DOI: 10.1002/ejoc.200600842

Concave Pyridines for Bifunctional Acid–Base Catalysis[‡]

Timo Liebig,[a] Michael Abbass,[a] and Ulrich Lüning*[a]

Keywords: Acid catalysis / Base catalysis / Bifunctional catalysis / Heterocycles / Macrocycles / Supramolecular chemistry

Two bifunctional concave acid–base catalysts, **1** and **2**, have been synthesized starting from 2,6-dibromopyridine (**9**) and 2,6-bis(ω-alkenyloxy)phenylboronic acids **8** and **10** which end up as bridgeheads in final bimacrocycles **1** and **2**. One bridgehead contained an additional substituent in the 4-position. The respective protected 4-hydroxymethyl-substituted phenylboronic acids **8** were synthesized from 4-bromo-3,5-dihydroxybenzoic acid (**3**) in five steps. 4-Unsubstituted boronic acid **10** and 4-substituted boronic acid **8** were then attached to **9** by subsequent Suzuki couplings to give tetra-ω-alkenes **12**. By ring-closing metathesis of **12**, bimacrocyclic dienes **13** and **17** were formed. After deprotection of the 4-hydroxymethyl group of one bridgehead, a 3-hydroxybenzoate was coupled to **14** to give ester **15** which gave bifunctional acid–base catalyst **1** upon hydrolysis. Analogously, homologue **2** was synthesized, but before coupling the bimacrocycle to the benzoate, tetraene **14** was hydrogenated to **18**. Acidic and basic centers in **1** (49 % from **9**) and **2** (19 % from **9**) are at least 5 Å apart.

Introduction

Among all catalysts, acid and bases are the most important ones. Nature uses acidic and basic side chains of the amino acids to carry out respective catalyses within enzymes. Aside from a single acid or a single base, a large number of enzymes contain an acid–base array in the active center. The special geometrical placement of an acid and a base enables the enzymes to carry out bifunctional catalysis, for example in proteases.[1] Bifunctional catalysis[2] can also be carried out with small organic molecules, the simplest model being the hydrogen bond donor–acceptor array in a carboxylic acid or the prominent 2-pyridone.[3] Although catalytically active in many reactions, the applicability of these catalysts is limited for two reasons: the hydrogen-bond donor and acceptor act in parallel, and their distance is fixed to approximately 2.5 Å.

In order to imitate the concave shielding of the active site in an enzyme, the bifunctional acid–base catalyst should be placed in a cavity. Concave reagents imitate the geometry of enzymes for acids, bases, or other catalysts and reagents.[4] As a first example of concave bases, concave pyridines had been synthesized.[5] By using different strategies, several classes of concave pyridines are accessible. All classes have in common that they consist of a bimacrocyclic structure with one bridge containing a pyridine ring. The two necessary macrocyclizations can be performed sequentially or in one pot. The synthesis of concave pyridines with amide bridgeheads[5,6] used the first strategy (synthesis of a macrocyclic pyridine-containing diamine which is then bridged with a diacyl dichloride). Also, the syntheses of concave pyridines based on calixarenes[7–9] used a two-step strategy but there the pyridine-containing bridge was only introduced in the final construction of the bimacrocycle when a calixarene was treated with bis(bromomethyl)pyridine. In the third approach, two aryl bridgeheads were connected with the pyridine first, then both bridges were introduced in a double macrocyclization in a one pot reaction.[10]

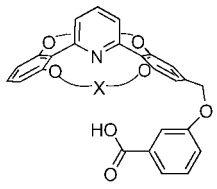
With other heterocycles such as 1,10-phenanthroline, a highly efficient route that uses metal catalyzed C–C bond formations has been established in the past years for the synthesis of related bimacrocycles.[11] The key steps were: (1) generation of the bridgeheads in the form of boronic acids, (2) Suzuki coupling of the two bridgeheads to a doubly halogenated heterocycle, and (3) bimacrocyclization by ruthenium-catalyzed ring-closing metathesis (RCM). For 2,9-disubstituted 1,10-phenanthrolines, it has also been demonstrated that a 4-substituted aryl bridgehead can be introduced.[12]

Building upon these findings, the synthetic scheme for the synthesis of a bifunctional acid–base catalyst such as **1** or **2** based on a concave pyridine develops as follows: (1) generation of aryl boronic acids as bridgeheads which have alkenyloxy groups in the *ortho* position and an additional protected functional group in the 4-position, (2) sequential addition of a 4-unsubstituted and a 4-substituted aryl

[‡] Concave Reagents, 51. Part 50: S. Konrad, M. Bolte, C. Näther, U. Lüning, *Eur. J. Org. Chem.* **2006**, 4717–4730.

[a] Otto-Diels-Institut für Organische Chemie, Christian-Albrechts-Universität zu Kiel,
Olshausenstr. 40, 24098 Kiel, Germany
Fax: +49-431-880-1558
E-mail: luening@oc.uni-kiel.de

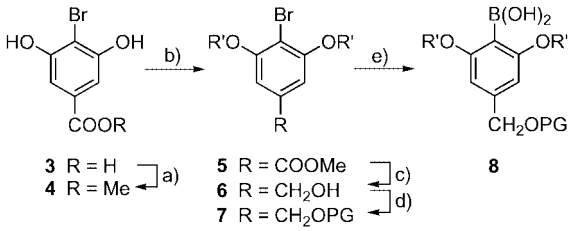
bridgehead into the 2- and 6-positions of a pyridine, (3) ring-closing metathesis (and possibly hydrogenation of the double bonds), (4) deprotection of the additional functional group and connection with an acid.



1 X = –$(CH_2)_3CH{=}CH(CH_2)_3$–
2 X = –$(CH_2)_{10}$–

Results and Discussion

A 4-substituted boronic acid with two *ortho*-methoxy groups has already been described.[12] Its synthesis started from commercially available 4-bromo-3,5-dihydroxybenzoic acid (**3**) (Scheme 1).



	R'	PG
a	$(CH_2)_3CH{=}CH_2$	TBDMS
b	$(CH_2)_4CH{=}CH_2$	THP

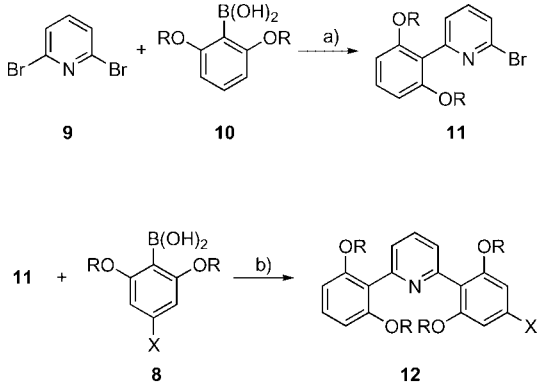
Scheme 1. a) MeOH, H_2SO_4 (cat.), reflux, 18 h; b) (i) THF, PPh_3, diisopropyl azodicarboxylate (DIAD), 4-penten-1-ol, room temp., 18 h (ii) DMF, K_2CO_3, KI, 6-bromohex-1-ene, 70 °C, 16 h; c) THF, iBu_2AlH, room temp., 3 h; d) (i) CH_2Cl_2, TBDMS–Cl, imidazole, room temp., 1 h (ii) CH_2Cl_2, DHP, *p*-TsOH, room temp., 16 h; e) THF, *n*BuLi, –78 °C, 1 h, $(MeO)_3B$, –78 °C→room temp., 2 h, dest. H_2O.

First, the carboxylic group of **3** was protected as methyl ester **4** in 64% yield. To introduce the future chains of the bimacrocycle, the phenolic groups of **3** had to be alkylated with the ω-alkenoxy residues. This connection between the phenolic groups of **4** and the alkenyl residue could be achieved either by Williamson ether synthesis or by a Mitsunobu reaction and was dependent on the availability of the alkenyl precursors. For **5a**, we performed a Mitsunobu reaction with 4-penten-1-ol (97%). Compound **5b** was obtained by Williamson ether synthesis with the use of 6-bromohex-1-ene (80%).

Next, the methyl esters were reduced to methanols **6a** and **6b** with the use of di-isobutylaluminium hydride (90 and 87%, respectively). For the transformation into boronic acids **8**, the methanol function had to be protected. Two protecting groups (PGs) were tested; pentenyl derivative **6a** was protected as *tert*-butyldimethylsilyl (TBDMS) ether **7a** (87%), whereas hexenyl diether **6b** was treated with 3,4-dihydro-2*H*-pyran (DHP) under acidic conditions to give THP ether **7b** in 88% yield. In the final reaction step, the bromine atoms were exchanged with lithium atoms by using *n*-butyllithium. Without isolation, the resulting aryllithium compounds were treated with trimethylborate to yield boronic acids **8** after hydrolysis in 81% (**8a**) and 60% (**8b**) yield.

By using boronic acids **8** and unsubstituted analogues **10** as described in the literature,[12] the connection of the bridgeheads with the pyridine core was the next task.

2,6-Dibromopyridine (**9**) was chosen as the pyridine building block, and the use of 1.1 equiv. of 4-unsubstituted boronic acids **10a** or **10b** under standard Suzuki coupling conditions gave 81% of **11a** and 73% of **11b**. Respective boronic acids **8** with the protected functional groups in the 4-position were then coupled with the remaining bromide functionality. *tert*-Butyldimethylsilyl (TBDMS) protected tetrapentenyl derivative **12a** was obtained in 92% yield, whereas tetrahydropyranyl (THP) protected tetrahexenyl derivative **12b** could be isolated in 84% yield (Scheme 2).

