Pd-catalyzed amination of dibromobiphenyls in the synthesis of macrocycles comprising two biphenyl and two polyamine moieties

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Dedicated to Prof. Usein M. Dzhemilev on the occasion of his 65th anniversary

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Abstract

Two approaches to the synthesis of polyazamacrocycles containing two biphenyl and two polyamine moieties are described. The first route comprises the synthesis of *N*,*N*′-bis(bromobiphenyl) substituted di- and poly-amines by the reactions of 2.2-3 equivalents of 4,4′- or 3,3′-dibromobiphenyls with corresponding di- and polyamines followed by the reaction with a second molecule of the amine. The second approach includes the synthesis of bis(polyamine) substituted biphenyls by the reactions of 4,4′- or 3,3′-dibromobiphenyls with four equivalents of di- and poly-amines with subsequent reaction of these *in situ* prepared intermediates with dibromobiphenyls. The yields of target macrocycles obtained according to two routes are compared and the advantage of the approach *via* bis(polyamine) substituted biphenyls in the majority of cases is established. Side products, when formed in all reactions, were analyzed.

Keywords: Amination, macrocycles, Pd catalysis, polyamines, dibromobiphenyls

Introduction

Macrocycles containing biphenyl units are of constant interest due to their interesting coordination possibilities which arise from the combination of flexible and tunable polyoxa- and polyaza-cycles with a rigid non-planar aryl moiety. Many cyclic polyethers were formed starting from 2,2′-dihydroxybiphenyl;[1-3] their coordination with organic cations like *tert*-butylammonium was studied,[2] as well as the transport of Li, Na, K cations[4,5] and of $Hg(CF_3)_2$[6,7] through a liquid membrane. In such macrocycles one or two polyoxaethylene chains were attached to one biphenyl unit. Molecular structures of various 2,2′-biphenyl-based crown ethers and their

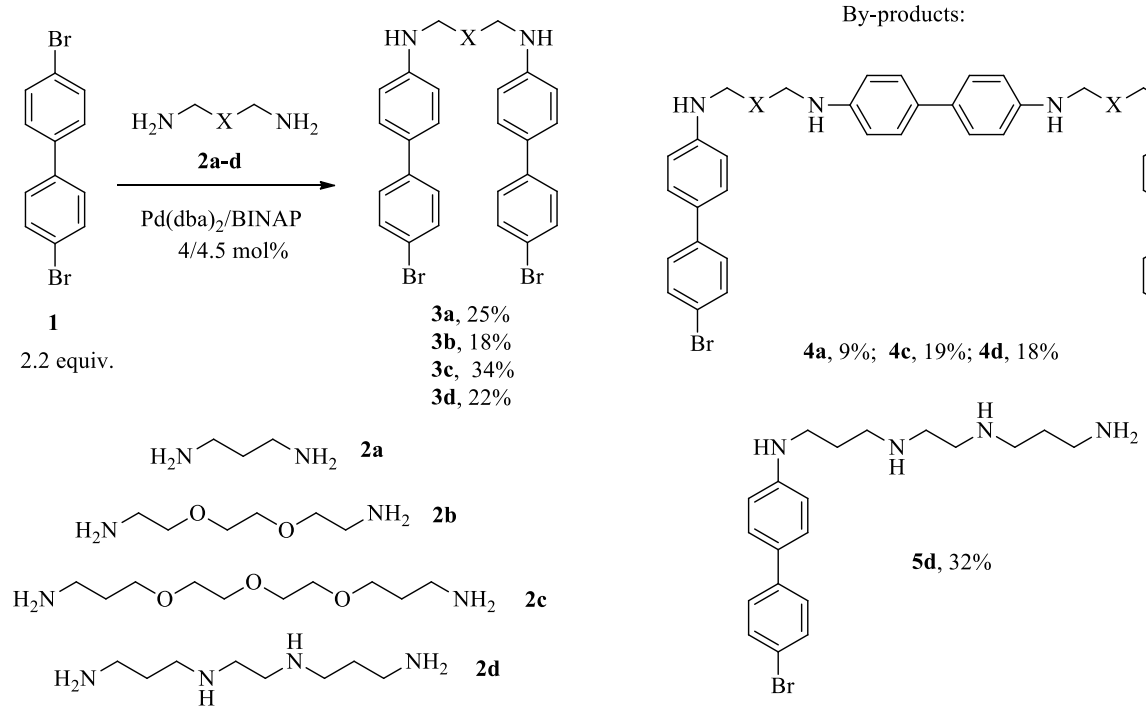
coordination with anions have been studied.[8,9] Polyoxadiaminomacrocycles were also synthesized on the basis of 2,2′-disubstituted biphenyl and their coordination with primary alkylammonium salts, including chiral compounds, was investigated.[10] Polyazamacrocycles with 3, 4 and 8 nitrogen atoms were studied for binding Cu^{2+}, Zn^{2+} and $[PdCl_4]^{2-}$ ions.[11] Macrobicycles of cryptand type with N and S atoms have been shown to form complexes with Cu(I) and Ag(I).[12] Biphenyl-containing macrolactams have been tested as colorimetric sensors for nitrophenolate anions,[13] and fluorescent and electrochemical sensors were elaborated on the basis of the macrocycles containing 2,2′-biphenyls substituted with amino goups in positions 4 and 4′.[14] Recently more sophisticated macrocycles like peptide-biphenyl hybrid[15] and hemispherand macrocycle[16] with bi- and quaterphenyl moietes have been reported. Cyclic triamides[17] as well as cyclic Schiff bases (trianglimines)[18,19] are known, usually comprised of three 3,3′- or 4,4′-disubstituted biphenyls. Among them the most interesting are chiral non-racemic molecules with 1,2-diaminocyclohexane and 4,4′- and 3,4′-biphenyl fragments.[20] Atropoisomeric biphosphine ligands were synthesized by functionalizing macrocycles constructed on the basis of 3,3′-biphenyls, and tested in the asymmetric hydrogenation of alkenes.[21] π-Electron donor[22] and acceptor[23] macrocyclic systems with 4,4′-biphenyls were reported, the first being tested as hosts for fused aromatic systems. There are some unusual macrocycles with long rigid units which combine two 4,4′-biphenyl fragments with four triple bonds linked through sulfur atoms which possess interesting electronic properties.[24] The majority of known macrocycles based on biphenyls were synthesized using non-catalytic approaches which are often multistep procedures, however, in some cases one-step formation of macrocycles can be achieved, e.g. for the synthesis of aromatic tetrasulfonate 2,2′-biphenyl-based macrocycles.[25] In some approaches biphenyl fragment was built using Pd-catalyzed coupling of two benzene moieties at the step of macrocyclization, as it was in the case of the compound with diazacrown, dipeptide and biphenyl fragments.[26] Palladium catalysis was also employed for the synthesis of an unusual macrobicycle where anomalously bent 4,4′-biphenyl is incorporated into calix[4]amide.[27] Another example of the application of the catalytic method for the synthesis of biphenyl-based macrocycles is zirconocene-mediated macrocyclization which afforded strained cyclophanes with two 4,4′-biphenyls.[28] It was mentioned that biphenyls were incorporated in some biologically active macrocycles, e.g. tricyclic glucopeptides of vancomycin group.[29] All these data envisage biphenyl-based macrocycles as valuable compounds with numerous applications.

Recently we have shown the possibility to synthesize earlier unknown family of polyazamacrocycles with C(sp^2-N) bonds by the Pd-catalyzed amination reaction of 4,4′- and 3,3′-dibromobiphenyls with di- and polyamines.[30,31] Macrocycles based on 3,3′-disubstituted biphenyl were obtained in rather high yields up to 40%, whereas macrocycles containing 4,4′-disubstituted biphenyl were formed only with the longest diamines and in tiny yields not exceeding 10% due to geometrical factors. In all cases the formation of cyclic dimers and oligomers was noted, and in many reactions these compounds were isolated in pure state. We decided to reveal the reaction paths according to which these symmetrical macrocycles

containing two biphenyl and two polyamine units (cyclic dimers) may be formed, to elaborate particular methods for their synthesis because these molecules are of the utmost interest due to their versatile coordination properties, to find out scope and limitations of tested approaches and their dependence on the nature of starting compounds.

Results and Discussion

At first the synthesis of cyclodimers *via* intermediate *N*,*N*′-bis(bromobiphenyl) substituted polyamines was studied. For the first experiments with 4,4′-dibromobiphenyl **1** we chose 1,3-propanediamine **2a,** dioxadiamine **2b**, trioxadiamine **2c**¸ and tetraamine **2d** as model polyamines. The reactions were run with 2.2 equivalents of compound **1** in boiling dioxane at c = 0.1 M, and were catalyzed with 4 mol% $Pd(dba)_2$/BINAP (Scheme 1). BINAP was taken as a ligand because

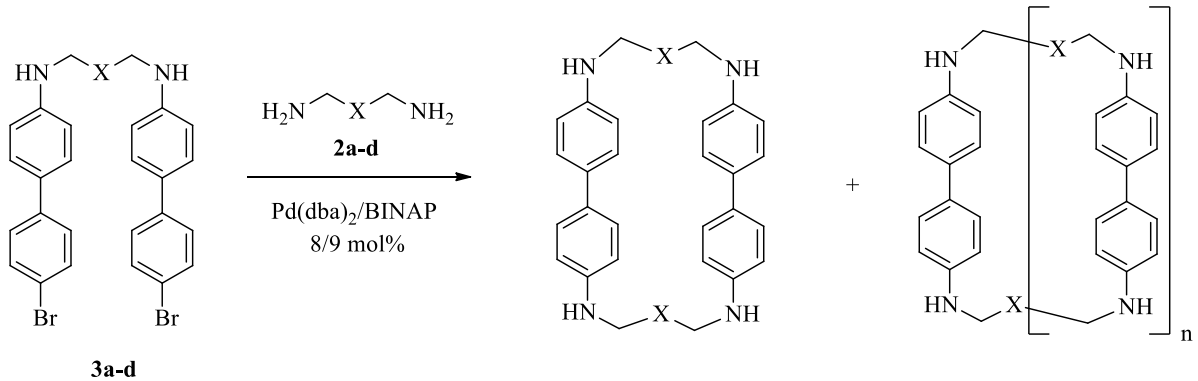


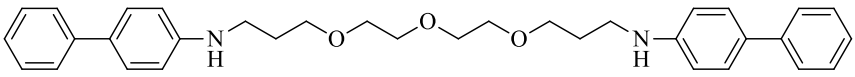
Scheme 1

it was found to be the most versatile for the Pd-mediated amination of aryl halides in general,[32] and the best ligand for the diarylation of linear polyamines in particular.[33] In 10 h the diarylation was completed and the reaction mixtures were evaporated and subjected to column chromatography on silica gel. The yields of the target compounds **3a-d** after purification were not high due to the formation of linear oligomers like **4**, which were formed due to the diamination of one biphenyl fragment in compounds **3**. However, it was impossible to increase the yields of the desired diarylated polyamines **3** either by decreasing the catalyst loading or by

the application of a greater excess of **1**: in the first case the diarylation process would not come to completion, in the second case the N,N-diarylation process would take place giving rise to triarylated species. Compound **3b** was obtained in pure state by washing the reaction mixture with small amounts of dichloromethane because its solubility was found to be unusually low. In one case, with tetraamine **3d**, the diarylation process was not completed, and monoarylated derivative **5d** was obtained in 32% yield.

The formation of the macrocycles **6a-d** was accomplished by the reactions of *N*,*N*'-bis(bromobiphenyl) polyamines **3a-d** with one equivalent of corresponding di- and polyamines **2a-d**, which were catalyzed by 8 mol% $Pd(dba)_2$/BINAP (Scheme 2). In these processes more dilute solutions were employed (c = 0.02 M) to suppress the formation of linear and cyclic oligomers. The reactions ran to completion after 30-40 h of reflux. Macrocycles with trioxadiamine and tetraamine chains **6c,d** were isolated in 20 and 23% yields, respectively, while the yield of the macrocycle with dioxadiamine unit was small (9%), and the shortest 1,3-propanediamine **2a** gave a mixture of the cyclic dimer **6a** with cyclotetramer **7a** (n=4) in total 6% yield. In the reaction of compound **4c** with trioxadiamine **2c** the formation of cyclic oligomers was also noted, and the mixture of **6c** with **7c** (n=4, 6) was isolated by column chromatography as a separate fraction. In this reaction the product of the bromine reduction **8c** was obtained in 16% yield, though the reduction processes are not common in the Pd-catalyzed amination with di- and polyamines. We also tried to accomplish the synthesis of cyclodimers *via* a one-step procedure without isolation of the intermediate diaryl derivatives **3**.



