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The Chemistry of Dibenzo[*d*,*f*][1,3]diazepines. 3.[1] The Electrolytic Preparation of 2,2′-Dihydroxylaminobiphenyl and its Reaction with Aldehydes and Ketones

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Preparative scale electrolytic reduction of 2,2′-dinitrobiphenyl gives 2,2′-dihydroxylaminobiphenyl which, although not isolated, combines either *in situ* or after electrolysis with various aliphatic aldehydes and ketones to give the corresponding 5,7-dihydroxy-6,7-dihydrodibenzo[*d*,*f*][1,3]diazepine derivatives. A few activated heterocyclic aldehydes and cycloalkanones underwent this reaction, but generally aromatic aldehydes and ketones and some aliphatic ketones did not react under similar conditions.

The structures of the products were established according to spectroscopic and chemical evidence. A comparison of the results of controlled potential electrolyses and *in situ* catalytic hydrogenations suggests that the former method is usually the preferred method.

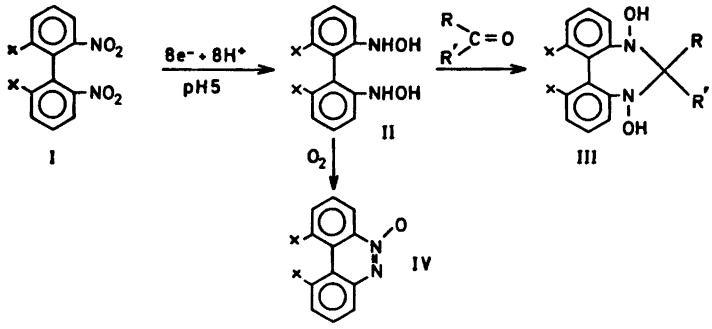
Recently Laviron and Lewandowska [2] have shown that 2,2′-dihydroxylaminobiphenyl (II) is formed by cathodic reduction of 2,2′-dinitrobiphenyl (I). Isolation of the bishydroxylamine (II) was not recorded but compelling evidence for its formation comes from the use of electroanalytical techniques and air (or anodic) oxidation to benzo[*c*]cinnoline-*N*-oxide (IV). The investigations have since been extended to 2,2′,6,6′-tetranitrobiphenyl [3,4] with similar results. The reductive cyclization of 2,2′-dinitrodiphenyl with a few aliphatic aldehydes to give 6-alkyl-5,7-dihydroxy-6,7-dihydrodibenzo[*d*,*f*][1,3]diazepines (III) has been described by Becher [5] and their mass spectra have been discussed.[1] The catalytic hydrogenation method gives low yields [5] and accordingly an electrochemical approach was adopted with the aim of exploring the scope of the cyclization reaction by using a variety of carbonyl compounds.

The trapping of hydroxylamines from electrolytic reduction of nitroalcohols by *in situ* reaction with aldehydes and ketones has been reported by Petrov and Barkhash.[6] In this case, however, the primary condensation products were not isolated but the nitrones postulated as intermediates were further reduced to the corresponding amines at the amply negative cathode potential employed. The present work thus provides new examples of a general reaction type in cathodic electrolysis, *i.e.* the reaction of an electrophile (the carbonyl compound) with an electrochemically generated nucleophile [the bishydroxylamine (II)]. The same principle has been used by Lund [7] to effect many electrochemical cyclizations leading to heterocyclic systems. In such cases the reducible group (which should be transformed into a nucleophile by cathodic reduction) and the unsaturated electrophilic function were present within the same molecule.

A related condensation with ketones was found by Volodarsky and Kutikova who prepared the 1-hydroxy-3-imidazoline-3-oxide derivatives by reaction of α-hydroxylamino oximes with acetone.[8]

RESULTS AND DISCUSSION

Electrochemical preparation. From investigations of the cathodic reduction of aromatic



nitro compounds [9] it has been concluded that weakly acidic media will favour hydroxylamine formation. Similar optimum conditions are required [10] for the reaction between carbonyl compounds and N-containing nucleophiles (which lose their nucleophilic activity by protonation). It proved convenient to conduct preparative scale electrolyses in an acetate buffer (*ca.* pH 5) and add varying amounts of organic polar solvents which by increasing the solubility of the depolarizer allowed the passage of a larger cell current with a consequent shortening of the electrolysis time.