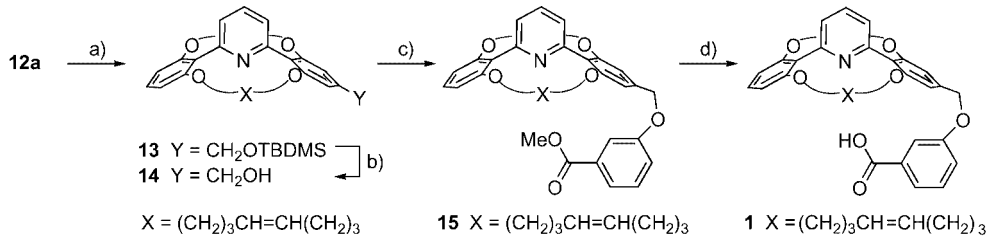


	R	X
a	$(CH_2)_3CH{=}CH_2$	$CH_2OTBDMS$
b	$(CH_2)_4CH{=}CH_2$	CH_2OTHP

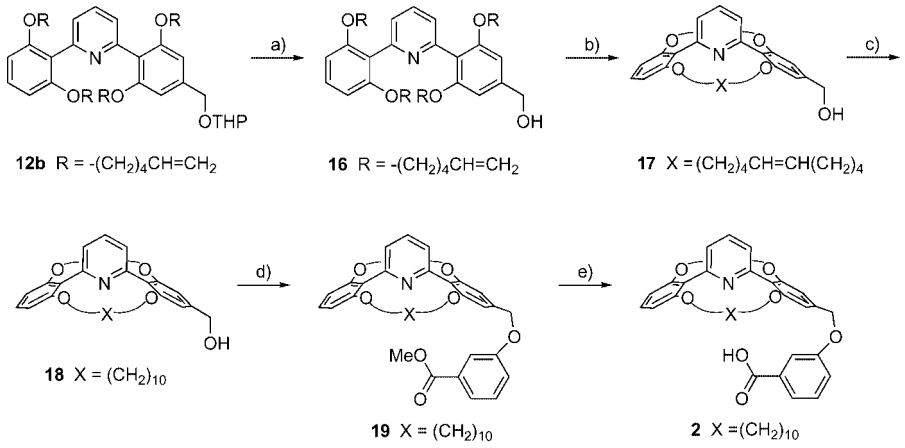
Scheme 2. a) Dimethoxyethane, $Pd(PPh_3)_4$, 2 N Na_2CO_3, reflux, 16–18 h; b) Dimethoxyethane, $Pd(PPh_3)_4$, $Ba(OH)_2{\cdot}H_2O$, reflux, 16–19 h.

Double ring-closing metatheses, deprotection, and connection with an acidic group remained to complete the synthesis. At this step of the synthesis, however, the decision as to whether and when to hydrogenate the double bonds that resulted from the metathesis reaction needed to be made. To elucidate saturated and unsaturated products, we left the pentyl derivatives unsaturated, whereas in the hexenyl case, the double bonds of the bimacrocycle were hydrogenated to finally give decamethylene chains.

Thus, tetrapentenyl ether **12a** was mixed with Grubbs′ catalyst and the resulting mixture of (*E,E*)-, (*E,Z*)-, and (*Z,Z*)-dialkene bimacrocycles **13** could be isolated in 92% yield. Next, the *tert*-butyldimethylsilyl group was cleaved off with the use of tetrabutylammonium fluoride to give methanol **14** in 98% efficiency. Again, with the use of the Mitsunobu protocol, the primary alcohol function was coupled with methyl 3-hydroxybenzoate (87% of **15**) before de-



Scheme 3. a) CH_2Cl_2, Grubbs' cat. (1st generation), room temp., 48 h; b) THF, $NBu_4F{\cdot}3H_2O$, room temp., 45 min; c) THF, PPh_3, diisopropyl azodicarboxylate (DIAD), methyl 3-hydroxybenzoate, 0 °C→room temp., 18 h; d) THF, MeOH, LiOH, H_2O, 40 °C, 4 h, room temp., 18 h.



Scheme 4. a) *p*-TsOH, MeOH, reflux, 90 min; b) CH_2Cl_2, Grubbs' cat. (1st generation), room temp., 21 h; c) Pd/C, H_2, MeOH, room temp., 18 h; d) THF, PPh_3, diisopropyl azodicarboxylate (DIAD), methyl 3-hydroxybenzoate, 0 °C, room temp. 18 h; e) THF, MeOH, LiOH, H_2O, 40 °C, 4 h, room temp., 18 h.

protection of the carboxylic acid with lithium hydroxide to give final product **1** in 84% yield (Scheme 3).

Spectroscopic analysis proved the structure of the final product but also showed the (*Z*) and (*E*) isomers of the double bonds. Of course, the ESI-MS spectra showed only one signal for the mixture of the isomers.

To avoid the problems arising from the (*E*) and (*Z*) double bonds, second tetraether **12b** was transformed into a bimacrocycle with saturated chains. For the synthesis of **2**, first the protecting THP group of **12b** was cleaved off by acid (98% of **16**), then the ring-closing metathesis was carried out. The (*E,E*)-, (*E,Z*)-, and (*Z,Z*)-mixture of **17**, obtained in 89% yield, was then hydrogenated with palladium on charcoal to give isomer-free macrocycle **18** in 96% yield. The rest of the synthesis was carried out as follows: Mitsunobu coupling of **18** to methyl 3-hydroxybenzoate (65% of **19**), and hydrolysis of the methyl ester with an aqueous lithium hydroxide solution gave 57% of bifunctional acid–base catalyst **2** (Scheme 4).

Conclusions

Compounds **1** and **2** are the first two examples of concave bases that carry an additional acidic function. Starting from 2,6-dibromopyridine (**9**), bifunctional catalysts **1** and **2** can be obtained in five or six reaction steps with overall yields of 49 and 19%, respectively. The geometry of **1** and **2** was chosen in such a way that the acid and the base cannot react intramolecularly. The methylenoxy connection between bridgehead and benzoic acid assures some flexibility to allow for an induced fit in future catalysis. The distance between the acid and base functionalities was calculated to be at least 5 Å, which guarantees that the acid and base moieties cannot form an intramolecular hydrogen bond.[13] Thus, acid and base are favorably oriented for bifunctional acid–base catalysis.

Although separated by more than 5 Å, the pyridine and the carboxylic acid, in principle, can react with one another to give a zwitterion by proton transfer. Such a reaction can take place intra- or intermolecularly. In water, pyridine and acetic acid possess almost identical pK_a values, and thus a mixture of acid and base and conjugate acid and conjugate base is expected. However, in less polar solvents, the acidity of a neutral carboxylic acid is decreased more than that of a protonated pyridine.[14,15] For instance, in ethanol the pK_a values of pyridines are only slightly altered,[16] whereas for several benzoic acids, pK_a values between 10 and 12 have been determined[17] and correspond to a decrease in the acidity by four orders of magnitude. This striking difference in solvent dependence of the acidity is not surprising. The

difference in stabilization by polar and less polar solvents is larger for charged species. In the case of carboxylic acids, the base is charged, whereas for pyridines, the acid, the pyridinium ion, is charged.[14] Thus, the formation of betaines is not expected in organic solvents for bifunctional catalysts **1** and **2**.

Unfortunately, in a first catalytic test, the rates of hydrolysis of a *p*-nitrophenyl ester catalyzed by these concave acid–base catalysts were only marginally larger than the background reaction. Application of these catalysts in hydrolyses, ring-opening reactions, and isomerizations are under investigation.

Experimental Section

General Remarks: The following chemicals were obtained commercially and used without further purification: barium hydroxide octahydrate (Merck), benzylidenebis(tricyclohexylphosphane)dichlororuthenium (Fluka), 4-bromo-3,5-dihydroxybenzoic acid (Aldrich), 6-bromohex-1-ene (Fluka), *tert*-butylchlorodimethylsilane (Fluka), *n*-butyllithium (2.5 M in hexanes, Aldrich), 2,6-dibromopyridine (Aldrich), 3,4-dihydro-2*H*-pyran (Fluka), diisobutylaluminium hydride (1.0 M in hexanes, Aldrich), diisopropyl azodicarboxylate (Fluka), 1,2-dimethoxyethane (Aldrich), *N*,*N*-dimethylformamide (≥99.8%, Fluka), methyl 3-hydroxybenzoate (Aldrich), Pd/C (10%) (Merck), 4-penten-1-ol (Alfa Aesar), tetrabutylammonium fluoride trihydrate (Fluka), tetrakis(triphenylphosphane)palladium(0) (Aldrich), trimethyl borate (Fluka). 2,6-Bis(hex-5-enyloxy)phenylboronic acid and 2,6-bis(pent-4-enyloxy)phenylboronic acid were prepared according to literature procedures.[12] Dry solvents were obtained with suitable desiccants: ethyl acetate and cyclohexane were distilled from calcium chloride, and tetrahydrofuran was distilled from lithium aluminium hydride. Column chromatography was carried out with silica gel (Macherey–Nagel, activity I). The preparative, centrifugally accelerated, thin layer chromatograph (Chromatotron) was model 7924T from Harrison Research. ^{1}H and ^{13}C NMR spectra were recorded with Bruker AC 200, ARX 300, DRX 500, or Avance 600 spectrometers with the use of tetramethylsilane as the internal standard. IR spectra were measured with a Perkin–Elmer 1600 Series spectrometer. Mass spectra were recorded with Finnigan MAT 8200 or 8230 spectrometers, or with an ESI mass spectrometer Mariner™ (Applied Biosystems, by using methanol/dichloromethane, 1:1, as the solvent). Elemental analyses were carried out with an Euro EA3000CHNS instrument (HEKAtech).

General Procedure for the Synthesis of Boronic Acids 8: Aryl bromide **7** was dissolved in dry tetrahydrofuran and then cooled to –78 °C. *n*-Butyllithium (1.1 equiv., 2.5 M in hexane) was added, and the mixture stirred for 1 h at –78 °C. After the addition of ca. 3.3 equiv. of trimethyl borate, stirring was continued for 2 h. During this period, the mixture was warmed to room temp. After quenching with water (20 mL), the layers were separated, and the aqueous layer was extracted with diethyl ether (3 × 20–30 mL). The combined organic layers were washed with brine (20–30 mL) and dried with magnesium sulfate. After evaporation of the solvent, the crude product was purified as detailed below.

General Procedure for Ring Closing Metathesis (13, 17): 2,6-Disubstituted pyridinetetraene **12a** or **16** was dissolved in dichloromethane ($c \approx 0.01$ mol/L). Benzylidenebis(tricyclohexylphosphane)-dichlororuthenium (5–10 mol-%) was added, and the mixture was stirred for 16–48 h at room temp. Afterwards, diisopropylamine (5–10 mL) was added and after an additional 45 min of stirring at room temp., the solvents were evaporated in vacuo, and the residue was purified as detailed below.

