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Dedicated to Professor I.A. Nuretdinov on His 70th Anniversary

Quinoxaline–Benzimidazole Rearrangement in the Synthesis of Benzimidazole-Based Podands

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Abstract—Alkylation of 3-benzoylquinoxalin-2(1*H*)-one with 1,5-dibromo-3-oxapentane, 1,8-dibromo-3,6-dioxaoctane, and α,ω-dihaloalkanes with different lengths of the polymethylene chain gave the corresponding quinoxaline podands. In the reaction with 1,2-dibromoethane, the N,O- rather than N,N'-alkylation product was obtained. The reaction of the obtained quinoxaline-based podands with benzene-1,2-diamine followed the quinoxaline–benzimidazole rearrangement pattern with formation of 2-(3-phenylquinoxalin-2-yl)benzimidazole-based podands.

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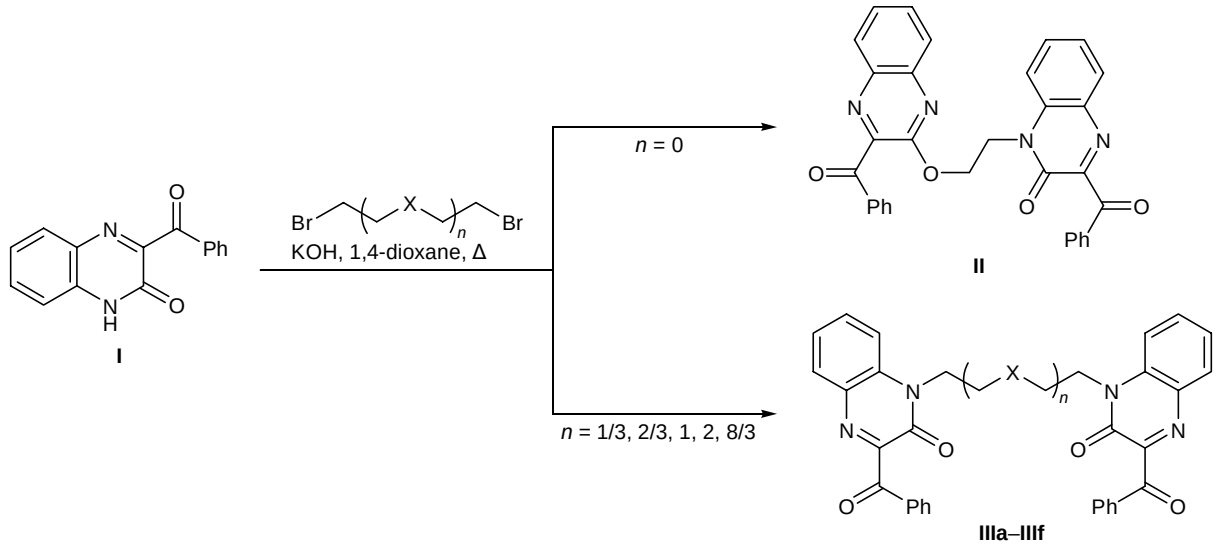
Podands [1] are open-chain analogs of crown ethers; in the recent years, they have attracted increased attention due to their accessibility, fairly high efficiency, and the possibility for controlling their complexing properties over a wide range via structural modifications [2, 3]. The applicability of podands as phase-transfer catalysts [4, 5], extractants [6], and components of ion-selective electrodes [7] is also the subject of extensive studies. According to the terminal group concept proposed by Vögtle [8, 9], the presence of aromatic substituents having donor centers at the ends of the oligo(ethylene glycol) chain strongly facilitates complex formation, for these donor centers fix a metal cation, and the ligand molecule adopts a conformation ensuring coordination at donor centers in the oligo(ethylene glycol) chain. Following the results of studies performed by Vögtle [8, 9], various aromatic analogs of oligo(ethylene glycol) ethers having rigid fragments at one or both ends of the polyether chain have been synthesized, and a new stage in the chemistry of podands has started; it involved replacement of solvating solvents by solid complexing agents as solvating additives. Nevertheless, compounds possessing functionalized heterocyclic systems at the ends of the polyether chain have been studied to a considerably lesser extent than common acyclic polyether complexing agents. Most procedures for the synthesis of such compounds are based on the Williamsom alkylation of heterocyclic systems having active NH groups with dihaloalkanes [10, 11] or related reactions [12, 13].

The present article reports on the synthesis of quinoxaline-based podands with various conformationally flexible spacer groups and on a new and convenient procedure for the transformation of these compounds into quinoxaline-containing benzimidazole podands via the quinoxaline–benzimidazole rearrangement which was discovered by us previously [14, 15]. Quinoxaline-based podands were synthesized by alkylation of 3-benzoylquinoxalin-2(1*H*)-one (**I**) [16] with 1,5-dibromo-3-oxapentane, 1,8-dibromo-3,6-dioxaoctane, and various α,ω-dibromoalkanes in boiling dioxane in the presence of potassium hydroxide (reaction time 12 h; Scheme 1). The yields of podands **II** and **IIIa**–**IIIf** ranged from 30 to 70%; unreacted compound **I** was readily removed from the alkylation products by washing with an aqueous solution of sodium hydroxide and was isolated by subsequent acidification of the alkaline solution.

Compounds **II** and **IIIa**–**IIIf** showed no NH absorption in the IR spectra, and their ^{1}H NMR spectra contained no NH signal, indicating that the alkylation was complete. As followed from the presence in the IR spectra of two carbonyl absorption bands at 1675–

Scheme 1.



X = O, n = 1 (**a**), 2 (**b**); X = CH_2, n = 1/3 (**c**), 4/3 (**d**), 8/3 (**e**), 1 (**f**).

1692 (benzoyl) and 1635–1660 cm^{-1} (lactam), the products contained a 3-benzoylquinoxalin-2(1*H*)-one fragment. However, the ^1H NMR spectrum of the product obtained by alkylation of benzoylquinoxalinone **I** with 1,2-dibromoethane (compound **II**) considerably differed from those typical of compounds **IIIa**–**IIIf** derived α,ω-dibromoalkanes with n = 1/3, 1, 4/3, and 8/3. In the spectrum of **II**, all proton-containing groups resonated separately, while the number of signals in the spectra of **IIIa**–**IIIf** was twice as low as the number of proton-containing groups. The spectrum of compound **IIIc** (obtained from 1,3-dibromopropane) contained a quintet from protons in the middle methylene group and signals from the other methylene protons.

3-Benzoylquinoxalin-2-(1*H*)-one (**I**) reacted with 1,5-dibromo-3-oxapentane and 1,8-dibromo-3,6-dioxaoctane under the same conditions as with α,ω-dibromoalkanes, and the products were the corresponding N,N'-dialkylated derivatives **IIIa** and **IIIb**. The IR spectra of **IIIa** and **IIIb** contained absorption bands belonging to stretching vibrations of the benzoyl carbonyl group (1690 cm^{-1}) and lactam carbonyl (1655 and 1646 cm^{-1}, respectively). In the ^1H NMR spectrum of **IIIa**, protons of the 3-oxapentane fragment resonated as two triplets at δ 4.44 (J = 4.70 Hz) and 3.83 ppm (J = 4.70 Hz), while compound **IIIb** displayed a singlet at δ 3.53 ppm and two triplets at δ 3.74 and 4.40 ppm from protons of the 3,6-dioxaoctane fragment. These data indicate that methylene protons on C^1/C^5 and C^2/C^4 in molecule **IIIa** and those on C^1/C^8, C^2/C^7, and C^4/C^5 in **IIIb** are equivalent in pairs. Signals from protons of the two quinoxaline fragments in **IIIa**–**IIIf**, including phenyl groups, are superimposed on each other; this means that the alkylation products have symmetric structure.