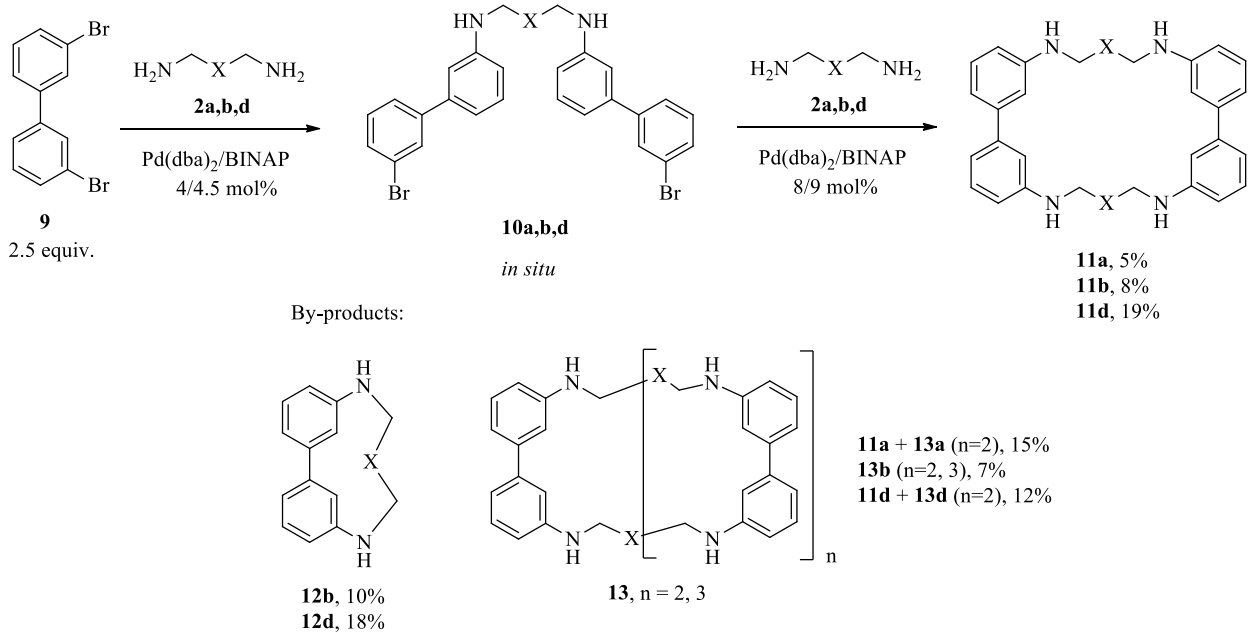


8c, 16% (from isolated **3c**), 28% (from *in situ* obtained **3c**)

Scheme 2

For this purpose 2.5 equivalents of 4,4′-dibromobiphenyl were reacted with trioxadiamine **2c** using 4 mol% catalyst at c = 0.1 M. After 10 h the reaction mixture was diluted to get 0.02 M solution, additional amount of the catalyst (8 mol%) and one equivalent of trioxadiamine **2c** were added, and the reaction was refluxed for 35 h. The chromatography gave 28% of the reduction product **8c**, only 5% of pure cyclic dimer **6c**, and a separate fraction containing cyclodimer **6c** with cyclic trimer **7c** (n=3) (9% yield). This unsatisfactory result demonstrates the difficulties in the separation of cyclic oligomers and thus the pressure to diminish their amount and diversity, which can be done only using pure *N*,*N*′-bis(4-biphenyl) derivatives of polyamines for the synthesis of cyclic dimers.

While macrocycles based on 4,4′-biphenyls are well documented in the literature, macrocycles incorporating 3,3′-biphenyls are quite rare examples, and this fact makes the synthesis of cyclic dimers with two 3,3′-biphenyl moieties an important task. At first we tried a one-step approach described above without isolation of the intermediate N,N′-diarylated derivatives of polyamines (Scheme 3).

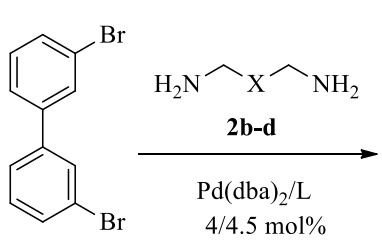


Scheme 3

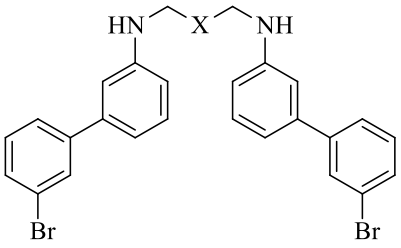
N,N′-diarylation of polyamines **2a,b,d** was achieved using 2.5 equivalents of 3,3′-dibromobiphenyl **9**, 4 mol% catalyst, and 0.1 M solutions of polyamines in dioxane. After 10 h of reflux the reaction mixtures were analyzed by ^{1}H NMR to verify the formation of diaryl derivatives **10**, they were diluted to make 0.02 M solutions and new portions of the catalyst (8 mol%) were added. The additional reflux for 35-40 h was necessary to complete the intramolecular diamination, and after it the reaction mixtures were subjected to chromatography on silica gel. The result was moderate only for tetraamine derivative **11d** (19%), while in other

cases pure cyclodimers **11a,b** were obtained in low yields. Cyclic oligomers **13** were isolated in all reactions, and in the case of dioxadiamine **2b** and tetraamine **2d** also macrocycles **12b,d** were obtained in comparable yields (10 and 18%, respectively). The reaction of equimolar amounts of 1,3-diaminopropane **2a** with 3,3′-dibromobiphenyl **9** described by us previously afforded 24% yield of the cyclic dimer **11a**.[31] Thus it is clear that the approach *via in situ* obtained *N*,*N*′-bis(3-bromobiphenyl)diamine is not suitable for this compound.

Next we investigated the possibilities of this method with chromatographic isolation of compounds **10**; this was thought also to reveal the formation of by-products (Scheme 4).

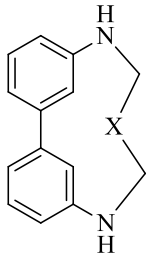


9
2.2-3 equiv.

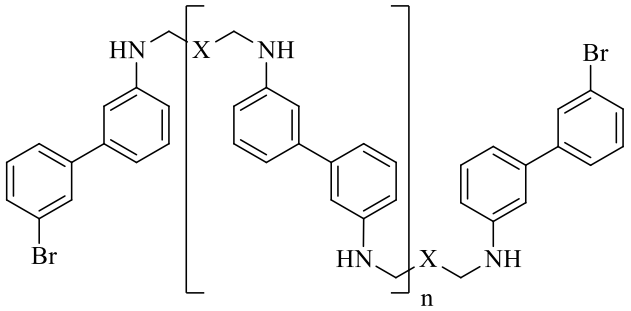


10b, 27% (L = Xanthphos, 3 equiv. of **9**)
10c, 21% (L = BINAP, 2,2 equiv. of **9**)
35% (L = Xanthphos, 3 equiv. of **9**)
10d, 26% (L = BINAP, 2.2 equiv. of **9**)
34% (L = BINAP, 3 equiv. of **9**)

By-products:



12c, 11% (L = BINAP, 2,2 equiv. of **9**)
12d, 7% (L = BINAP, 2,2 equiv. of **9**)



14b-d (n = 1), **15d** (n = 2)

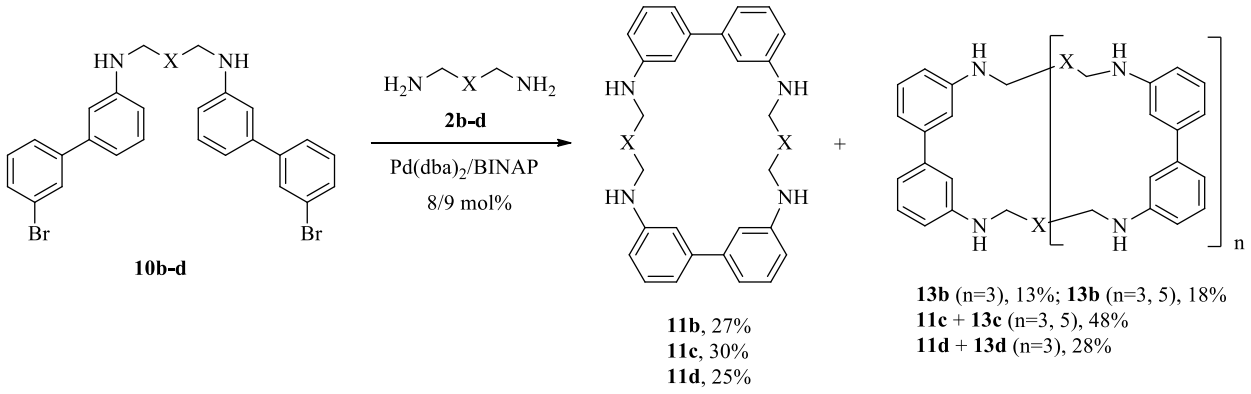
14b, 5% (L = Xanthphos, 3 equiv. of **9**)
14c, 11% (L = BINAP, 2,2 equiv. of **9**)
19% (L = Xanthphos, 3 equiv. of **9**)
14d, 28% (L = BINAP, 2,2 equiv. of **9**)
32% (L = BINAP, 3 equiv. of **9**)
15d, 12% (L = BINAP, 2,2 equiv. of **9**)

Scheme 4

According to a given consideration, diamine **2a** was excluded from this series of experiments. The reactions were run using 2.2 equivalents of **9**, and at first they were catalyzed by 4 mol% $Pd(dba)_2$/BINAP. The reactions of trioxadiamine **2c** and tetraamine **2d** gave target

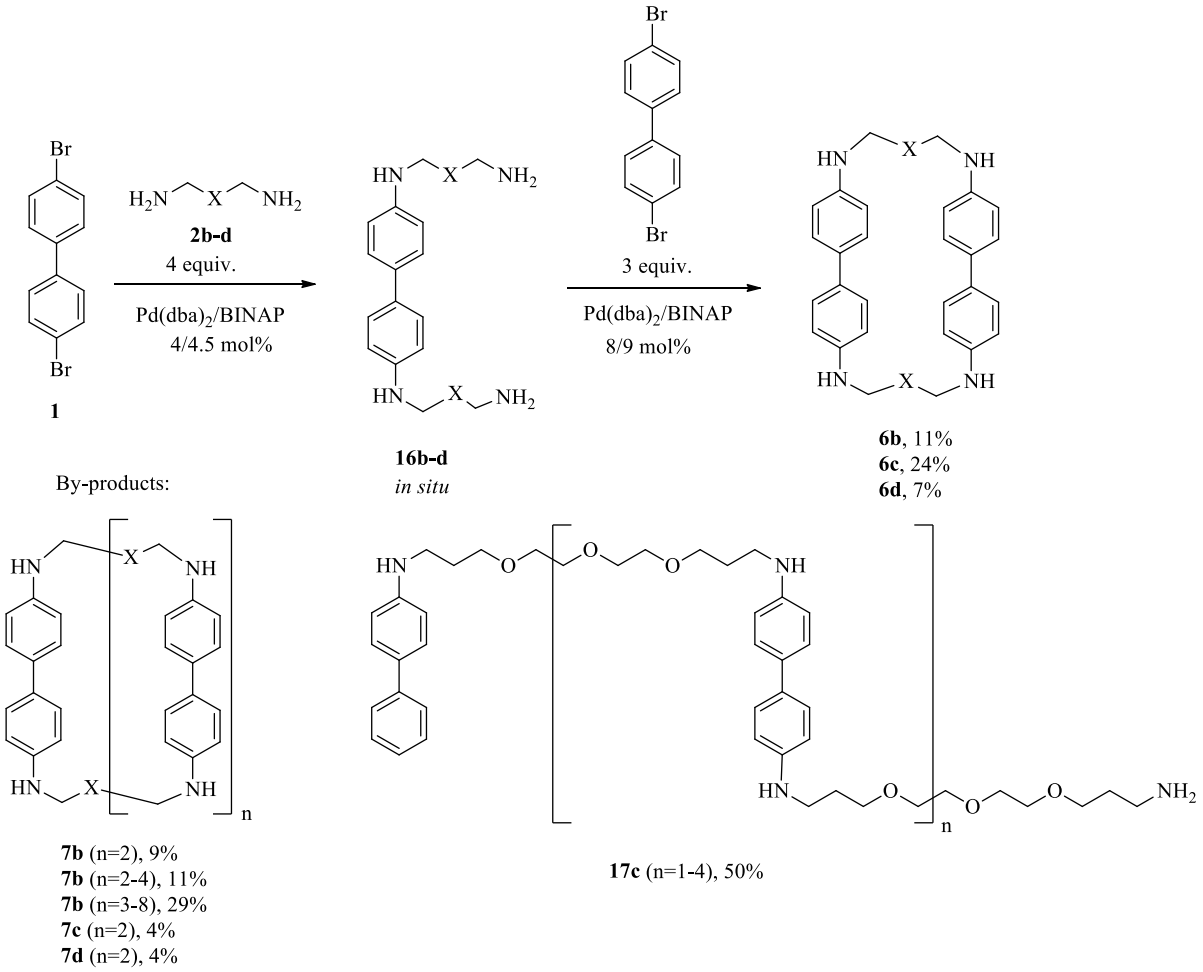
products **10c,d** in 21 and 26% yields, macrocycles **12c,d** as well as linear oligomers **14c,d** and **15d** were also obtained. In the case of tetraamine **2d** the application of 3 equivalents of **9** allowed to increase the yield of **10d** to 34%. However, for dioxadiamine **2b** it was found impossible to isolate the target compound **10b** in pure state because it contained admixtures – products of N,N-diarylation and diamination reactions. The application of less amount of the catalyst (2 mol%) did not improve the situation. The change of BINAP ligand for a less active Xanthphos suppressed the undesirable reactions but the standard catalyst loading (4 mol%) together with the standard reaction time (10 h) led mainly to monoaryl derivative of dioxadiamine. The use of more catalyst (8 mol%) was unsuccessful because it promoted N,N-diarylation process, but the employment of 3 equivalents of **9** and prolonged reflux (45 h) with 4 mol% $Pd(dba)_2$/Xanthphos resulted in 27% yield of pure product **10b**. We tested the same conditions with trioxadiamine **2c** and increased the yield of **10c** to 35%.