The reductions were performed at room temperature using a mercury cathode and a conventional H-type 3-electrode cell of 250 ml volume. Potentials less cathodic than -0.8 V *vs.* Ag/AgCl were used with 1 – 2 g of the 2,2′-dinitrobiphenyl (I) and in most cases a large excess (5 ml or 5 g) of the carbonyl compound. For the more reactive carbonyl compounds the excess could be smaller. A few experiments using a 500 ml cell with 10 – 12 g of I and acetaldehyde, acetone, or cyclopentanone, gave similar results.

For aldehydes and ketones which were not reduced at ≥ -0.8 V *in situ* techniques could be used. However, an electrochemically prepared solution of II was found to be stable in the absence of oxygen and similar yields of the dihydrodibenzodiazepines (III) were obtained by adding the carbonyl compound to a freshly electrolysed solution of (I). This procedure was necessary for condensations involving the easily reducible heteroaromatic aldehydes. If oxygen is not excluded, oxidation to IV predominates. The *in situ* method is quicker and therefore preferable when the reduction potential of the carbonyl component will allow it. The products are reducible but at more negative potentials than used in this work. The further electroreduction has not yet been investigated. However, for these reasons careful control of the cathode potential is essential. For both procedures the consumption of electricity was generally very close to the theoretical value of 8 F/mol, which thus confirms the findings of Laviron.[9]

Following electrolysis the catholyte was kept under nitrogen at room temperature for 1 – 7 days to allow complete condensation. The product was isolated by filtration and/or extraction with ether after partial evaporation, and purified by recrystallization from a suitable solvent. The yields were estimated from the 60 MHz ^{1}H NMR spectra (DMSO-d_6) of the crude materials and are given in Table 1 together with the yields of recrystallized, pure substances; results from elemental analysis and melting points are to be found in Table 3 in the experimental section. The pH-conditions, methods of isolation and purification for every product were not optimised.

In the original experiments ethanol [9] was used as a co-solvent which was suitable for condensations involving the lower aliphatic aldehydes and acetone. With less reactive carbonyl reagents such as ethyl methyl ketone or cyclohexanone, NMR-analysis of the crude product revealed the presence of IIIb and IV in addition to the expected products. Compound IV was detected in all cases in amounts ranging from traces to its being the main product. It was presumably formed from unreacted II by air oxidation during the work-up, and could be isolated in high yield after purging the electrolysed solution of I with oxygen. The mechanism of formation of IIIb is not yet clear, but it is suggested that an Oppenauer-type of

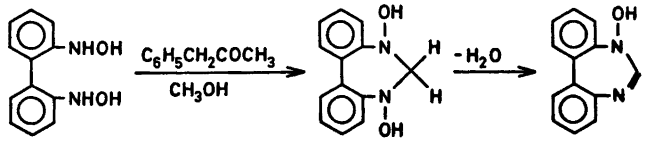
Table 1. Yields of dibenzo[*d,f*][1,3]diazepine derivatives.

Compound	R	R'	X	% Crude	% Recryst.	Solvent
IIIa	H	H	H	(45)	–	B
IIIb	CH_3	H	H	80	66	A
IIIc	CH_2CH_3	H	H	38	22	B
IIId	$(CH_2)_2CH_3$	H	H	85	30	A
IIIe	$(CH_2)_3CH_3$	H	H	45	25	A
IIIf	CH_3	CH_3	H	79	61	A
IIIg	CH_2CH_3	CH_3	H	56	45	B
IIIh	$(CH_2)_2CH_3$	CH_3	H	52	28	B
IIIi	CD_3	CD_3	H	76	48	A
IIIj	$(CH_2)_4$		H	90	72	B
IIIk	$(CH_2)_5$		H	47	25	C
IIIl	4-pyridyl	H	H	64	32	C
IIIm	4-methyl-2-thiazolyl	H	H	55	36	C
IIIn	CH_3	H	CH_3	73	20	A
IIIo	CH_3	CH_3	CH_3	77	42	A

oxidation of the ethanol takes place with the added carbonyl reagent as an oxidant in the presence of II. The acetaldehyde formed would then react rapidly with II to give IIIb. The alcohol corresponding to the carbonyl reagent has not yet been detected but support for the suggestion comes from an experiment using benzyl methyl ketone and methanol as co-solvent which resulted in the main product (V) being derived from formaldehyde. Compound V is the dehydrated derivative 5-hydroxydibenzo[*d,f*][1,3]diazepine, a hitherto unknown and simple representative of the parent ring system (eqn. 2).