3-({2,11,13,22-Tetraoxa-1,12(1,3,2)-dibenzena-23(2,6)-pyridinabicyclo[10.10.1]tricosaphan-6,17-dien-1^5-yl}methyloxy)benzoic Acid (1): Methyl 3-({2,11,13,22-tetraoxa-1,12(1,3,2)-dibenzena-23(2,6)-pyridinabicyclo[10.10.1]tricosaphan-6,17-dien-1^5-yl}methyloxy)-benzoate (**15**, 70.0 mg, 104 μmol) was dissolved in a mixture of tetrahydrofuran and methanol (each 5 mL). Lithium hydroxide (71.3 mg, 1.69 mmol) in water (3 mL) was added, and the reaction mixture was stirred for 4 h at 40 °C. After an additional 18 h of stirring at room temp., the solvents were evaporated in vacuo, and the residue was dissolved in a mixture of dichloromethane and saturated ammonium chloride (each 10 mL). The layers were separated, and the aqueous layer was extracted with dichloromethane and ethyl acetate (2 × 25 mL each). The combined organic layer was dried with magnesium sulfate, and the solvent was evaporated in vacuo. The crude product was purified by recrystallization from chloroform/*n*-pentane to yield 55.7 mg (84%) of **1**. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.78 (t, J = 7.7 Hz, 1 H, 4-*H*), 7.66–7.63 (m, 2 H, Ar-4-*H*, Ar-6-*H*), 7.33 (t, J = 7.9 Hz, 1 H, Ar-5-*H*), 7.26, 7.25 (2 d, J = 7.7 Hz, J = 7.7 Hz, 2 H, 3-*H*, 5-*H*), 7.22 (t, J = 8.4 Hz, 1 H, 4′′-*H*), 7.17–7.15 (m, 1 H, Ar-2-*H*), 6.34 (s, 2 H, 3′-*H*, 5′-*H*), 6.55 (d, J = 8.4 Hz, 2 H, 3′′-*H*, 5′′-*H*), 5.36–5.30 (m, 4 H, C*H*=), 5.08 (s, 2 H, ArO-CH_2), 3.91 (s, 3 H, Ar-COOCH_3), 3.94–3.83 (m, 8 H, OCH_2), 2.00–1.91, 1.89–1.81 (2 m, 8 H, CH_2CH=), 1.66–1.58, 1.56–1.48 (2 m, 8 H, OCH$_2$CH_2) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 168.5 (s, Ar*C*OOH), 158.6 (Ar-C-3), 157.6 (s, C-2′, C-6′), 157.5 (s, C-2′′, C-6′′), 153.8 (s, C-2), 153.5 (s, C-6), 138.1 (s, C-4′), 135.2 (d, C-4), 131.8 (s, Ar-C-1), 129.8, 129.7 (2 d, *C*H=), 129.3 (d, Ar-C-5), 129.2 (d, C-4′′), 124.1, 124.0 (2 d, C-3, C-5), 122.5 (d, Ar-C-6), 120.0 (d, Ar-C-2), 119.1 (s, C-1′′), 118.6 (s, C-1′), 115.4 (d, Ar-C-4), 104.2 (d, C-3′′, C-5′′), 103.3 (d, C-3′, C-5′), 70.4 (t, ArO-*C*H$_2$), 66.4, 66.3 (2 t, O*C*H$_2$), 29.3, 29.2 (2 d, *C*H$_2$CH=), 23.2, 23.1 (2 t, OCH$_2$*C*H$_2$) ppm. IR (KBr): $\tilde{\nu}$ = 2936, 1700, 1595, 1438, 1248, 1109, 758 cm^{-1}. MS (ESI): *m*/*z* (%) = 684 (13) [M + Na]$^+$, 662 (100) [M + H]$^+$. $C_{41}H_{43}NO_7$ (661.78): calcd. C 74.41, H 6.55, N 2.21; found C 74.18, H 7.12, N 2.27.

3-({2,13,15,26-Tetraoxa-1,14(1,3,2)-dibenzena-27(2,6)-pyridinabicyclo[12.12.1]heptacosaphan-1^5-yl}methyloxy)benzoic Acid (2): Methyl 3-({2,13,15,26-tetraoxa-1,14(1,3,2)-dibenzena-27(2,6)-pyridinabicyclo[12.12.1]heptacosa-phan-1^5-yl}methyloxy)benzoate (**19**, 50.0 mg, 67.9 μmol) was dissolved in a mixture of tetrahydrofuran and methanol (each 5 mL). Lithium hydroxide (71.3 mg, 1.69 mmol) in water (3 mL) was added, and the reaction mixture was stirred for 4 h at 40 °C. After an additional 18 h of stirring at room temp., the solvents were evaporated in vacuo, and the residue was dissolved in a mixture of dichloromethane and saturated ammonium chloride (each 10 mL). The layers were separated, and the aqueous layer was extracted with dichloromethane and ethyl acetate (2 × 25 mL each). The combined organic layer was dried with magnesium sulfate, and the solvent was evaporated in vacuo. The crude product was purified by recrystallization from chloroform/*n*-pentane to yield 28.0 mg (57%) of **2**. ^{1}H NMR (600 MHz, $CDCl_3$): δ = 7.73 (t, J = 7.7 Hz, 1 H, 4-*H*), 7.68–7.64 (m, 2 H, Ar-4-*H*, Ar-6-*H*), 7.34 (t, J = 8.0 Hz, 1 H, Ar-5-*H*), 7.19 (t, J = 8.4 Hz, 1 H, 4′′-*H*), 7.18 (d, J = 7.7 Hz, 1 H, 3-*H*), 7.17 (d, J = 7.7 Hz, 1 H, 5-*H*), 7.17–7.15 (m, 1 H, Ar-2-*H*), 6.63 (s, 2 H, 3′-*H*, 5′-*H*), 6.56 (d, J = 8.4 Hz, 2 H, 3′′-*H*, 5′′-*H*), 5.08 (s, 2 H, ArO-CH_2), 4.04–3.95, 3.90–3.81 (2 m, 8 H, OCH_2), 1.62–1.51 (m, 8 H, OCH$_2$CH_2), 1.36–

1.07 (m, 24 H, CH_2) ppm. ^{13}C NMR (150 MHz, $CDCl_3$): δ = 170.5 (s, Ar*C*OOH), 158.6 (Ar-C-3), 157.9 (s, C-2′, C-6′), 157.8 (s, C-2′′, C-6′′), 153.7 (s, C-2), 153.4 (s, C-6), 137.9 (s, C-4′), 135.1(d, C-4), 131.4 (s, Ar-C-1), 129.4 (d, Ar-C-5), 129.0 (d, C-4′′), 124.3, 124.1 (2 d, C-3, C-5), 122.8 (d, Ar-C-6), 120.6 (s, C-1′′), 120.5 (s, C-1′), 120.2 (d, Ar-C-2), 115.6 (d, Ar-C-4), 104.9 (d, C-3′′, C-5′′), 103.9 (d, C-3′, C-5′), 70.5 (t, ArO-*C*H_2), 68.5, 68.3 (2 t, O*C*H_2), 28.0, 27.9, 26.9, 26.8, 25.7, 25.6, 24.4, 24.3 (8 t, *C*H_2) ppm. IR (KBr): $\tilde{\nu}$ = 2936, 1700, 1595, 1438, 1248, 1109, 758 cm^{-1}. MS (ESI): *m*/*z* (%) = 722 (100) $[M + H]^+$. $C_{45}H_{55}NO_7$ (721.92): calcd. C 74.87, H 7.68, N 1.94; found C 74.91, H 7.78, N 2.07.

Methyl 4-Bromo-3,5-dihydroxybenzoate (4):[18] 4-Bromo-3,5-dihydroxybenzoic acid (**3**, 10.0 g, 42.9 mmol) was dissolved in dry methanol (100 mL). After addition of conc. sulfuric acid (2.5 mL), the mixture was heated to reflux for 18 h. The solvent was removed in vacuo, and the residue was dissolved in a mixture of water (100 mL) and diethyl ether (400 mL). The water layer was extracted with diethyl ether (3 × 50 mL), and the combined organic layers were dried with magnesium sulfate. The solvent was evaporated in vacuo, and the residue was purified by recrystallization from chloroform to yield 6.80 g (64%) of **4**. M.p. 230 °C. ^1H NMR (200 MHz, $CDCl_3$): δ = 9.11 (s, 2 H, Ar-O*H*), 7.15 (s, 2 H, 2-*H*, 6-*H*), 3.83 (s, 3 H, ArCOOCH_3) ppm. IR (KBr): $\tilde{\nu}$ = 3425, 1703, 1600, 1424, 1373, 1273, 1036 cm^{-1}. MS (EI, 70 eV): *m*/*z* (%) = 248, 246 (52, 48) $[M]^+$, 217, 215 (69, 61) $[M–OCH_3]^+$, 189, 187 (19, 13) $[M–COOCH_3]^+$.

Methyl 4-Bromo-3,5-bis(pent-4-enyloxy)benzoate (5a): Methyl 4-bromo-3,5-dihydroxybenzoate (**4**, 12.1 g, 48.9 mmol), 4-penten-1-ol (9.22 g, 107 mmol), and triphenylphosphane (32.3 g, 123 mmol) were dissolved in tetrahydrofuran (200 mL). At 0 °C, diisopropyl azodicarboxylate (29.3 mL, 149 mmol) dissolved in tetrahydrofuran (15 mL) was added, and the mixture was stirred for 18 h at room temp. After addition of water (20 mL), the layers were separated, and the aqueous layer was extracted with diethyl ether (3 × 20 mL). The combined organic layer was washed with brine (2 × 10 mL) and dried with magnesium sulfate. The solvent was evaporated in vacuo, and the residue was purified by column chromatography (silica gel, cyclohexane/ethyl acetate, 5:1) to yield 18.2 g (97%) of **5a**. ^1H NMR (300 MHz, $CDCl_3$): δ = 7.20 (s, 2 H, 2-*H*, 6-*H*), 5.87 (tdd, *J* = 6.6 Hz, *J* = 10.2 Hz, *J* = 16.9 Hz, 2 H, C*H*=), 5.11 (tdd, *J* = 1.5 Hz, *J* = 2.1 Hz, *J* = 16.9 Hz, 2 H, CH=C$H_{(Z)}$H), 4.98 (tdd, *J* = 1.2 Hz, *J* = 2.1 Hz, *J* = 10.2 Hz, 2 H, CH=C$H_{(E)}$H), 4.09 (t, *J* = 6.30, 4 H, OCH_2), 3.91 (s, 3 H, OCH_3), 2.36–2.26 (m, 4 H, CH_2CH=), 2.01–1.90 (m, 4 H, OCH_2CH_2) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 166.5 (s, Ar*C*OOCH$_3$), 156.5 (s, C-3, C-5), 137.6 (d, *C*H=CH$_2$), 129.9 (s, C-1), 115.4 (t, CH=*C*H$_2$), 107.7 (s, C-4), 106.4 (d, C-2, C-6), 68.6 (t, O*C*H$_2$CH$_2$), 52.4 (q, ArCOO*C*H$_3$), 29.9 (t, *C*H$_2$CH=CH$_2$), 28.2 (t, OCH$_2$*C*H$_2$) ppm. IR (KBr): $\tilde{\nu}$ = 2946, 1723, 1640, 1586, 1426, 1243, 1110 cm^{-1}. MS (ESI): *m*/*z* (%) = 405 (50) $[M + Na]^+$, 384 (100) $[M + H]^+$.

