Reactions of 2,2′-Biphenyldicarboxaldehyde[1]

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The chemical reactivity of 2,2′-biphenyldicarboxaldehyde, readily obtainable from phenanthrene, was studied. Reductive amination of the dialdehyde by sodium hydrosulfite was found to be a new method of preparation for 6,7-dihydro-5*H*-dibenz[*c*,*e*]azepine and its 6-substituted derivatives. Several new azepine derivatives were prepared also. The aldol condensation of the dialdehyde with acetophenone, as well as the reduction of the dialdehyde to the corresponding diol, was investigated. A light-catalyzed internal condensation of the dialdehyde yielded phenanthraquinone. Other selected reactions were studied.

Although 2,2′-biphenyldicarboxaldehyde (I) was first reported by Kenner and Turner[3,4] in 1911 and later by other workers,[5] it has received only limited study because no simple method has existed for its preparation. Recent studies[6] on the ozonolysis of phenanthrene have resulted in a relatively simple preparation of the dialdehyde from a potentially abundant starting material. The ready availability of this dialdehyde thus served as a practical stimulus to our investigation of its chemical behavior.

2,2′-Biphenyldicarboxaldehyde (I) reacted with ammonia and primary amines to give Schiff-type bases. When I was heated with ammonium hydroxide, 5-hydroxy-5*H*-dibenz[*c*,*e*]azepine (II) was formed. The structure of II was assigned from elemental analysis and its infrared and n.m.r. spectra. Infrared adsorption bands appeared at 6.15 μ (—N=C—) and 3.2–3.3 μ (—O—H). When I reacted with benzylamine, methylamine, or aniline, 2,2′-bi(N-benzylbenzylidenimine) (IIIa), 2,2′-bi(N-methylbenzylidenimine) (IIIb), or 2,2′-bi(N-phenylbenzylidenimine) (IIIc) were the respective products. F. Mayer[5a] reported IIIc from the reaction of N-(*o*-iodobenzylidene)aniline and "Naturkupfer C." Infrared adsorption bands for the —N=C— linkage in these compounds occurred at 6.10 to 6.15 μ.

When II, IIIa, and IIIb were refluxed with aqueous sodium hydrosulfite, 6,7-dihydro-5*H*-dibenz[*c*,*e*]azepine (IVa) and the 6-substituted derivatives (IVb and IVc) were the respective products. Hydrosulfite reduction of 2,2′-biphenyldicarboxaldehyde monoxime also gave IVa.

Raney nickel catalyst was sufficiently active for the low-pressure hydrogenation of IIIc to IVd but not II to IVa. However, hydrogenation at higher pressure of an ethanolic solution of I and methylamine over Raney nickel yielded IVc. Low-pressure hydrogenation of I with benzylamine or methylamine over palladium catalyst gave the respective products, IVb and IVc. Only representative azepines were prepared by the various methods of reduction, and no attempt was made to study exhaustively the several different possible combinations.

It was found unnecessary to isolate the Schiff bases prior to reduction by sodium hydrosulfite. By first refluxing I with the proper amine in methanol followed by treatment with the hydrosulfite, 6-allyl (IVe), 6-(3-dimethylaminopropyl) (IVf), 6-(3-diethylaminopropyl) (IVg), and 6-(2-aminoethyl)-6,7-dihydro-5*H*-dibenz[*c*,*e*]azepine (IVh) were prepared also.

With the exception of the latter three derivatives, these 6,7-dihydroazepines had been prepared by the reaction of *o*,*o*′-bis(bromomethyl)biphenyl with ammonia or with primary amines.[7] A second method involved the reaction of diphenic anhydride with ammonia to give diphenamic acid. Diphenamic acid was cyclized to diphenimide, which was in turn reduced by lithium aluminum hydride to IVa.[8] Recently, 2,2′-bis(hydroxymethyl)biphenyl has reacted with ammonia to give IVa.[9]

The present method of synthesizing these azepines is superior to previous methods because of the availability of the initial starting material, phenanthrene. The yields of the azepines, isolated as acid salts, ranged from 57 to 92%.

During the present work, a British patent[10] was granted to Hoffman–LaRoche Company for the reductive amination of the dialdehyde to azepines. However, the use of sodium hydrosulfite in reductive amination of an aldehyde appears to be novel.

Randall and Smith[11] screened the 6-substituted azepines for pharmacological activity and demonstrated their antiepinephrine properties. Compound IVe was the most effective member of the group that was tested.

When a solution of IIIa in N,N-dimethylformamide was refluxed with copper chromite, dehydrocyclization occurred to yield 2,3-diphenyldibenz[*f*,*h*]quinoxaline (V).[12]

Sparatore[13] reacted I and *o*-phenylenediamine in methanol for 48 hours and obtained a glass, m.p. 52–57°, for which he assigned the probable structure of 15*H*-dibenzo[*c*,*e*]benzimidazo[1,2-*a*]azepine (VI) rather than the other possible structure, VIa. An uncharacterized hydrochloride melted at 260–265°.

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(3) J. Kenner and G. Turner, *J. Chem. Soc. Proc.*, **27**, 92 (1911).

