PORPHYRINS

II.* SYNTHESIS OF meso-DIMETHYLAMINOMETHYLBORANOPORPHYRINS

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UDC 547.749.07

Treatment of porphyrins or their copper complexes containing meso-dimethylaminomethyl or meso-dimethylformaldimino groups with lithium borohydride or diborane leads to the corresponding aminoborane derivatives. The reaction of the aminoboranes with trifluoroacetic acid was investigated, and trifluoroacetoxyborane complexes were isolated.

In a previous communication [1] we described the synthesis of a copper complex (I) of meso-dimethylaminomethyl-1-etioporphyrin, which consisted in the reduction of II by means of sodium borohydride. In this case we detected small amounts of a complex of unknown structure (X), the IR spectrum of which contains a number of bands at 2400 cm^{-1}. The aim of the present research was to establish the structure of this compound.

Demetallation of complex X by means of concentrated sulfuric acid gave a porphyrin, which, with respect to all of its physicochemical characteristics, was identical to meso-dimethylaminomethyl-1-etioporphyrin (III) obtained from its copper complex (I). Consequently, complex X contained a meso-dimethylaminomethyl group.

At the same time, the characteristic (for I and III) absorption bands at 2760 and 2810 cm^{-1}, which are due to stretching vibrations of the methyl groups in the $N(CH_3)_2$ group [2], were absent in the IR spectra of X. One might therefore have assumed that chemical bonding of the dimethylaminomethyl group occurs in complex X. The high mobility of this compound as compared with I during chromatography on silica gel indicated a considerable decrease in the basicity of the nitrogen atom in the dimethylaminomethyl group.

Intense bands at 2268, 2312, and 2363 cm^{-1}, which are characteristic for the stretching vibrations of B–H bonds in trialkylaminoboranes, and an intense band at 1160 cm^{-1}, which is related to the deformation vibrations of the BH_3 group [3], are observed in the IR spectrum of complex X in CCl_4 solution.

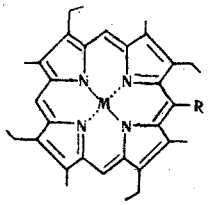
All of these data constitute evidence that complex X has an aminoborane structure (IV). The mass spectral data confirm this conclusion. The molecular ion peak with m/e 610 corresponds to the addition of one molecule of borane to complex I.

The formation of small amounts of aminoborane IV in the reduction of complex II with sodium borohydride can be explained by the presence in it of a reactive acidic PO_2Cl_2 grouping, the reaction of which with sodium borohydride in chloroform or tetrahydrofuran (THF) solution leads to the formation of diborane. The latter should react readily with complex I obtained as a result of the reduction. It might have been assumed that the formation of aminoborane IV should not occur during the reduction of II with sodium borohydride in aqueous alcohol, inasmuch as the solution is slowly neutralized under these conditions, and diborane is not formed. In order to confirm this assumption we carried out the reduction of

* See [1] for communication I.

Institute of Biophysics, Ministry of Public Health of the USSR, Moscow. Translated from Khimiya Geterotsiklicheskikh Soedinenii, No. 11, pp. 1518-1524, November, 1975. Original article submitted January 21, 1975.

complex II in alcohol. In fact, in this case we isolated complex I in practically quantitative yield based on the starting copper complex (V) of etioporphyrin. The yield of aminoborane IV in the reaction of diborane with I after chromatographic purification and crystallization reaches 89%.



I-IX

I R = $CH_2N(CH_3)_2$ (A), M = Cu; II R = $CH(OPOCl_2)$–$N(CH_3)_2$, M = Cu; III R = A, M = 2H; IV R = = A·BH_3, M = Cu; V R = H, M = Cu; VI R = A·BH_3, M = 2H; VII R = A·BH_3, M = Zn; VIII R = A·BH_2OCOCF_3, M = Cu; IX R = A·BH_2OCOCF_3, M = 2H

Lithium borohydride, the reductive capacity of which lies between that of diborane and sodium borohydride, also reacts readily with I and II. Thus treatment of complexes I and II with lithium borohydride in THF leads to aminoborane IV in 88 and 66% yields, respectively.

Free porphyrin I, obtained from complex I by allowing the latter to stand in concentrated sulfuric acid for 1.5 h, also forms aminoborane complex VI on treatment with lithium borohydride or on reaction with diborane. This compound had a higher R_f value than the starting porphyrin. Bands characteristic for vibrations of the BH_3 group in aminoboranes were observed in its IR spectrum.