Methyl 4-Bromo-3,5-bis(hex-5-enyloxy)benzoate (5b): Methyl 4-bromo-3,5-dihydroxybenzoate (**4**, 6.61 g, 26.7 mmol) was dissolved in dry *N*,*N*-dimethylformamide (120 mL). After the addition of potassium carbonate (23.6 g, 170 mmol), potassium iodide (500 mg, 3.01 mmol), and 6-bromohex-1-ene (10.9 g, 66.7 mmol), the reaction mixture was stirred for 16 h at 70 °C. The solvent was removed in vacuo, and the residue was dissolved in a mixture of water (20 mL) and diethyl ether (40 mL). The water layer was extracted with diethyl ether (3 × 20 mL), and the combined organic layer was washed with brine (15 mL) and dried with magnesium sulfate. The solvent was evaporated in vacuo, and the residue was purified by column chromatography (silica gel, cyclohexane/ethyl acetate, 5:1) to yield 8.78 g (80%) of **5b**. M.p. 31 °C. ^1H NMR (300 MHz, $CDCl_3$): δ = 7.20 (s, 2 H, 2-*H*, 6-*H*), 5.84 (tdd, *J* = 6.7 Hz, *J* = 10.3 Hz, *J* = 17.1 Hz, 2 H, C*H*=), 5.05 (tdd, *J* = 1.5 Hz, *J* = 2.1 Hz, *J* = 17.1 Hz, 2 H, =C$H_{(Z)}$H), 4.98 (tdd, *J* = 1.2 Hz, *J* = 2.1 Hz, *J* = 10.3 Hz, 2 H, CH=C$H_{(E)}$H), 4.09 (t, *J* = 6.4 Hz, 4 H, OCH_2CH$_2$), 3.92 (s, 3 H, ArCOOCH_3), 2.2–2.1 (m, 4 H, CH_2CH=), 1.9–1.8 (m, 4 H, OCH$_2$CH_2), 1.7–1.5 (m, 4 H, OCH$_2$CH$_2$CH_2) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 166.6 (s, Ar*C*OOCH$_3$), 156.5 (s, C-3, C-5), 138.5 (d, *C*H=), 129.9 (s, C-1), 114.8 (t, =*C*H$_2$), 106.3 (d, C-2, C-6), 107.7 (s, C-4), 69.3 (t, ArO*C*H$_2$), 52.4 (q, ArCOO*C*H$_3$), 33.3(t, *C*H$_2$CH=), 28.4 (t, OCH$_2$*C*H$_2$), 25.2 (t, OCH$_2$CH$_2$*C*H$_2$) ppm. IR (KBr): $\tilde{\nu}$ = 2947, 1724, 1639, 1584, 1425, 1243, 1113 cm^{-1}. MS (EI, 70 eV): *m*/*z* (%) = 412, 410 (1, 1) $[M]^+$, 381, 379 (2, 2) $[M – CH_3O]^+$, 331 (100) $[M – Br]^+$, 248, 246 (78, 78) $[M – C_{12}H_{20}]^+$. $C_{20}H_{27}BrO_4$ (411.33): calcd. C 58.40, H 6.62; found C 58.50, H 6.73.

4-Bromo-3,5-bis(pent-4-enyloxy)phenylmethanol (6a): Methyl 4-bromo-3,5-bis(pent-4-enyloxy)benzoate (**5a**, 6.86 g, 17.9 mmol) was dissolved in tetrahydrofuran (50 mL). After the addition of a solution of diisobutylaluminium hydride (1.0 M in hexanes, 40 mL, 40 mmol), the reaction mixture was stirred for 2 h at room temp. Water (15 mL) was added. The precipitated solid was filtered off and washed with ethyl acetate (3 × 25 mL). The filtrate was evaporated in vacuo and the residue was purified by column chromatography (silica gel, cyclohexane/ethyl acetate, 2:1) to yield 5.70 g (90%) of **6a**. ^1H NMR (300 MHz, $CDCl_3$): δ = 6.52 (s, 2 H, 2-*H*, 6-*H*), 5.86 (tdd, *J* = 6.6 Hz, *J* = 10.2 Hz, *J* = 17.1 Hz, 2 H, C*H*=), 5.11 (tdd, *J* = 1.6 Hz, *J* = 2.1 Hz, *J* = 17.1 Hz, 2 H, CH=C$H_{(Z)}$H), 5.02 (tdd, *J* = 1.2 Hz, *J* = 2.1 Hz, *J* = 10.2 Hz, 2 H, CH=C$H_{(E)}$H), 4.61 (s, ArCH_2O), 4.02 (t, *J* = 6.4 Hz, 4 H, OCH_2), 2.36–2.22 (m, 4 H, CH_2-CH=), 2.00–1.85 (m, 4 H, OCH$_2$CH_2) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 156.6 (s, C-3, C-5), 141.4 (s, C-1), 137.7 (d, *C*H=), 115.3 (t, =*C*H$_2$), 104.1 (d, C-2, C-6), 100.9 (s, C-4), 68.5 (t, HO*C*H$_2$Ar), 65.1 (t, ArO*C*H$_2$), 30.0 (t, *C*H$_2$-CH=), 28.3 (t, ArOCH$_2$*C*H$_2$) ppm. IR (Film): $\tilde{\nu}$ = 3354, 2937, 1640, 1587, 1434, 1237, 1114 cm^{-1}. MS (ESI): *m*/*z* (%) = 356 (100) $[M + H]^+$.

4-Bromo-3,5-bis(hex-5-enyloxy)phenylmethanol (6b): Methyl 4-bromo-3,5-bis(hex-5-enyloxy)benzoate (**5b**, 823 mg, 2.00 mmol) was dissolved in tetrahydrofuran (10 mL). After the addition of a solution of diisopropylaluminium hydride (1.0 M in hexanes, 5 mL, 5 mmol), the reaction mixture was stirred for 3 h at room temp. Water (5 mL) was added. The precipitated solid was filtered off and washed with ethyl acetate (3 × 20 mL). The filtrate was evaporated in vacuo, and the residue was purified by column chromatography (silica gel, cyclohexane/ethyl acetate, 2:1) to yield 667 mg (87%) of **6b**. ^1H NMR (300 MHz, $CDCl_3$): δ = 6.55 (s, 2 H, 2-*H*, 6-*H*), 5.84 (tdd, *J* = 6.6 Hz, *J* = 10.3 Hz, *J* = 17.1 Hz, 2 H, C*H*=), 5.04 (tdd, *J* = 1.6 Hz, *J* = 2.1 Hz, *J* = 17.1 Hz, 2 H, CH=C$H_{(Z)}$H), 4.97 (tdd, *J* = 1.2 Hz, *J* = 2.1 Hz, *J* = 10.3 Hz, 2 H, CH=C$H_{(E)}$H), 4.64 (s, 2 H, ArCH_2OH), 4.03 (t, *J* = 6.4 Hz, 4 H, ArOCH_2), 2.20–2.07 (m, 4 H, CH_2CH=), 1.91–1.76 (m, 4 H, OCH$_2$CH_2), 1.67–1.53 (m, 4 H, CH_2) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 156.7 (s, C-3, C-5), 141.4 (s, C-1), 138.6 (d, *C*H=CH$_2$), 114.8 (t, CH=*C*H$_2$), 104.0 (d, C-2, C-6), 100.8 (s, C-4), 69.1 (t, ArO*C*H$_2$), 65.2 (t, Ar*C*H$_2$O), 33.4 (t, *C*H$_2$CH=), 28.6 (t, OCH$_2$*C*H$_2$), 25.2 (t, *C*H$_2$) ppm. IR (Film): $\tilde{\nu}$ = 3354, 2937, 1640, 1587, 1434, 1237, 1114 cm^{-1}. MS (EI, 70 eV): *m*/*z* (%) = 384, 382 (4, 5) $[M]^+$, 303 (100) $[M – Br]^+$, 220, 218 (70, 72) $[M – C_{12}H_{20}]^+$. $C_{19}H_{27}BrO_3$ (383.32): calcd. C 59.53, H 7.10; found C 59.24, H 7.14.

2-Bromo-4-(*tert*-butyldimethylsilyloxymethyl)-1,3-bis(pent-4-enyloxy)benzene (7a): 4-Bromo-3,5-bis(pent-4-enyloxy)phenylmethanol (**6a**, 5.70 g, 16.1 mmol) and imidazole (6.60 g, 96.9 mmol) were dis-

solved in dry dichloromethane (200 mL). At 0 °C, *tert*-butylchlorodimethylsilane (2.51 g, 16.6 mmol) was added, and the mixture was stirred for 1 h at room temp. After addition of water (20 mL), the layers were separated, and the aqueous layer was extracted with dichloromethane (3 × 25 mL). The combined organic layers were washed with brine (20 mL) and dried with magnesium sulfate. The solvent was evaporated in vacuo, and the residue was purified by column chromatography (silica gel, cyclohexane/ethyl acetate, 1:1) to yield 6.57 g (87%) of **7a**. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 6.55 (s, 2 H, 4-*H*, 6-*H*), 5.88 (tdd, *J* = 6.6 Hz, *J* = 10.2 Hz, *J* = 17.1 Hz, 2 H, C*H*=CH_2), 5.11 (tdd, *J* = 1.6 Hz, *J* = 2.1 Hz, *J* = 17.1 Hz, 2 H, CH=C$H_{(Z)}$H), 5.02 (tdd, *J* = 1.2 Hz, *J* = 2.1 Hz, *J* = 10.2 Hz, 2 H, CH=C$H_{(E)}$H), 4.70 (s, 2 H, ArCH_2O), 4.05 (t, *J* = 6.4 Hz, 4 H, OCH_2), 2.36–2.26 (m, 4 H, CH_2-CH=), 2.01–1.90 (m, 4 H, OCH$_2$CH_2), 0.97 [s, 9 H, C(CH_3)$_3$], 0.12 [s, 6 H, Si-(CH_3)$_2$] ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 156.4 (s, C-1, C-3), 142.1 (s, C-5), 137.7 (d, *C*H=), 115.2 (t, =CH_2), 103.2 (d, C-4, C-6), 99.9 (s, C-2), 68.3 (t, Si-OCH$_2$Ar), 64.6 (t, ArOCH_2), 30.1 (t, *C*H$_2$-CH=), 28.3 (t, ArOCH$_2$*C*H$_2$), 25.9 [q, C(*C*H$_3$)], 18.4 [s, *C*(CH$_3$)], –5.24 [q, Si-(*C*H$_3$)] ppm. IR (Film): $\tilde{\nu}$ = 3015, 2952, 2929, 1588, 1433, 1216, 1108, 839 cm^{-1}. MS (EI, 70 eV): *m*/*z* (%) = 470, 468 (5, 4) [M]$^+$, 413, 411 (100, 96) [M – C_4H_9]$^+$, 389 (39) [M – Br]$^+$, 333 (83) [M – C_4H_9 – Br]$^+$.