The cyclization reactions of diaryl derivatives **10b-d** were accomplished under standard conditions (Scheme 5) and their results were similar: the yields of target macrocycles **12b-d** ranged from 25 to 30%, cyclic oligomers (cyclotetramers and cyclohexamers) were obtained as side products in comparable yields. In the case of the reaction of **10b** with **2b** cyclooligomers **13b** (n=3, 5) were fully separated from the target cyclodimer **11b**, while in other reactions the fractions containing cyclooligomers **13c,d** contained also cyclodimers **11c,d** what to some extent diminished the yields of the target macrocycles-cyclodimers. This macrocyclization was more successful than that with *N*,*N'*-bis(4-bromobiphenyl) derivatives **3** and here no influence of the nature of polyamine was noted.



Scheme 5

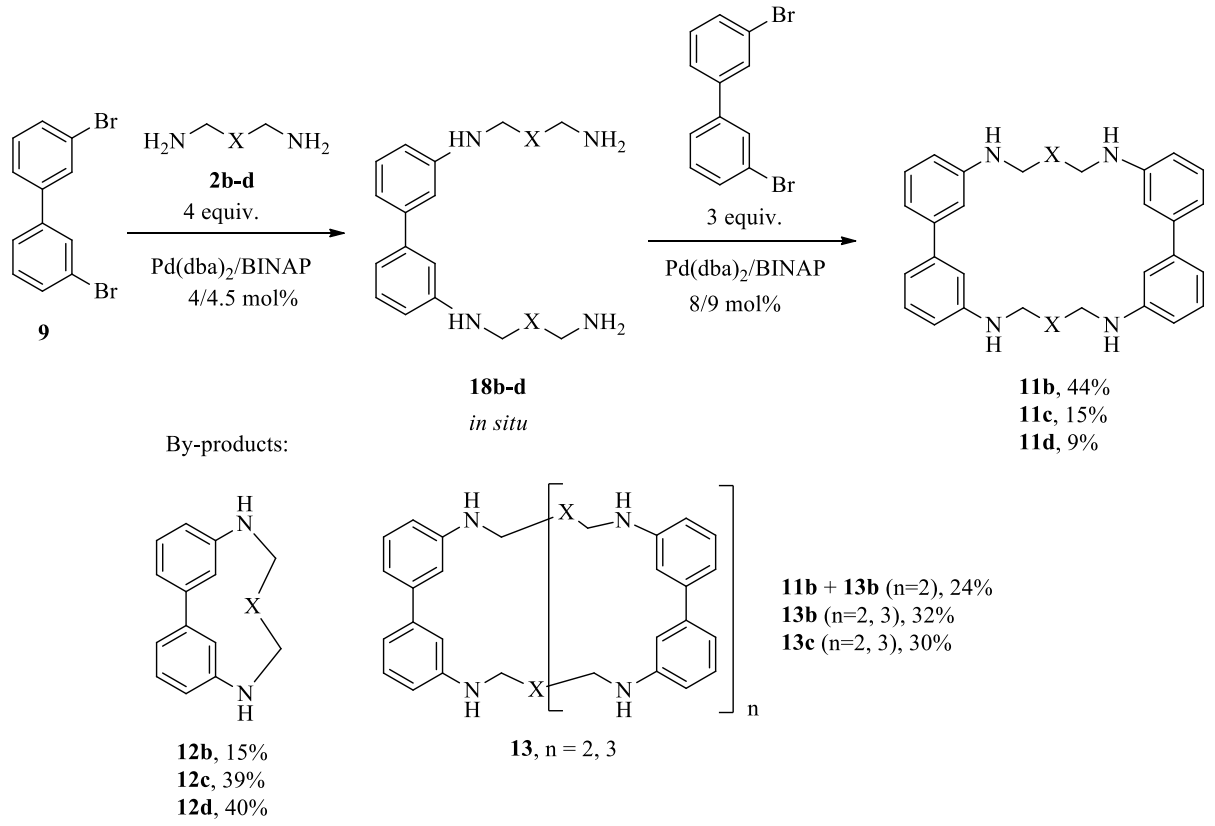
Having obtained data on the synthesis of the biphenyl-containing macrocycles *via* intermediate *N*,*N'*-bis(bromobiphenyl)polyamines, we tried an alternative approach, i.e. *via* intermediate bis(polyamine) substituted biphenyls. In this method intermediates were not isolated by column chromatography due to great difficulties caused by the presence of an excess of polyamines in the reaction mixture which possess very close R_f to that of bis(polyamine) derivatives of biphenyls.



Scheme 6

The reactions of 4,4′-dibromobiphenyl **1** with 4 equivalents of di- and polyamines **2b-d** were run in boiling dioxane (C = 0.1 M) and catalyzed by 8 mol% $Pd(dba)_2$/BINAP, they were complete in 8-10 h (Scheme 6). Intermediate 4,4′-bis(polyamine) biphenyls **16a-d** were analyzed by NMR and MALDI-TOF mass-spectra in the reaction mixtures. Then 3 equivalents of 4,4′-dibromobiphenyl, additional catalyst (8 mol%) and dioxane to make 0.02 M solution were added, and the reactions were refluxed for 35-40 h. Target cyclodimers **6b-d** were isolated by column chromatography on silica gel. The best result was obtained for the macrocycle **6c** (24%), the reactions with dioxadiamine **2b** and tetraamine **2d** gave poor yields of macrocycles (11 and 7% respectively). In these reactions substantial amounts of cyclic oligomers of higher masses were obtained (up to cyclononamer **7b** (n=8)), obviously, they were formed *via* intermediate linear oligomers containing n biphenyl and n+1 polyamine units. It is notable that the reaction with trioxadiamine **2c** gave rise to linear oligomers **17c** with terminal biphenyl which were formed due to the reduction of the bromine atom.

A similar reaction with the isomeric 3,3′-dibromobiphenyl **9** conducted under the same conditions gave somewhat different results (Scheme 7).



Scheme 7

Intermediate 3,3′-bis(polyamine)biphenyls **18b-d**, obtained *in situ* using 4 equivalents of corresponding di- and polyamines **2b-d**, were analyzed by NMR and MALDI-TOF spectroscopy, and they were further reacted with 3 equivalents of 3,3′-dibromobiphenyl. The best result was recorded for the macrocycle **11b** with its highest 44% yield, whereas the yields of compounds **11c** and **11d** were much more modest (15 and 9% respectively). In all cases the formation of the macrocycles **12** containing one set of biphenyl and polyamine units was observed, and with longer trioxadiamine **2c** and tetraamine **2d** their yields were about 40% which is equal to the yields of these compounds when the reactions were run with equimolar amounts of starting compounds.[31] Higher mass cyclooligomers were also formed in the case of dioxadiamine **2b** and trioxadiamine **2c**.

Conclusions

As a result of the experiments described above, we can outline the following general findings. The synthesis of the macrocycles containing two biphenyl and two polyamine moieties can be carried out using two approaches: *via N,N′*-bis(bromobiphenyl) substituted polyamines or *via* bis(polyamine)biphenyls. The first route in a two-step version affords target macrocycles in

yields up to 30%, 3,3′-dibromobiphenyl providing better yields of the macrocycles than 4,4′-dibromobiphenyl. One-step version with *in situ* obtained *N*,*N*′-bis(bromobiphenyl) derivative can be recommended only for the synthesis of the cyclodimer with two 3,3′-biphenyls and two tetraamine chains (yield 19%). The second approach *via* bis(polyamine)biphenyls provides better yields of some cyclodimers, and in this case the dependence of the result on the nature of starting compounds is pronounced: 4,4′-dibromobiphenyl gave 24% yield of the macrocycle with two trioxadiamine chains, whereas 3,3′-dibromobiphenyl afforded the cyclodimer with dioxadiamine in the highest yield (44%). We suppose that two main factors govern the results of these two-step syntheses: the conformational factors of di- and polyamine chains at the macrocyclization step and the activity of the bromine atom in 4,4′- and 3,3′-dibromobiphenyls in competitive amination and reduction reactions at both steps of the processes. The application of more powerful separation techniques like HPLC may undoubtedly increase the yields of the target macrocycles.

Experimental Section

General. All chemicals were purchased from Aldrich and Acros companies and used without further purification. 3,3′-Dibromobiphenyl **9** was synthesized from 2-bromonitrobenzene according to a procedure described in ref. 34. $Pd(dba)_2$ was synthesized according to a described method.[35] Commercial dioxane was distilled over NaOH and sodium under argon, dichloromethane and methanol were distilled prior to use. Column chromatography was carried out using silica gel (40-60 mkm) purchased from Fluka. ^1H and ^{13}C NMR spectra were registered in $CDCl_3$ using Bruker Avance 400 spectrometer at 400 and 100.6 MHz respectively. Chemical shift values δ are given in ppm and coupling constants *J* in Hz. MALDI-TOF mass spectra of positive ions were recorded with Briker Ultraflex spectrometer using 1,8,9-trihydroxyanthracene as matrix and PEGs as internal standards. Spectral data for compounds **6b,c**, **7c** (n=2) are given in ref. 30, and spectral data for compounds **11a-d**, **12b-d** and **13c** (n=2) are given in ref. 31.
Standard method for the synthesis of *N*,*N*′-bis(bromobiphenyl)polyamines **3a-d** and **10b-d**. A two-neck flask equipped with a magnetic stirrer, flushed with dry argon was charged with 4,4′-dibromobiphenyl **1** or 3,3′-dibromobiphenyl **9** (2.2 mmol, 686 mg), $Pd(dba)_2$ (0.04 mmol, 23 mg), BINAP (0.045 mmol, 28 mg), absolute dioxane (10 ml), the mixture was stirred for 2 min, then appropriate polyamine **2a-d** (1 mmol) was added, followed by *t*BuONa (3 mmol, 290 mg). The reaction mixture was refluxed for 10 h, cooled to ambient temperature, filtered and evaporated *in vacuo*. The residue was chromatographed on silica gel using a sequence of eluents: CH_2Cl_2, CH_2Cl_2/MeOH 500:1 – 3:1, CH_2Cl_2/MeOH/NH_3aq 100:20:1 – 10:4:1.

***N*^{1},*N*^{3}-Bis(4′-bromobiphenyl-4-yl)propane-1,3-diamine (3a)** was synthesized from 1,3-propanediamine (**2a**) (74 mg). Eluent CH_2Cl_2, CH_2Cl_2-MeOH 500:1, yield 135 mg (25%), pale-yellow crystals, m.p. 209-210°C. ^1H NMR δ 1.99 (quintet, ^3J = 6.7 Hz, 2H), 3.32 (t, ^3J = 6.7 Hz, 4H), 6.68 (d, ^3J = 8.7 Hz, 4H), 7.38 (d, ^3J = 8.4 Hz, 4H), 7.40 (d, ^3J = 8.7 Hz, 4H), 7.49 (d, ^3J =

8.4 Hz, 4H), NH protons were not assigned; ^{13}C NMR δ 29.1 (1C), 42.0 (2C), 113.3 (4C), 120.0 (2C), 127.8 (8C), 129.0 (2C), 131.7 (4C), 140.0 (2C), 147.6 (2C); HRMS MALDI-TOF *m/z*: calcd. for $C_{27}H_{25}Br_2N_2$ 535.0384 $[M+H]^+$, found 535.0359.

***N*^{1},*N*$^{1'}$-(Biphenyl-4,4′-diyl)bis(*N*^{3}-(4′-bromobiphenyl-4-yl)propane-1,3-diamine) (4a)** was obtained as the second product in the synthesis of compound **3a**. Eluent CH_2Cl_2-MeOH 200:1, yield 35 mg (9%), pale-yellow glassy solid. ^{1}H NMR δ 1.98 (quintet, ^3J = 6.6 Hz, 4H), 3.31 (t, ^3J = 6.4 Hz, 4H), 3.32 (t, ^3J = 6.4 Hz, 4H), 3.80 (br s, 2H), 3.91 (br s, 2H), 6.66 (d, ^3J = 8.5 Hz, 4H), 6.67 (d, ^3J = 8.5 Hz, 4H), 7.35-7.42 (m, 12H), 7.49 (d, ^3J = 8.2 Hz, 4H); ^{13}C NMR δ 29.2 (2C), 41.9 (2C), 42.1 (2C), 113.1 (4C), 113.2 (4C), 120.0 (2C), 127.2 (4C), 127.8 (8C), 129.0 (2C), 131.7 (4C), 132.0 (2C), 140.1 (2C), 146.7 (2C), 147.8 (2C); HRMS MALDI-TOF *m/z*: calcd. for $C_{42}H_{41}Br_2N_4$ 759.1698 $[M+H]^+$, found 759.1662.

***N*,*N*′-(2,2′-(Ethane-1,2-diylbis(oxy))bis(ethane-2,1-diyl))bis(4′-bromobiphenyl-4-amine) (3b)** was synthesized from dioxadiamine **2b** (148 mg). Isolated from the reaction mixture by treatment with CH_2Cl_2. Pale-yellow crystals, m.p. 184-185ºC. ^{1}H NMR δ 3.34 (t, ^3J = 5.2 Hz, 4H), 3.67 (s, 4H), 3.73 (t, ^3J = 5.2 Hz, 4H), 4.21 (br s, 2H), 6.65 (d, ^3J = 8.6 Hz, 4H), 7.35 (d, ^3J = 8.7 Hz, 8H), 7.47 (d, ^3J = 8.3 Hz, 4H); ^{13}C NMR δ 43.4 (2C), 69.6 (2C), 70.3 (2C), 113.3 (4C), 120.0 (2C), 127.7 (4C), 127.8 (4C), 129.0 (2C), 131.7 (4C), 140.1 (2C), 147.9 (2C); HRMS MALDI-TOF *m/z*: calcd. for $C_{30}H_{31}Br_2N_2O_2$ 609.0752 $[M+H]^+$, found 609.0784.