In view of this complication other solvents which would not form carbonyl compounds by oxidation were tried. Acetone-water could of course only be used for the derivative IIIf and did work satisfactorily. Acetonitrile-water mixtures were suitable solvents for the aromatic dinitro derivatives but could not be buffered satisfactorily because of the low solubility of sodium acetate. *t*-Butyl alcohol-water was also tried but proved to be too poor a solvent which led to inconveniently long electrolysis times. The most convenient mixture was 1:1 DMF-water which even so made work-up difficult in some cases because of its relatively low volatility and good dissolving power for the products. The present results show clearly that care must be exercised when alcohols and acetone (which are common co-solvents for polarographic work [2,3] in aqueous media) are considered for use in preparative electrolysis water-organic solvent mixtures.

Because of its thermal instability the formaldehyde derivative (IIIa) could not be isolated with a sufficient purity for elemental analysis. Evaporation of an ethereal solution at below 10 °C gave a solid material from which a satisfactory ^1H NMR spectrum was obtained. It was stored for several weeks at below −20 °C but deteriorated rapidly to a brownish tar at room temperature.



IIa IIIa V

From Table 1 it is seen that the condensation goes well with the lower aliphatic aldehydes, acetone, and cyclopentanone. Higher straight-chain methyl ketones, cyclohexanone and some heterocyclic aldehydes were also found to react, a longer reaction time being necessary with the ketones.

Surprisingly benzyl methyl ketone did not condense, even after 10 days, and the same was true for diethyl ketone and cycloheptanone. The sterically hindered ketone methyl isopropyl ketone did not react nor did two aromatic ketones (acetophenone and α,α,α-trifluoroacetophenone). Aromatic aldehydes, exemplified by benzaldehyde and *p*-nitrobenzaldehyde failed to condense (benzaldehyde was even tried at 70 – 80 °C for two days with negative result). It is, however, known that 2,3-dihydroxylamino-2,3-dimethylbutane needs more severe conditions to condense with aromatic aldehydes to give a 5-membered ring.[12] Despite the fact that 4-methyl-2-thiazolealdehyde and 4-pyridinealdehyde did react, no condensed product could be isolated from 2-pyridinealdehyde, *N*-benzyl-2-imidazolealdehyde and 5-nitro-2-furanaldehyde. The deuterated derivative IIIi and the dimethyl derivatives IIIn and IIIo were prepared for use in a MS-investigation,[13] but the corresponding cyclopentanone derivative could not be obtained. Cyclobutanone did react with IIa but TLC analysis showed the presence of several products and the characteristic hydroxyl proton signal did not feature in the ^{1}H NMR spectrum of the product mixture. The nature of the products has not yet been investigated. Negative results were also found with a number of α,β-unsaturated carbonyl compounds.

Catalytic reduction. A few condensations initiated by hydrogenation were performed to allow comparison with the electrochemical procedure. It has previously been found [5] that the yields of IIIb and IIIc were in the range 26 – 37 %, and that the use of larger aliphatic aldehydes to condense with the intermediate II gave poor results. However, when the hydrogenation of I was carried out in a mixture of acetone and acetate buffer, IIIf could be isolated in 76 % yield. This is similar to that obtained with much less acetone by the electrochemical method. A lower yield of 61 % was found with cyclopentanone under similar conditions, but the corresponding electrochemical yield of 90 % of IIIj is superior. These results suggested that a more general investigation of the hydrogenation method would be unrewarding.

It may well be that a catalytic hydrogenation procedure can be devised for the more reactive carbonyl compounds in which case a medium of pH 5 – 6 is probably preferable to the neutral conditions originally used.[5] For the less reactive ketones it would be necessary to use a catalyst which does not promote the further reduction of the bishydroxylamine II to the corresponding 2,2′-diaminophenyl. Apart from the simple experimental procedure the advantage of the controlled potential electrolysis lies in the fact that a stable solution of the intermediate II can be prepared thus allowing the use of carbonyl reagents with other reducible functions in the moecule.

Properties of products. The tentative assignment [5] of the *N*,*N*′-dihydroxydiazepine structure III for the condensation products is supported by the interpretation of the fragmentation pattern evident in the mass spectra of members of this family of compounds.[1,13] Further spectroscopic and chemical evidence is presented below which supports the 7-ring structure, and so far all of the information collected is consistent with this conclusion. However, the direct proof which would follow from an X-ray crystal structure determination has yet to be obtained. The symmetric acetone derivative IIIf has been selected for this purpose, and a structure determination has been undertaken in collaboration with the Inorganic Department of the University of Aarhus. Suitable single crystals could be grown from isopropanol solution, and preliminary findings show that IIIg crystallizes in the monoclinic space group $P2_1/c$ with 2 asymmetric units and the following cell constants: $a = 18.78$ Å, $b = 15.53$ Å, $c = 10.04$ Å, $\cos\alpha = \cos\gamma = 0$, $\cos\beta = -0.412$.