2-Bromo-1,3-bis(hex-5-enyloxy)-5-(2-tetrahydropyranyloxymethyl)-benzene (7b): 4-Bromo-3,5-bis(hex-5-enyloxy)phenylmethanol (**6b**, 3.73 g, 9.82 mmol) was dissolved in dry dichloromethane (60 mL). After the addition of 3,4-dihydro-2*H*-pyran (2.4 mL, 27 mmol) and *p*-toluenesulfonic acid (100 mg, 526 μmol), the reaction mixture was stirred for 16 h at room temperature. The solvent was removed, and the residue was purified by column chromatography (silica gel, cyclohexane/ethyl acetate, 6:1) to yield 4.03 g (88%) of **7b**. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 6.55 (t, *J* = 0.6 Hz, 2 H, 4-*H*, 6-*H*), 5.84 (tdd, *J* = 6.6 Hz, *J* = 10.2 Hz, *J* = 17.1 Hz, 2 H, C*H*=), 5.04 (tdd, *J* = 1.6 Hz, *J* = 2.1 Hz, *J* = 17.1 Hz, 2 H, CH=C$H_{(Z)}$H), 4.97 (tdd, *J* = 1.2 Hz, *J* = 2.1 Hz, *J* = 10.2 Hz, 2 H, CH=C$H_{(E)}$H), 4.71 (d, *J* = 0.6 Hz, *J* = 12.2 Hz, 1 H, ArCH_2O), 4.67 (dd, *J* = 2.5 Hz, *J* = 4.1 Hz, 1 H, OC*H*O), 4.46 (d, *J* = 0.6 Hz, *J* = 12.2 Hz, 1 H, ArCH_2O), 4.03 (t, *J* = 6.4 Hz, 4 H, ArOCH_2CH$_2$), 4.03–3.81 (m, 1 H, CH_2O), 3.62–3.56 (m, 1 H, CH_2O), 2.21–2.10 (m, 4 H, CH_2CH=), 1.91–1.57 (m, 14 H, CH_2) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 156.5 (s, C-1, C-3), 138.7 (s, C-5), 138.6 (d, *C*H=), 114.7 (t, =CH_2), 105.1 (d, C-4, C-6), 100.9 (s, C-2), 97.6 (d, O*C*HO), 69.0 (t, ArO*C*H$_2$CH$_2$), 68.6 (t, *C*H$_2$O), 62.3 (t, Ar*C*H$_2$O), 33.3 (t, *C*H$_2$CH=), 30.6 (t, *C*H$_2$), 28.5 (t, OCH$_2$*C*H$_2$), 25.4 (d, *C*H), 25.2 (t, OCH$_2$CH$_2$*C*H$_2$), 19.4 (t, *C*H$_2$) ppm. IR (Film): $\tilde{\nu}$ = 2940, 1587, 1433, 1232, 1114 cm^{-1}. MS (EI, 70 eV): *m*/*z* (%) = 468, 466 (2, 3) [M]$^+$, 387 (19) [M – Br]$^+$, 368, 366 (31, 34) [M – $C_5H_8O_2$]$^+$, 204, 202 (98, 100) [M – $C_{17}H_{28}O_2$]$^+$. $C_{24}H_{35}BrO_4$ (467.44): calcd. C 61.67, H 7.55; found C 61.43, H 7.45.

4-(*tert*-Butyldimethylsilyloxymethyl)-2,6-bis(pent-4-enyloxy)phenylboronic Acid (8a): Synthesis according to the general procedure: 2-Bromo-4-(*tert*-butyldimethylsilyloxymethyl)-1,3-bis(pent-4-enyloxy)benzene (**7a**, 7.20 g, 15.4 mmol) in tetrahydrofuran (110 mL) with the use of *n*-butyllithium (2.5 M in hexane, 8.00 mL, 20.0 mmol) and trimethylborate (7.00 mL, 62.8 mmol). Purification by column chromatography on silica gel eluting with cyclohexane/ethyl acetate (8:1). Yield: 5.41 g (81%). M.p. <20 °C. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.28 [s, 2 H, ArB(O*H*)$_2$], 6.59 (s, 2 H, 3-*H*, 5-*H*), 5.81 (tdd, *J* = 6.7 Hz, *J* = 10.2 Hz, *J* = 16.9 Hz, 2 H, C*H*=CH_2), 5.08, 5.02 (tdd, *J* = 1.2 Hz, *J* = 2.0 Hz, *J* = 10.2 Hz, =C$H_{(E)}$H, tdd, *J* = 1.5 Hz, *J* = 2.0 Hz, *J* = 17.1 Hz, 4 H, CH=C$H_{(Z)}$H), 4.72 (s, 2 H, Ar-CH_2-O), 4.08 (t, *J* = 6.5 Hz, 4 H, ArOCH_2), 2.27–2.21 (m, 4 H, CH_2-CH=), 1.98–1.92 (m, 4 H, OCH$_2$CH_2), 0.96 [s, 9 H, C(CH_3)$_3$], 0.12 [s, 6 H, Si (CH_3)$_2$] ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 164.9 (s, C-2, C-6), 147.4 (s, C-4), 136.9 (d, *C*H=), 115.8 (t, =CH_2), 102.4 (d, C-3, C-5), 68.2 (t, Si-OCH$_2$Ar), 64.5 (t, ArOCH_2-), 30.0 (t, *C*H$_2$-CH=), 28.2 (t, Ar-OCH$_2$*C*H$_2$), 25.1 [q, C(*C*H$_3$)], 18.3 [s, *C*(CH$_3$)], –5.28 [q, Si-(*C*H$_3$)] ppm. IR (KBr): $\tilde{\nu}$ = 3522, 2939, 2867, 164 1, 1567, 1445, 1335, 1217, 1106 cm^{-1}. Because of relaxation effects with ^{11}B-isotopes, the signal for C-1 is not detectable. MS (ESI): *m*/*z* (%) = 891 (100) [2 M]$^+$. $C_{23}H_{39}BO_5Si$ (434.45): calcd. C 63.59, H 9.05; found C 63.86, H 9.23.

2,6-Bis(hex-5-enyloxy)-4-(2-tetrahydropyranyloxymethyl)phenylboronic Acid (8b): Synthesis according to the general procedure: 2-Bromo-1,3-bis(hex-5-enyloxy)-5-(2-tetrahydropyranyloxymethyl)-benzene (**7b**, 800 mg, 1.71 mmol) in tetrahydrofuran (45 mL) with the use of *n*-butyllithium (2.5 M in hexane, 1.00 mL, 2.50 mmol) and trimethylborate (800 μL, 7.18 mmol). Purification by column chromatography on silica gel eluting with cyclohexane/ethyl acetate (3:1). Yield: 440 mg (60%). M.p. <20 °C. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.30 [s, 2 H, ArB(O*H*)$_2$], 6.61 (s, 2 H, 3-*H*, 5-*H*), 5.81 (tdd, *J* = 6.7 Hz, *J* = 10.2 Hz, *J* = 17.1 Hz, 2 H, C*H*=), 5.04, 4.99 (tdd, *J* = 1.2 Hz, *J* = 2.0 Hz, *J* = 10.2 Hz, CH=C$H_{(E)}$H, tdd, *J* = 1.5 Hz, *J* = 2.0 Hz, *J* = 17.1 Hz, 4 H, CH=C$H_{(Z)}$H), 4.76 (td, *J* = 0.7 Hz, *J* = 12.7 Hz, 1 H, ArCH_2O), 4.69 (dd, *J* = 2.8 Hz, *J* = 4.5 Hz, 1 H, OC*H*O), 4.50 (td, *J* = 0.7 Hz, *J* = 12.7 Hz, 1 H, Ar-CH_2O-), 4.08 (t, *J* = 6.5 Hz, 4 H, ArOCH_2CH$_2$), 3.94–3.86, 3.58–3.52 (m, 2 H, OCH_2), 2.18–2.10 (m, 4 H, CH_2CH=), 1.90–1.82 (m, 4 H, OCH$_2$CH_2), 1.61–1.54 (m, 4 H, OCH$_2$CH$_2$CH_2) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 165.0 (s, C-2, C-6), 143.9 (s, C-4), 138.0 (d, *C*H=), 115.2 (t, =CH_2), 104.2 (d, C-3, C-5), 97.9 (d, O*C*HO), 68.9 (t, ArO*C*H$_2$CH$_2$), 68.5 (t, *C*H$_2$O), 62.4 (t, Ar*C*H$_2$O), 33.3 (*C*H$_2$-CH=), 30.6 (t, *C*H$_2$), 28.5 (t, ArOCH$_2$*C*H$_2$), 25.4 (t, *C*H$_2$), 25.2 (t, ArOCH$_2$CH$_2$*C*H$_2$), 19.4 (t, *C*H$_2$) ppm. IR (KBr): $\tilde{\nu}$ = 3520, 2939, 2867, 1640, 1567, 1445, 1336, 1217, 1106 cm^{-1}. Because of relaxation effects with ^{11}B-isotopes, the signal for C-1 is not detectable. MS (EI, 70 eV): *m*/*z* (%) = 304 (11) [M – B(OH)$_2$ – C_6H_{11}]$^+$, 283 (100) [M – $C_5H_9BO_4$]$^+$.