***N*,*N*′-(3,3′-(2,2′-Oxybis(ethane-2,1-diyl)bis(oxy))bis(propane-3,1-diyl))bis(4′-bromobiphenyl-4-amine) (3c)** was synthesized from trioxadiamine **2c** (220 mg). Eluent CH_2Cl_2-MeOH 200:1-100:1, yield 235 mg (34%), pale-yellow crystals, m.p. 104-105ºC. ^{1}H NMR δ 1.91 (quintet, ^3J = 6.1 Hz, 4H), 3.27 (t, ^3J = 6.5 Hz, 4H), 3.63 (t, ^3J = 5.8 Hz, 4H), 3.62-3.66 (m, 4H), 3.69-3.73 (m, 4H), 4.23 (br s, 2H), 6.65 (d, ^3J = 8.5 Hz, 4H), 7.38 (d, ^3J = 8.7 Hz, 4H), 7.39 (d, ^3J = 8.5 Hz, 4H), 7.49 (d, ^3J = 8.7 Hz, 4H); ^{13}C NMR δ 28.9 (2C), 41.7 (2C), 69.7 (2C), 70.2 (2C), 70.5 (2C), 112.9 (4C), 119.7 (2C), 127.5 (4C), 127.6 (4C), 128.3 (2C), 131.6 (4C), 140.1 (2C), 148.1 (2C); HRMS MALDI-TOF *m/z*: calcd. for $C_{34}H_{39}Br_2N_2O_3$ 681.1327 $[M+H]^+$, found 681.1345.

***N*^{4},*N*$^{4'}$-Bis[3-[2-[2-[3-(4′-bromobiphenyl-4-ylamino)propoxy]ethoxy]ethoxy]propyl]-biphenyl-4,4′-diamine (4c)** was obtained as the second product in the synthesis of compound **3c**. Eluent CH_2Cl_2-MeOH 50:1, yield 102 mg (19%), pale-yellow glassy solid. ^{1}H NMR δ 1.90 (quintet, ^3J = 6.1 Hz, 8H), 3.25 (t, ^3J = 6.3 Hz, 4H), 3.26 (t, ^3J = 6.3 Hz, 4H), 3.61 (t, ^3J = 5.9 Hz, 8H), 3.61-3.65 (m, 8H), 3.67-3.71 (m, 8H), 4.07 (br s, 4H), 6.64 (d, ^3J = 8.4 Hz, 4H), 6.65 (d, ^3J = 8.6 Hz, 4H), 7.33-7.41 (m, 12H), 7.48 (d, ^3J = 8.5 Hz, 4H); ^{13}C NMR δ 28.9 (2C), 29.0 (2C), 41.5 (2C), 41.8 (2C), 69.6 (4C), 70.1 (4C), 70.5 (4C), 112.8 (4C), 113.0 (4C), 119.6 (2C), 126.8 (4C), 127.4 (4C), 127.5 (4C), 128.5 (2C), 130.2 (2C), 131.5 (4C), 140.1 (2C), 146.8 (2C), 148.2 (2C); HRMS MALDI-TOF *m/z*: calcd. for $C_{56}H_{69}Br_2N_4O_6$ 1051.3584 $[M+H]^+$, found 1051.3532.

***N*^{1},*N*$^{1'}$-(Ethane-1,2-diyl)bis[*N*^{3}-(4′-bromobiphenyl-4-yl)propane-1,3-diamine] (3d)** was synthesized from tetraamine **2d** (174 mg). Eluent CH_2Cl_2-MeOH-NH_3aq 100:20:1, yield 142 mg (22%), pale-yellow crystals, m.p. 158-160ºC. ^{1}H NMR δ 1.81 (quintet, ^3J = 6.6 Hz, 4H), 2.75 (s, 4H), 2.77 (t, ^3J = 6.6. Hz, 4H), 3.22 (t, ^3J = 6.6 Hz, 4H), 6.63 (d, ^3J = 8.7 Hz, 4H), 7.36 (d, ^3J =

8.4 Hz, 8H), 7.47 (d, ^3J = 8.6 Hz, 4H), NH protons were not assigned; ^{13}C NMR δ 29.4 (2C), 42.7 (2C), 48.2 (2C), 49.4 (2C), 112.9 (4C), 119.9 (2C), 127.7 (8C), 128.5 (2C), 131.6 (4C), 140.1 (2C), 148.2 (2C); HRMS MALDI-TOF *m/z*: calcd. for $C_{32}H_{37}Br_2N_4$ 635.1385 $[M+H]^+$, found 635.1357.

***N*^{1},*N*$^{1'}$-(Biphenyl-4,4′-diyl)bis[*N*^{3}-[2-[3-(4′-bromobiphenyl-4-ylamino)propylamino]ethyl] propane-1,3-diamine] (4d)** was obtained as the second product in the synthesis of compound **3d**. Eluent CH_2Cl_2-MeOH-NH_3aq 100:20:2, yield 86 mg (18%), pale-yellow crystals, m.p. 164-165ºC. ^{1}H NMR δ 1.79 (quintet, ^3J = 5.8 Hz, 8H), 2.73 (s, 8H), 2.75 (t, ^3J = 6.4 Hz, 8H), 3.20 (t, ^3J = 5.9 Hz, 8H), 6.61 (d, ^3J = 8.2 Hz, 4H), 6.64 (d, ^3J = 8.7 Hz, 4H), 7.32-7.39 (m, 12H), 7.46 (d, ^3J = 8.3 Hz, 4H), NH protons were not assigned; ^{13}C NMR δ 29.3 (2C), 29.5 (2C), 42.6 (2C), 42.8 (2C), 48.1 (4C), 49.4 (4C), 112.8 (4C), 113.0 (4C), 119.7 (2C), 126.9 (4C), 127.6 (8C), 128.2 (2C), 130.3 (2C), 131.5 (4C), 140.1 (2C), 146.9 (2C), 148.2 (2C); HRMS MALDI-TOF *m/z*: calcd. for $C_{52}H_{65}Br_2N_8$ 959.3699 $[M+H]^+$, found 959.3743.

***N*^{1}-(2-(3-Aminopropylamino)ethyl)-*N*^{3}-(4′-bromobiphenyl-4-yl)propane-1,3-diamine (5d)** was obtained as the third product in the synthesis of compound **3d**. Eluent CH_2Cl_2-MeOH-NH_3aq 10:4:1, yield 131 mg (32%), pale-yellow oil. ^{1}H NMR δ 1.62 (quintet, ^3J = 6.7 Hz, 2H), 1.80 (quintet, ^3J = 6.4 Hz, 2H), 2.67 (t, ^3J = 6.6 Hz, 2H), 2.72 (s, 4H), 2.72-2.77 (m, 4H), 3.21 (t, ^3J = 6.5 Hz, 2H), 6.63 (d, ^3J = 8.2 Hz, 2H), 7.36 (d, ^3J = 8.2 Hz, 2H), 7.37 (d, ^3J = 8.1 Hz, 2H), 7.46 (,^3J = 8.1 Hz, 2H), NH protons were not assigned; ^{13}C NMR δ 29.1, 32.8, 40.2, 42.4, 47.6, 47.8, 49.1, 49.2, 112.7 (2C), 119.6, 127.4 (4C), 128.1, 131.4 (2C), 140.0, 148.1; HRMS MALDI-TOF *m/z*: calcd. for $C_{20}H_{30}BrN_4$ 405.1654 $[M+H]^+$, found 405.1670.

***N*,*N*′-[2,2′-[Ethane-1,2-diylbis(oxy)]bis(ethane-2,1-diyl)]bis(3′-bromobiphenyl-3-amine) (10b)** was synthesized from 3,3-dibromobiphenyl **9** (0.75 mmol, 234 mg) and dioxadiamine **2b** (0.25 mmol, 37 mg) in the presence of $Pd(dba)_2$ (6 mg) and Xanthphos (6.5 mg) in dioxane (2.5 ml), after 46 h reflux. Eluent CH_2Cl_2-MeOH 500:1-200:1, yield 41 mg (27%), pale-yellow glassy solid. ^{1}H NMR δ 3.36 (t, ^3J = 5.2 Hz, 4H), 3.68 (s, 4H), 3.74 (t, 5.2 Hz, 4H), 4.19 (br s, 2H), 6.62 (dd, ^3J = 8.0 Hz, ^4J = 2.2 Hz, 2H), 6.77 (t, ^4J = 1.6 Hz, 2H), 6.88 (d, ^3J = 7.6 Hz, 2H), 7.22 (t, ^3J = 7.8 Hz, 2H), 7.25 (t, ^3J = 7.7 Hz, 2H), 7.41-7.46 (m, 4H), 7.69 (t, ^4J = 1.6 Hz, 2H); ^{13}C NMR δ 43.5 (2C), 69.6 (2C), 70.2 (2C), 111.6 (2C), 112.6 (2C), 116.6 (2C), 122.7 (2C), 125.7 (2C), 129.7 (2C), 129.9 (2C), 130.0 (2C), 130.1 (2C), 140.8 (2C), 143.8 (2C), 148.6 (2C); HRMS MALDI-TOF *m/z*: calcd. for $C_{30}H_{31}Br_2N_2O_2$ 609.0752 $[M+H]^+$, found 609.0739.

***N*^{3},*N*$^{3'}$-Bis[2-[2-[2-(3′-bromobiphenyl-3-ylamino)ethoxy]ethoxy]ethyl]biphenyl-3,3′-diamine (14b)** was obtained as the second product in the synthesis of compound **10b**. Eluent CH_2Cl_2-MeOH 100:1, yield 6 mg (5%), pale-yellow glassy solid. ^{1}H NMR δ 3.34 (t, ^3J = 5.0 Hz, 4H), 3.35 (t, ^3J = 5.0 Hz, 4H), 3.66 (s, 8H), 3.72 (t, ^3J = 5.0 Hz, 4H), 3.73 (t, ^3J = 5.0 Hz, 4H), 6.58 (dd, ^3J = 8.0 Hz, ^4J = 1.8 Hz, 2H), 6.61 (dd, ^3J = 8.2 Hz, ^4J = 1.5 Hz, 2H), 6.76 (br s, 2H), 6.79 (br s, 2H), 6.87 (d, ^3J = 7.2 Hz, 2H), 6.89 (d, ^3J = 7.7 Hz, 2H), 7.13-7.29 (m, 6H), 7.40-7.46 (m, 4H), 7.68 (t, ^4J = 1.8 Hz, 2H), NH protons were not assigned; ^{13}C NMR δ 43.5 (4C), 69.6 (4C), 70.3 (4C), 111.7 (2C), 112.0 (4C), 112.7 (2C), 116.6 (2C), 116.8 (2C), 122.7 (2C), 125.8 (2C), 129.4 (2C), 129.7 (2C), 130.0 (2C), 130.1 (2C), 130.2 (2C), 140.8 (2C), 142.9 (2C), 143.9 (2C),

148.4 (2C), 148.6 (2C); HRMS MALDI-TOF *m/z*: calcd. for $C_{48}H_{53}Br_2N_4O_4$ 907.2434 $[M+H]^+$, found 907.2479.

***N,N′*-[3,3′-[2,2′-Oxybis(ethane-2,1-diyl)bis(oxy)]bis(propane-3,1-diyl)]bis(3′-bromo biphenyl-3-amine) (10c)** was synthesized from 3,3-dibromobiphenyl **9** (0.75 mmol, 234 mg) and trioxadiamine **2c** (0.25 mmol, 55 mg) in the presence of $Pd(dba)_2$ (6 mg) and Xanthphos (6.5 mg) in dioxane (2.5 ml). Eluent CH_2Cl_2-MeOH 200:1, yield 59 mg (35%), pale-yellow glassy solid. ^{1}H NMR δ 1.90 (quintet, ^3J = 6.1 Hz, 4H), 3.28 (t, ^3J = 6.4 Hz, 4H), 3.61 (t, ^3J = 5.8 Hz, 4H), 3.62–3.65 (m, 4H), 3.67–3.71 (m, 4H), 4.22 (br s, 2H), 6.62 (dd, ^3J = 8.1 Hz, ^4J = 2.3 Hz, 2H), 6.75 (br s, 2H), 6.86 (d, ^3J = 7.4 Hz, 2H), 7.23 (t, ^3J = 7.8 Hz, 2H), 7.27 (t, ^3J = 7.8 Hz, 2H), 7.45 (d, ^3J = 7.9 Hz, 2H) 7.49 (d, ^3J = 7.8 Hz, 2H), 7.73 (br s, 2H); ^{13}C NMR δ 29.0 (2C), 41.8 (2C), 69.7 (2C), 70.2 (2C), 70.6 (2C), 111.2 (2C), 112.2 (2C), 115.9 (2C), 122.6 (2C), 125.7 (2C), 129.6 (2C), 129.9 (2C), 130.0 (2C), 130.1 (2C), 140.7 (2C), 144.0 (2C), 148.9 (2C); HRMS MALDI-TOF *m/z*: calcd. for $C_{34}H_{38}Br_2N_2O_3$ 680.1249 $[M]^+$, found 680.1283.