[13] *C NMR analysis.* The best evidence to date comes from the proton decoupled Fourier Transform (FT) ^{13}C NMR spectrum of IIIg (Fig. 1) in which the numbering of the biphenyl system has been retained for simplicity. The compound has a total of 15 C-atoms and the presence of only 8 lines clearly points to a symmetric structure. The intensity ratio for seven pairs and one single carbon would in

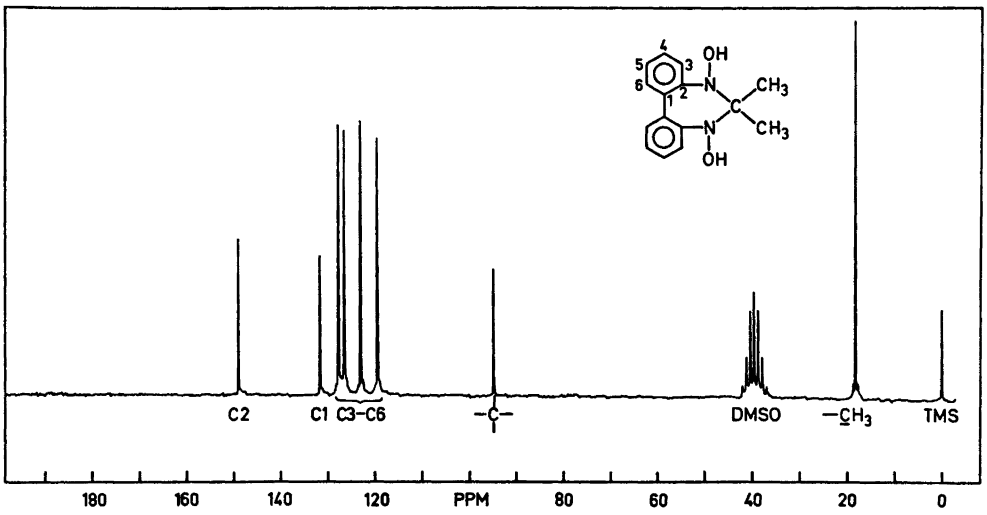


Fig. 1. ^{13}C NMR spectrum of 6,6-dimethyl-5,7-dihydroxy-6,7-dihydrodibenzo[*d,f*][1,3]diazepine IIIf in DMSO-d_6.

practice differ from 2:2:2:2:2:2:1:2 because of differences in the nuclear Overhauser effect which tend to give lines from nuclei bound to hydrogen an enhanced intensity.[14]

By considering likely substituent effects on chemical shifts[15] the interpretation of the spectrum is straightforward. The line at lowest field occurs in the region observed for C1 in aniline and is attributed to C2 bearing the hydroxylamine function. The next line upfield (C1) is due to the quaternary biphenyl carbon, and the group of 4 lines (C4-C6, C5 and C3, respectively) correspond to the remaining biphenyl carbons attached to protons and these carbon signals show an increased intensity relative to C1 and C2. The next upfield signal originates from the quaternary aliphatic carbon, showing more than half of the intensity of C1, and the last and most intense line corresponds to the methyl carbons.

Open structures and a 6-ring (with oxygen in the ring) are not symmetric and thus could not give a simple 8 line spectrum. Symmetry arguments, however, could not distinguish between a 7- and a 9-membered ring, but the 9-ring is highly improbable both because of the presence of absorption lines attributed to the NOH function in the ^1H NMR and IR spectra (see below), and because the nitrogen atom in hydroxylamines is known to be the nucleophilic centre in similar additions to carbonyl compounds. Furthermore IIIf is easily acetylated at the NOH groups (see below and experimental).

IR, ^1H NMR and UV-spectra. Cyclic and acyclic *N,N'*-dihydroxyamines have been studied by Zinner and Kliegel[16] and their spectroscopic data are similar to those found for the derivatives under study here thus confirming the presence of the NOH functions. The IR-spectra (Table 2) of nearly all the *N,N'*-dihydroxydiazepines IIId–IIIo show a strong absorption due to OH in the range 3230–3280 cm^{-1} in all cases with nearly the same intensity. An absorption with exactly the same shape and intensity was found at 3240 cm^{-1} for the known 1,3-dihydroxy-2-phenyl-4,4,5,5-tetramethylimidazoline.[17]

The ^1H NMR spectra (Table 2) of the diazepines IIId–IIIo showed the same pattern as found previously.[5] However, for the dimethylated derivative (IIIn) two NOH signals were observed at room temperature which coalesced on heating above *ca.* 80 °C.