(4) J. Kenner and G. Turner, *J. Chem. Soc.*, **99**, 2101 (1911).

(5) (a) F. Mayer, *Ber.*, **45**, 1108 (1912); (b) F. Weygand, G. Eberhardt, H. Linden, F. Schafer, and I. Eigen, *Angew. Chem.*, **65**, 525 (1953); (c) O. Chapman and J. Meinwald, *J. Org. Chem.*, **23**, 162 (1958).

(6) (a) W. J. Schmitt, R. J. Moriconi, and W. F. O'Connor, *J. Am. Chem. Soc.*, **77**, 5640 (1955); (b) P. S. Bailey, *ibid.*, **78**, 3811 (1956); (c) P. S. Bailey, *J. Org. Chem.*, **23**, 1089 (1958); (d) M. G. Sturrock, E. L. Cline, and K. R. Robinson, U. S. Patent 2,898,350.

(7) (a) W. Wenner, *J. Org. Chem.*, **16**, 1475 (1951); (b) **17**, 1451 (1952); (c) W. Wenner, U. S. Patent 2,619,484 (November 25, 1952).

(8) R. A. Schmidt and W. Wenner, U. S. Patent 2,693,465 (November 2, 1954).

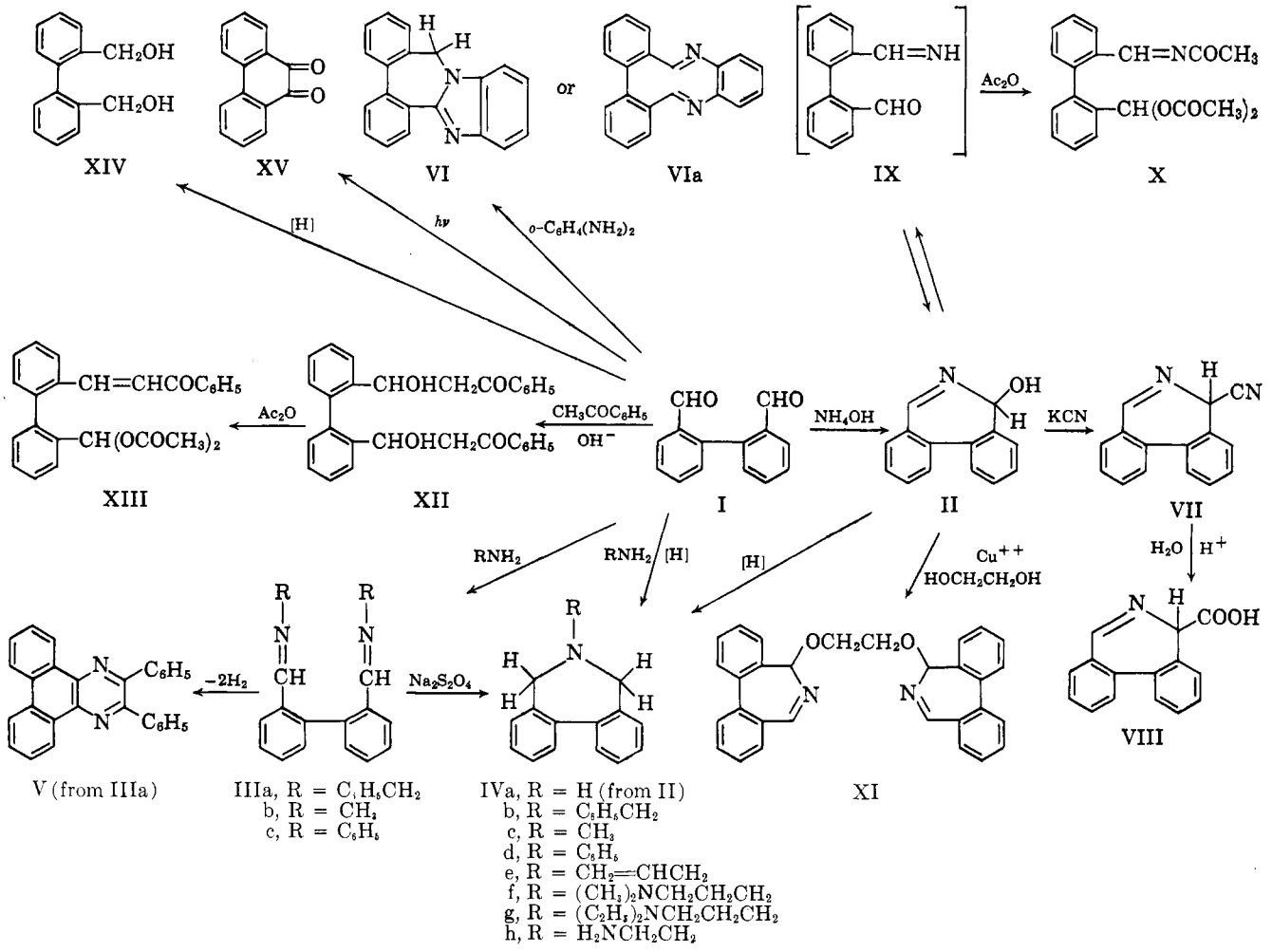
(9) T. Cohen, A. H. Dinwoodie, and L. D. McKeever, *J. Org. Chem.*, **27**, 3385 (1962).