The structure of compound **IIIb** was determined by X-ray analysis. Compound **IIIb** crystallized with no solvent molecules. The general view of molecule **IIIb** in crystal is shown in Fig. 1. The dioxaoctamethylene fragment in **IIIb** adopts an asymmetric twisted conformation; in keeping with the torsion angles about the C^9–C^{10}, C^{10}–C^{11}, ..., C^{30}–C^{29} bonds, this conformation may be described as *gauche*,*trans*,*trans*,orthogonal,-orthogonal,*gauche* (the torsion angles are as follows:

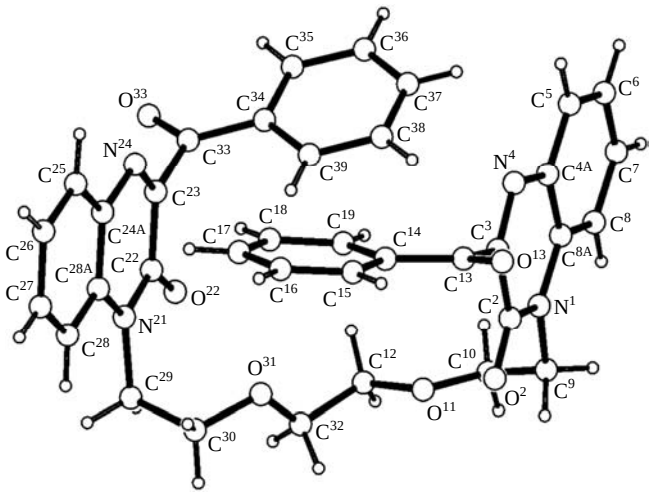


Fig. 1. Structure of molecule **IIIb** according to the X-ray diffraction data.

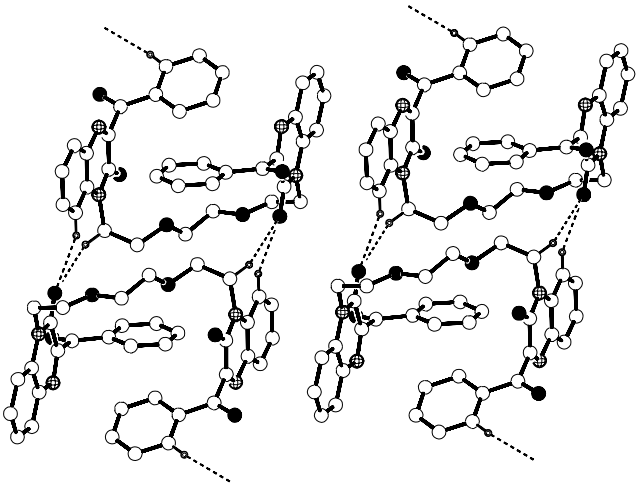


Fig. 2. Formation of H-dimers in the crystalline structure of compound **IIIb**; C–H···O hydrogen bonds are shown with dashed lines.

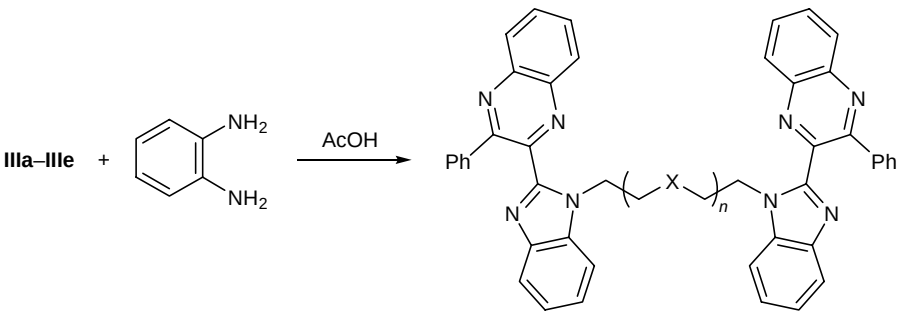
$N^1C^9C^{10}O^{11}$ –69.8, $C^9C^{10}O^{11}C^{12}$ 171.0, $C^{32}C^{12}O^{11}C^{10}$ 160.5, $O^{11}C^{12}C^{32}O^{31}$ 89.5, $C^{29}C^{30}O^{31}C^{32}$ –102.6, $N^{21}C^{29}C^{30}O^{31}$ –57.3°). The quinoxaline fragments are almost coplanar: the dihedral angle between their planes is 0.5°. The benzoyl fragments are planar, and they are arranged almost orthogonally to the planes of the corresponding quinoxaline systems. On the whole, the conformation of molecule **IIIb** in crystal ensures its minimal volume, i.e., the molecule is curled like a globule. Analysis of the free space shows that there is no cavity with a sufficient size to accommodate a solvent molecule. The bond lengths and bond angles in molecule **IIIb** have their standard values, indicating the absence of appreciable steric strains or conjugation (hyperconjugation). The conformation of the benzoylquinoxaline fragments in **IIIb** coincides with that found previously for 3-benzoylquinoxalin-2(1*H*)-one [16]; the bond lengths and bond angles therein were also similar.

Packing of molecules **IIIb** in crystal is governed by weak intermolecular interactions, hydrogen bonds like C–H···O and stacking of the aromatic fragments. Presumably, the intramolecular contacts C^9–$H^{91}\cdots O^2$ and C^{29}–$H^{291}\cdots O^{22}$ should not be regarded as those conforming to formal H-bonding criteria; these contacts originate from the forcedly shortened distance between the substituents in positions *1* and *2* of the pyrazine ring.

The O^2 carbonyl oxygen atom is involved in bifurcate hydrogen bond with hydrogen atoms of the neighboring molecule, giving rise to centrosymmetric H-dimer (Fig. 2). This hydrogen bond is characterized by the following parameters: C^{28}–$H^{28}\cdots O^{2'}$, C^{28}–H^{28} 0.93, $H^{28}\cdots O^{2'}$ 2.51, $C^{28}\cdots O^{2'}$ 3.39(1) Å, $\angle C^{28}H^{28}O^{2''}$ 158°; C^{29}–$H^{292}\cdots O^{2'}$, C^{29}–H^{292} 0.97, $H^{292}\cdots O^{2'}$ 2.59, $C^{29}\cdots O^{2'}$ 3.50(2) Å, $\angle C^{29}H^{292}O^{2'}$ 156°; symmetry operation [1 – *x*, –*y*, 1 – *z*]. The H-dimers are linked to each other along the 0*c* axis through intermolecular hydrogen bond with the O^{22} carbonyl oxygen atom in the other benzoylquinoxaline fragment of molecule **IIIb**: C^8–$H^8\cdots O^{22''}$ [1 – *x*, –*y*, –*z*], C^8–H^8 0.93, $H^8\cdots O^{22''}$ 2.36, $C^8\cdots O^{22''}$ 3.25(1) Å, $\angle C^8H^8O^{22''}$ 160°. The resulting molecular chains are linked along the 0*a* axis to give a layered structure through the intramolecular hydrogen bond C^{35}–$H^{35}\cdots O^{13'''}$: C^{35}–H^{35} 0.93, $H^{35}\cdots O^{13'''}$ 2.52, $C^{35}\cdots O^{13'''}$ 3.43(1) Å, $\angle C^{35}H^{35}O^{13'''}$ 168°; symmetry operation [–1 + *x*, *y*, –1 + *z*]. Numerous contacts between parallel or almost parallel aromatic systems (π-stacking) are formed along the same axis. The dihedral angles between the planar fragments vary from 1.7 to 2.6°, and the interplanar distances, from 3.3 to 3.5 Å.

We previously found that the reaction of 3-benzoylquinoxalin-2(1*H*)-one and its N^1-alkyl derivatives with benzene-1,2-diamines is accompanied by ring contraction (quinoxaline–benzimidazole rearrange-

Scheme 2.

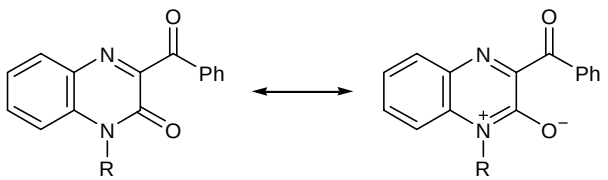


IVa–IVe

X = O, *n* = 1 (**a**), 2 (**b**); X = CH_2, *n* = 1/3 (**c**), 4/3 (**d**), 8/3 (**e**).

ment) to give 2-(benzimidazol-2-yl)-substituted quinoxalines [14, 15]. The presence of two benzoylquinoxalinone fragments in molecules of podands **IIIa**–**IIIf** allowed us to anticipate that these compounds could react with *o*-phenylenediamine according to the quinoxaline–benzimidazole rearrangement pattern with formation of benzimidazole-based podands containing quinoxaline fragments; on the other hand, the condensation could involve only the benzoyl carbonyl groups to give macrocyclic and/or oligomeric structures.