All of the diazepines show UV absorption at 231–239 nm (Table 2) which is characteristic of benzene rings. For the aldehyde derivatives with unsubstituted benzene rings (IIId, IIIe, and IIIl and IIIm) the long wavelength absorption falls within the range 291–296 nm.

Table 2. Spectral properties of dibenzo[*d*,*f*][1,3]diazepine derivatives.

Compound	IR absorption spectra in KBr NOH band in cm^{-1}	UV absorption spectra in abs. ethanol λ_{max} nm	(log ε)	NMR spectral assignments chemical shifts in τ ppm[b] J in cps, recorded in DMSO-d_6, internal ref. TMS.
IIId	3260	295	(3.45)	τ 9.50–8.17 (m, 7 H, alkyl H), τ 5.40
		232	(4.34)	(t, 1 H, CH), τ 3.08–2.42 (m, 8 H, aryl H), τ 1.63 (s, 2 H, NOH)
IIIe	3280	296	(3.42)	τ 9.55–8.00 (m, 9 H, alkyl H), τ 5.45
		231	(4.35)	(m, 1 H, CH), τ 3.10–2.45 (m, 8 H, aryl H), τ 1.29 (s, 2 H, NOH)
IIIf	3260	285	(3.56)	τ 8.48 (s, 6 H, CH_3), τ 3.02–2.45 (m, 8 H,
		233	(4.54)	aryl H), τ 1.48 (s, 2 H, NOH)
IIIg	3260	289 sh[a]	(3.26)	τ 9.06 (t, J=7.5, 3 H, CH_3), τ 8.62 (s, 3
		234	(4.24)	H, CH_3), τ 7.96 (q, J=7.5, 2 H, CH_2), τ 3.05–2.40 (m, 8 H, aryl H), τ 1.55 (s, 2 H, NOH)
IIIh	3250	290 sh	(3.56)	τ 9.20 (t, 3 H, CH_3), τ 8.61 (s, 3 H, CH_3), τ
		235	(4.43)	7.90–8.75 (m, 4 H, CH_2), τ 3.06–2.41 (m, 8 H, aryl H), τ 1.55 (s, 2 H, NOH)
IIIi	3270	285	(3.59)	τ 3.05–2.40 (m, 8 H, aryl H), τ 1.46
		233	(4.56)	(s, 2 H, NOH)
IIIj	3250	286	(3.24)	τ 8.21 (m, 4 H, CH_2), τ 7.94 (m, 4 H, CH_2),
		233	(4.22)	τ 2.93–2.34 (m, 8 H, aryl H), τ 1.42 (s, 2 H, NOH)
IIIk	3240	307	(3.48)	τ 8.70–7.85 (m, 10 H, CH_2), τ 2.93–2.50
		239	(4.44)	(m, 8 H, aryl H), τ 1.78 (s, 2 H, NOH)
IIIl	3340(sharp)	297 sh	(2.91)	τ 4.46 (s, 1 H, CH), τ 2.97–2.52 (m, 10 H,
		252 sh	(3.42)	aryl H), τ 1.55 (d, d, J=1.5, 4.5, 2 H,
		231	(3.81)	H_2 and H_6 τ 1.15 (s, 2 H, NOH)
IIIm	3540(sharp)	295 sh	(2.51)	τ 7.62 (d, J=1, 3 H, CH_3) τ 4.15 (d, J=1,
	3150	258 sh	(3.05)	1 H, alkyl CH), τ 2.93–2.50 (m, 9 H,
		237	(3.45)	aryl H), τ=1.48 (s, 2 H, NOH)
IIIn	3260	279 sh	(3.79)	τ 8.80 (d, J=5.2, 3 H, CH_3), τ 7.94 (s, 3 H,
		234	(4.29)	aryl CH_3), τ 7.90 (s, 3 H, aryl CH_3), τ 5.72 (q, J=5.2, 1 H, CH), τ 3.11–2.53 (m, 6 H, aryl H), τ 1.63 and τ 1.58 (s, s, 2 H, NOH)
IIIo	3240	279 sh	(3.44)	τ 8.79 (s, 6 H, alkyl CH_3), τ 7.93 (s, 6 H,
		235	(4.34)	aryl CH_3), τ 3.13–2.65 (m, 6 H, aryl H), τ 1.45 (s, 2 H, NOH)
V	3200	305	(3.72)	τ 5.37 (s, 1 H, CH), τ 2.90–2.35 (m, 4 H,
		249	(4.39)	aryl H), τ 2.04–1.81 (m, 2 H, aryl H), τ
		243	(4.40)	1.35–1.00 (m, 2 H, aryl H), τ 0.93 (s)
		231	(4.42)	1 H, NOH)

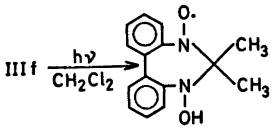
[a] sh, shoulder. [b] s, singlet; d, doublet; t, triplet; q, quartet; and m, multiplet.