(10) British Patent 860,907 (February 15, 1961).

(11) L. O. Randall and T. H. Smith, *J. Pharmacol. Exp. Therap.*, **103**, 10 (1951).

(12) J. O. Hawthorne and E. L. Mihelic, U. S. Patent 2,988,549 (June 13, 1961).

(13) F. Sparatore, *Ann. chim.* (Rome), **49**, 2102 (1959).



In our hands, the product from this reaction was obtained as a crystalline solid, m.p. 189–190°, and was thought to exhibit dimorphism. Two different interconvertible crystal forms were isolated, which had different infrared spectra as Nujol mulls, but the same spectrum in carbon disulfide and the same empirical formula. The structure of the product was confirmed by its n.m.r. spectrum to be that of VI rather than VIa. Similar compounds have been reported from the reaction of the diamine and either diphenic acid or diphenic anhydride.[14]

A more convenient synthesis is to treat the dialdehyde with *o*-phenylenediamine dihydrochloride in isopropyl alcohol, wherein the azepine precipitates, presumably, as the dihydrochloride monohydrate. The free base can be regenerated by treatment with alkali. The melting point of the hydrochloride is not definitive because it is believed to exist as the dihydrochloride, the monohydrochloride monohydrate, as well as the dihydrochloride monohydrate. Decomposition occurs during melting point determination, and the recorded melting point may be that of a decomposition product.

When II was treated with aqueous sodium bisulfite and then with potassium cyanide, 5-cyano-5*H*-dibenz[*c*,*e*]azepine (VII) was obtained. When the dialdehyde reacted with ammonium chloride and potassium cyanide, VII was isolated in almost quantitative yield.

Acid hydrolysis of VII gave a product, 5*H*-dibenz[*c*,*e*]azepine-5-carboxylic acid (VIII), which could not be sufficiently separated from inorganic material for characterization. The acid complexed with metallic ions to give colored, water-insoluble chelates. The copper chelate was characterized.

On acetylation of II by acetic anhydride, the 5-acetoxyazepine was not isolated, but rather 2-diacetoxymethyl-2′-acetyliminomethylbiphenyl (X). The reaction might involve the isomeric structure, IX, although no physical evidence was found for this form.

Compound II reacted with copper ion to give an insoluble complex, the structure of which could not be determined. However, II reacted with ethylene glycol and cupric acetate to form 5,5′-ethylenedioxybis(5*H*-dibenz[*c*,*e*]azepine) (XI). Monohydric alcohols gave oils, which were not identified.

When I reacted with two molecular equivalents of acetophenone in the presence of sodium hydroxide, a 55% yield of 2,2′-bis(1-hydroxy-2-benzoylethyl)biphenyl (XII) was isolated, and 2,2′-diphenide was identified as a by-product. With an equal molecular ratio of reactants, a 35% yield of XII and a 57% yield of the diphenide, resulting from a competing Cannizzaro reaction, were isolated. Reaction of XII with acetic anhydride afforded 2-diacetoxymethyl-2′-(benzoylvinylene)biphenyl (XIII).

2,2′-Bis(hydroxymethyl)biphenyl (XIV) was obtained from I by either catalytic hydrogenation over Raney nickel or reduction by aluminum isopropoxide. The diol has been prepared by lithium aluminum hy-

(14) F. Sparatore and G. Bignardi, *Gazz. chim. ital.*, **92** [7], 606 (1962).

dride reduction of dimethyl diphenate[15] and diphenic acid[16] or by lithium borohydride reduction of dimethyl diphenate.[17]

Mayer[5a] had prepared 9,10-phenanthraquinone (XV) by a cyanide-catalyzed benzoin-type condensation of 2,2′-biphenyldicarboxaldehyde. It was found, however, that the intramolecular condensation also was light catalyzed, although a peroxide, such as benzoyl peroxide, was necessary as an initiator.[18] The choice of solvent had a marked effect upon the yield of the quinone (Table I).

TABLE I

YIELD OF PHENANTHRAQUINONE OBTAINED FROM IRRADIATION OF 2,2′-BIPHENYLDICARBOXALDEHYDE IN VARIOUS SOLVENTS

Solvent	Yield of phenanthraquinone, %	Reaction conditions
t-Butyl alcohol	5	Irradiation (mercury arc) for
Acetic acid	15	48 hr. at room temperature;
Benzene	5	3 hr. at reflux. One weight
Ethyl ether	0	per cent of benzoyl peroxide
Tetrahydrofuran	0	catalyst
Xylene	0	
Acetone[a]	32	

[a] The yield in acetone was increased from 32% to 50% by reflux for 72 hr. The remaining material was unchanged dialdehyde.

Experimental[19]

5-Hydroxy-5*H*-dibenz[*c*,*e*]azepine (II).—Four grams of I was refluxed with 28% ammonium hydroxide (60 ml.) for 15 min. The mixture was cooled, and 3.7 g. (97%) of colorless crystals of II, m.p. 126.8–128.8°, was collected.