A distinctive feature of the aminoborane complexes (IV and VI) obtained in this study is their high stability in acidic media: for example, refluxing aminoborane IV in acetic acid for 10-15 min does not lead to any appreciable splitting out of BH_3.

The formation of a complex with borane stabilizes the meso substituent considerably in the case of both free porphyrin VI and its copper complex (IV). For example, the zinc complex of porphyrin III cannot be obtained by the usual heating of the porphyrin in chloroform solution in the presence of zinc acetate because of rapid splitting out of the meso-dimethylaminomethyl group and formation of the zinc complex of etioporphyrin. Zinc complex VII was obtained in 59% yield from aminoborane VI under the same conditions.

The reaction of the aminoboranes with trifluoroacetic acid (TFA) is surprising. Thus, while treatment of complex I with TFA in chloroform leads to rapid splitting out of the meso substituent and formation of V, its addition to a solution of complex IV in chloroform leads to a gradual disappearance of the porphyrin structure. The solution becomes light yellow, the Cope band and the bands in the visible portion of the spectrum disappear, and bands appear at 378 and 458 nm. When the solution has access to air, it again turns red after a certain length of time. The copper complex of a new porphyrin, which has lower mobility on silica gel than the starting complex, is formed after evaporation of the solution to dryness and redissolving of the residue in chloroform. The electronic spectra of the newly developed complex and IV are practically identical, and this indicates retention of the same porphyrin structure. Intense bands at 1760 and 1150 cm^{-1}, which are unambiguously interpreted as C=O and C–O stretching vibrations of the trifluoroacetate, are observed in the IR spectrum of this compound. There is a broad band of medium intensity at 2430 cm^{-1} in the region of B–H absorption. All of these data make it possible to assume that the new complex is a trifluoroacetoxyborane derivative (VIII) of IV. The number of trifluoroacetoxy groups was determined by means of mass-spectral data. The molecular ion peak at m/e 722 corresponds to replacement of the hydrogen atom by one trifluoroacetate residue.

The addition of small amounts of TFA to aminoborane VI does not bring about disruption of the aminoborane complex, and the corresponding blue dication is stable for several hours. The further addition of TFA leads to a gradual change in the color of the solution to greenish-yellow, which is then converted to red-brown. The addition of TFA to VI, as in the case of complex IV, probably leads to disruption of the aromatic character of the porphyrin ring; this is manifested in the pronounced complication of the PMR spectrum. The corresponding trifluoroacetoxy derivative (IX), which has an electronic spectrum identical to that of aminoborane VI, was isolated after neutralization of the solution and chromatographic purification. The copper complex obtained from porphyrin IX was similar to complex VIII with respect to its IR, UV, and mass spectra and chromatographic mobility.

TABLE 1. Physicochemical Properties of the Porphyrins

Compound	Electronic spectra, λ_{max}, nm ($\varepsilon \cdot 10^{-3}$)					IR spectra, ν, cm^{-1}	TLC	
	Cope	IV (β)	III (α)	II	I		a*	b†
I‡	408 (130)	542 (10)	585 (12,6)			2760, 2810	0,05	0,40
III‡	408 (188)	508 (10,6)	543 (7,45)	579 (5,6)	632 (3,35)	2760, 2820		0,43
III, Dication	421 (226)	563 (11,7)	610 (8,4)					
IV	412 (354)	548 (9,2)	592 (15,3)			2268, 2312 2363	0,84	—
VI	411 (163)	512 (10,4)	550 (9,4)	583 (5,95)	638 (4,8)	3280, 2265, 2312, 2370	0,05	0,46
VI, Dication	426 (197)	567 (10,7)	618 (11,3)					
VII	418 (223)	554 (10,8)	597 (12,5)			2265, 2310 2365	0,40	
VIII	412 (365)	549 (9,75)	592 (17,0)			2420 1765, 1140	0,52	
IX	412 (170)	512 (10,6)	551 (9,5)	582 (6,1)	638 (4,8)	3300, 2420 1765, 1140	0,01	0,23
IX, Dication	425 (180)	566 (10,8)	619 (11,4)					

* The letter "a" indicates chloroform–CCl_4 (1 : 1) on Silufol.
† The letter "b" indicates methanol–ether–chloroform (1 : 2 : 14) on a loose layer of silica gel.
‡ These are the IR spectra of KBr pellets of the compounds.