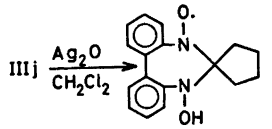
For the ketone derivatives (IIIf–IIIi) this absorption is in the range 285–290 nm, the cyclohexanone derivative being an exception. When the benzene rings are substituted (IIIn and IIIo) a hypsochromic shift to 279 nm is observed.

The spectral observations for V (Table 2) are also in good accord with the proposed structure, which is further supported by its mass spectrum (M^+: m/e 210) in which a large peak at m/e = 193 due to the $M^+ - OH$ ion is present together with the benzo[*c*]cinnoline ion (m/e 180) and the expected [1] peaks at m/e 166 and 167.

ESR-spectroscopy. It was originally reported [5] that oxidation of the bishydroxylamines IIIb and IIIc gave a mixture of relatively stable radicals. When IIIf was irradiated at room temperature with UV light in methylene chloride solution in the cavity of an ESR-spectrometer, strong signals appeared com-

prising a triplet with $a_N = 14.2$ G which compares well with $a_N = 14.0$ for the *t*-butyl-*o*-tolyl nitroxide radical.[18] The radical was quite stable and the ESR spectrum contained no hyperfine splitting, facts which are consistent with the postulation of the nitroxide:





Similarly oxidation of the spiro cyclopentane derivative IIIj either with lead dioxide in benzene on with silver oxide in methylene chloride yielded the corresponding nitroxide with a characteristic triplet in the ESR spectrum ($a_N = 13.7$ G). The use of other reagents such as alkaline DMSO [19] for oxidation of the bishydroxylamines III gave in most cases radicals or mixtures of radicals showing rather complex (often time-dependent) unsymmetrical ESR-signals. The spectra have not yet been assigned fully but the line pattern did not vary with the 6-substituent. The possibility of stabilizing the radicals by appropriate substitution in the biphenyl rings is currently under investigation.

Chemical reactions. The compounds have been formulated as cyclic secondary bishydroxylamines and their thermal and chemical stability has been found to depend strongly on the nature of substituents in the 6-position. Thus a pure sample of the unsubstituted derivative IIIa has not been obtained and the aliphatic aldehyde derivatives are relatively unstable and difficult to handle especially when impure.

The heteroaromatic aldehyde products and the ketone derivatives are relatively stable and a preliminary exploration of their chemistry has been attempted. From the ESR-work described above it is known that all of the derivatives can be easily oxidized chemically, but the products have not yet been isolated and identified. The compounds are also electroreducible (see above) although the electrode reaction has not been investigated.

The aldehyde derivatives would be expected to undergo dehydration under suitable conditions, but so far our attempts have been unsuccessful, and the parent compound V has been obtained indirectly in a side reaction as mentioned above.

Acylation of the acetone product IIIf by treatment with an excess of acetic anhydride gave the bis-acetylated derivative VI in 80 % yield. Product VI was also obtained by reaction with one equivalent of acetic anhydride, and contained none of the monoacetyl derivative. This correlates well with the findings of Zinner and Wilwing [20] who recently acylated a series of 1,3-dihydroxy-4,4,5,5-tetramethylimidazolines. Attempted acetylation of the aliphatic aldehyde products under the same conditions failed, and only black tars were obtained.

EXPERIMENTAL

Apparatus. The electrochemical and MS euipment has been described.[21,1] Microanalyses were carried out at the Microanalytical Laboratory of the University of Copenhagen by Mr. P. Hansen and by Dr. A. Bernhardt, Mülheim/Ruhr, BRD. Melting points (uncorrected) were determined on a Büchi melting point apparatus. IR-spectra were recorded using a Perkin-Elmer Model 137 or Model 457 spectrophotometer and UV-spectra were recorded using a Beckman Acta III spectrophotometer. ^{1}H NMR spectra were recorded using a JEOL C-60 HL or a Varian A-60 NMR spectrometer. The FT ^{13}C NMR spectrum of IIIg was measured at Varian Ass., Zug, Switzerland, using a Varian XL-100 NMR spectrometer. ESR-spectra were recorded using a Varian E-3 EPR spectrometer. Unit cell constants for IIIf were determined using a Picker four-circle diffractometer.