Anal. Calcd. for $C_{14}H_{11}NO$: C, 80.36; H, 5.20; N, 6.70. Found: C, 80.59; H, 5.59; N, 7.00.

A comparison of the n.m.r. spectra of I, IIIb, and II confirmed the assigned structure.

Preparation of Schiff Bases.—I was refluxed with toluene containing two molecular equivalents of benzylamine or aniline, or heated at 75–80° with 15% aqueous monomethylamine to give the appropriate Schiff's base. The results are listed in Table II.

6,7-Dihydro-5*H*-dibenz[*c*,*e*]azepine (IVa). Method A.—Compound II (3.0 g.) and sodium hydrosulfite (9.0 g.) were refluxed in water (100 ml.) for 30 min. On cooling the solution, colorless crystals separated and were collected. Additional material was separated by adding sodium chloride to the filtrate. The combined solids were dissolved in water (200 ml.) containing concentrated hydrochloric acid (20 ml.), and the solution was refluxed for 30 min. After concentrating the solution to 50 ml. and cooling it, IVa hydrochloride (3.0 g., 92%), m.p. 290.2–291.2° (lit.[7b] m.p. 286–288°), separated.

Method B.—Compound I (2.1 g., 0.01 mole) in methanol (30 ml.) was added to a solution of hydroxylamine hydrochloride (0.7 g., 0.10 mole) in water (300 ml.). The precipitated 2,2′-biphenyldicarboxaldehyde monoxime (2.0 g., 91%), m.p. 97–99°, was collected.

Anal. Calcd. for $C_{14}H_{11}NO_2$: C, 74.65; H, 4.92; N, 6.21. Found: C, 74.63; H, 4.96; N, 6.30.

The monoxime (1.0 g., 0.005 mole) and sodium hydrosulfite (4.0 g., 0.023 mole) were refluxed in water (50 ml.) for 30 min. The solid which separated on cooling was collected and refluxed for 30 min. in 10% hydrochloric acid (50 ml.). The solution was cooled and neutralized with sodium bicarbonate to precipitate IVa (0.7 g., 81%), m.p. 88–93°. Since the amine had not been reported as a solid, it was converted to the hydrochloride salt, m.p. 290–291°, the infrared spectrum of which was identical to that of the product from method A.

The N-nitroso derivative of IVa melts at 107–112° dec.

Anal. Calcd. for $C_{14}H_{12}N_2O$: C, 75.00; H, 5.36; N, 12.50. Found: C, 74.90; H, 5.55; N, 12.53.

6-Substituted 6,7-Dihydro-5*H*-dibenz[*c*,*e*]azepines. (A) By Hydrosulfite Reduction.—6-Substituted azepines were prepared by refluxing an aqueous solution of sodium hydrosulfite (10–12 g.) for 0.5–1 hr. with either (1) a solution of I (0.01 mole) and the appropriate amine (0.02 mole) in methanol (15 ml.) or (2) the appropriate crude Schiff base (0.01 mole) in methanol (15 ml.). The cooled mixture was extracted with diethyl ether. After the ether extract was dried over potassium hydroxide, the azepine hydrochloride was precipitated by passing anhydrous hydrogen chloride into the ether solution. Phosphate salts were prepared by dissolving the azepine in isopropyl alcohol after removal of the ether and adding phosphoric acid to a congo red end point. The data are given in Table III.

(B) By Hydrogenation.—A solution of I (0.0238 mole) and two molecular equivalents of the appropriate amine in ethanol (35 ml.) with the appropriate catalyst (10% on the dialdehyde) was subjected to hydrogenation in a low-pressure (50–60 p.s.i.g.) autoclave (Parr Instrument Co.) or in a Magne-Dash autoclave (Autoclave Engineers) at higher pressures. After hydrogenation and removal of catalyst and solvent, the residue was refluxed with water (300 ml.) and sufficient hydrochloric acid to give pH 2. Any unchanged dialdehyde was collected by filtration, and the filtrate was concentrated to allow crystallization of the azepine hydrochloride. The data are listed in Table IV.

6-Phenyl-6,7-dihydro-5*H*-dibenz[*c*,*e*]azepine (IVd).—2,2′-Bi-(N-phenylbenzylidenimine) (IIIc, 2.27 g.) in ethanol (50 ml.) was hydrogenated over Raney nickel (0.1 g.) at room temperature and 50 p.s.i. for 7 hr. After removal of catalyst and evaporation of the ethanol, the semisolid product was crystallized from *n*-heptane to give 1.3 g. (76%) of IVd, m.p. 87–90°. Upon recrystallization it had m.p. 89.5–91.6°.