***N*^{3},*N*$^{3′}$-Bis[3-[2-[2-[3-(3′-bromobiphenyl-3-ylamino)propoxy]ethoxy]ethoxy]propyl] biphenyl-3,3′-diamine (14c)** was obtained as the second product in the synthesis of compound **10c**. Eluent CH_2Cl_2-MeOH 75:1-50:1, yield 25 mg (19%), pale-yellow glassy solid. ^{1}H NMR δ 1.89 (quintet, ^3J = 5.9 Hz, 8H), 3.26 (t, ^3J = 6.3 Hz, 4H), 3.27 (t, ^3J = 6.1 Hz, 4H), 3.56–3.62 (m, 16H), 3.65–3.69 (m, 8H), 4.16 (br s, 4H), 6.56 (d, ^3J = 8.2 Hz, 2H), 6.58 (d, ^3J = 8.3 Hz, 2H), 6.74 (br s, 2H), 6.78 (br s, 2H), 6.84 (d, ^3J = 7.5 Hz, 2H), 6.88 (d, ^3J = 7.2 Hz, 2H), 7.19 (t, ^3J = 7.8 Hz, 2H), 7.21 (t, ^3J = 8.2 Hz, 2H), 7.25 (t, ^3J = 8.1 Hz, 2H), 7.44 (d, ^3J = 7.1 Hz, 2H), 7.48 (d, ^3J = 6.8 Hz, 2H), 7.71 (br s, 2H); ^{13}C NMR δ 29.0 (2C), 29.1 (2C), 41.8 (4C), 69.7 (4C), 70.2 (4C), 70.6 (4C), 111.2 (2C), 111.5 (2C), 111.6 (2C), 112.2 (2C), 115.9 (2C), 116.2 (2C), 122.6 (2C), 125.7 (2C), 129.3 (2C), 129.6 (2C), 129.9 (2C), 130.0 (2C), 130.1 (2C), 140.7 (2C), 143.0 (2C), 144.0 (2C), 148.7 (2C), 149.0 (2C); HRMS MALDI-TOF *m/z*: calcd. for $C_{56}H_{68}Br_2N_4O_6$ 1050.3506 $[M]^+$, found 1050.3516.

***N*^{1},*N*$^{1′}$-(Ethane-1,2-diyl)bis[*N*^{3}-(3′-bromobiphenyl-3-yl)propane-1,3-diamine] (10d)** was synthesized from 3,3-dibromobiphenyl **9** (1.1 mmol, 343 mg) and tetraamine **2d** (0.5 mmol, 87 mg) in the presence of $Pd(dba)_2$ (12 mg) and BINAP (14 mg) in dioxane (5 ml). Eluent CH_2Cl_2-MeOH-NH_3aq 100:20:1, yield 82 mg (26%), pale-yellow glassy solid. ^{1}H NMR δ 1.81 (quintet, ^3J = 6.5 Hz, 4H), 2.76 (s, 4H), 2.78 (t, ^3J = 6.6 Hz, 4H), 3.23 (t, ^3J = 6.5 Hz, 4H), 6.61 (dd, ^3J = 8.1 Hz, ^4J = 1.5 Hz, 2H), 6.75 (br s, 2H), 6.87 (d, ^3J = 7.6 Hz, 2H), 7.23 (t, ^3J = 7.8 Hz, 2H), 7.27 (t, ^3J = 7.8 Hz, 2H), 7.45 (d, ^3J = 8.1 Hz, 2H), 7.49 (d, ^3J = 7.7 Hz, 2H), 7.72 (br s, 2H), NH protons were not assigned; ^{13}C NMR δ 29.4 (2C), 42.7 (2C), 48.1 (2C), 49.3 (2C), 111.2 (2C), 112.2 (2C), 116.0 (2C), 122.6 (2C), 125.7 (2C), 129.6 (2C), 129.9 (2C), 130.0 (4C), 140.7 (2C), 143.9 (2C), 148.9 (2C); HRMS MALDI-TOF *m/z*: calcd. for $C_{32}H_{37}Br_2N_4$ 635.1385 $[M+H]^+$, found 635.1370.

***N*^{1},*N*$^{1′}$-(Biphenyl-3,3′-diyl)bis[*N*^{3}-[2-[3-(3′-bromobiphenyl-3-ylamino)propylamino]ethyl] propane-1,3-diamine] (14d)** was obtained as the second product in the synthesis of compound **10d**. Eluent CH_2Cl_2- MeOH-NH_3aq 100:20:2, yield 68 mg (28%), pale-yellow glassy solid. ^{1}H NMR δ 1.79 (quintet, ^3J = 5.8 Hz, 8H), 2.74 (s, 8H), 2.75 (t, ^3J = 6.4 Hz, 8H), 3.21 (t, ^3J = 5.7

Hz, 8H), 6.57 (d, ^3J = 7.8 Hz, 2H), 6.59 (d, ^3J = 8.2 Hz, 2H), 6.73 (br s, 2H), 6.79 (br s, 2H), 6.85 (d, ^3J = 7.2 Hz, 2H), 6.89 (d, ^3J = 6.8 Hz, 2H), 7.17-7.29 (m, 6H), 7.43 (d, ^3J = 6.9 Hz, 2H), 7.47 (,^3J = 7.7 Hz, 2H), 7.71 (br s, 2H), NH protons were not assigned; ^{13}C NMR δ 29.4 (2C), 29.5 (2C), 42.7 (4C), 48.1 (4C), 49.4 (4C), 111.5 (2C), 111.6 (4C), 112.2 (2C), 116.0 (2C), 116.3 (2C), 122.6 (2C), 125.7 (2C), 129.3 (2C), 129.6 (2C), 129.9 (2C), 130.1 (4C), 140.7 (2C), 142.9 (2C), 143.9 (2C), 148.7 (2C), 148.9 (2C); HRMS MALDI-TOF *m/z*: calcd. for $C_{52}H_{65}Br_2N_8$ 959.3699 $[M+H]^+$, found 959.3662.

***N*^{3},*N*$^{3'}$-(3,3′-[Ethane-1,2-diylbis(azanediyl))bis(propane-3,1-diyl)]bis[*N*$^{3'}$-[3-[2-[3-(3′-bromobiphenyl-3-ylamino)propylamino]ethylamino]propyl]biphenyl-3,3′-diamine] (15d)** obtained as the third product in the synthesis of compound **10d**. Eluent CH_2Cl_2- MeOH-NH_3aq 100:20:3, yield 12 mg (12%), pale-yellow glassy solid. ^{1}H NMR δ 1.77 (br s, 12H), 2.72 (br s, 24H), 3.20 (br s, 12H), 6.55 (d, ^3J = 7.6 Hz, 4H), 6.57 (d, ^3J = 8.0 Hz, 2H), 6.72 (br s, 2H), 6.77 (br s, 4H), 6.84 (d, ^3J = 8.5 Hz, 2H), 6.87 (d, ^3J = 7.0 Hz, 4H), 7.14-7.28 (m, 8H), 7.42 (d, ^3J = 8.0 Hz, 2H), 7.46 (d, ^3J = 7.7 Hz, 2H), 7.69 (br s, 2H), NH protons were not assigned; ^{13}C NMR δ 29.4 (2C), 29.5 (4C), 42.8 (6C), 48.2 (6C), 49.4 (6C), 111.2 (2C), 111.6 (4C), 111.7 (4C), 112.3 (2C), 116.0 (2C), 116.3 (4C), 125.8 (2C), 129.4 (4C), 129.7 (2C), 129.9 (2C), 130.0 (2C), 130.1 (4C), 140.8 (2C), 143.0 (4C), 144.0 (2C), 148.7 (4C), 149.0 (2C) HRMS MALDI-TOF *m/z*: calcd. for $C_{72}H_{93}Br_2N_{12}$ 1283.6013 $[M+H]^+$, found 1283.5970.

Standard method for the synthesis of cyclic dimers 6a-d and 11b-d via isolated *N*,*N*′-bis(bromobiphenyl)polyamines (3a-d) and (10b-d)

A two-neck flask equipped with a magnetic stirrer, flushed with dry argon was charged with *N*,*N*′-bis(bromobiphenyl)polyamines **3a-d** and **10b-d** (1 equiv.), $Pd(dba)_2$ (8 mol%), BINAP (9 molo%), absolute dioxane (to make 0.02 M conc.), the mixture was stirred for 2 min, then appropriate polyamine **2a-d** (1 equiv.) was added, followed by *t*BuONa (3 equiv.). The reaction mixture was refluxed for 30-40 h, cooled to ambient temperature, filtered and evaporated *in vacuo*. The residue was chromatographed on silica gel using a sequence of eluents: CH_2Cl_2, CH_2Cl_2/MeOH 200:1 – 3:1, CH_2Cl_2/MeOH/NH_3aq 100:20:1 – 10:4:1.

6,10,19,23-Tetraazapentacyclo[22.2.2.2^{2,5}.2^{11,14}.2^{15,18}]tetratriaconta-1(26),2,4,11,13,15,17,24,27,29,31,33-dodecaene (6a) was synthesized from compound **3a** (0.3 mmol, 175 mg), 1,3-diaminopropane **2a** (0.3 mmol, 23 mg) in the presence of $Pd(dba)_2$ (14 mg), BINAP (17 mg), *t*BuONa (90 mg), in 15 ml dioxane. Isolated as a mixture with cyclic tetramer **7a** (n=3) Eluent CH_2Cl_2/MeOH 75:1, yield (for the mixture) 8 mg (6%) ^{1}H NMR δ 1.97 (br s, 4H), 3.30 (br s, 8H), 6.42 (d, ^3J = 8.5 Hz, 8H), 7.07 (d, ^3J = 8.5 Hz, 8H), NH protons were not assigned; ^{13}C NMR δ 29.2 (2C), 42.2 (4C), 113.2 (8C), 127.2 (8C), quaternary carbons were not detected; MS MALDI-TOF *m/z*: calcd. for $C_{30}H_{33}N_4$ 449.27 $[M+H]^+$, found 449.25.

6,10,19,23,32,36,45,49-Octaazanonacyclo[48.2.2.2^{2,5}.2^{11,14}.2^{15,18}.2^{24,27}.2^{28,31}.2^{37,40}.2^{41,44}]-octahexaconta-1(52),2,4,11,13,15,17,24,26,28,30,37,39,41,43,50,53,55,57,59,61,63,65,67-tetracosaene (7a, n=3) was isolated together with cyclic dimer **6a**. ^{1}H NMR δ 1.97 (br s, 8H), 3.30 (br s, 16H), 6.61 (d, ^3J = 8.4 Hz, 16H), 7.37 (d, ^3J = 8.4 Hz, 16H), NH protons were not

assigned; ^{13}C NMR δ 29.2 (4C), 42.2 (8C), 113.1 (16C), 127.2 (16C), quaternary carbons were not detected; MS MALDI-TOF *m/z*: calcd. for $C_{60}H_{65}N_8$ 897.53 $[M+H]^+$, found 897.57.

9,12,27,30-Tetraoxa-6,15,24,33-tetraazapentacyclo[32.2.2.2^{2,5}.2^{16,19}.2^{20,23}]tetratetraconta-1(36),2,4,16,18,20,22,34,37,39,41,43-dodecaene (6b) was synthesized from compound **3b** (0.18 mmol, 110 mg), dioxadiamine **2b** (0.18 mmol, 27 mg) in the presence of $Pd(dba)_2$ (8 mg), BINAP (10 mg), *t*BuONa (52 mg), in 9 ml dioxane. Eluent CH_2Cl_2/MeOH 50:1, yield 10 mg (9%).

10,13,16,33,36,39-Hexaoxa-6,20,29,43-tetraazapentacyclo[42.2.2.2^{2,5}.2^{21,24}.2^{25,28}]-tetrapentaconta-1(46),2,4,21,23,25,27,44,47,49,51,53-dodecaene (6c) was synthesized from compound **3c** (0.3 mmol, 205 mg), trioxadiamine **2c** (0.3 mmol, 65 mg) in the presence of $Pd(dba)_2$ (14 mg), BINAP (17 mg), *t*BuONa (90 mg), in 15 ml dioxane. Eluent CH_2Cl_2/MeOH 50:1, yield 44 mg (20%).

***N,N′*-[Oxybis(ethane-2,1-diyloxypropane-3,1-diyl)]dibiphenyl-4-amine (8c)** was obtained as the second product in the synthesis of compound **6c**. Eluent CH_2Cl_2/MeOH 100:1, yield 25 mg (16%), slightly beige glassy solid. ^{1}H NMR δ 1.91 (quintet, ^3J = 5.9 Hz, 4H), 3.28 (t, ^3J = 6.5 Hz, 4H), 3.59-3.65 (m, 8H), 3.67-3.72 (m, 4H), 4.05 (br s, 2H), 6.67 (d, ^3J = 8.6 Hz, 4H), 7.24 (t, ^3J = 7.9 Hz, 2H), 7.38 (t, ^3J = 7.7 Hz, 4H), 7.43 (d, ^3J = 8.5 Hz, 4H), 7.54 (d, ^3J = 7.8 Hz, 4H); ^{13}C NMR δ 29.1 (2C), 41.7 (2C), 69.7 (2C), 70.2 (2C), 70.6 (2C), 112.9 (4C), 125.9 (2C), 126.2 (4C), 127.8 (4C), 128.6 (4C), 129.8 (2C), 141.3 (2C), 148.0 (2C); HRMS MALDI-TOF *m/z*: calcd. for $C_{34}H_{41}N_2O_3$ 525.3117 $[M+H]^+$, found 525.3092.