On the basis of the experimental data, we noted that the introduction of a dimethylaminomethyl group and, especially, the formation of an aminoborane complex lead to an appreciable increase in the solubility of the prophyrin in organic solvents. For the investigation of the PMR spectra of the aminoboranes we therefore also obtained meso-dimethylaminomethylboranooctamethylporphyrin (X) via the scheme described above from the copper complex (XI) of octamethylporphyrin. We obtained the latter complex by heating octamethylporphyrinogen [5] in chloroform solution in the presence of copper acetate. Inasmuch as complex XI is only very slightly soluble in dichloroethane and chloroform, it was necessary to considerably increase the time required for the Vilsmeier reaction. The reduction of the intermediate phosphorus complex proceeds readily, but after demetallation of the copper complex of dimethylaminomethyloctamethylporphyrin, the corresponding porphyrin has low solubility in chloroform, and this hinders chromatographic purification. The aminoborane (X) formed after treatment of this porphyrin with lithium borohydride had sufficient solubility and was isolated in chromatographically pure form.

Chromatographic Properties

As seen from Table 1, all of the synthesized compounds are satisfactorily separated by means of thin-layer chromatography (TLC) on silica gel. However, it must be noted that these compounds, particularly zinc complex VII, decompose rapidly to the corresponding meso-unsubstituted product when the chromatographic plates are dried to remove the solvent.

The behavior of aminoboranes VI, IX, and X during chromatography on silica gel (Silufol) is anomalous. On these supports, the porphyrins each had two spots, one of which (the more mobile spot) corresponded to the free base, the other of which corresponded to the protonated form. The relative ratio of these two forms changed continuously as the chromatogram developed. Only one spot was observed on aluminum oxide or on inactive silicic acid when low-polarity solvents were used.

Electronic Spectra

The formation of an aminoborane or trifluoroacetoxyborane complex leads to a small bathochromic shift (~4-6 nm) for all of the bands in the visible region of the spectrum both for porphyrins and their metal complexes. However, the considerable increase in the ratio of the intensities of the bands (α/β) for complexes IV and VIII and dications VI and IX as compared with complex I and dication III (see Table 1) makes it possible to assume appreciable redistribution of the electron density on each of the four pyrrole rings of the porphyrin ring under the influence of the bulky dimethylaminomethylborane group. We have previously observed [6] a similar increase in the intensity ratio (α/β) of the bands associated with re-

TABLE 2. PMR Spectra of the Porphyrins*

Compound	meso-H	$-CH_2-N<$	CH_3	C_2H_5			$(CH_3)_2N-$	N—H
				$-CH_2-$	CH_3	J, Hz		
III	9,94 (2H) 9,76 (1H)	5,76 (2H)	3,45 (3H) 3,49 (6H) 3,59 (3H)	3,94 (4H) 3,91 (4H)	1,77 (6H) 1,75 (6H)	7,7 7,7	1,83 (6H)	−1,82 (2H)
VI	9,88 (2H) 9,76 (1H)	6,40 (1H) 6,60 (1H) $J=15$ Hz	3,65 (3H) 3,66 (6H) 3,73 (3H)	3,86 (2H) 3,88 (2H) 3,94 (2H) 4,01 (2H)	1,63 (3H) 1,70 (3H) 1,74 (3H) 1,77 (3H)	7,0 7,0 7,0 7,0	1,22 (3H) 12,5 (3H)	−2,89 (2H)
VII	9,72 (1H) 9,58 (1H) 9,50 (1H)	6,39 (1H) 6,61 (1H) $J=14,5$ Hz	3,26 (3H) 3,29 (3H) 3,65 (3H) 3,72 (3H)	3,8—4,1 (8H)	1,5—1,8 (12H)		0,99 (6H)	
IX	9,93 (2H) 9,83 (1H)	6,42 (1H) 6,66 (1H) $J=16$ Hz	3,46 (6H) 3,48 (3H) 3,55 (3H)	3,8—4,06 (8H)	1,6—1,85 (12H)		1,24 (6H)	−2,50 (2H)
X	9,93 (2H) 9,90 (1H)	6,55 (2H)	3,46 (18H) 3,58 (6H)				1,29 (6H)	

* The PMR spectra of $CDCl_3$ solutions of the compounds were recorded; the chemical shifts in parts per million are presented on the δ scale.

distribution of the electron density in the porphyrin ring when β-electronegative substituents are introduced during an investigation of metal complexes of porphyrins with ethoxycarbonyl substituents.

PMR Spectra

The PMR spectra presented in Table 2 confirm the conclusion of the appreciable interaction of the system of the porphyrin ring with the meso substituent that was originally drawn on the basis of a study of the electronic spectra of the synthesized compounds.