2,3-Diphenyldibenz[*f*,*h*]quinoxaline (V).—Compound I (5.0 g.) and benzylamine (5.1 g.) were refluxed in toluene (20 ml.) for 30 min. The water of reaction was collected in a Dean–Stark trap. After evaporation of the toluene, the residual oil, in N,N-dimethylformamide (35 ml.), was refluxed with powdered copper chromite (0.5 g.) for 2 hr. After removal of catalyst and solvent, the oily residue was triturated with methanol (15 ml.). The insoluble portion (1.5 g.), m.p. 260–265°, was crystallized from benzene to give crystals of V (1.4 g., 15%), m.p. 272–275° (lit.[20] m.p. 272°). Compound V gave a violet coloration in sulfuric acid.[20]

Anal. Calcd. for $C_{28}H_{18}N_2$: C, 87.92; H, 4.74; N, 7.32. Found: C, 87.17; H, 4.62; N, 7.92.

15*H*-Dibenzo[*c*,*e*]benzimidazo[1,2-*a*]azepine (VI). Method A.—A solution of I (2.10 g.) and *o*-phenylenediamine (1.08 g.) in methanol (40 ml.) remained at ambient temperature for 48 hr. After removal of the solvent by vacuum evaporation, a benzene (25 ml.) solution of the residual oil was absorbed on a column (2 × 16 cm.) of neutral alumina (Bio Rad AG7, 100–200 mesh). Elution with benzene gave 2.35 g. of a solid, m.p. 135–150°. Recrystallization from benzene gave the product (1.37 g., 50%), m.p. 189–190°; picrate, 279–281° dec. (lit.[13] 278–280°).

Anal. Calcd. for $C_{20}H_{14}N_2$: C, 85.08; H, 4.99; N, 9.93. Found: C, 85.08; H, 5.34; N, 10.15.

N.m.r..—The chemical shift value for the aliphatic protons was 5.03 τ (area ratio, aromatic to aliphatic protons, 5.5; theory, 6.0). A comparison of 1.82 τ for the methine proton in salicaldoxime and 6.38 τ for the methylene protons adjacent to the phenyl group in N,N,N′,N′-tetrabenzylmethylene diamine[21] led to the assignment of structure VI rather than structure VIa.

The dialdehyde (2.10 g.) and *o*-phenylenediamine dihydrochloride (1.81 g.), dissolved in methanol (25 ml.) (a deep red solution), were heated at reflux for 20 min. (red color was discharged). The volume was reduced by one-half and the mixture cooled. The crystals thus formed (2.36 g.), m.p. 252–256° beginning at ambient temperature, were collected. If a sample were introduced into the melting point block at 240°, the sample melted with gas evolution, solidified, and remelted at 252–256°. The infrared spectrum contained peaks at 2.8, 3.8, and 4.3 μ. Thus, the composition VI·2HCl·H_2O was assigned. A sample

(15) D. M. Hall, M. S. Lesslie, and E. E. Turner, *Nature*, **163**, 537 (1949).

(16) A. J. Weinheimer, W. S. Kanter, and C. R. Hauser, *J. Org. Chem.*, **18**, 801 (1953).

(17) G. Wittig, P. Davis, and G. Koenig, *Chem. Ber.*, **84**, 627 (1951).

(18) E. L. Mihelic, U. S. Patent 2,930,742 (March 29, 1960).

(19) Analyses are by the Analytical Chemistry Section, Mellon Institute, and the Galbraith Laboratories, Knoxville, Tenn. All melting points are uncorrected. 2,2,-Biphenyldicarboxaldehyde was prepared by the method of P. S. Bailey.[6b]

(20) N. P. Buu-Hoï and P. Jacquignon, *Compt. rend.*, **226**, 2155 (1948).

(21) "N.m.r. Spectra Catalog," Varian Associates, Palo Alto, Calif., 1962; spectra 156 and 365, respectively.

TABLE II

SCHIFF BASES

Compound	Yield, %	M.p.,[a] °C.	Formula	Carbon, % Calcd.	Carbon, % Found	Hydrogen, % Calcd.	Hydrogen, % Found	Nitrogen, % Calcd.	Nitrogen, % Found
IIIa	99	96–97	$C_{28}H_{24}N_2$	86.56	86.53	6.23	6.25	7.21	7.21
IIIb	98	151–152	$C_{16}H_{16}N_2$	81.32	81.32	6.82	6.84	11.86	11.84
IIIc	89	98–99[b]	$C_{26}H_{20}N_2$	...	...	..	..	7.77	8.03

[a] Recrystallization solvent, *n*-heptane. [b] Lit.[5a] m.p. 98–99°.