Cyclic oligomers 7c, (n=3, 5) were isolated as a mixture in the synthesis of compound **6c**. Eluent CH_2Cl_2/MeOH 20:1-10:1, yield 50 mg (23%). ^{1}H NMR δ 1.88 (quintet, ^3J = 5.8 Hz, 4(n+1)H), 3.28 (br s, 4(n+1)H), 3.56-3.64 (m, 8(n+1)H), 3.68 (br s, 4(n+1)H), 6.62 (d, ^3J = 8.1 Hz, 4(n+1)H), 7.34 (d, ^3J = 8.1 Hz, 4(n+1)H), NH protons were not assigned; ^{13}C NMR δ 29.1 (2(n+1)C), 41.9 (2(n+1)C), 69.7 (2(n+1)C), 70.2 (2(n+1)C), 70.6 (2(n+1)C), 113.0 (4(n+1)C), 127.0 (4(n+1)C), 128.6 (2(n+1)C), 147.0 (2(n+1)C); MS MALDI-TOF *m/z*: calcd. for $C_{88}H_{121}N_8O_{12}$ 1481.91 $[M+H]^+$, found 1481.85 (**7c**, n=3); *m/z*: calcd. for $C_{132}H_{181}N_{12}O_{18}$ 2222.36 $[M+H]^+$, found 2222.21 (**7c**, n=5).

6,10,13,17,26,30,33,37-Octaazapentacyclo[36.2.2.2^{2,5}.2^{18,21}.2^{22,25}]octatetraconta-1(40),2,4,18,20,22,24,38,41,43,45,47-dodecaene (6d) was synthesized from compound **3d** (0.26 mmol, 175 mg), tetraamine **2d** (0.26 mmol, 45 mg) in the presence of $Pd(dba)_2$ (12 mg), BINAP (14 mg), *t*BuONa (75 mg), in 13 ml dioxane. Eluent CH_2Cl_2/MeOH/NH_3aq 100:20:2-100:20:3, yield 39 mg (23%), pale-yellow crystals, m.p. 99-100ºC. ^{1}H NMR δ 1.78 (quintet, ^3J = 6.4 Hz, 8H), 2.75 (s, 8H), 2.76 (t, ^3J = 6.2 Hz, 8H), 3.18 (t, ^3J = 6.4 Hz, 8H), 6.55 (d, ^3J = 8.6 Hz, 8H), 7.24 (d, ^3J = 8.6 Hz, 8H), NH protons were not assigned; ^{13}C NMR δ 29.4 (4C), 43.1 (4C), 48.1 (4C), 49.0 (4C), 113.1 (8C), 127.0 (8C), 130.4 (4C), 147.0 (4C); HRMS MALDI-TOF *m/z*: calcd. for $C_{40}H_{57}N_8$ 649.4706 $[M+H]^+$, found 649.4725.

Synthesis of cyclic dimer (6c) via in situ obtained compound (3c). A two-neck flask equipped with a magnetic stirrer, flushed with dry argon was charged with 4,4′-dibromobiphenyl **1** (1.25 mmol, 390 mg), $Pd(dba)_2$ (12 mg), BINAP (14 mg), absolute dioxane (5 ml), the mixture was

stirred for 2 min, then trioxadiamine **2c** (0.5 mmol, 110 mg) was added, followed by *t*BuONa (144 mg). The reaction mixture was refluxed for 10 h, cooled to ambient temperature, then $Pd(dba)_2$ (35 mg), BINAP (42 mg), absolute dioxane (20 ml) were added, the reaction mixture was stirred for 2 min, trioxadiamine **2c** (0.75 mmol, 155 mg) was added, followed by *t*BuONa (200 mg). The reaction mixture was refluxed for 35 h, cooled to ambient temperature, filtered and evaporated *in vacuo*. The residue was chromatographed on silica gel using a sequence of eluents: CH_2Cl_2, CH_2Cl_2/MeOH 200:1 – 3:1. Compound **8c** was isolated with eluent CH_2Cl_2/MeOH 75:1 (74 mg, 28%), cyclic dimer **6c** was isolated with eluent CH_2Cl_2/MeOH 50:1 (17 mg, 5%), a mixture of cyclic dimer **6c** and cyclic trimer **7c** (n = 2) was isolated with eluent CH_2Cl_2/MeOH 20:1 (34 mg, 9%).

10,13,16,33,36,39,56,59,62-Nonaoxa-6,20,29,43,52,66-hexaazaheptacyclo [65.2.2.2^{2,5}.2^{21,24}.2^{25,28}.2^{44,47}.2^{48,51}]henoctaconta-1(69),2,4,21,23,25,27,44,46,48,50,67,70,72, 74,76,78,80-octadecaene (7c, n=2): ^{1}H NMR δ 1.88 (br s, 12H), 2.35 (br s, 12H), 3.58-3.65 (m, 24H), 3.68 (br s, 12H), 6.62 (d, ^3J = 8.3 Hz, 12H), 7.34 (d, ^3J = 8.3 Hz, 12H), NH protons were not assigned; ^{13}C NMR δ 29.1 (6C), 41.8 (6C), 69.7 (6C), 70.2 (6C), 70.6 (6C), 113.0 (12C), 126.9 (12C), 129.0 (6C), 147.0 (6C); MS MALDI-TOF *m/z*: calcd. for $C_{66}H_{91}N_6O_9$ 1111.68 $[M+H]^+$, found 1111.73.

10,13,30,33-Tetraoxa-7,16,27,36-tetraazapentacyclo[35.3.1.1^{2,6}.1^{17,21}.1^{22,26}]-tetratetraconta-1(41),2(44),3,5,17(43),18,20,22(42),23,25,37,39-dodecaene (11b) was synthesized from compound **10b** (0.1 mmol, 60 mg), dioxadiamine **2b** (0.1 mmol, 15 mg) in the presence of $Pd(dba)_2$ (4.5 mg), BINAP (5.5 mg), *t*BuONa (29 mg), in 5 ml dioxane. Eluent CH_2Cl_2/MeOH 100:1-75:1, yield 16 mg (27%).

10,13,30,33,50,53,70,73-Octaoxa-7,16,27,36,47,56,67,76-octaazanonacyclo [75.3.1.1^{2,6}.1^{17,21}.1^{22,26}.1^{37,41}.1^{42,46}.1^{57,61}.1^{62,66}]octaoctaconta-1(81),2(88),3,5,17(87),18,20, 22(86),23,25,37(85), 38,40,42(84),43,45,57(83),58,60,62(82),63,65,77,79-tetracosaene (13b, n=3) was obtained as the second product in the synthesis of compound **10b**. Eluent CH_2Cl_2/MeOH 50:1, yield 8 mg (13%), pale-yellow glassy solid. ^{1}H NMR δ 3.31 (t, ^3J = 5.2 Hz, 16H), 3.62 (s, 16H), 3.68 (t, ^3J = 5.2 Hz, 16H), 6.56 (d, ^3J = 7.5 Hz, 8H), 6.79 (s, 8H), 6.88 (d, ^3J = 7.3 Hz, 8H), 7.15 (t, ^3J = 7.8 Hz, 8H), NH protons were not assigned; ^{13}C NMR δ 43.5 (8C), 69.6 (8C), 70.2 (8C), 111.9 (8C), 112.1 (8C), 116.7 (8C), 129.4 (8C), 142.8 (8C), 148.4 (8C), HRMS MALDI-TOF *m/z*: calcd. for $C_{72}H_{89}N_8O_8$ 1193.6803 $[M+H]^+$, found 1193.6758.

Cyclic oligomers (13b, n=3, 5) were isolated as a mixture in a separate fraction in the synthesis of cyclic dimer **11b**. Eluent CH_2Cl_2/MeOH 20:1, yield 11 mg (18%). **Cyclic hexamer 13b** (n=5): ^{1}H NMR δ 3.31 (br s, 24H), 3.63 (s, 24H), 3.68 (br s, 24H), 3.98 (br s, 12H), 6.57 (d, ^3J = 8.1 Hz, 12H), 6.78 (s, 12H), 6.88 (d, ^3J = 7.3 Hz, 12H), 7.16 (t, ^3J = 7.6 Hz, 12H); ^{13}C NMR δ 43.5 (12C), 69.7 (12C), 70.2 (12C), 111.9 (12C), 112.0 (12C), 116.8 (12C), 129.4 (12C), 142.8 (12C), 148.4 (12C); MS MALDI-TOF *m/z*: calcd. for $C_{108}H_{133}N_{12}O_{12}$ 1790.02 $[M+H]^+$, found 1790.14.

11,14,17,36,39,42-Hexaoxa-7,21,32,46-tetraazapentacyclo[45.3.1.1^{2,6}.1^{22,26}.1^{27,31}]-tetrapentaconta-1(51),2(54),3,5,22(53),23,25,27(52),28,30,47,49-dodecaene (11c) was synthesized from

compound **10c** (0.085 mmol, 58 mg), trioxadiamine **2c** (0.085 mmol, 19 mg) in the presence of $Pd(dba)_2$ (4 mg), BINAP (5 mg), *t*BuONa (26 mg), in 4 ml dioxane. Eluent CH_2Cl_2/MeOH 75:1-50:1, yield 19 mg (30%).

Cyclic oligomers 13c (n=3, 5) were isolated as a mixture in a separate fraction in the synthesis of cyclic dimer **11c**, contains also cyclic dimer **11c**. Eluent CH_2Cl_2/MeOH 50:1-10:1, yield 30 mg (48%). ^{1}H NMR δ 1.87 (quintet, ^3J = 5.5 Hz, 4(n+1)H), 3.23 (t, ^3J = 6.0 Hz, 4(n+1)H), 3.52-3.60 (m, 8(n+1)H), 3.61-3.66 (m, 4(n+1)H), 6.55 (d, ^3J = 6.6 Hz, 2(n+1)H), 6.76 (br s, 2(n+1)H), 6.86 (d, ^3J = 7.5 Hz, 2(n+1)H), 7.17 (t, ^3J = 7.3 Hz, 2(n+1)H), NH protons were not assigned; ^{13}C NMR δ 29.1 (2(n+1)C), 41.8 (2(n+1)C), 69.7 (2(n+1)C), 70.2 (2(n+1)C), 70.6 (2(n+1)C), 111.6 (4(n+1)C), 116.2 (2(n+1)C), 129.3 (2(n+1)C), 142.9 (2(n+1)C), 148.7 (2(n+1)C); MS MALDI-TOF *m/z*: calcd. for $C_{88}H_{121}N_8O_{12}$ 1481.91 $[M+H]^+$, found 1481.85 (**13**, n=3); *m/z*: calcd. for $C_{132}H_{181}N_{12}O_{18}$ 2222.36 $[M+H]^+$, found 2222.24 (**13**, n=5).

7,11,14,18,29,33,36,40-Octaazapentacyclo[39.3.1.1^{2,6}.1^{19,23}.1^{24,28}]octatetraconta-1(45),2(48),3,5,19(47),20,22,24(46),25,27,41,43-dodecaene (11d) was synthesized from compound **10d** (0.19 mmol, 120 mg), tetraamine **2d** (0.19 mmol, 33 mg) in the presence of $Pd(dba)_2$ (9 mg), BINAP (11 mg), *t*BuONa (55 mg), in 10 ml dioxane. Eluent CH_2Cl_2/MeOH/NH_3aq 100:20:3, yield 31 mg (25%).

7,11,14,18,29,33,36,40,51,55,58,62,73,77,80,84-Hexadecaazanonacyclo [83.3.1.1^{2,6}.1^{19,23}.1^{24,28}.1^{41,45}.1^{46,50}.1^{63,67}.1^{68,72}]hexanonaconta-1(89),2(96),3,5,19(95),20,22,24(94),25,27,41(93),42,44,46(92),47,49,63(91),64,66,68(90),69,71,85,87-tetracosaene (13d, n=3) was obtained as a mixture with cyclic compound **11d** in a separate fraction. Eluent CH_2Cl_2/MeOH/NH_3aq 100:25:5, yield (for a mixture) 34 mg (28%). ^{1}H NMR δ 1.75 (br s, 16H), 2.70 (br s, 32H), 3.16 (br s, 16H), 6.53 (br s, 8H), 6.76 (br s, 8H), 6.86 (br s, 8H), 7.15 (br s, 8H), NH protons were not assigned; ^{13}C NMR δ 29.4 (8C), 42.7 (8C), 48.1 (8C), 49.2 (8C), 111.5 (8C), 111.6 (8C), 116.2 (8C), 129.4 (8C), 142.9 (8C), 148.8 (8C); MS MALDI-TOF *m/z*: calcd. for $C_{80}H_{113}N_{16}$ 1297.93 $[M+H]^+$, found 1297.84.

