] and photolytic reaction conditions[4,8,9] together with other transformation products derived from IV.

Nitration with benzoyl nitrate[5] (reactive species, N_2O_5), which is preferred over nitric acid[3] for stoichiometric control and for homogeneous reaction conditions or bromination using iron catalyst[3,6] afforded substituted 4,5,9,10-tetrahydropyrene *via* IV. Attempted iodination of I using iodine and silver perchlorate[4,6] or iodine chloride[6] gave a high yield of IV. No further iodination occurred under the reaction conditions.

SCHEME I



A similar dehydrogenation–substitution scheme was postulated for a derivative of I.[3,10,11] Photolysis of I in the presence of iodine[4,8] or a suitable oxidant[9] afforded IV as the main product. Lack of conjugation between two aryl moieties in I demands a different mechanism from that postulated for *cis*-stilbene → phenanthrene.[12] It is likely to involve photoexcitation of the charge-transfer complex between I and iodine followed by dehydroiodination.[8] With iodine as a reactant the formation of IV is illustrated in Scheme I, where an addition–elimination mechanism is postulated for the attack of an electrophile.

We have found still another type of iodine-induced reaction of I which gives 1,2,3,3a,4,5-hexahydropyrene (III) with remarkable ease and with high selectivity.[1] When a benzene solution of I containing iodine was warmed at 60°, III[13] was produced in a quantitative yield. These reactions carried out in benzene and cyclohexane are summarized in Table I. No reaction

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