TABLE III

6-SUBSTITUTED 6,7-DIHYDRO-5*H*-DIBENZ[*c,e*]AZEPINES BY HYDROSULFITE REDUCTION

Compound	IV, where R =	Yield, %	M.p., °C. Found	M.p., °C. Literature	Formula	Carbon, % Calcd.	Carbon, % Found	Hydrogen, % Calcd.	Hydrogen, % Found	Nitrogen, % Calcd.	Nitrogen, % Found
IVb[a]	$C_6H_6CH_2$	87	203–205	207[h]	$C_{21}H_{20}N\cdot HCl\cdot 0.5H_2O$	...	...	..	..	..	..
IVc[b]	CH_3	81	221–224		$C_{15}H_{15}N\cdot HCl$	...	...	..	..	..	..
IVd	C_6H_5	76	90–92		$C_{20}H_{17}N$	...	...	..	..	5.17	5.38
IVe	$CH_2{=}CH{-}CH_2$	57[c]	214–215	214–215[i]	$C_{17}H_{17}N\cdot HCl$	...	...	..	..	..	..
IVf	$(CH_3)_2N(CH_2)_3$	62[d]	231–232		$C_{19}H_{24}N_2\cdot 2HCl\cdot H_2O$[e]	61.45	61.29	7.60	7.91	7.55	7.35
IVg	$(C_2H_5)_2N(CH_2)_3$	70[f]	222–223	220–222[j]	$C_{21}H_{28}N_2\cdot 2H_3PO_4\cdot H_2O$	48.27	48.82	6.94	6.72	5.36	5.19
IVh	$H_2NCH_2CH_2$	63[g]	268–270		$C_{16}H_{18}N_2\cdot 2HCl$	61.73	61.42	6.47	6.29	9.00	9.38

[a] Methiodide, m.p. 186–188° (lit.[7b] m.p. 188–189°). [b] Methiodide, m.p. 287–289° (lit.[7c] m.p. 287–288°). [c] Recrystallized from methanol–diethyl ether. [d] Recrystallized from isopropyl alcohol. [e] Chlorine: Calcd., 19.10. Found, 18.64. [f] Recrystallized from ethanol–water. [g] Recrystallized from methanol. [h] Ref. 7c. [i] Ref. 7a. [j] Ref. 10.

TABLE IV

6-SUBSTITUTED 6,7-DIHYDRO-5*H*-DIBENZ[*c,e*]AZEPINES BY CATALYTIC HYDROGENATION

Product	Catalyst	Hydrogen pressure, p.s.i.g.	Temp., °C.	Time, hr.	Yield, %	M.p., °C.
IVa	Raney Ni	850	75	17	51	287–290
IVa	5% Platinum on carbon	800	85	24	84	284–290
IVb	5% Palladium on carbon	60	50	18	91	202–208
IVc	5% Palladium on carbon	60	50	7	97	221–227

of this, heated at 140° under vacuum, lost 4.34% in weight (theory for $1H_2O$: 4.83%) and now melted at 256–260°. The 2.8-μ peak was now missing in the infrared spectrum of the dihydrochloride. VI·2HCl (1.0 g.) was recrystallized from isopropyl alcohol (25 ml.) and water (1 ml.). The crystals (0.5 g.) now melted at 263–267° when placed in the apparatus at 240° (m.p. 240–245° from ambient temperature). The infrared spectrum now contained peaks at 2.8 and 3.8 μ but none at 4.3 μ, giving support to the composition $VI\cdot HCl\cdot H_2O$.

Anal. Calcd. for $C_{20}H_{14}N_2\cdot HCl\cdot H_2O$: N, 8.32; Cl, 10.53. Found: N, 8.40; Cl, 10.40.

Method B.—Compound I (2.10 g., 0.01 mole) and *o*-phenylenediamine dihydrochloride (1.81 g., 0.01 mole) in isopropyl alcohol (50 ml.) were refluxed for 2 hr. The reaction mixture was cooled to 0° and filtered. The residue (2.34 g.) was washed with cold isopropyl alcohol (10 ml.) and dried. The hydrochloride was dissolved in boiling 95% ethanol (30 ml.), and water (60 ml.) was added. The solution was made alkaline (pH 8) with aqueous 20% sodium hydroxide solution. The azepine base separated. After concentrating to one-half of the volume, the free base was collected. The yield was 1.99 g. (70%) of buff-colored product melting at 185–188°. Crystallization from benzene gave rhomboid-like crystals, m.p. 186–189°. Recrystallization from *n*-heptane gave mixed crystals, which on repeated recrystallization from *n*-heptane gave solely a needle form, m.p. 189–192°.

Anal. Calcd. for $C_{20}H_{14}N_2$: C, 85.08; H, 4.99; N, 9.93. Found: C, 85.26; H, 5.28; N, 10.19.

The needle form of VI could be reconverted to the rhomboid form by dissolving in methanol, evaporating to an oily semisolid, and crystallizing from ethyl acetate. A few repetitions of this process gave solely the rhomboid form of VI, m.p. 188–191°.

Anal. Calcd. for $C_{20}H_{14}N_2$: C, 85.08; H, 4.99; N, 9.93. Found: C, 85.24; H, 5.05; N, 9.85.

Comparison of the infrared spectra of the two forms in Nujol mulls showed sufficient dissimilarity to suggest dimorphism. The rhomboid form showed bands at 6.2 and 14.1 μ, which were absent in the needle form. The needle form showed bands at 10.8 and 11.9 μ, which were absent in the rhomboid form. Solution infrared spectra of the crystal forms in carbon bisulfide were identical, with no absorption at the foregoing wave lengths.