Standard method for the synthesis of cyclic dimers 11a,c,d via in situ obtained *N,N′*-bis(bromobiphenyl)polyamines (10a,c,d)

A two-neck flask equipped with a magnetic stirrer, flushed with dry argon was charged with 3,3′-dibromobiphenyl **9** (1.25 mmol, 390 mg), $Pd(dba)_2$ (12 mg), BINAP (14 mg), absolute dioxane (5 ml), the mixture was stirred for 2 min, then appropriate polyamine **2a,c,d** (0.5 mmol) was added, followed by *t*BuONa (144 mg). The reaction mixture was refluxed for 10 h, cooled to ambient temperature, then $Pd(dba)_2$ (34 mg), BINAP (41 mg), absolute dioxane (20 ml) were added, the reaction mixture was stirred for 2 min, appropriate polyamine **2a,c,d** (0.6 mmol) was added, followed by *t*BuONa (170 mg). The reaction mixture was refluxed for 30-40 h, cooled to ambient temperature, filtered and evaporated *in vacuo*. The residue was chromatographed on silica gel using a sequence of eluents: CH_2Cl_2, CH_2Cl_2/MeOH 200:1 – 3:1, CH_2Cl_2/MeOH/NH_3aq 100:20:1 – 10:4:1.

7,11,22,26-Tetraazapentacyclo[25.3.1.1^{2,6}.1^{12,16}.1^{17,21}]tetratriaconta-1(31),2(34),3,5,12(33),13,15, 17(32),18,20,27,29-dodecaene (11a) was synthesized from 1,3-diaminopropane **2a**. Eluent CH_2Cl_2/MeOH 200:1, yield 12 mg (5%).

7,11,22,26,37,41-Hexaazaheptacyclo[40.3.1.1^{2,6}.1^{12,16}.1^{17,21}.1^{27,31}.1^{32,36}]henpentaconta-1(46), 2(51),3,5,12(50),13,15,17(49),18,20,27(48),28,30,32(47),33,35,42,44-octadecaene (13a, n=2) was obtained as the second product in the synthesis of cyclic dimer **11a** and isolated as a mixture with it in a separate fraction. Eluent CH_2Cl_2/MeOH 100:1, yield (for a mixture) 35 mg (15%). ^{1}H NMR δ 1.93 (quintet, ^3J = 6.3 Hz, 6H), 3.29 (t, ^3J = 6.3 Hz, 12H), 3.63 (br s, 6H), 6.58 (d, ^3J = 7.6 Hz, 6H), 6.76 (br s, 6H), 6.90 (d, ^3J = 7.7 Hz, 6H), 7.20 (t, ^3J = 7.8 Hz, 6H); ^{13}C NMR δ 29.1 (3C), 41.9 (6C), 111.7 (6C), 111.8 (6C), 116.6 (6C), 129.5 (6C), 142.8 (6C), 148.4 (6C); MS MALDI-TOF *m/z*: calcd. for $C_{45}H_{49}N_6$ 673.40 $[M+H]^+$, found 673.42.

Cyclic dimer (11b) was synthesized from dioxadiamine **2b**. Eluent CH_2Cl_2/MeOH 75:1, yield 24 mg (8%).

10,13-Dioxa-7,16-diazatricyclo[15.3.1.1^{2,6}]docosa-1(21),2(22),3,5,17,19-hexaene (12b) was obtained as the second product in the synthesis of cyclic dimer **11b** Eluent CH_2Cl_2/MeOH 100:1, yield 15 mg (10%).

Cyclic oligomers (13b, n=2, 3) was obtained as a separate mixture in the synthesis of cyclic dimer **11b**. Eluent CH_2Cl_2/MeOH 50:1-20:1, yield 20 mg (7%).

Cyclic dimer (11d) was synthesized from tetraamine **2d**. Eluent CH_2Cl_2/MeOH/NH_3aq 100:25:5, yield 63 mg (19%).

7,11,14,18-Tetraazatricyclo[17.3.1.1^{2,6}]tetracosa-1(23),2(24),3,5,19,21-hexaene (12d) was obtained as the second product in the synthesis of cyclic dimer **11d** Eluent CH_2Cl_2/MeOH/NH_3aq 100:20:1-100:20:2, yield 30 mg (18%).

7,11,14,18,29,33,36,40,51,55,58,62-Dodecaazaheptacyclo-[61.3.1.1^{2,6}.1^{19,23}.1^{24,28}.1^{41,45}.1^{46,50}] doheptaconta-1(67),2(72),3,5,19(71),20,22,24(70),25,27,41(69),42,44,46(68),47,49,63,65-octadecaene (13d, n=2) was obtained as a mixture with cyclic dimer **11d** in a separate fraction. Eluent CH_2Cl_2/MeOH/NH_3aq 100:35:8, yield (for a mixture) 38 mg (12%). ^{1}H NMR δ 1.78 (br s, 12H), 2.70 (br s, 24H), 3.18 (t, ^3J = 7.0 Hz, 12H), 6.55 (br s, 6H), 6.77 (br s, 6H), 6.87 (d, ^3J = 6.2 Hz, 6H), 7.16 (t, ^3J = 6.9 Hz, 6H), NH protons were not assigned; ^{13}C NMR δ 29.4 (6C), 42.6 (6C), 48.0 (6C), 49.2 (6C), 111.5 (12C), 116.2 (6C), 129.3 (6C), 142.8 (6C), 148.7 (6C); MS MALDI-TOF *m/z*: calcd. for $C_{60}H_{85}N_{12}$ 973.70 $[M+H]^+$, found 973.74.

Standard method for the synthesis of cyclic dimers 6b-d and 11b-d via in situ obtained bis(polyamine) substituted biphenyls (16b-d) and (18b-d)

A two-neck flask equipped with a magnetic stirrer, flushed with dry argon was charged with 4,4′-dibromobiphenyl **1** or 3,3′-dibromobiphenyl **9** (0.25 mmol, 78 mg), $Pd(dba)_2$ (6 mg), BINAP (7 mg), absolute dioxane (2.5 ml), the mixture was stirred for 2 min, then appropriate polyamine **2b-d** (1 mmol) was added, followed by *t*BuONa (72 mg). The reaction mixture was refluxed for 10 h, cooled to ambient temperature, 0.25 ml of the reaction mixture was taken for NMR and mass-spectroscopic investigations of compounds **16** and **18**, then $Pd(dba)_2$ (28 mg), BINAP (34

mg), absolute dioxane (10 ml) were added, the reaction mixture was stirred for 2 min, 4,4′-dibromobiphenyl **1** or 3,3′-dibromobiphenyl **9** (0.6 mmol, 187 mg) was added, followed by *t*BuONa (170 mg). The reaction mixture was refluxed for 30-40 h, cooled to ambient temperature, filtered and evaporated *in vacuo*. The residue was chromatographed on silica gel using a sequence of eluents: CH_2Cl_2, CH_2Cl_2/MeOH 200:1 – 3:1, CH_2Cl_2/MeOH/NH_3aq 100:20:1 – 10:4:1.

***N,N′*-Bis[2-[2-(2-aminoethoxy)ethoxy]ethyl]biphenyl-4,4′-diamine (16b)** was obtained *in situ* from dioxadiamine **2b** (1mmol, 148 mg). ^{1}H NMR δ 2.82 (t, ^3J = 5.1 Hz, 4H), 3.29 (t, ^3J = 5.2 Hz, 4H), 3.48 (t, ^3J = 5.2 Hz, 4H), 3.59-3.63 (m, 8H), 3.69 (t, ^3J = 5.2 Hz, 4H), 6.64 (d, ^3J = 8.6 Hz, 4H), 7.34 (d, ^3J = 8.6 Hz, 4H), NH protons were not assigned; ^{13}C NMR δ 41.5 (2C), 43.5 (2C), 69.5 (2C), 70.2 (4C), 73.4 (2C), 113.4 (4C), 127.0 (4C), 130.8 (2C), 146.7 (2C); MS MALDI-TOF *m/z*: calcd. for $C_{24}H_{39}N_4O_4$ 447.30 $[M+H]^+$, found 447.32.

Cyclic dimer 6b was synthesized from compound **16b**. Eluent CH_2Cl_2/MeOH 75:1, yield 16 mg (11%).

9,12,27,30,45,48-Hexaoxa-6,15,24,33,42,51-hexaazaheptacyclo-[50.2.2.2^{2,5}.2^{16,19}.2^{20,23}2^{34,37}.2^{38,41}] hexahexaconta-1(54),2,4,16,18,20,22,34,36,38,40,52,55,57,59,61,63,65-octadecaene (7b, n=2) was obtained as the second product in the synthesis of cyclic dimer **6b**. CH_2Cl_2/MeOH 75:1, yield 14 mg (9%).

A mixture of cyclic oligomers (7b, n=2-4) was obtained as a separate fraction in the synthesis of cyclic dimer **6b**. Eluent CH_2Cl_2/MeOH 50:1, yield 17 mg (11%).

9,12,27,30,45,48,63,66-Octaoxa-6,15,24,33,42,51,60,69-octaazanonacyclo-[68.2.2.2^{2,5}.2^{16,19}. 2^{20,23}.2^{34,37}.2^{38,41}.2^{52,55}.2^{56,59}]octaoctaconta-1(72),2,4,16,18,20,22,34,36,38, 40,52,54,56,58,70,73,75,77,79,81,83,85,87-tetracosaene (7b, **n=3)**. ^{1}H NMR δ 3.31 (t, ^3J = 5.0 Hz, 16H), 3.64 (s, 16H), 3.72 (t, ^3J = 5.0 Hz, 16H), 6.59 (d, ^3J = 8.6 Hz, 16H), 7.27 (d, ^3J = 8.6 Hz, 16H), NH protons were not assigned; ^{13}C NMR δ 43.7 (8C), 69.6 (8C), 70.3 (8C), 113.5 (16C), 127.1 (16C), 130.8 (8C), 146.6 (8C); MS MALDI-TOF *m/z*: calcd. for $C_{72}H_{89}N_8O_8$ 1193.68 $[M+H]^+$, found 1193.62.

9,12,27,30,45,48,63,66,81,84-Decaoxa-6,15,24,33,42,51,60,69,78,87-decaazaundecacyclo [86.2.2.2^{2,5}.2$^{16.19}$.2^{20,23}.2^{34,37}.2^{38,41}.2^{52,55}.2^{56,59}.2^{70,73}.2^{74,77}]decahecta-1(90),2,4,16,18,20,22,34,36, 38,40,52,54,56,58,70,72,74,76,88,91,93,95,97,99,101,103,-105,107,109-triacontaene (7b, **n=4)**. ^{1}H NMR δ 3.31 (t, ^3J = 5.0 Hz, 20H), 3.64 (s, 20H), 372 (t, ^3J = 5.0 Hz, 20H), 6.62 (d, ^3J = 8.5 Hz, 20H), 7.32 (d, ^3J = 8.5 Hz, 20H), NH protons were not assigned; ^{13}C NMR δ 43.7 (10C), 69.7 (10C), 70.3 (10C), 113.5 (20C), 127.1 (20C), 130.8 (10C), 146.7 (10C); MS MALDI-TOF *m/z*: calcd. for $C_{90}H_{111}N_{10}O_{10}$ 1491.85 $[M+H]^+$, found 1491.78.

Cyclic oligomers (7b, n=3-8) were obtained as a separate fraction in the synthesis of cyclic dimer **6b**. Eluent CH_2Cl_2/MeOH 20:1, yield 43 mg (29%). **7b**, n>4: ^{1}H NMR δ 3.33 (br s, 4(n+1)H), 3.65 (s, 4(n+1)H), 3.71 (br s, 4(n+1)H), 3.99 (br s, 2(n+1)H), 6.65 (d, ^3J = 8.2 Hz, 4(n+1)H), 7.35 (d, ^3J = 8.2 Hz, 4(n+1)H); ^{13}C NMR δ 43.6 (2(n+1)C), 69.6 (2(n+1)C), 70.2 (2(n+1)C), 113.4 (4(n+1)C), 127.0 (4(n+1)C), 130.7 (2(n+1)C), 146.7 (2(n+1)C); MS MALDI-TOF *m/z*: calcd. for $C_{108}H_{133}N_{12}O_{12}$ 1790.0 $[M+H]^+$, found 1789.9 **7b** (n=5); *m/z*: calcd. for

$C_{126}H_{155}N_{14}O_{14}$ 2088.2 $[M+H]^+$, found 2088.0 **7b** (n=6); *m/z*: calcd. for $C_{144}H_{177}N_{16}O_{16}$ 2386.4 $[M+H]^+$, found 2386.1 (**7b**, n=7); *m/z*: calcd. for $C_{162}H_{199}N_{18}O_{18}$ 2684.5 $[M+H]^+$, found 2684.1 (**7b**, n=8).

***N*⁴,*N*⁴′-Bis(3-(2-(2-(3-aminopropoxy)ethoxy)ethoxy)propyl)biphenyl-4,4′-diamine (16c)** was obtained *in situ* from trioxadiamine **2c** (1mmol, 220 mg). ^{1}H NMR δ 1.67 (quintet, ^3J = 6.5 Hz, 4H), 1.85 (quintet, ^3J = 5.2 Hz, 4H), 2.71 (t, ^3J = 6.7 Hz, 4H), 3.20 (t, ^3J = 6.4 Hz, 4H), 3.50 (t, ^3J = 6.2 Hz, 4H), 3.52-3.64 (m, 20H), 6.59 (d, ^3J = 8.6 Hz, 4H), 7.30 (d, ^3J = 8.6 Hz, 4H), NH protons were not assigned; ^{13}C NMR δ 29.0 (2C), 33.2 (2C), 39.3 (2C), 41.7 (2C), 69.3 (2C), 69.6 (2C), 70.0 (2C), 70.1 (2C), 70.5 (4C), 112.9 (4C), 126.9 (4C), 130.3 (2C), 146.9 (2C); MS MALDI-TOF *m/z*: calcd. for $C_{32}H_{55}N_4O_6$ 591.41 $[M+H]^+$, found 591.38.