2-[2,6-Bis(pent-4-enyloxy)-phenyl]-6-bromopyridine (11a): 2,6-Dibromopyridine (**9**, 487 mg, 2.06 mmol), 2,6-bis(pent-4-enyloxy)-phenylboronic acid (**10a**, 660 mg, 2.27 mmol), and tetrakis(triphenylphosphane)palladium(0) (235 mg, 206 μmol) were dissolved in dimethoxyethane (50 mL). After the addition of aqueous sodium carbonate (2 N, 2.3 mL), the reaction mixture was heated to reflux for 18 h. Water and chloroform (10 mL each) were added, the water layer was extracted with chloroform (3 × 15 mL), and the combined organic layers were washed with brine (15 mL) and dried with magnesium sulfate. The solvent was evaporated in vacuo, and the residue was purified by column chromatography (silica gel, cyclohexane/ethyl acetate, 9:1) to yield 680 mg (81%) of **11a**. ^{1}H NMR (600 MHz, $CDCl_3$): δ = 7.55 (t, *J* = 7.8 Hz, 1 H, 4-*H*), 7.39 (dd, *J* = 7.8 Hz, *J* = 1.1 Hz, 1 H, 3-*H*), 7.28 (dd, *J* = 7.4 Hz, *J* = 1.1 Hz, 1 H, 5-*H*), 7.24 (t, *J* = 8.4 Hz, 1 H, 4′-*H*), 6.59 (d, *J* = 8.4 Hz, 2 H, 3′-*H*, 5′-*H*), 5.74 (tdd, *J* = 6.7 Hz, *J* = 10.2 Hz, *J* = 16.9 Hz, 2 H, C*H*=), 5.02–4.88 (m, 4 H, =CH_2), 3.92 (t, *J* = 6.2 Hz, 4 H, OCH_2), 2.12–1.97 (m, 4 H, CH_2CH=), 1.77–1.61 (m, 4 H, OCH$_2$CH_2) ppm. ^{13}C NMR (150 MHz, $CDCl_3$): δ = 157.4 (s, C-2′, C-6′), 155.7 (s, C-6), 140.8 (s, C-2), 137.9 (d, CH$_2$*C*H=), 137.6 (d, C-4), 130.0 (d, C-4′), 125.7 (d, C-3), 125.2 (d, C-5), 118.4 (s, C-1′), 114.9 (t, =CH_2), 105.2 (d, C-3′, C-5′), 67.8 (t, O*C*H$_2$), 30.0 (t, *C*H$_2$CH=), 28.3 (t, OCH$_2$*C*H$_2$). IR (KBr): $\tilde{\nu}$ = 3053, 2985, 1640, 1598, 1421, 1101, 896 cm^{-1}. HRMS: calcd. for $C_{21}H_{24}{}^{79}BrNO_2$ 401.09903; found 401.09901 (δ =0.05 ppm), calcd. for $C_{20}{}^{13}CH_{24}{}^{79}BrNO_2$ 402.10239; found 402.09972 (δ =6.64 ppm). $C_{21}H_{24}BrNO_2$ (402.33): calcd. C 62.69, H 6.01, N 3.48,

$C_{21}H_{24}BrNO_2 \cdot 0.1C_6H_{12}$: calcd. C 63.16, H 6.18, N 3.41; found C 63.26, H 6.18, N 3.43.

2-[2,6-Bis(hex-5-enyloxy)phenyl]-6-bromopyridine (11b): 2,6-Dibromopyridine (**9**, 500 mg, 2.11 mmol), 2,6-bis(hex-5-enyloxy)phenylboronic acid (**10b**, 738 mg, 2.32 mmol), and tetrakis(triphenylphosphane)palladium(0) (235 mg, 206 μmol) were dissolved in dimethoxyethane (50 mL). After the addition of aqueous sodium carbonate (2 N, 2.5 mL), the reaction mixture was heated to reflux for 16 h. Water and chloroform (10 mL each) were added, the water layer was extracted with chloroform (3 × 15 mL), and the combined organic layers were washed with brine (15 mL) and dried with magnesium sulfate. The solvent was evaporated in vacuo, and the residue was purified by column chromatography (silica gel, cyclohexane/ethyl acetate, 9:1) to yield 660 mg (73%) of **11b**. ^{1}H NMR (600 MHz, $CDCl_3$): δ = 7.53 (t, J = 7.7 Hz, 1 H, 4-*H*), 7.38 (dd, J = 7.7 Hz, J = 0.9 Hz, 1 H, 3-*H*), 7.27 (dd, J = 7.7 Hz, J = 0.9 Hz, 1 H, 5-*H*), 7.24 (t, J = 8.4 Hz, 1 H, 4′-*H*), 6.58 (d, J = 8.4, 2 H, 3′-*H*, 5′-*H*), 5.74 (tdd, J = 6.7 Hz, J = 10.2 Hz, J = 16.9 Hz, 2 H, C*H*=), 4.97–4.89 (m, 4 H, =CH_2), 3.91 (t, J = 6.3, 1 H, OCH_2), 2.02–1.96 (m, 4 H, CH_2CH=), 1.64–1.58 (m, 4 H, OCH$_2$CH_2), 1.41–1.35 (m, 4 H, CH_2) ppm. ^{13}C NMR (150 MHz, $CDCl_3$): δ = 157.5 (s, C-2′, C-6′), 155.7 (s, C-6), 140.8 (s, C-2), 138.7 (d, CH$_2$*C*H=), 137.6 (d, C-4), 130.1 (d, C-4′), 125.3 (d, C-3), 125.2 (d, C-5), 118.5 (s, C-1′), 114.5 (t, =*C*H$_2$), 105.2 (d, C-3′, C-5′), 68.5 (t, O*C*H$_2$), 33.3 (t, *C*H$_2$CH=), 28.5 (t, OCH$_2$*C*H$_2$), 25.2 (t, *C*H$_2$) ppm. IR (KBr): $\tilde{\nu}$ = 3053, 2985, 1649, 1598, 1421, 1100, 896 cm^{-1}. MS (EI, 70 eV): *m*/*z* (%) = 431, 429 (28, 27) [M]$^+$, 350 (100) [M – Br]$^+$, 267, 264 (64, 68) [M – 2–C_6H_{11}]$^+$. MS (CI, Isobutane): *m*/*z* (%) = 432, 430 (89, 100) [M + H]$^+$, 352, 350 (8, 13) [M + H – Br]$^+$. $C_{23}H_{28}BrNO_2$ (430.38): calcd. C 64.19, H 6.56, N 3.25, $C_{23}H_{28}BrNO_2 \cdot 0.1CH_3COOEt$ calcd. C 63.99, H 6.61, N 3.19; found C 63.76, H 6.59, N 3.15.

2-[2,6-Bis(pent-4-enyloxy)-phenyl]-6-[2,6-bis(pent-4-enyloxy)-4-(*tert*-butyldimethylsilyloxymethyl)phenyl]pyridine (12a): 2,6-Bis(pent-4-enyloxy)-4-(*tert*-butyldimethylsilyloxymethyl)phenylboronic acid (**8a**, 900 mg, 2.07 mmol), tetrakis(triphenylphosphane)palladium(0) (115 mg, 99.5 μmol), barium hydroxide (1.41 g, 8.22 mmol), and water (20.0 mL) were added to a solution of 2-[2,6-bis(pent-4-enyloxy)phenyl]-6-bromopyridine (**11a**, 650 mg, 1.62 mmol) in 1,2-dimethoxyethane (120 mL). The reaction mixture was heated to reflux for 19 h. After the addition of water and chloroform (50 mL each), the water layer was extracted with chloroform (3 × 50 mL), and the combined organic layer was washed with brine (20 mL). The solvent was removed in vacuo, and the residue was purified by column chromatography (silica gel, cyclohexane/ethyl acetate, 6:1) to yield 1.07 g (92%) of **12a**. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.69 (t, J = 7.7 Hz, 1 H, 4-*H*), 7.19 (t, J = 8.3 Hz, 1 H, 4′′-*H*), 7.18 (d, J = 7.7 Hz, 2 H, 3-*H*, 5-*H*), 6.57 (t, J = 8.3 Hz, 2 H, 3′′-*H*, 5′′-*H*), 6.56 (s, 2 H, 3′-*H*, 5′-*H*), 5.71, 5.70 (2 tdd, J = 6.7 Hz, J = 10.2 Hz, J = 16.9 Hz, 4 H, C*H*=), 4.95–4.86 (m, 8 H, =CH_2), 4.72 (s, 2 H, Ar-CH_2-O), 3.87 (t, J = 6.5 Hz, 8 H, OCH_2), 2.03–1.96 (m, 8 H, CH_2CH=), 1.69–1.61 (m, 4 H, OCH$_2$CH_2), 0.95 [s, 9 H, SiC(CH$_3$)$_3$], 0.11 [s, 6 H, Si-(CH_3)$_2$] ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 157.8 (s, C-2′′, C-6′), 157.6 (s, C-2′, C-6′), 154.2 (s, C-2), 154.0 (s, C-6), 142.82 (s, C-4′), 138.0 (d, *C*H=), 134.5 (d, C-4), 128.9 (d, C-4′′), 123.8 (d, C-3), 123.6 (d, C-5), 121.3 (s, C-1′′), 119.6 (s, C-1′), 114.8 (t, =*C*H$_2$), 105.7 (d, C-3′′, C-5′′), 103.1 (d, C-3′, C-5′), 67.9, 67.8 (2 t, O*C*H$_2$), 65.1 (t, Ar-*C*H$_2$-O), 30.0, 29.9 (2 t, *C*H$_2$CH=), 28.3, 28.2 (2 t, OCH$_2$*C*H$_2$), 25.9 [q, C(*C*H$_3$)], 18.4 [s, *C*(CH$_3$)], –5.17 [q, Si-(*C*H$_3$)] ppm. IR (KBr): $\tilde{\nu}$ = 3053, 2986, 1640, 1598, 1432, 1102, 895 cm^{-1}. MS (ESI): *m*/*z* (%) = 712 (100) [M + H]$^+$.