5-Cyano-5*H*-dibenz[*c,e*]azepine (VII). Method A.—A solution of II (6.3 g., 0.03 mole) in acetic acid (30 ml.) was added to a solution of sodium bisulfite (3.1 g., 0.03 mole) in water (75 ml.) and evaporated to dryness. A solution of potassium cyanide (1.9 g., 0.03 mole) in water (30 ml.) was added to the residue dissolved in water (200 ml.). The solution was heated at 90° for 1 hr., and after cooling, VII (5.0 g., 82%), m.p. 150–152°, crystallized. Recrystallization from ethyl acetate–*n*-heptane gave the pure product, m.p. 154–156°.

Anal. Calcd. for $C_{15}H_{10}N_2$: C, 82.56; H, 4.62; N, 12.83. Found: C, 82.46; H, 5.21; N, 12.84.

Method B.—A solution of I (21.0 g., 0.1 mole) in methanol (300 ml.) was slowly poured into water (3 l.) containing ammonium chloride (16 g., 0.33 mole) and potassium cyanide (6.5 g., 0.11 mole). The solution was refluxed for 30 min. and cooled, whereupon crystalline VII (20 g., 99%), m.p. 150–153°, was collected.

5*H*-Dibenz[*c,e*]azepine-5-carboxylic Acid (VIII).—5-Cyano-5*H*-dibenz[*c,e*]azepine (2.6 g., 0.012 mole) was refluxed for 2 hr. in 67% sulfuric acid (50 ml.). The cooled reaction solution was poured into cold water (100 ml.) containing sodium hydroxide (34.6 g.). The pH of the solution was then adjusted to 6.8, and the solids, consisting of the product and sodium sulfate, which separated, were collected and dried. 5*H*-Dibenz[*c,e*]-azepine-5-carboxylic acid was extracted from the solid into hot methanol. Evaporation of the methanol gave 2.4 g. (87%) of the acid, m.p. 249–253°. Since the acid was difficult to free of sodium sulfate, an analytical sample was prepared in the form of a water-insoluble copper chelate. A solution of copper sulfate pentahydrate (0.628 g., 0.0025 mole) in water (25 ml.) was added to a solution of the acid (1.1 g., 0.005 mole) in water (25 ml.). The lavender colored complex (1.2 g.), m.p. 221–222°, which precipitated was collected, washed, and dried.

Anal. Calcd. for $(C_{15}H_{10}NO_2)_2Cu\cdot 2H_2O$: C, 62.98; H, 4.22; Cu, 11.10; H_2O, 6.29. Found: C, 63.10; H, 4.20; Cu, 10.77; H_2O, 6.12.

2-Diacetoxymethyl-2′-acetyliminobiphenyl (X).—Compound II (2.3 g.) was refluxed in acetic anhydride (50 ml.) for 30 min. After removing the excess acetic anhydride by vacuum distillation, the crude product (3.5 g.), m.p. 132–160°, was washed with ethyl acetate (15 ml.). The undissolved material was 2-diacetoxymethyl-2′-acetyliminomethylbiphenyl (2.0 g., 51%), m.p. 177–181°. Recrystallization from ethyl acetate gave the pure compound, m.p. 184–186°.

Anal. Calcd. for $C_{20}H_{19}NO_5$: C, 67.97; H, 5.42; N, 3.98. Found: C, 67.81; H, 5.40; N, 4.26.

5,5′-Ethylenedioxybis(5*H*-dibenz[*c*,*e*]azepine) (XI).—Cupric acetate monohydrate (7.5 g., 0.038 mole) was added to a solution of II (15 g., 0.072 mole) in ethylene glycol (150 ml.) and water (30 ml.) and the mixture refluxed for 1.5 hr. Precipitated cupric hydroxide was removed by filtration and chloroform added to the filtrate. The chloroform was washed with 7% aqueous sodium bicarbonate (300 ml.) and then with water. After separation, the chloroform layer was evaporated to a volume of 200 ml., and *n*-heptane was added to cause crystallization of the crude product (11.7 g., 71%), m.p. 227–232°. Recrystallization from chloroform–acetone gave the pure compound, m.p. 244–246°.

Anal. Calcd. for $C_{30}H_{24}N_2O_2$: C, 80.96; H, 5.44; N, 6.30. Found: C, 80.79; H, 5.58; N, 6.26.

2,2′-Bis(1-hydroxy-2-benzoylethyl)biphenyl (XII).—A solution of sodium hydroxide (2.1 g.) in water (80 ml.) was added to a solution of I (4.6 g., 0.022 mole) in ethanol (80 ml.). Acetophenone (5.2 g., 0.044 mole) was added to the resulting solution over a 1-min. period. Colorless crystals soon formed and after only several minutes were collected, washed with ethanol (−5 to 0°), and dried. This yielded 5.5 g. (55%) of crude XII, m.p. 175–185°. Recrystallization from methanol gave the pure compound, m.p. 238.5–239.0° dec.

Anal. Calcd. for $C_{30}H_{26}O_4$: C, 79.75; H, 5.81. Found: C, 79.74; H, 5.69.

The use of one molar equivalent of acetophenoneas before gave 35% yield of XII and 57% yield of diphenide, m.p. 124–130° (lit.[3,4] m.p. 132°). The infrared spectrum was identical with that of authentic diphenide.