Cyclic dimer (6c) was synthesized from compound **16c**. Eluent CH_2Cl_2/MeOH 50:1-20:1, yield 46 mg (24%).

Cyclic trimer (7c, n=2) was obtained as the second product in the synthesis of cyclic dimer **6c**. Eluent CH_2Cl_2/MeOH 20:1, yield 8 mg (4%).

Oligomers (17c, n=1-4) were isolated as separate mixture in the synthesis of cyclic dimer **6c**. Eluent CH_2Cl_2/MeOH 10:1-5:1, yield 94 mg (50%). 1.81 (br s, 2H), 1.88 (quintet, ^3J = 5.0 Hz, (4n+2)H), 2.99 (br s, 2H), 3.23 (t, ^3J = 5.2 Hz, (4n+2)H), 4.59 (br s, (2n+1)H), 6.62 (d, ^3J = 8.1 Hz, 4nH), 6.70 (d, ^3J = 8.6 Hz, 2H), 7.24 (t, ^3J = 8.0 Hz, 1H), 7.34 (d, ^3J = 8.1 Hz, 4nH), 7.38 (t, ^3J = 7.7 Hz, 2H), 7.42 (d, ^3J = 8.5 Hz, 2H), 7.52 (d, ^3J = 7.5 Hz, 2H), protons of NH_2 group were not assigned; ^{13}C NMR δ 26.6 (1C), 28.8 (1C), 29.0 (2nC), 39.7 (1C), 41.6 (1C), 41.7 (2nC), 69.6 (2(n+1)C), 70.1 (2(n+1)C), 70.5 (2(n+1)C), 112.9 (4nC), 113.5 (2C), 126.0 (2C), 126.9 (4nC), 127.7 (2C), 128.5 (2C), 129.0 (1C), 130.2 (2nC), 146.9 (2(n+1)C), two aromatic quaternary carbons were not detected; MS MALDI-TOF *m/z*: calcd. for $C_{44}H_{63}N_4O_6$ 743.47 $[M+H]^+$, found 743.44 (**17c**, n=1); *m/z*: calcd. for $C_{66}H_{93}N_6O_9$ 1113.70 $[M+H]^+$, found 1113.65 **17c** (n=2); *m/z*: calcd. for $C_{88}H_{123}N_8O_{12}$ 1483.93 $[M+H]^+$, found 1483.85 **17c** (n=3); *m/z*: calcd. for $C_{110}H_{153}N_{10}O_{15}$ 1854.15 $[M+H]^+$, found 1854.01 **17c** (n=4).

***N*¹,*N*¹′-(Biphenyl-4,4′-diyl)bis[*N*³-[2-(3-aminopropylamino)ethyl]propane-1,3-diamine] (16d)** was obtained *in situ* from tetraamine **2d** (1mmol, 174 mg). ^{1}H NMR δ 1.58 (quintet, ^3J = 6.9 Hz, 4H), 1.76 (quintet, ^3J = 6.4 Hz, 4H), 2.61 (t, ^3J = 7.0 Hz, 4H), 2.67 (s, 8H), 2.68-2.72 (m, 8H), 3.16 (t, ^3J = 6.4 Hz, 4H), 6.59 (d, ^3J = 8.5 Hz, 4H), 7.31 (d, ^3J = 8.5 Hz, 4H), NH protons were not assigned; ^{13}C NMR δ 29.5 (2C), 33.8 (2C), 40.2 (2C), 42.8 (2C), 47.6 (2C), 48.0 (2C), 49.4 (4C), 112.9 (4C), 129.9 (4C), 130.4 (2C), 146.9 (2C); MS MALDI-TOF *m/z*: calcd. for $C_{28}H_{51}N_8$ 499.42 $[M+H]^+$, found 499.43.

Cyclic dimer (6d) was synthesized from compound **16d**. Eluent CH_2Cl_2/MeOH/NH_3aq 100:20:3, yield 12 mg (7%).

6,10,13,17,26,30,33,37,46,50,53,57-Dodecaazaheptacyclo-[56.2.2.2^{2,5}.2^{18,21}.2^{22,25}.2^{38,41}.2^{42,45}] doheptaconta-1(60),2,4,18,20,22,24,38,40,42,44,58,61,63,65,67,69,71-octadecaene (7d, n=2) was obtained as the second product in the synthesis of cyclic dimer **6d**. Eluent CH_2Cl_2/MeOH/NH_3aq 100:20:3, yield 6 mg (4%), pale-yellow glassy solid. ^{1}H NMR δ 1.77 (quintet, ^3J = 6.5 Hz, 12H), 2.73 (s, 12H), 2.76 (t, ^3J = 6.2 Hz, 12H), 3.13 (t, ^3J = 6.4 Hz, 12H),

6.60 (d, ^3J = 8.5 Hz, 12H), 7.33 (d, ^3J = 8.5 Hz, 12H), NH protons were not assigned; ^{13}C NMR δ 29.2 (6C), 42.9 (6C), 48.1 (6C), 49.0 (6C), 113.1 (12C), 127.0 (12C), 130.4 (6C), 147.0 (6C); HRMS MALDI-TOF *m/z*: calcd. for $C_{60}H_{85}N_{12}$ 973.7020 $[M+H]^+$, found 973.7039.

***N*^{3},*N*$^{3'}$-Bis[2-[2-(2-aminoethoxy)ethoxy]ethyl]biphenyl-3,3′-diamine (18b)** was obtained *in situ* from dioxadiamine **2b** (1mmol, 148 mg). ^{1}H NMR δ 2.83 (t, ^3J = 5.2 Hz, 4H), 3.32 (t, ^3J = 5.2 Hz, 4H), 3.49 (t, ^3J = 5.2 Hz, 4H), 3.61-3.65 (m, 8H), 3.71 (t, ^3J = 5.2 Hz, 4H), 6.58 (dd, ^3J = 8.0 Hz, ^4J = 2.3 Hz, 2H), 6.80 (t, ^4J = 1.9 Hz, 2H), 6.89 (d, ^3J = 7.6 Hz, 2H), 7.19 (t, ^3J = 7.8 Hz, 2H), NH protons were not assigned; ^{13}C NMR δ 41.5 (2C), 43.4 (2C), 69.6 (2C), 70.2 (4C), 73.4 (2C), 112.0 (4C), 116.7 (2C), 129.3 (2C), 142.8 (2C), 148.4 (2C); MS MALDI-TOF *m/z*: calcd. for $C_{24}H_{39}N_4O_4$ 447.30 $[M+H]^+$, found 447.27.

Cyclic dimer (11b) was synthesized from compound **18b**. Eluent CH_2Cl_2/MeOH 100:1, yield 66 mg (44%).

Cyclic oligomers (13b, n=2, 3) were obtained as a separate fraction in the synthesis of cyclic dimer **11b**. Eluent CH_2Cl_2/MeOH 50:1, yield 56 mg (32%).

Cyclic trimer (13b, n=2) was isolated as a mixture with cyclic dimer **11b** in a separate fraction. Eluent CH_2Cl_2/MeOH 20:1, yield 46 mg (24%).

Macrocycle (12b) was obtained as the second product in the synthesis of cyclic dimer **11b**. Eluent CH_2Cl_2/MeOH 20:1, yield 24 mg (15%).

***N*^{3},*N*$^{3'}$-Bis[3-[2-[2-(3-aminopropoxy)ethoxy]ethoxy]propyl]biphenyl-3,3′-diamine (18c)** was obtained *in situ* from trioxadiamine **2c** (1mmol, 220 mg). ^{1}H NMR δ 1.64 (quintet, ^3J = 6.5 Hz, 4H), 1.85 (quintet, ^3J = 5.6 Hz, 4H), 2.70 (t, ^3J =6.8 Hz, 4H), 3.21 (t, ^3J = 5.5 Hz, 4H), 3.45-3.60 (m, 24H), 6.51 (d, ^3J = 8.0 Hz, 2H), 6.72 (s, 2H), 6.81 (d, ^3J = 7.4 Hz, 2H), 7.12 (t, ^3J = 7.7 Hz, 2H), NH protons were not assigned; ^{13}C NMR δ 29.0 (2C), 33.2 (2C), 39.4 (2C), 41.6 (2C), 69.3 (2C), 69.6 (2C), 70.0 (2C), 70.1 (2C), 70.5 (4C), 111.4 (4C), 116.0 (2C), 129.2 (2C), 142.8 (2C), 148.6 (2C); MS MALDI-TOF *m/z*: calcd. for $C_{32}H_{55}N_4O_6$ 591.41 $[M+H]^+$, found 591.39.

Cyclic dimer (11c) was synthesized from compound **18c**. Eluent CH_2Cl_2/MeOH 75:1-50:1, yield 28 mg (15%).

11,14,17-Trioxa-7,21-diazatricyclo[20.3.1.1^{2,6}]heptacosa-1(26),2(27),3,5,22,24-hexaene (12c) was obtained as the second product in the synthesis of cyclic dimer **11c**. Eluent CH_2Cl_2/MeOH 100:1, yield 72 mg (39%).

Cyclic oligomers (13c, n=2, 3) were obtained as a separate fraction in the synthesis of cyclic dimer **11c**. Eluent CH_2Cl_2/MeOH 20:1, yield 56 mg (30%).

11,14,17,36,39,42,61,64,67-Nonaoxa-7,21,32,46,57,71-hexaazaheptacyclo-[70.3.1.1^{2,6}.1^{22,26}.1^{27,31}.1^{47,51}.1^{52,56}]henoctaconta-1(76),2(81),3,5,22(80),23,25,27(79),28,30,47(78),48,50,52(77),53,55,72,74-octadecaene (13c, n=2). ^{1}H NMR δ 1.87 (quintet, ^3J = 6.0 Hz, 12H), 3.24 (t, ^3J = 6.2 Hz, 12H), 3.53-3.62 (m, 24H), 3.63-3.68 (m, 12H), 4.00 (br s, 6H), 6.55 (br s, 6H), 6.78 (s, 6H), 6.88 (br s, 6H), 7.18 (t, ^3J = 7,7 Hz, 6H); ^{13}C NMR δ 29.0 (6C), 41.7 (6C), 69.6 (6C), 70.2 (6C), 70.5 (6C), 111.4 (6C), 111.6 (6C), 116.1 (6C), 129.2 (6C), 142.9 (6C), 148.7 (6C); MS MALDI-TOF *m/z*: calcd. for $C_{66}H_{91}N_6O_9$ 1111.68 $[M+H]^+$, found 1111.63.

11,14,17,36,39,42,61,64,67,86,89,92-Dodecaoxa-7,21,32,46,57,71,82,96-octaazanonacyclo [95.3.1.1^{2,6}.1^{22,26}.1^{27,31}.1^{47,51}.1^{52,56}.1^{72,76}.1^{77,81}]octahecta-1(101),2(108),3,5,22(107),23,25, 27(106),28,30,47(105),48,50,52(104),53,55,72(103),73,75,77(102),78,80,97,99-tetracosaene (13c, n=3). ^{1}H NMR δ 1.88 (quintet, ^3J = 6.2 Hz, 16H), 3.25 (t, ^3J = 6.2 Hz, 16H), 3.53-3.62 (m, 32H), 3.63-3.68 (m, 16H), 4.05 (br s, 8H), 6.57 (br s, 8H), 6.78 (s, 8H), 6.88 (br s, 8H), 7.19 (t, ^3J = 7.8 Hz, 8H); ^{13}C NMR δ 29.0 (8C), 41.7 (8C), 69.6 (8C), 70.2 (8C), 70.5 (8C), 111.5 (16C), 116.1 (8C), 129.2 (8C), 142.9 (8C), 148.7 (8C); MS MALDI-TOF *m/z*: calcd. for $C_{88}H_{121}N_8O_{12}$ 1481.91 $[M+H]^+$, found 1481.83.

***N*^{1},*N*$^{1'}$-(Biphenyl-3,3′-diyl)bis[*N*^{3}-[2-(3-aminopropylamino)ethyl]propane-1,3-diamine] (18d)** was obtained *in situ* from tetraamine **2d** (1mmol, 174 mg). ^{1}H NMR δ 1.58 (quintet, ^3J = 7.0 Hz, 4H), 1.77 (quintet, ^3J = 5.9 Hz, 4H), 2.62 (t, ^3J = 7.0 Hz, 4H), 2.67 (s, 8H), 2.68-2.73 (m, 8H), 3.18 (t, ^3J = 5.7 Hz, 4H), 6.53 (d, ^3J =7.3 Hz, 2H), 6.74 (s, 2H), 6.83 (d, ^3J = 7.3 Hz, 2H), 7.15 (t, ^3J = 7.6 Hz, 2H), NH protons were not assigned; ^{13}C NMR δ 29.5 (2C), 33.8 (2C), 40.3 (2C), 42.7 (2C), 47.7 (2C), 48.1 (2C), 49.5 (4C), 111.4 (2C), 111.5 (2C), 116.2 (2C), 129.3 (2C), 142.9 (2C), 148.7 (2C); MS MALDI-TOF *m/z*: calcd. for $C_{28}H_{51}N_8$ 499.42 $[M+H]^+$, found 499.40

Cyclic dimer (11d) was synthesized from compound **18d**. Eluent CH_2Cl_2/MeOH/MH_3aq 100:20:3, yield 14 mg (9%).

Macrocycle (12d) was obtained as the second product in the synthesis of cyclic dimer **11d**. Eluent CH_2Cl_2/MeOH/NH_3aq 100:20:1-100:20:2, yield 65 mg (40%).

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