In fact, compounds **IIIa**–**IIIe** reacted with *o*-phenylenediamine in acetic acid on heating for 1 h, and the products were crystalline substances with sharp melting points. Their ^{1}H NMR spectra contained signals from protons of methylene groups and aromatic protons, whose position and multiplicity were similar to the corresponding parameters of the products obtained by reaction of 1-alkyl-3-benzoylquinoxalin-2(1*H*)-ones with *o*-phenylenediamine [14, 15]. Therefore, we concluded that the reaction was accompanied by quinoxaline–benzimidazole rearrangement with formation of benzimidazole-based podands **IVa**–**IVe** (Scheme 2). The IR spectra of the products lacked absorption bands assignable to benzoyl (1682 ± 7 cm^{-1}) or lactam carbonyl group (1645 ± 10 cm^{-1}), while a low-frequency band typical of benzimidazole ring appeared at 1612 ± 2 cm^{-1} [17]. The ^{1}H NMR spectra of **IVa**–**IVe** contained multiplet signals intrinsic to benzimidazolylquinoxaline system [14, 15]. An appreciable upfield shift (by 0.1 to 0.5 ppm) of signals from methylene protons in the polyether bridge of compounds **IVa**–**IVe**, as compared to the initial quinoxaline-based podands, must be noted. This fact may be regarded as an indirect support for the occurrence of quinoxaline–benzimidazole rearrangement which involves transformation of the π-deficient quinoxaline system (it may be represented as resonance hybrid with increased contribution of the 10π-electron ionic structure) into relatively π-excessive benzimidazole system [18].



It follows from the ^{1}H NMR spectra of initial quinoxaline-based podands **IIIa**–**IIIe** and rearrangement products **IVa**–**IVe** that the chemical shifts of methylene protons, especially of those in the NCH_2 group, depend not only on the nature of the heterocyclic system but also on the length of the polymethylene chain. For example, the chemical shift of the NCH_2 protons decreases by 0.2 ppm in going from compound **IIIc** to **IIId**, and by 0.25 ppm, in going from **IVc** to **IVd**.

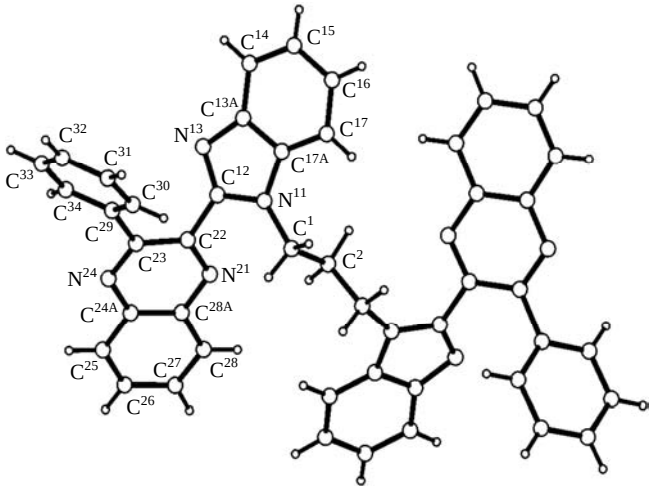


Fig. 3. Structure of molecule **IVc** according to the X-ray diffraction data. Disordered solvent molecule (EtOH) is not shown.

The structure of compounds **IVc** and **IVd** in crystal was proved by X-ray analysis. Compound **IVc** crystallizes with two solvent molecules (ethanol), and the molecule of **IVc** occupies a partial position at the second-order axis (Fig. 3), so that the asymmetric part of a unit cell contains only a half of molecule **IVc** and one disordered ethanol molecule (it is not shown in Fig. 3). Molecule **IVc** is symmetric: the second-order axis passes through the C^2 atom; therefore, geometric

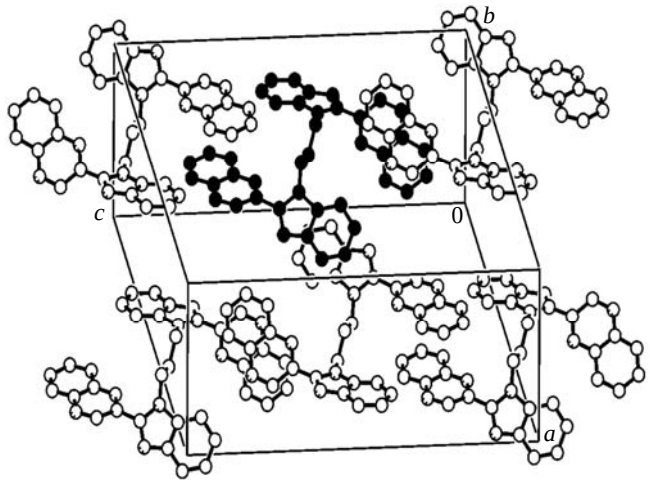


Fig. 4. Three-dimensional supramolecular structure formed by molecules **IVc** in crystal. Solvate molecules, hydrogen atoms, and phenyl substituents are not shown.

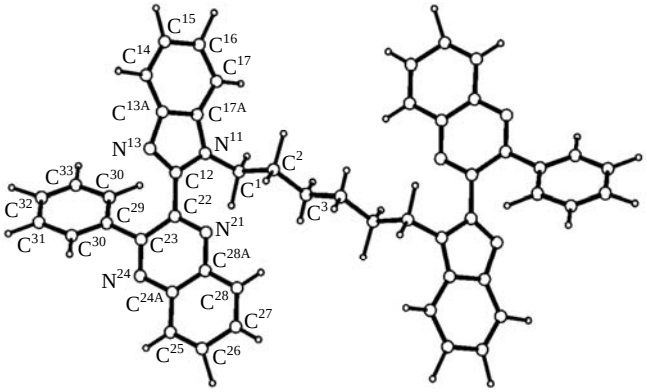


Fig. 5. Structure of molecule **IVd** according to the X-ray diffraction data.

parameters of one half equally apply to the other. The quinoxaline and benzimidazole fragments are planar within experimental error [0.016(4) and 0.054(4) Å, respectively]; the dihedral angle between their planes is 44.6(2)°. The benzene ring is turned through an angle of 46.2(2)° with respect to the quinoxaline ring plane. This configuration hampers effective conjugation between the corresponding aromatic systems. The bond lengths and bond angles in molecule **IVc** have their usual values, indicating the absence of strong steric strains.

Analysis of inter- and intramolecular contacts in the crystalline structure of **IVc** revealed one intramolecular C–H···N interaction [$H^{11}\cdots N^{5}$ 2.61(2) Å, $\angle C^{11}H^{11}N^{5}$ 103.5(2)°], one intermolecular C–H···O interaction between molecule **IVc** and ethanol [$H^{24}\cdots O^{1a}$ 2.37(2) Å, $\angle C^{24}H^{24}O^{1a}$ 157.1(4)°], and numerous π–π contacts between the aromatic fragments. Presumably,