2-[2,6-Bis(hex-5-enyloxy)phenyl]-6-[2,6-bis(hex-5-enyloxy)-4-(2-tetrahydropyranyloxymethyl)phenyl]pyridine (12b): 2,6-Bis(hex-5-enyloxy)-4-(2-tetrahydropyranyloxymethyl)phenylboronic acid (**10b**, 440 mg, 1.02 mmol), tetrakis(triphenylphosphane)palladium(0) (94 mg, 82 μmol), barium hydroxide (300 mg, 1.75 mmol), and water (5.00 mL) were added to a solution of 2-[2,6-bis(hex-5-enyloxy)phenyl]-6-bromopyridine (**11b**, 351 mg, 816 μmol) in 1,2-dimethoxyethane (60 mL). The reaction mixture was heated to reflux for 19 h. After the addition of water and chloroform (50 mL each), the water layer was extracted with chloroform (3 × 50 mL), and the combined organic layer was washed with brine (20 mL). The solvent was removed in vacuo, and the residue was purified by chromatography (silica gel, cyclohexane/ethyl acetate, 6:1) to yield 500 mg (84%) of **12b**. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.66 (t, J = 7.7 Hz, 1 H, 4-*H*), 7.19 (t, J = 8.3 Hz, 1 H, 4′′-*H*), 7.16 (d, J = 7.7 Hz, 2 H, 3-*H*, 5-*H*), 6.58 (s, 2 H, 3′-*H*, 5′-*H*), 6.57 (d, J = 8.3 Hz, 2 H, 3′′-*H*, 5′′-*H*), 5.70 (tdd, J = 6.7 Hz, J = 10.2 Hz, J = 16.9 Hz, 4 H, C*H*=), 4.95–4.87 (m, 8 H, =CH_2), 4.74 (td, J = 0.7 Hz, J = 12.7 Hz, 1 H, ArCH_2O), 4.67 (dd, J = 2.8 Hz, J = 4.5 Hz, 1 H, OC*H*O), 4.52 (td, J = 0.7 Hz, J = 12.7 Hz, 1 H, Ar-CH_2O), 3.94–3.86, 3.56– 3.50 (2 m, 1 H, CH_2O), 3.85 (t, J = 6.5 Hz, 4 H, ArOCH_2CH$_2$), 2.01–1.84 (m, 8 H, CH_2CH=), 1.62–1.50, 1.38–1.30 (2 m, 22 H, CH_2) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 157.8 (s, C-2′, C-6′), 157.7 (s, C-2′′, C-6′′), 154.1 (s, C-2), 153.9 (s, C-6), 139.4 (s, C-4′), 138.7 (d, CH$_2$*C*H=), 134.6 (d, C-4), 128.9 (d, C-4′′), 123.7 (d, C-3, C-5), 121.3 (s, C-1′), 120.4 (s, C-1′′), 114.4 (t, =*C*H$_2$), 105.7 (d, C-3′′, C-5′′), 105.4 (d, C-3′, C-5′), 97.2 (d, O*C*HO), 68.8 (t, ArO*C*H$_2$CH$_2$), 68.5 (t, *C*H$_2$O), 62.4 (t, Ar*C*H$_2$O), 33.2 (*C*H$_2$-CH=), 30.7, 29.0, 28.5, 25.5, 19.6 (5 t, *C*H$_2$) ppm. IR (KBr): $\tilde{\nu}$ = 3053, 2986, 1640, 1598, 1432, 1102, 895 cm^{-1}. MS (ESI): *m*/*z* (%) = 738 (100) [M + H]$^+$.

1^5-[(*tert*-Butyldimethylsilyloxy)methyl]-2,11,13,22-tetraoxa-1,12(1,3,2)-dibenzena-23(2,6)-pyridinabicyclo[10.10.1]tricosaphan-6,17-diene (13): Synthesis according to the general procedure: Benzylidenebis(tricyclohexylphosphane)dichlororuthenium (112 mg, 137 μmol) and 2-[2,6-bis(pent-4-enyloxy)phenyl]-6-[2,6-bis(pent-4-enyloxy)-4-(*tert*-butyldimethylsilyloxymethyl)phenyl]pyridine (**12a**, 1.22 g, 1.71 mmol). Purification: column chromatography on silica gel eluting with cyclohexane/ethyl acetate (9:1). Yield: 1.03 g (92%). ^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.71 (t, J = 7.7 Hz, 1 H, 4-*H*), 7.19 (t, J = 8.3 Hz, 1 H, 4′′-*H*), 7.18 (d, J = 7.7 Hz, 2 H, 3-*H*, 5-*H*), 6.54 (d, J = 8.3 Hz, 2 H, 3′′-*H*, 5′′-*H*), 6.53 (s, 2 H, 3′-*H*, 5′-*H*), 5.37–5.30 (m, 4 H, C*H*=), 4.72 (s, 2 H, Ar-CH_2-O), 3.91–3.84 (m, 8 H, OCH_2), 2.01–1.92, 1.89–1.81 (2 m, 8 H, CH_2CH=), 1.67–1.58, 1.56–1.49 (2 m, 8 H, OCH$_2$CH_2), 0.95 [s, 9 H, SiC(CH$_3$)$_3$], 0.11 [s, 6 H, Si-(CH_3)$_2$] ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 157.7 (s, C-2′′, C-6′′), 157.5 (s, C-2′, C-6′), 154.4 (s, C-2), 154.3 (s, C-6), 142.7 (s, C-4′), 134.6 (d, C-4), 129.9 (d, =*C*H), 128.9 (d, C-4′′), 123.7 (d, C-3), 123,5 (d, C-5), 120.5 (s, C-1′′), 118.9 (s, C-1′), 104.3 (d, C-3′′, C-5′′), 101.8 (d, C-3′, C-5′), 66.5, 66.4 (2 t, O*C*H$_2$), 65.2 (t, Ar-*C*H$_2$-O), 29.5, 29.4 (2 t, OCH$_2$*C*H$_2$), 25.9 [q, C(*C*H$_3$)], 23.3 (t, *C*H$_2$CH=), 18.4 [s, *C*(CH$_3$)], –5.14 [q, Si-(*C*H$_3$)] ppm. IR (KBr): $\tilde{\nu}$ = 2939, 2867, 1597, 1431, 1248 cm^{-1}. MS (ESI): *m*/*z* (%) = 656 (100) [M + H]$^+$.

1^5-(Hydroxymethyl)-2,11,13,22-tetraoxa-1,12(1,3,2)-dibenzena-23(2,6)-pyridinabicyclo[10.10.1]tricosaphan-6,17-diene (14): 1^5-[(*tert*-Butyldimethylsilyloxy)methyl]-2,11,13,22-tetraoxa-1,12(1,3,2)-dibenzena-23(2,6)-pyridinabicyclo[10.10.1]tricosaphan-6,17-diene (**13**, 1.14 g, 1.73 mmol) was dissolved in tetrahydrofuran (20 mL) and tetrabutylammonium fluoride trihydrate (723 mg, 1.91 mmol) was added. After 45 min stirring at room temp., the solvent was evaporated in vacuo, and the residue was purified by column chromatography (silica gel, cyclohexane/ethyl acetate, 1:3)

to yield 918 mg (98%) of **14**. ^{1}H NMR (500 MHz, $CDCl_3$/CD_3OD): δ = 7.79 (t, J = 7.7 Hz, 1 H, 4-*H*), 7.27, 7.26 (4 d, each J = 7.7 Hz, 2 H, 3-*H*, 5-*H*), 7.24 (t, J = 8.4 Hz, 1 H, 4′-*H*), 6.57 (s, 2 H, 3′-*H*, 5′-*H*), 6.56 (d, J = 8.4 Hz, 2 H, 3′′-*H*, 5′′-*H*), 5.36–5.27 (m, 4 H, =C*H*, *E*/*Z*), 4.60 (s, 2 H, Ar-CH_2-OH), 3.95–3.81 (m, 8 H, OCH_2), 1.98–1.80 (m, 8 H, CH_2CH=), 1.70–1.60, 1.56–1.46 (2 m, 8 H, OCH_2CH_2) ppm. ^{13}C NMR (125 MHz, $CDCl_3$/CD_3OD): δ = 157.4 (s, C-2′, C-6′), 157.3 (s, C-2′′, C-6′′), 153.7 (s, C-2), 153.6 (s, C-6), 142.9 (s, C-4′), 135.2 (d, C-4), 129.6 (d, =*C*H), 129.3 (d, C-4′′), 124.1, 124.0 (2 d, C-3, C-5), 118.9 (s, C-1′), 117.4 (s, C-1′′), 103.9 (d, C-3′′, C-5′′), 102.3 (d, C-3′, C-5′), 66.2 (t, O*C*H$_2$), 64.8 (t, Ar-*C*H$_2$-OH), 29.1 (t, *C*H$_2$CH=), 22.9 (t, OCH_2CH_2) ppm. IR (KBr): $\tilde{\nu}$ = 3405, 2928, 2856, 1598, 1458, 1432, 1102 cm^{-1}. MS (ESI): *m*/*z* (%) = 564 (72) [M + Na]$^+$, 542 (100) [M + H]$^+$.

Methyl 3-({2,11,13,22-Tetraoxa-1,12(1,3,2)-dibenzena-23(2,6)-pyridinabicyclo[10.10.1]tricosaphan-6,17-dien-1^5-yl}methyloxy)benzoate (15): 1^5-(Hydroxymethyl)-2,11,13,22-tetraoxa-1,12(1,3,2)-dibenzena-23(2,6)-pyridinabicyclo[10.10.1]tricosaphan-6,17-diene (**14**, 332 mg, 612 μmol), methyl-3-hydroxybenzoate (94.0 mg, 614 μmol) and triphenylphosphane (204 mg, 776 μmol) were dissolved in tetrahydrofuran (20 mL). At 0 °C, diisopropyl azodicarboxylate (184 μL, 946 μmol) was added and the mixture was stirred for 18 h at room temp. After addition of water (10 mL), the layers were separated and the aqueous layer was extracted with diethyl ether (3 × 15 mL). The combined organic layer was washed with brine (2 × 15 mL) and dried with magnesium sulfate. The solvent was evaporated in vacuo, and the residue was purified by column chromatography (silica gel, cyclohexane/ethyl acetate, 3:1) and by chromatography with a chromatotron (silica gel, cyclohexane/ethyl acetate, 9:1 to 3:1) to yield 360 mg (87%) of **15**. ^{1}H NMR (600 MHz, $CDCl_3$): δ = 7.73 (t, J = 7.7 Hz, 1 H, 4-*H*), 7.67–7.64 (m, 2 H, Ar-4-*H*, Ar-6-*H*), 7.35 (t, J = 7.9 Hz, 1 H, Ar-5-*H*), 7.20 (t, J = 8.3 Hz, 1 H, 4′′-H), 7.19 (2 d, J = 7.7 Hz, J = 7.7 Hz, 2 H, 3-*H*, 5-*H*), 7.17–7.15 (m, 1 H, Ar-2-*H*), 6.62 (s, 2 H, 3′-*H*, 5′-*H*), 6.55 (d, J = 8.3 Hz, 2 H, 3′′-*H*, 5′′-*H*), 5.36–5.30 (m, 4 H, =C*H*), 5.08 (s, 2 H, ArO-CH_2), 3.91 (s, 3 H, Ar-COOCH_3), 3.90–3.84 (m, 8 H, OCH_2), 2.01–1.92, 1.89–1.81 (2 m, 8 H, CH_2CH=), 1.66–1.58, 1.56–1.48 (2 m, 8 H, OCH_2CH_2) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 166.9 (s, Ar*C*OOCH$_3$), 158.7 (Ar-C-3), 157.7 (s, C-2′, C-6′), 157.6 (s, C-2′′, C-6′′), 154.3 (s, C-2), 154.0 (s, C-6), 137.6 (s, C-4′), 134.8 (d, C-4), 131.4 (s, Ar-C-1), 129.9, 129.8 (2 d, =*C*H), 129.5 (d, Ar-C-5), 128.9 (d, C-4′′), 123.8, 123.7 (2 d, C-3, C-5), 122.2 (d, Ar-C-6), 120.2 (d, Ar-C-2), 120.1 (s, C-1′′), 119.8 (s, C-1′), 115.3 (d, Ar-C-4), 104.2 (d, C-3′′, C-5′′), 103.3 (d, C-3′, C-5′), 70.6 (t, ArO-*C*H$_2$-), 66.6, 66.5 (2 t, O*C*H$_2$), 52.2 (q, ArCOO*C*H$_3$), 29.4, 29.3 (2 d, *C*H$_2$CH=), 23.2, 23.1 (2 t, OCH_2CH_2-) ppm. IR (KBr): $\tilde{\nu}$ = 2922, 2867, 1721, 1582, 1455, 1435, 1290, 1279, 1116, 1103 cm^{-1}. MS (ESI): *m*/*z* (%) = 698 (19) [M + Na]$^+$, 676 (100) [M + H]$^+$. $C_{42}H_{46}NO_7$ (675.81): calcd. C 74.64, H 6.71, N 2.07; found C 74.68, H 6.91, N 2.12.