2-Diacetoxymethyl-2′-(benzoylvinylene)biphenyl (XIII).—Six grams of XII was refluxed in acetic anhydride (100 ml.) for 1 hr. The acetic anhydride was removed by flash evaporation. The residual oil was dissolved in ethanol, from which, on concentration, 3.9 g. (70%) of crude XIII, m.p. 197–204°, was obtained. Recrystallization from ethyl acetate gave the pure compound, m.p. 208.5–209.5°.

Anal. Calcd. for $C_{26}H_{22}O_5$: C, 75.30; H, 5.36. Found: C, 74.92; H, 5.46.

2,2′-Bis(hydroxymethyl)biphenyl (XIV). Method A.—Aluminum isopropoxide (2.8 g., 0.014 mole) was mixed with anhydrous isopropyl alcohol (100 ml.) containing I (4.2 g., 0.02 mole). Acetone was distilled from the reaction through a 12-in. Vigreux column followed by the majority of the isopropyl alcohol. The cooled reaction mixture was poured into 20% hydrochloric acid (100 ml.). The precipitated 2,2′-bis(hydroxymethyl)biphenyl (4.01 g.), m.p. 92–100°, was collected, washed, and dried. Recrystallization from benzene gave 2.79 g. (65%) of material melting at 109.4–109.8° (lit.[15] m.p. 112–113°).

Method B.—Compound I (15 g.) in ethanol (100 ml.) was hydrogenated (50 p.s.i.) over Raney nickel catalyst (0.5 g.) at 52° for 18 hr. After removal of the catalyst by filtration, the ethanol was flash evaporated and the residue recrystallized from benzene to give 12.4 g. (81%) of XIV, m.p. 109.0–109.8°.

9,10-Phenanthraquinone (XV).—A solution of I (2.1 g., 0.01 mole) in acetone (100 ml.) containing benzoyl peroxide (0.02 g.) was refluxed for 7 hr. with continuous irradiation from a mercury vapor lamp (Hanovia Chemical and Manufacturing Co., type 16200; filter removed) at a distance of 5–6 in. The solution was aerated at the rate of approximately 0.06 S.C.F.M. The acetone was flash evaporated, and a 50% yield of 9,10-phenanthraquinone, m.p. 196–206° (lit.[22] m.p. 206–207°), was recovered by washing residue with ethyl ether. The material dissolved in the ether was largely unchanged dialdehyde, identified by an infrared spectrum.

Other solvents—*t*-butyl alcohol, acetic acid, benzene, ethyl ether, tetrahydrofuran, and xylene—were employed similarly, except that the reaction time was 48 hr. at room temperature followed by 3 hr. at reflux.

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Carboxylation of Propargyl Alcohol

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The carboxylation of propargyl alcohol with stoichiometric quantities of nickel carbonyl and with carbon monoxide in the presence of catalytic amounts of nickel carbonyl has been accomplished. Carboxylation of propargyl alcohol in ethyl alcohol at 55° with stoichiometric quantities of nickel carbonyl followed by esterification of the resulting products gave a 58% yield of ethyl α-(hydroxymethyl)acrylate (IV) and, surprisingly, an 11% yield of ethyl *trans*-γ-hydroxycrotonate (V). In general, the addition of the elements of formic acid (H–CO_2H) to a terminal acetylene group is expected to give a product of the type of IV. This is the first time that a substantial amount of the reversed addition product V has been isolated. When the sequence of reactions was carried out in methyl, isobutyl, and *n*-butyl alcohols, the corresponding esters were obtained. The carboxylation of propargyl alcohol was also accomplished for the first time with carbon monoxide in the presence of catalytic quantities of nickel carbonyl. The yields of IV and V were equal to those obtained in the stoichiometric reaction. In the catalytic carboxylation it was found that for a given temperature, over the range studied, there was a corresponding maximum pressure above which no reaction occurred.

Jones, Shen, and Whiting[4] reported that an exotherm was observed when nickel carbonyl was added to a solution containing propargyl alcohol and acetic acid, but they were not able to isolate any identifiable product. When we carried out the reaction by adding the propargyl alcohol to the other reactants, an 18% yield of α-(hydroxymethyl)acrylic acid (I) was obtained. An

$$4\text{H-C}{\equiv}\text{C—CH}_2\text{OH} + \text{Ni(CO)}_4 + 4\text{H}_2\text{O} + 2\text{CH}_3\text{CO}_2\text{H} \xrightarrow[\text{C}_2\text{H}_5\text{OH}]{55^\circ} 4\underset{\text{I}}{\text{CH}_2{=}\text{C(CH}_2\text{OH)—COOH}} + \text{Ni(CH}_3\text{CO}_2)_2 + 2[H] \quad (1)$$

analysis of the crude carboxylation product was then undertaken to find the reason for the low yield of acid isolated. Quantitative hydrogenation of the product indicated a higher degree of unsaturation than was shown by bromination. An increase in acid content after hydrogenation suggested that an ester initially present had undergone hydrogenolysis. When the crude product was freed of nickel and treated with diazomethane, esters were obtained which were analyzed by vapor phase chromatography. It was found that the esterified product consisted of 2.4% methyl meth-

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