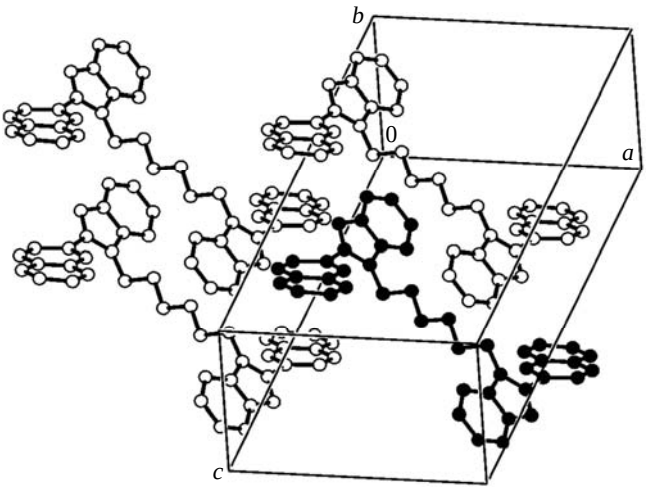


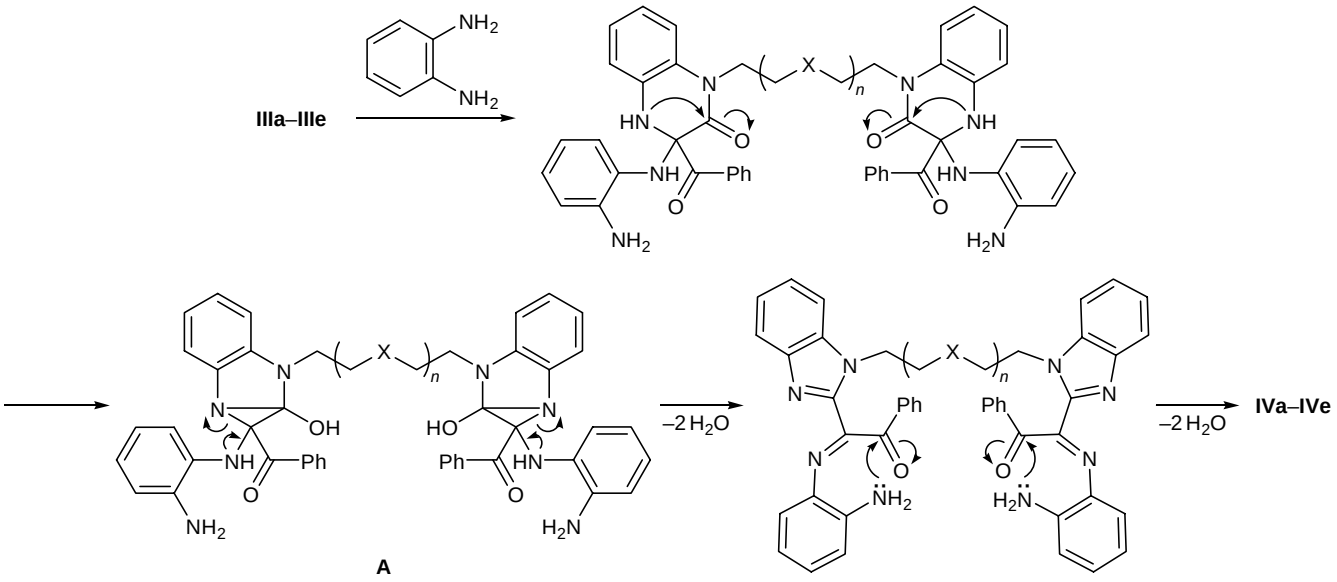
Fig. 6. Packing of molecules **IVd** in crystal (a fragment). Hydrogen atoms and phenyl substituents are not shown.

just the latter interactions affect packing of molecules in crystal and the type of the resulting supramolecular structure most strongly. Let us consider these interactions in more detail. Interactions between the electron systems of the phenyl substituents give rise to infinite chains of molecules along the [201] crystallographic direction [the distance between the planes of the phenyl rings is 3.33(3) Å, and the dihedral angle is 0°]. The benzimidazole rings in symmetrically linked molecules are also involved in π–π contacts with each other, leading to molecular chains along the [100] axis. The distance between the centroids of the benzimidazole fragments in the neighboring molecules is 3.839(3) Å, the distance between their plains is 3.49 Å, and the dihedral angle is 0.6°. Interactions between the quinoxaline fragments link molecules **IVc** along the [001] crystallographic axis to form zigzag chains (the distance between the planes is 3.87 Å, and the dihedral angle is 3.3°). As a result, a three-dimensional supramolecular structure is formed (Fig. 4).

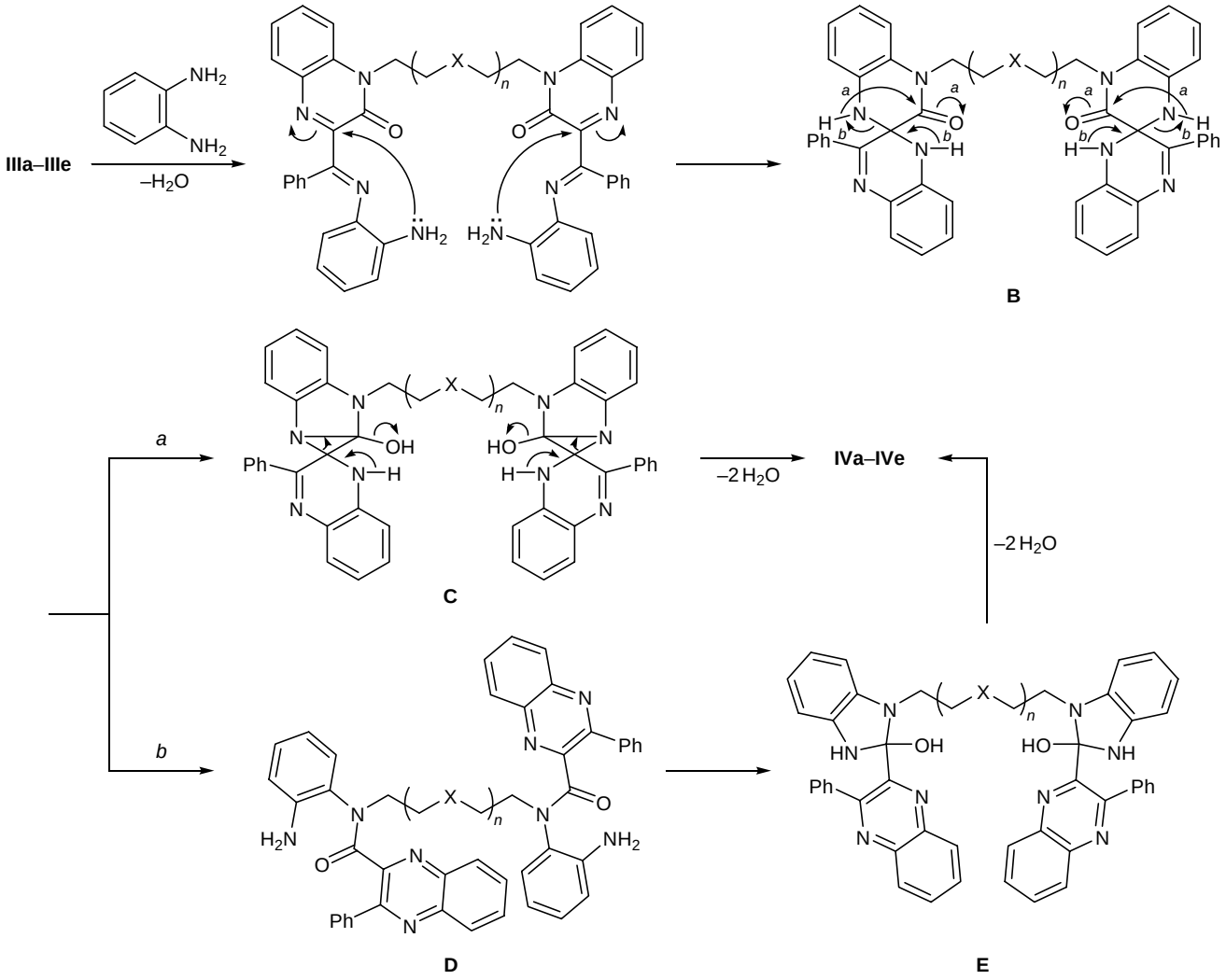
Unlike **IVc**, compound **IVd** crystallizes with no solvent molecules. Molecule **IVd** in crystal occupies a partial position in the symmetry center which is located at the middle of the C^{3}–C^{3a} bond (Fig. 5). The quinoxaline fragment is turned with respect to the benzimidazole fragment through a dihedral angle of 48.9(2)°, and the dihedral angle between the phenyl ring and the quinoxaline fragment is 38.5(2)°. This means that, as in molecule **IVc**, the aromatic substituents occupying *ortho* positions in the quinoxaline system of molecule **IVd** are forced out from conjugation for steric reasons. The hexamethylene bridge adopts a planar transoid zigzag conformation. Thus the molecular symmetry is likely to be determined by the symmetry of the polymethylene bridge. To verify this assumption, it is necessary to examine other related structures having odd and even numbers of bridging methylene units.