Materials. 2,2′-Dinitrobiphenyl (Ia) was obtained from Aldrich Chemical Company, Inc. and used without further purification and 6,6′-dimethyl-2,2′-dinitrobiphenyl (Ib) was prepared by Lothop's method.[22]

The aldehydes and ketones were obtained commercially and were mostly used without further purification. The preparation of the heteroaromatic aldehydes has been described [11,23] and 5-nitro-2-furanaldehyde was prepared from the diacetate.[24]

Preparative scale electro-reduction; general procedure. A conventional H-type cell of about 175 ml catholyte volume was used immersed

in a water bath and the cathode potential was controlled using a Juul Electronic potentiostat. Usually a suspension of 1.0 or 2.0 g of Ia (or Ib) in an acetate buffer mixture (A, B, or C, see below) was reduced at room temperature at potentials more positive than −0.8 V *vs.* Ag/AgCl with consumption of approximately 8 F/mol. Nitrogen was bubbled slowly through the catholyte, the middle compartment of the cell was filled with saturated aqueous potassium chloride, and the anolyte was 1:1 (approx.) ethanol (resp. methanol or DMF) − water saturated with sodium chloride. An excess (usually 5 ml or 5 g) of the carbonyl compound was added either before or after the electrolysis which was normally of 1−2 days duration. The catholyte was kept under nitrogen for further 1−7 days to allow completion of the cyclization reaction. Three different aqueous solvent mixtures were used:

A: 60 % EtOH, 0.2 M acetic acid, 0.4 M potassium acetate
B: 80 % MeOH } 15 g sodium acetate +
C: 50 % DMF } 5 ml acetic acid/200 ml

For electrolyses involving greater amounts of starting material additional acetic acid was added during the reduction. The products from the aliphatic aldehydes were usually soluble in the reaction mixture whereas those from the ketone and heteroaromatic aldehydes were partially precipitated. The catholyte was diluted with 1−2 volumes of water (except in the formaldehyde case) and cooled to −15 °C (except for C which was cooled to 0 °C). The precipitate was removed by filtration, washed with water, and dried under reduced pressure over silica gel. The filtrate was worked up by partial evaporation, neutralisation, and shaking with ether which led to the extraction of a small crop of usually impure product contaminated with IV. The extraction procedure (without prior dilution with water) was used in some of the early experiments but purer products (free from IV) are obtained by the precipitation method even though some material is lost with the filtrate. For the formaldehyde derivative IIIa, however, the extraction procedure is unavoidable, and in the final evaporation of the ethereal solution the temperature must be kept below 10 °C to avoid decomposition of the product which should then be kept in a refrigerator. Table 3 summarises microanalytical results, melting points and recrystallisation solvent.

Benzo[c]*cinnoline-N-oxide (IV).* Ia (1.0 g) was reduced as described above (solvent B), and after the electrolysis oxygen was bubbled through the catholyte (4 h). The methanol was

Table 3. Melting points and analytical results for the dibenzo[*d*,*f*][1,3]diazepine derivatives.

Compound	Melting point °C	Solvent of recrystallization	Formula	Analyses Calculated	Found
IIId	120−122 d	methylcyclohexane	$C_{16}H_{18}N_2O_2$	C 71.09, H 6.71, N 10.36	C 70.91, H 6.85, N 10.17
IIIe	110−112 d	ether-pentane	$C_{17}H_{20}N_2O_2$	C 71.80, H 7.09, N 9.85	C 72.00, H 7.28, N 9.67
IIIf	231−232 d	benzene	$C_{15}H_{16}N_2O_2$	C 70.29, H 6.29, N 10.93	C 70.46, H 6.39, N 11.00
IIIg	188−189 d	benzene	$C_{16}H_{18}N_2O_2$	see above	C 70.89, H 6.56, N 10.22
IIIh	202−203 d	benzene	$C_{17}H_{20}N_2O_2$	see above	C 71.60, H 7.10, N 9.95
IIIi	227−230 d	benzene	$C_{15}H_{10}D_6N_2O_2$	C 68.70, D+H 6.15, N 10.67	C 68.54, D+H 6.34, N 10.79
IIIj	202−204 d	ethanol	$C_{17}H_{18}N_2O_2$	C 72.32, H 6.43, N 9.92	C 72.09, H 6.34, N 9.99
IIIk	175−178 d	benzene	$C_{18}H_{20}N_2O_2$	C 72.95, H 6.80, N 9.45	C 72.81, H 6.66, N 9.60
IIIl	215−217 d	methanol	$C_{16}H_{15}N_3O_2$	C 70.80, H 4.95, N 13.76	C 70.60, H 4.96, N 13.87
IIIm	185−186 d	ethanol-water	$C_{17}H_{15}N_3O_2S$	C 62.75, H 4.65, N 12.91, S 9.85	C 62.70, H 4.65, N 12.83, S 9.72
IIIn	145−147 d	methylcyclohexane-benzene	$C_{16}H_{18}N_2O_2$	see above	C 70.96, H 6.79, N 10.17
IIIo	187−189 d	benzene	$C_{17}H_{20}N_2O_2$	see above	C 72.00, H 6.92, N 10.03
V	186−188 d	benzene	$C_{13}H_{10}N_2O$	C 74.27, H 4.79, N 13.33	C 74.07, H 4.92, N 13.53