The introduction of an aminoborane group leads to an increase in the multiplicity of the signals of the β-ethyl substituents. This coupling appears most distinctly in the PMR spectrum of the zinc complex from the presence of three different signals from the meso protons.

It must be noted that while a broad singlet is observed in the spectrum of porphyrin III for protons of the $-CH_2-N<$ group, an AB quartet corresponds to it in the spectra of VI, VII, and IX. Unfortunately, the solubility of aminoborane X proved to be insufficient for the recording of a high-quality PMR spectrum, but the protons of the $-CH_2-N<$ group evidently give a broad singlet.

It follows from an examination of Eugon structural models that the magnetic nonequivalence of the protons of the $CH_2-N<$ group in the case of the aminoboranes gives rise to the peculiarities of the three-dimensional orientation of the substituent in the meso position relative to the plane of the porphyrin ring. From the point of view of steric interactions, the appearance of broad singlets in the spectra of III and X instead of distinctly expressed quartets seems stranger. This fact can be explained by the effect of the disruption of the planar structure of the porphyrin ring.

EXPERIMENTAL

The electronic spectra were recorded with a Shimadzu MPS-50L spectrophotometer. The IR spectra of KBr pellets of the compounds were recorded with a UR-10 spectrometer; the spectra of CCl_4 solutions were recorded with a Perkin—Elmer model 325 spectrometer. The mass spectra were obtained with an LKB-9000 spectrometer with introduction of the samples into the ion source of the mass spectrometer. The PMR spectra were recorded with an HA-100D spectrometer with hexamethyldisiloxane as the internal standard. Thin-layer chromatography was carried out on a loose layer of 50/100 μ silica gel.

Copper Complex (I) of meso-Dimethylaminomethyl-1-etioporphyrin. A 310-g sample of complex V and a mixture prepared from 3 ml of dimethylformamide (DMF) and 3.4 ml of phosphorus oxychloride was heated in 100 ml of dichloroethane at 60° for 20 min, after which the solvent was removed in vacuo, and the oily residue was poured into 200 ml of cold water. The resulting precipitate was removed by filtration and suspended in 50 ml of alcohol. Sodium borohydride (150 mg) was added to the suspension, and 10 ml of water was added dropwise gradually after 10 min. After 1 h, the resulting red crystalline precipitate

was removed by filtration and washed successively with hot water and cold methanol to give 345 mg (97%) of complex I, which was identical to the complex obtained by the method in [1].

meso-Dimethylaminomethyl-1-etioporphyrin (III). A 1.46-g sample of complex I was dissolved in 20 ml of concentrated sulfuric acid, and the mixture was allowed to stand with stirring for 1.5 h. It was poured into 1 liter of cold water, and the aqueous mixture was neutralized to pH 5-6 with ammonium hydroxide. The porphyrin was extracted with chloroform and subjected to chromatographic purification with a column filled with activity II aluminum oxide (elution with chloroform) and crystallization from chloroform–methanol to give 1.07 g (82%) of porphyrin III with mp > 300°. Found: C 78.6; H 8.5; N 12.6%. $C_{35}H_{45}N_5$. Calculated: C 78.5; H 8.5; N 13.0%.

Copper Complex (IV) of meso-Dimethylaminomethylborano-1-etioporphyrin. A) A 200-mg sample of complex II was dissolved in 30 ml of dry THF, and 100 mg of lithium borohydride was added immediately. After 1 h, the solvent was vacuum evaporated, and the residue was chromatographed on a thin layer of silica gel with chloroform–carbon tetrachloride (1 : 1). The dark-violet major product was extracted with chloroform and crystallized from chloroform–methanol to give 110 mg (66%) of long prisms of complex IV with mp > 300° (dec.). Found: C 68.5; H 7.6; N 11.1%. $C_{35}H_{46}BCuN_5$. Calculated: C 68.8; H 7.6; N 11.4%.

B) A 100-mg sample of complex I was dissolved in 15 ml of THF, and 100 mg of lithium borohydride was added in portions. After 15 min, the solvent was removed in vacuo, and 90 mg (88%) of a complex that, according to its IR and UV spectra and chromatographic properties, was identical to the sample obtained by method A was isolated chromatographically.