There are no classical hydrogen bonds in the crystalline structure of compound **IVd**. Among other interactions, intra- and intermolecular C–H···N contacts [$H^{11}\cdots N^{21}$ 2.53(2) Å, $\angle C^{1}H^{11}N^{21}$ 103.4(2)°; $H^{11}\cdots N^{24}$ 2.60(2) Å, $\angle C^{1}H^{11}N^{24}$ 136.3(2)°] and π–π interactions should be noted, only the quinoxaline fragments being involved in these interactions. The contacts between the electron systems of the quinoxaline rings in symmetry-related molecules are characterized by an interplane distance of 3.35 Å and a dihedral angle of 3.15°. These contacts give rise to infinite chains along the [001] crystallographic axis. Insofar as each quinox-

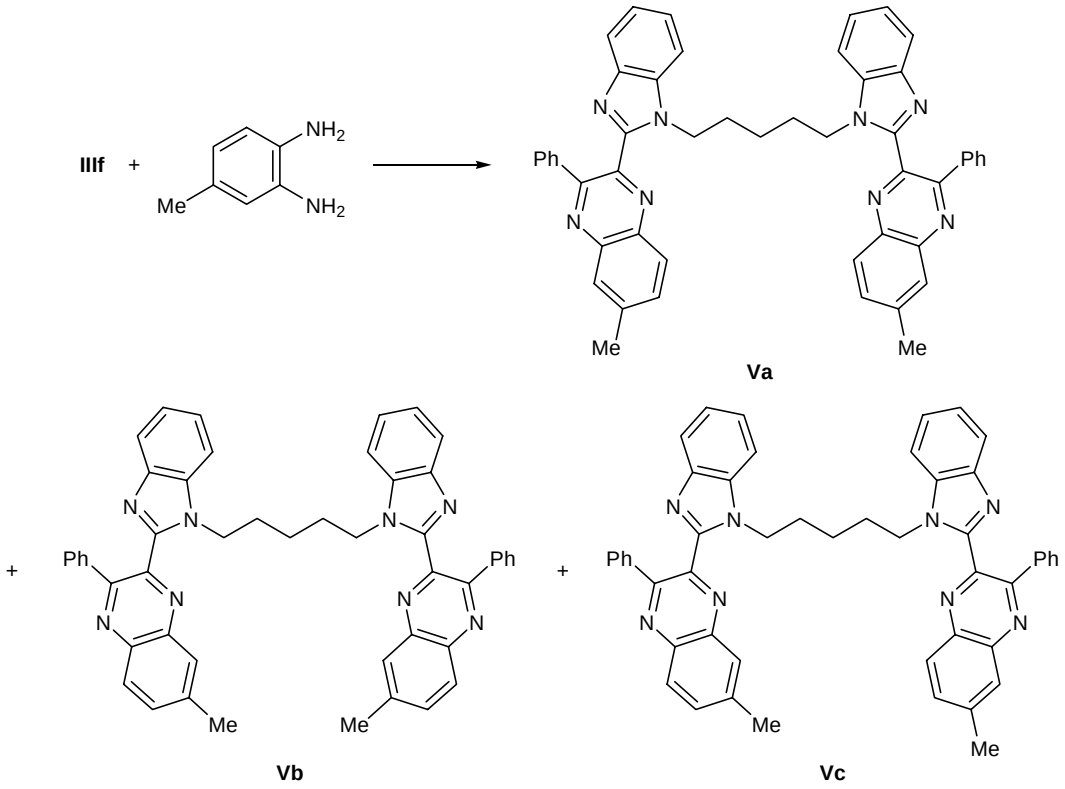
Scheme 3.



Scheme 4.



Scheme 5.



aline ring participates in π–π interactions with quinoxaline systems of two molecules related to the first molecule through a screw axis, the molecular chains are linked to form a layered supramolecular structure (Fig. 6).

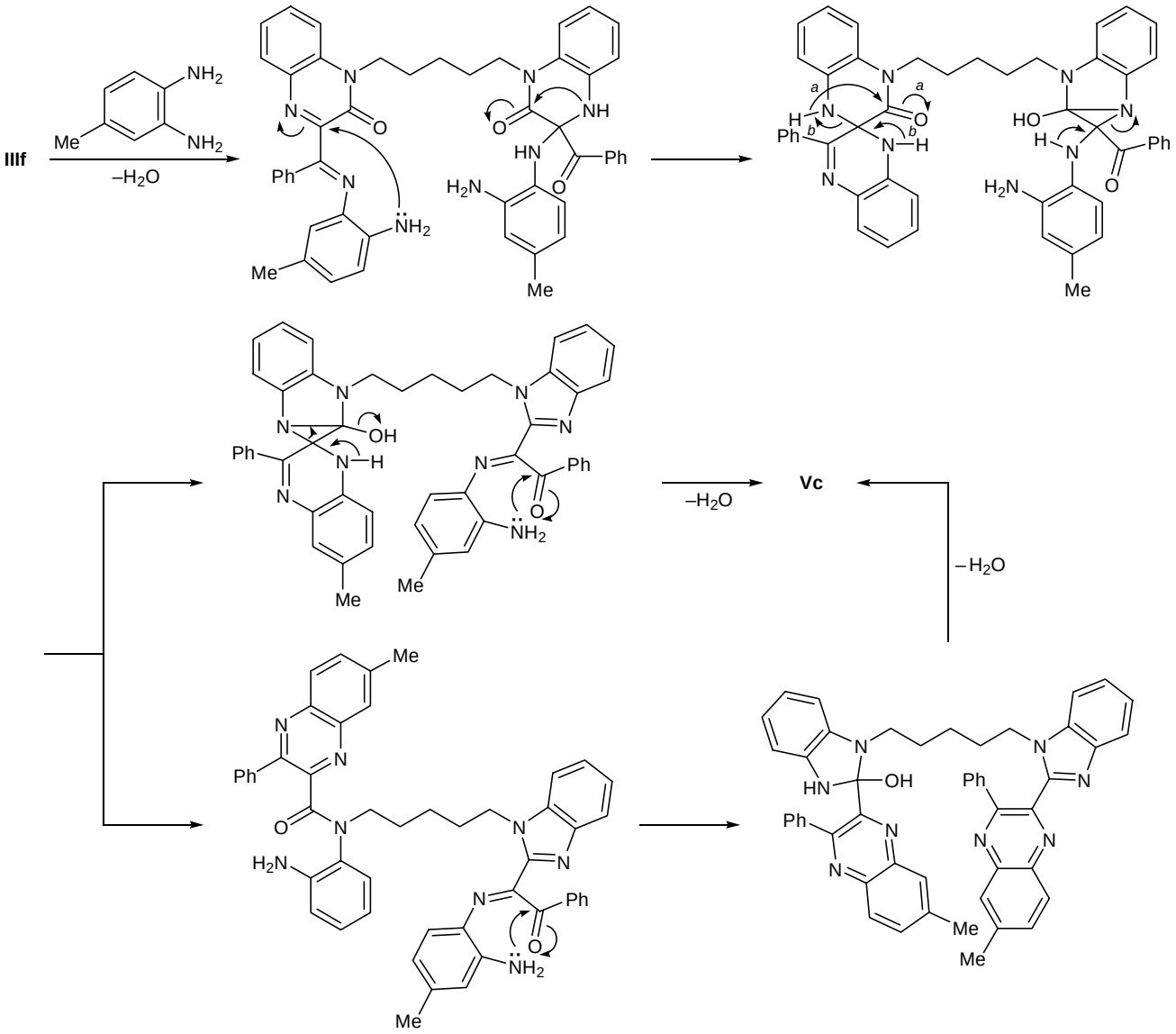
The results of X-ray diffraction study of three podand molecules, two of which having polymethylene bridges and one having a diether bridge, suggest that polymethylene chains (which generally adopt a planar zigzag conformation) determine the symmetry of the molecule as a whole: chains with an odd number of units have a C_2 symmetry, and those with an even number of units have a *C*–1 symmetry (symmetry center). Being more flexible, polyether bridging systems allow a molecule to curl into a globule having no cavities. However, additional studies on compounds with polymethylene and polyether bridges of different lengths are necessary to draw final conclusions.