evaporated *in vacuo*, the precipitate filtered off, washed with water, and dried over silica gel giving 0.8 g of light yellow material m.p. 117–119 °C, identified as nearly pure IV by comparing its IR and ^{1}HNMR spectrum with those of an authentic specimen.

5-Hydroxydibenzo[d,f][*1,3*]*diazepine (V).* Ia (1.0 g) was reduced in the presence of benzyl methyl ketone (3.0 ml, solvent B) as described above and kept at room temperature under nitrogen for totally 4 days. The clear yellowish catholyte was partially evaporated *in vacuo*, neutralized by addition of solid sodium hydrogencarbonate, and extracted twice by ether (100 ml + 50 ml). Removal of the solvent after drying over magnesium sulphate left a semi-solid residue (1.4 g) which by recrystallisation (chloroform – petrol ether) gave 0.4 g of crude product, m.p. 153 – 5°d. TLC showed some IV to be present, and an analytically pure sample (0.12 g, bright yellow needles, m.p. 186 – 8°d) was obtained by recrystallizing 0.32 g of the crude product twice from benzene.

Catalytic reductions

6,6-Dimethyl-5,7-dihydroxy-6,7-dihydrodibenzo[d,f][*1,3*]*diazepine (IIIf).* A mixture of 2,2′-dinitrobiphenyl (Ia), (5.0 g), 50 ml of acetone, 100 ml of aqueous acetate buffer (0.5 M acetic acid, 1.0 M potassium acetate) and 0.5 g of 10 % palladium on barium sulfate were shaken for 20 h with hydrogen (1.05 atm) at room temperature. Subsequent addition of 100 ml of water to this suspension and filtration gave 4.5 g of a mixture of IIIf and the catalyst, *i.e.* the yield of IIIf was 4.0 g (76 %). Recrystallization from benzene (1.5 l) gave white needles (3.64 g), m.p. 231 – 232 °C, d.

5,7-Dihydroxy-6,7-dihydrodibenzo[d,f][*1,3*]*diazepine-6-spirocyclopentane (IIIj).* Cyclopentanone (10 ml) and ethanol (50 ml) were hydrogenated as above. Similar work-up gave grey crystals (4.05 g) corresponding to 3.55 g (61 %) of crude IIIj. Recrystallization of this material from benzene (1.4 l) yielded white crystals (0.91 g, 16 %), m.p. 178 – 180 °C, d. Concentration of the mother liquor yielded additional impure material (0.6 g). Recrystallization of the first crop gave analytically pure IIIj m.p. 202 – 204 °C, d.

Acetylation

6,6-Dimethyl-5,7-diacetoxydibenzo[d,f][*1,3*]*diazepine (VI).* IIIf (0.15 g) was stirred for 1 h at 50° with a mixture of acetic anhydride (15 ml) and one drop of pyridine. Concentration under reduced pressure and washing with pentane yielded pale grey crystals of VI (0.16 g, 80 %) m.p. 128 – 130 °C. Recrystallization of a sample from methanol gave VI as white crystals, m.p. 140 – 141 °C, d. IR (KBr): Strong absorption at 1775 cm^{-1} (ester C=O). UV (abs. ethanol): λ 288 (sh, log ε 2.26), λ 254 (sh, log ε 3.94) and λ_{max} 231 (log ε 4.37). NMR (DMSO-d_6): τ 8.51 (s, 6 H, CH_3), τ 8,00 (s, 6 H, $OCOCH_3$) and τ 2.70 – 2.45 (m, 8 H, aryl H).

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