C) A 1-ml sample of a saturated solution of diborane in dry THF was added to a solution of 80 mg of complex I in 10 ml of methylene chloride. After 5 min, the solution was evaporated, and 73 mg (89%) of complex IV, identical to the complex obtained by methods A and B, was isolated chromatographically.

meso-Dimethylaminomethylborano-1-etioporphyrin (VI). A) Lithium borohydride (25 mg) was added to 50 mg of porphyrin III in 5 ml of THF. After 1 h, the solvent was removed in vacuo, and the residue was chromatographed in a thin layer of silica gel [chloroform–methanol (95 : 5)]. The major product was extracted with chloroform–methanol (10 : 1) and crystallized from chloroform–methanol to give 38 mg (71.5%) of porphyrin VI with mp > 300°. Found: C 76.3; H 8.8; B 2.4; N 13.1%. $C_{35}H_{48}BN_5$. Calculated: C 76.5; H 8.8; B 2.0; N 12.7%.

B) The yield of aminoborane VI was 82% when diborane was bubbled into a solution of III in chloroform.

Zinc Complex (VII) of meso-Dimethylaminomethylborano-1-etioporphyrin. A 200-mg sample of zinc acetate was refluxed for 10 min in 20 ml of chloroform, after which a solution of 100 mg of aminoborane VI in 10 ml of chloroform was added to the hot solution. After 20 min, the solvent was vacuum evaporated to a small volume, and the residual solution was chromatographed rapidly with chloroform on a thin layer of silica gel. The product was extracted from each plate with chloroform. Crystallization from chloroform–pentane gave 72 mg (59%) of complex VII with mp > 300°. Found: N 11.6%. $C_{35}H_{46}BN_5Zn$. Calculated: N 11.4%.

Copper Complex (VIII) of meso-Dimethylaminomethyltrifluoroacetoxyborano-2-etioporphyrin. Three drops of TFA were added to a solution of 18 mg of complex IV in 5 ml of chloroform. After 2 min, the solution was vacuum evaporated to dryness, and the residue was dissolved in chloroform and chromatographed on silica gel (TLC). The product was crystallized from chloroform–methanol to give 8.5 g of long prisms of complex VIII with mp > 300°. Found: N 9.7%. $C_{37}H_{45}BCuF_3N_5O_2$. Calculated: N 9.7%.

meso-Dimethylaminomethyltrifluoroacetoxyborano-1-etioporphyrin (IX). A 2-ml sample of TFA was added dropwise in the course of 2 min to a solution of 100 mg of aminoborane VI in 10 ml of chloroform. After 30 min, 20 ml of water was added, and the aqueous mixture was neutralized with ammonia. The chloroform layer was washed with water, dried with sodium sulfate, and chromatographed with a column filled with silicic acid (elution with chloroform). The major fraction was separated and evaporated to give 86 mg (71.5%) of the porphyrin, which was readily soluble in chloroform, methanol, and ether and partially soluble in petroleum ether. We were unable to obtain IX in crystalline form, and it was therefore analyzed in the form of its copper complex.

meso-Dimethylaminomethylboranooctamethylporphyrin (X). A 100-mg sample of octamethylporphyrin was dissolved in 10 ml of TFA, after which the solution was vacuum evaporated, and the residue was dissolved in 50 ml of chloroform. Acetic acid (10 ml) containing 200 mg of copper acetate was then added to

the chloroform solution, and the resulting precipitate (100 mg) of bright-red complex XI was suspended in 50 ml of dichloroethane. The suspension was added to the complex obtained from 1.6 ml of DMF and 2 ml of phosphorus oxychloride. The reaction mixture was refluxed for 3 h until starting complex XI was no longer present in a test sample, after which the solvent was vacuum evaporated, and the residue was poured into 100 ml of cold water. The resulting precipitated red crystalline phosphorus complex was suspended in 30 ml of ethanol, after which 0.3 g of sodium borohydride was added, and the mixture was allowed to stand at 40° for 30 min. The resulting red-brown crystalline precipitate (104 mg) of the copper complex of meso-dimethylaminomethyloctamethylporphyrin was removed by filtration. A 100-mg sample of the complex was dissolved in 20 ml of concentrated sulfuric acid, and the solution was stirred at 40° for 1 h. It was then poured into 0.5 liter of cold water, and the aqueous mixture was neutralized with ammonia. The precipitated porphyrin was extracted with chloroform, the chloroform was evaporated, the residue was suspended in dry THF (20 ml), and 100 mg of lithium borohydride was added. After 1 h, the solvent was evaporated, and the residue was chromatographed on silica gel (TLC) with chloroform to give 45 mg of porphyrin X, the electronic and IR spectra of which were completely identical to the spectra of aminoborane VI.

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