The rearrangement of quinoxaline-based podands **IIIa**–**IIIe** into benzimidazole derivatives **IVa**–**IVe** may be rationalized by analogy with the quinoxaline–benzimidazole rearrangement occurring in reactions of 3-benzoylquinoxalin-2(1*H*)-ones with benzene-1,2-diamines [15], which may follow two alternative schemes. According to the first of these, the initial step is attack by the amino group of *o*-phenylenediamine on the C^3 atom of the quinoxaline ring in **I**. The subsequent ring contraction in intermediate tricyclic system **A** is accompanied by cleavage of the C^3–N^4 bond, and nucleophilic attack by the second amino group of *o*-phenylenediamine at the benzoyl carbonyl group leads to benzimidazole system substituted at position *2* by quinoxaline fragment and elimination of two water molecules (Scheme 3). The first step in the second scheme (Scheme 4) is nucleophilic attack by the amino group of *o*-phenylenediamine on the benzoyl fragment, which is followed by attack by the second amino group on the quinoxaline C^3 atom with formation of intermediate **B**. The latter can be converted into final structure **IV** along at least two pathways, through intermediate **C** (path *a*) or intermediates **D** and **E** (path *b*).

To elucidate which of the above scheme is operative in the observed quinoxaline–benzimidazole rearrangement, we examined the reaction of quinoxaline-based podand **IIIf** with 4-methylbenzene-1,2-diamine, assuming that the first step of the process involves the more nucleophilic amino group in the *para* position with respect to the methyl substituent.

No matter of how the reaction started, according to Scheme 3 with initial nucleophilic attack on the quin-

Scheme 6.



oxaline C^3 atom or according to Scheme 4 with initial attack by the amino group on the benzoyl carbonyl carbon atom, the stoichiometry of the process should be as follows: 2**IIIf** + 4Nu → **Va** + **Vb** + (**Vb** + **Vc**) (Nu is 4-methylbenzene-1,2-diamine; Scheme 5). In this case, the ^{1}H NMR spectrum of the product mixture would contain three signals from methyl protons in possible products **Va** and **Vc** or **Vb** and **Vc** with approximately equal intensities. In fact, only two singlets from methyl protons were present in the ^{1}H NMR spectrum of the product mixture. This means that either equal amounts of symmetric products **Va** and **Vb** were formed or compound **Vc** was formed alone. Analysis of the mixture by HPLC using a column charged with aluminosilica gel (eluent CH_2Cl_2–hexane–*i*-PrOH) showed that the reaction of **IIIf** with 4-methylbenzene-1,2-diamine gave mainly one product (yield ~92%). Therefore, we rule out the possibility for formation of compounds **Va** and **Vb**, for in this case initial attack by the amino group of the nucleophile on the quinoxaline C^3 atom (Scheme 3) would occur only in a half of a molecule, while the other half would react with participation of the benzoyl moiety (Scheme 4), which seems to be imporbable.

Thus the mechanism of formation of compound **Vc** may be illustrated by Scheme 6 which is a combination of Schemes 3 and 4. As follows from Scheme 6, the formation of compound **Vc** is the most probable. Furthermore, there is no matter of the direction of initial nucleophilic attack by the amino group. In any

case (i.e., whether the initial step is nucleophilic attack on the quinoxaline C^3 atom or on the benzoyl carbonyl group), the rearrangement gives one thermodynamically stable asymmetric product.

EXPERIMENTAL

The melting points were determined on a Boetius melting point apparatus. The IR spectra were recorded on UR-20 (compounds **II**, **IIIc**–**IIIe**, **IVc**–**IVe**) and Bruker Vector-22 spectrometers (**IIIa**, **IIIb**, **IVb**, **IVc**, **Vc**) from samples dispersed in mineral oil. The ^{1}H NMR spectra were measured on Bruker WM-250 (250.13 MHz; **II**, **IIIc**–**IIIe**, **IVc**–**IVe**) and Bruker MSL-400 spectrometers (400.13 MHz; **IIIa**, **IIIb**, **IIIf**, **IVa**, **IVb**, **Vc**). HPLC analysis was performed on a Gilson chromatograph equipped with a UV detector (λ 300 nm); 25-cm × 4.6-mm column packed with Zorbax NH_2; eluent CH_2Cl_2–hexane–*i*-PrOH (30:70:1), flow rate 1.5 ml/min. The solvent used for the preparation of the eluent were dried and purified according to standard procedures [19].

X-Ray analysis of single crystals of compounds **IIIb**, **IVc**, and **IVd** was performed on an Enraf–Nonius CAD-4 automatic four-circle diffractometer at 20°C (λCuK_α, graphite monochromator, ω/2θ scanning, $\theta \le 56.6°$, $\lambda = 1.54184$ Å). No drop in intensity of three control reflections was observed during data acquisition. Correction for absorption by the crystals was not introduced since the absorption coefficients were small. The structures were solved by the direct method using SIR program [20] and were refined first in isotropic and then in anisotropic approximation. All hydrogen atoms were visualized from the difference series of electron density; and they were included in the refinement procedure with fixed positional and temperature parameters for structure **IVc** or were refined by the *rider* model in the final steps (structures **IIIb** and **IVd**). All calculations were performed using SHELX97 program [21] incorporated into WinGX software package [22] (**IIIb**, **IVc**) or using MolEN software [23] (Alpha Station 200, **IVd**). The principal crystallographic parameters and details of X-ray diffraction experiments and structure refinement are collected in table.

3-Benzoyl-1-[2-(3-benzoylquinoxalin-2-yloxy)-ethyl]quinoxalin-2(1*H*)-one (II). A mixture of 0.4 g (1.6 mmol) of compound **I** and 5.4 mmol of potassium hydroxide in 20 ml of dioxane was heated for 1 min under reflux, a solution of 0.36 g (1.9 mmol) of 1,2-dibromoethane in 5 ml of dioxane was added, and the mixture was heated for 24 h under reflux. The mixture was then poured into water, and the precipitate was filtered off and washed with a solution of potassium hydroxide and water (~50 ml). Yield 0.19 g (46%), mp 186–188°C (from AcOH). IR spectrum, ν, cm^{-1}: 720, 730, 760, 780, 825, 935, 955, 1150, 1175, 1210, 1250, 1280, 1320, 1350, 1410, 1470, 1570, 1580, 1600, 1660, 1680. ^{1}H NMR spectrum (DMSO-d_6), δ, ppm: 4.81 t (2H, NCH_2, J = 5.30 Hz), 5.04 t (4H, OCH_2, J = 5.30 Hz), 7.45–8.15 m (18H, H_{arom}). Found, %: C 73.06; H 4.08; N 10.80. $C_{32}H_{22}N_4O_4$. Calculated, %: C 72.99; H 4.21; N 10.64.

1,1'-[Polymethylene(oxapolymethylene)-α,ω-diyl)-bis[3-benzoylquinoxalin-2(1*H*)-ones] IIIa–IIIf (*general peocdure*). A mixture of 4.0 mmol of 3-benzoylquinoxalin-2(1*H*)-one (**I**) and 5.4 mmol of potassium hydroxide in 50 ml of dioxane was heated for 1 min under reflux, a solution of 2.4 mmol of the corresponding α,ω-dibromoalkane or α,ω-dibromooxaalkane in 5 ml of dioxane was added, and the mixture was heated for 12 h under reflux. The mixture was then poured into water, and the precipitate was filtered off, washed with 3% aqueous potassium hydroxide and water (~50 ml), and dried.

1,1'-(3-Oxapentane-1,5-diyl)bis[3-benzoylquinoxalin-2(1*H*)-one] (IIIa). Yield 0.34 g (30%), mp 201–203°C (from AcOH). IR spectrum, ν, cm^{-1}: 690, 720, 755, 1115, 1175, 1320, 1350, 1485, 1565, 1580, 1600, 1655, 1690. ^{1}H NMR spectrum (DMSO-d_6), δ, ppm: 3.83 t (4H, OCH_2, J = 4.70 Hz), 4.44 t (4H, NCH_2, J = 4.70 Hz), 7.42 d.d (2H, 6-H, J = 7.68, 7.25 Hz), 7.50–7.80 m (10H, 7-H, 8-H, *m*-H, *p*-H), 7.87 d (2H, 5-H, J = 7.68 Hz), 7.97 d (4H, *o*-H, J = 7.25 Hz). Found, %: C 71.75; H 4.48; N 9.83. $C_{36}H_{30}N_4O_6$. Calculated, %: C 71.57; H 4.59; N 9.82.

1,1'-(3,6-Dioxaoctane-1,8-diyl)bis[3-benzoylquinoxalin-2(1*H*)-one] (IIIb). Yield 0.86 g (70%), mp 178–180°C (from CD_3CN). IR spectrum, ν, cm^{-1}: 457, 591, 692, 724, 761, 942, 1093, 1173, 1254, 1298, 1323, 1449, 1562, 1600, 1646, 1690. ^{1}H NMR spectrum (CD_3CN), δ, ppm: 3.52 s (4H, OCH_2CH_2O), 3.74 t (4H, OCH_2CH_2N, J = 5.84 Hz), 4.40 t (4H, NCH_2, J = 5.84 Hz), 7.38 d.d.d (2H, 6-H, J = 8.08, 6.04, 2.04 Hz), 7.51–7.53 m (4H, 7-H, 8-H), 7.60–7.67 m (4H, *m*-H), 7.70 d.d (2H, *p*-H, J = 7.40, 7.40 Hz), 7.82 d (2H, 5-H, J = 7.84 Hz), 7.95 d.d (4H, *o*-H, J = 7.72, 1.2 Hz). Found, %: C 70.18; H 5.08; N 9.21. $C_{36}H_{30}N_4O_6$. Calculated, %: C 70.35; H 4.92; N 9.12.

1,1'-(Propane-1,3-diyl)bis[3-benzoylquinoxalin-2(1*H*)-one] (IIIc). Yield 0.54 g (50%), mp 180–182°C

Principal crystallographic data of compounds **IIIb**, **IVc**, and **IVd** and conditions of X-ray diffraction experiments and structure refinement

Parameter	**IIIb**	**IVc**	**IVd**
Formula	$C_{36}H_{30}N_4O_6$	$C_{45}H_{32}N_8 \cdot 2C_2H_5OH$	$C_{48}H_{38}N_8$
Color, habit	Colorless plates	Yellow prisms	Colorless plates
Crystal system	Monoclinic	Monoclinic	Monoclinic
Space group	$P2_1/a$	$I2/a$	$P2_1/n$
Unit cell parameters			
a, Å	11.93(2)	15.17(2)	11.0136(7)
b, Å	23.71(1)	13.44(2)	8.924(6)
c, Å	12.09(2)	20.43(2)	20.40(2)
β, deg	117.4(1)	103.83(9)	101.92(5)
Volume, Å^3	3033(7)	4045(5)	1962(2)
Z	4	4 (partial position at the 2 axis)	2 (partial position at the symmetry center)
M	614.64	776.92	726.89
d_{calc}, g/cm^3	1.346	1.276	1.230
μ (CuK_α), mm^{-1}	0.761	0.636	0.550
F(000)	1288	1640	764
θ, deg	$2.72 \le \theta \le 52.0$	$3.97 \le \theta \le 74.44$	$3.72 \le \theta \le 59.0$
Index variation limits	$-11 \le h \le 10$ $-23 \le k \le 0$ $-12 \le l \le 12$	$-10 \le h \le 8$ $-13 \le k \le 13$ $-18 \le l \le 0$	$-12 \le h \le 12$ $-10 \le k \le 0$ $-23 \le l \le 0$
Total number of reflections	6323	8966	3676
Number of reflections with $F^2 > 2\sigma(I)$	1379	2802	1428 [$F^2 > 3\sigma(I)$]
Number of refined parameters	416	279	253
Final divergence factors	$R_1 = 0.071$, $wR_2 = 0.173$	$R_1 = 0.1132$, $wR_2 = 0.3069$	$R_1 = 0.061$, $wR_2 = 0.064$
Goodness of fit	1.008	1.378	1.654

(from AcOH). IR spectrum, ν, cm^{-1}: 695, 750, 760, 1170, 1190, 1255, 1325, 1555, 1580, 1600, 1635, 1675 695, 750, 760, 1170, 1190, 1255, 1325, 1555, 1580, 1600, 1635, 1675. ^{1}H NMR spectrum (DMSO-d_6), δ, ppm: 2.35 q (2H, $CH_2C\mathbf{H}_2CH_2$, J = 7.50 Hz), 4.57 t (4H, NCH_2, J = 7.50 Hz), 7.47 d.d (2H, 6-H, J = 7.01, 7.00 Hz), 7.53 d.d (4H, 7-H, J = 7.50, 7.50 Hz), 7.55 d (2H, 8-H, J = 7.50 Hz), 7.67–7.85 m (6H, *m*-H, *p*-H), 7.90 d (2H, 5-H, J = 8.01 Hz), 7.96 d (4H, *o*-H, J = 7.50 Hz). Found, %: C 73.19; H 4.74; N 10.21. $C_{33}H_{24}N_4O_4$. Calculated, %: C 73.32; H 4.48; N 10.36.

1,1'-(Hexane-1,6-diyl)bis[3-benzoylquinoxalin-2(1*H*)-one] (IIId). Yield 0.58 g (50%), mp 210–212°C (from DMSO). IR spectrum, ν, cm^{-1}: 760, 950, 1175, 1325, 1565, 1640, 1675. ^{1}H NMR spectrum (DMSO-d_6), δ, ppm: 1.55–1.65 m (4H, $NCH_2CH_2C\mathbf{H}_2$), 1.75–1.90 m (4H, $NCH_2C\mathbf{H}_2$), 4.37 t (4H, NCH_2, J = 5.33 Hz), 7.53 d.d.d (2H, 6-H, J = 8.38, 6.48, 1.9 Hz), 7.64 d.d (2H, 7-H, J = 7.63, ~7.60 Hz), 7.66 d (2H, 8-H, J = 7.66 Hz), 7.76–7.85 m (6H, *m*-H, *p*-H), 7.97 d (2H, 5-H, J = 8.02 Hz), 8.03 d (4H, *o*-H, J = 7.50 Hz). Found, %: C 74.11; H 5.29; N 9.52. $C_{36}H_{30}N_4O_4$. Calculated, %: C 74.21; H 5.19; N 9.62.

1,1'-(Decane-1,10-diyl)bis[3-benzoylquinoxalin-2(1*H*)-one] (IIIe). Yield 0.52 g (41%), mp 155–159°C (from AcOH). IR spectrum, ν, cm^{-1}: 680, 695, 760, 900, 955, 1175, 1190, 1310, 1330, 1350, 1550, 1580, 1600, 1645, 1690. ^{1}H NMR spectrum (DMSO-d_6), δ, ppm: 1.23–1.57 m [12H, $N(CH_2)_2(C\mathbf{H}_2)_6$], 1.70–1.90 m (4H, $NCH_2C\mathbf{H}_2$), 4.36 t (4H, NCH_2, J = 7.25 Hz), 7.55 d.d.d (2H, 6-H, J = 8.38, 6.48, 1.9 Hz), 7.64 d.d (2H, 7-H, J = 7.63, ~7.60 Hz), 7.66 d (2H, 8-H, J = 7.66 Hz), 7.76–7.85 m (6H, *m*-H, *p*-H), 7.97 d (2H, 5-H, J = 8.02 Hz), 8.03 d (4H, *o*-H, J = 7.50 Hz). Found, %: C 75.65; H 6.19; N 8.52. $C_{40}H_{36}N_4O_4$. Calculated, %: C 75.21; H 6.00; N 8.77.

1,1'-(Pentane-1,5-diyl)bis[3-benzoylquinoxalin-2(1*H*)-one] (IIIf). Yield 0.74 g (65%), mp 163–165°C (from EtOH). IR spectrum, ν, cm^{-1}: 465, 557, 593, 690, 722, 760, 829, 914, 950, 1170, 1254, 1295, 1325, 1345, 1484, 1560, 1584, 1602, 1648, 1698. ^1H NMR spectrum ($CDCl_3$), δ, ppm: 1.55–1.65 m (2H, $NCH_2CH_2CH_2$), 1.85–1.95 m (4H, NCH_2CH_2), 4.31 t (4H, NCH_2, J = 7.48 Hz), 7.39 d.d (2H, 6-H, $J \approx 7.5$ Hz), 7.42 d (2H, 8-H, J = 7.62 Hz), 7.45–7.75 m (8H, 7-H, *m*-H, *p*-H), 7.93 d.d (2H, 5-H, J = 7.96, 1.44 Hz), 7.98 d.d (4H, 2-H, J = 8.44, 1.28 Hz). Found, %: C 73.98; H 4.82; N 9.90. $C_{35}H_{28}N_4O_4$. Calculated, %: C 73.90; H 4.96; N 9.85.

α,ω-Bis[2-(3-phenylquinoxalin-2-yl)-1*H*-benzimidazol-1-yl](oxa)alkanes IVa–IVe (*general procedure*). A solution of 0.95 mmol of compound **IIIa**–**IIIe** and 1.04 mmol of *o*-phenylenediamine in 10 ml of acetic acid was heated for 1 h under reflux. The mixture was cooled and poured into water, a solution of sodium carbonate was added, and the precipitate was filtered off, washed with water (~30 ml), and dried.

1,5-Bis[2-(3-phenylquinoxalin-2-yl)-1*H*-benzimidazol-1-yl]-3-oxapentane (IVa). Yield 0.54 g (80%), mp 121–123°C. IR spectrum, ν, cm^{-1}: 429, 552, 699, 751, 768, 991, 1068, 1127, 1220, 1285, 1337, 1414, 1480, 1612. ^1H NMR spectrum (CD_3CN), δ, ppm: 3.64 t (4H, OCH_2, J = 5.48 Hz), 4.34 t (4H, NCH_2, J = 5.48 Hz), 7.10–7.50 m (18H, H_{arom}), 7.83 d.d (2H, 7-H, J = 6.84, 7.20 Hz) 7.90 d.d (2H, 6-H, J = 6.88, 7.20 Hz), 8.03 d (2H, 8-H, J = 7.92 Hz), 8.15 d (2H, 5-H, J = 8.24 Hz). Found, %: C 77.40; H 4.63; N 15.57. $C_{46}H_{34}N_8O$. Calculated, %: C 77.29; H 4.79; N 15.68.

1,8-Bis[2-(3-phenylquinoxalin-2-yl)-1*H*-benzimidazol-1-yl]-3,6-dioxaoctane (IVb). Yield 0.54 g (75%), mp 108–110°C. IR spectrum, ν, cm^{-1}: 428, 552, 699, 751, 768, 991, 1030, 1067, 1127, 1173, 1247, 1285, 1334, 1415, 1480, 1613. ^1H NMR spectrum (CD_3CN), δ, ppm: 2.99 s (4H, OCH_2CH_2O); 3.41 t (4H, OCH_2CH_2N, J = 5.16 Hz); 4.37 t (4H, NCH_2, J = 5.16 Hz); 7.20–7.28 m (10H), 7.28–7.35 m (4H), 7.42–7.58 m (8H), and 8.08–8.16 m (4H) (H_{arom}). Found, %: C 76.09; H 5.11; N 14.48. $C_{48}H_{38}N_8O_2$. Calculated, %: C 75.93; H 5.05; N 14.76.

1,3-Bis[2-(3-phenylquinoxalin-2-yl)-1*H*-benzimidazol-1-yl]propane (IVc). Yield 0.45 g (69%), mp 125–127°C (from *i*-PrOH). IR spectrum, ν, cm^{-1}: 700, 740, 755, 770, 990, 1075, 1210, 1280, 1335, 1420, 1550, 1610. ^1H NMR spectrum (DMSO-d_6), δ, ppm: 2.45 q (2H, NCH_2CH_2, J = 6.65 Hz); 4.40 t (4H, NCH_2, J = 7.18 Hz); 7.22–7.43 m (10H), 7.45–7.75 m (8H), 7.85–7.95 m (4H), 8.03 d.d.d (2H, J = 6.93, 5.64, 2.56 Hz), and 8.28 d (2H, J = 8.20 Hz) (H_{arom}). Found, %: C 78.81; H 4.94; N 16.31. $C_{45}H_{32}N_8$. Calculated, %: C 78.93; H 4.71; N 16.36.

1,6-Bis[2-(3-phenylquinoxalin-2-yl)-1*H*-benzimidazol-1-yl]hexane (IVd). Yield 0.50 g (72%), mp 242–246°C (from DMSO). IR spectrum, ν, cm^{-1}: 550, 570, 700, 710, 740, 750, 760, 780, 1080, 1155, 1280, 1335, 1415, 1545, 1610. ^1H NMR spectrum (DMSO-d_6), δ, ppm: 1.08–1.18 m (4H, $NCH_2CH_2CH_2CH_2$); 1.53–1.67 m (4H, NCH_2CH_2); 4.15 t (4H, NCH_2, J = 7.25 Hz); 7.25–7.40 m (10H), 7.52–7.72 m (8H), 7.90 d.d.d (2H, J = 8.40, 6.88, 1.53 Hz), 8.04 d.d.d (2H, J = 7.63, 6.85, 1.53 Hz), 8.12 d.d (2H, J = 7.74, 1.53 Hz), and 8.28 d.d (2H, J = 8.00, 1.53 Hz) (H_{arom}). Found, %: C 79.41; H 5.24; N 15.61. $C_{48}H_{38}N_8$. Calculated, %: C 79.31; H 5.27; N 15.42.

1,10-Bis[2-(3-phenylquinoxalin-2-yl)-1*H*-benzimidazol-1-yl]decane (IVe). Yield 0.54 g (73%), mp 132–134°C (from *i*-PrOH). IR spectrum, ν, cm^{-1}: 710, 730, 745, 765, 785, 1070, 1090, 1165, 1240, 1280, 1340, 1400, 1515, 1610. ^1H NMR spectrum (DMSO-d_6), δ, ppm: 0.83–1.26 m [12H, $N(CH_2)_2(CH_2)_6$]; 1.70–1.90 m (4H, NCH_2CH_2); 4.25 t (4H, NCH_2, J = 6.19 Hz); 7.20–7.40 m (10H), 7.52–7.68 m (8H), 7.86–8.00 m (4H), and 8.12–8.28 m (4H) (H_{arom}). Found, %: C 79.93; H 6.00; N 14.09. $C_{52}H_{46}N_8$. Calculated, %: C 79.77; H 5.92; N 14.31.

1-[2-(3-Phenyl-6-methylquinoxalin-2-yl)-1*H*-benzimidazol-1-yl]-5-[2-(3-phenyl-7-methylquinoxalin-2-yl)-1*H*-benzimidazol-1-yl]pentane (Vc). A solution of 150 mg (0.26 mmol) of compound **IIIf** and 70 mg (57 mmol) of 4-methylbenzene-1,2-diamine in 10 ml of acetic acid was heated for 1 h under reflux. The mixture was cooled and poured into water, a solution of sodium carbonate was added, and the precipitate was filtered off, washed with water (~30 ml), and dried. Yield 150 mg (77%), mp 118–120°C (from EtOH). IR spectrum, ν, cm^{-1}: 431, 554, 576, 697, 745, 830, 1003, 1078, 1140, 1157, 1206, 1249, 1283, 1334, 1418, 1483, 1619. ^1H NMR spectrum ($CDCl_3$), δ, ppm: 0.90–1.05 m (2H, $NCH_2CH_2CH_2$), 1.30–1.45 m (4H, NCH_2CH_2), 2.58 s and 2.64 s (3H each, CH_3), 3.75 t and 3.77 t (2H each, NCH_2, $J \approx 7.40$ Hz), 7.15–7.40 m (14H, *m*-H, *p*-H, benzimidazole), 7.50 d (4H, *o*-H, J = 7.44 Hz), 7.58 d.d (1H, 7-H, benzimidazole, J = 8.46, 2.26 Hz), 7.69 d.d (1H, 7-H, benzimidazole, $J \approx 8.5$, 2.2 Hz), 7.78–7.84 m (2H, quinoxaline), 7.88 s (1H, quinoxaline), 7.97 d (1H, quinoxaline, J = 8.68 Hz),

7.99 s (1H, quinoxaline), 8.11 d (1H, quinoxaline, J = 8.64 Hz). Found, %: C 79.35; H 5.49; N 15.18. $C_{49}H_{40}N_8$. Calculated, %: C 79.43; N 5.44; N 15.12.

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