2-[2,6-Bis(hex-5-enyloxy)phenyl]-6-[2,6-bis(hex-5-enyloxy)-4-(hydroxymethyl)phenyl]pyridine (16): A solution of *p*-toluenesulfonic acid (100 mg, 525 μmol) in dry methanol (5 mL) was added dropwise over 5 min to a solution of 2-[2,6-bis(hex-5-enyloxy)phenyl]-6-[2,6-bis(hex-5-enyloxy)-4-(2-tetrahydropyranyloxymethyl)phenyl]-pyridine (**12b**, 321 mg, 437 μmol) heated to reflux in dry methanol (20 mL). Heating was continued for 90 min. The volume was reduced to 5 mL. After the addition of saturated aqueous sodium hydrogen carbonate (5 mL) and chloroform (20 mL), the water layer was extracted with chloroform (3 × 20 mL), and the combined organic layers were washed with brine (15 mL). The solvent was removed in vacuo, and the residue was purified by column chromatography (silica gel, cyclohexane/ethyl acetate, 1:3) to yield 280 mg (98%) of **16**. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.67 (t, J = 7.7 Hz, 1 H, 4-*H*), 7.19 (t, J = 8.3 Hz, 1 H, 4′′-*H*), 7.17 (d, J = 7.7 Hz, 2 H, 3-*H*, 5-*H*), 6.57 (d, J = 8.3 Hz, 2 H, 3′′-*H*, 5′′-*H*), 6.54 (s, 2 H, 3′-*H*, 5′-*H*), 5.71, 5.70 (2 tdd, J = 6.7 Hz, J = 10.2 Hz, J = 16.9 Hz, 4 H, C*H*=), 4.95–4.87 (m, 8 H, =CH_2), 4.63 (s, 2 H, Ar-CH_2-O), 3.88–3.83 (m, 8 H, OCH_2), 2.01–1.92, (m, 8 H, CH_2CH=), 1.64–1.54 (m, 8 H, OCH_2CH_2), 1.38–1.30 (m, 8 H, CH_2) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 157.8 (2 s, C-2′, C-6′, C-2′′, C-6′′), 154.1 (s, C-2), 153.9 (s, C-6), 142.6 (s, C-4′), 138.7 (d, *C*H=), 134.7 (d, C-4), 128.9 (d, C-4′′), 123.8 (d, C-3, C-5), 121.1 (s, C-1′′), 120.1 (s, C-1′), 114.4 (t, =*C*H$_2$), 105.7 (d, C-3′′, C-5′′), 103.9 (d, C-3′, C-5′), 68.5 (t, O*C*H$_2$), 65.4 (t, Ar-*C*H$_2$-OH), 33.2 (t, *C*H$_2$CH=), 28.5 (t, OCH_2CH_2), 25.1 (t, CH$_2$) ppm. IR (KBr): $\tilde{\nu}$ = 2937, 2865, 1639, 1598, 1458, 1431, 1249, 1121 cm^{-1}. MS (ESI): *m*/*z* (%) = 654 (100) [M + H]$^+$.

1^5-(Hydroxymethyl)-2,13,15,26-tetraoxa-1,14(1,3,2)-dibenzena-27(2,6)-pyridinabicyclo[12.12.1]heptacosaphan-7,20-diene (17): Synthesis according to the general procedure: Benzylidenebis(tricyclohexylphosphane)dichlororuthenium (41 mg, 50 μmol) and 2-[2,6-bis(hex-5-enyloxy)phenyl]-6-[2,6-bis(hex-5-enyloxy)-4-(hydroxymethyl)phenyl]pyridine (**16**, 405 mg, 621 μmol). Purification: column chromatography on silica gel eluting with cyclohexane/ethyl acetate (1:3). Yield: 330 mg (89%). ^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.69 (t, J = 7.7 Hz, 1 H, 4-*H*), 7.21 (t, J = 8.3 Hz, 1 H, 4′-*H*), 7.16, 7.12 (4 d, each J = 7.7 Hz, 2 H, 3-*H*, 5-*H*), 6.56 (d, J = 8.4 Hz, 2 H, 3′′-*H*, 5′′-*H*), 6.44 (s, 2 H, 3′-*H*, 5′-*H*), 5.29–5.16 (m, 4 H, =C*H*, *E*/*Z*), 4.55 (3 s, 2 H, Ar-CH_2-OH), 3.96–3.68 (m, 8 H, OCH_2), 2.14–1.89 (m, 8 H, CH_2CH=), 1.60–1.24 (m, 20 H, CH_2) ppm. ^{13}C NMR (125 MHz, $CDCl_3$/CD_3OD): δ = 157.9 (s, C-2′, C-6′), 157.7 (s, C-2′′, C-6′′), 154.4 (s, C-2), 154.3 (s, C-6), 143.3 (s, C-4′), 134.8 (d, C-4), 130.7 (d, =*C*H), 129.0 (d, C-4′′), 123.8, 123.7 (2 d, C-3, C-5), 120.2 (s, C-1′), 118.8 (s, C-1′′), 104.6 (d, C-3′′, C-5′′), 102.6 (d, C-3′, C-5′), 68.7 (t, O*C*H$_2$), 64.6 (t, Ar-*C*H$_2$-OH), 31.6 (t, *C*H$_2$CH=), 27.6 (t, OCH_2CH_2), 26.6, 24.9 (3 t, *C*H$_2$) ppm. IR (KBr): $\tilde{\nu}$ = 2936, 1641, 1598, 1458, 1431, 1249, 1109 cm^{-1}. MS (ESI): *m*/*z* (%) = 598 (100) [M + H]$^+$.

1^5-(Hydroxymethyl)-2,13,15,26-tetraoxa-1,14(1,3,2)-dibenzena-27(2,6)-pyridinabicyclo[12.12.1]heptacosaphane (18): Palladium on charcoal (10%, 110 mg) was mixed with methanol (50 mL) and hydrogen gas was bubbled through the mixture for 30 min. This activated mixture was then mixed with a solution of 1^5-(hydroxymethyl)-2,13,15,26-tetraoxa-1,14(1,3,2)-dibenzena-27(2,6)-pyridinabicyclo[12.12.1]heptacosaphan-7,20-diene (**17**, 300 mg, 503 μmol) in methanol/chloroform (1:1, 6 mL), and hydrogen gas was bubbled through the solution for 3 h while stirring at room temperature was continued. Stirring of the solution under an atmosphere of hydrogen was continued for 18 h at room temperature. The solvent was evaporated in vacuo and the residue was purified by column chromatography (silica gel, cyclohexane/ethyl acetate, 1:3) and by chromatography with a chromatotron (silica gel, cyclohexane/ethyl acetate, 1:1 to 1:3) to yield 290 mg (96%) of **18**. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.68 (t, J = 7.7 Hz, 1 H, 4-*H*), 7.20 (t, J = 8.3 Hz, 1 H, 4′′-*H*), 7.18, 7.16 (2 d, J = 7.7 Hz, 1 H, 3-*H*, 5-*H*), 6.56 (d, J = 8.3 Hz, 2 H, 3′′-*H*, 5′′-*H*), 6.46 (s, 2 H, 3′-*H*, 5′-*H*), 4.62 (s, 2 H, Ar-CH_2-OH), 4.03–3.94, 3.90–3.81 (2 m, 8 H, OCH_2), 1.62–1.50, 1.34–1.08 (m, 32 H, CH_2) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 157.8 (s, C-2′, C-6′), 157.6 (s, C-2′′, C-6′′), 154.2 (s, C-2), 154.1 (s, C-6), 143.2 (s, C-4′), 134.5 (d, C-4), 128.9 (d, C-4′′), 123.9 (d, C-3), 123.8 (d, C-5), 120.5 (s, C-1′′), 119.1 (s, C-1′), 104.9 (d, C-3′′, C-5′′), 103.1 (d, C-3′, C-5′), 68.5 (t, O*C*H$_2$), 64.7 (t, Ar-*C*H$_2$-OH), 28.1 (t, OCH_2CH_2), 26.7, 25.7, 24.3 (3 t, *C*H$_2$) ppm. IR (KBr): $\tilde{\nu}$ = 3405, 2928, 2856, 1598, 1458, 1432, 1102 cm^{-1}. MS

(ESI): *m*/*z* (%) = 602 (100) $[M + H]^+$. $C_{38}H_{51}NO_5$ (601.81): calcd. C 75.84, H 8.54, N 2.33; found C 75.92, H 8.71, N 2.32.

Methyl 3-({2,13,15,26-Tetraoxa-1,14(1,3,2)-dibenzena-27(2,6)-pyridinabicyclo[12.12.1]heptacosaphan-1^5-yl}methyloxy)benzoate (19): 1^5-(Hydroxymethyl)-2,13,15,26-tetraoxa-1,14(1,3,2)-dibenzena-27(2,6)-pyridinabicyclo[12.12.1]heptacosaphane (**18**, 150 mg, 249 μmol), methyl 3-hydroxybenzoate (38.0 mg, 249 μmol) and triphenylphosphane (83 mg, 316 μmol) were dissolved in tetrahydrofuran (10 mL). At 0 °C, diisopropyl azodicarboxylate (75.0 μL, 385 μmol) was added, and the mixture was stirred for 18 h at room temp. After addition of water (5 mL), the layers were separated and the aqueous layer was extracted with diethyl ether (3 × 15 mL). The combined organic layer was washed with brine (2 × 15 mL) and dried with magnesium sulfate. The solvent was evaporated in vacuo, and the residue was purified by column chromatography (silica gel, cyclohexane/ethyl acetate, 3:1) and by chromatography with a chromatotron (silica gel, cyclohexane/ethyl acetate, 9:1 to 3:1) to yield 120 mg (65%) of **19**. ^{1}H NMR (600 MHz, $CDCl_3$): δ = 7.69 (t, *J* = 7.7 Hz, 1 H, 4-*H*), 7.67–7.64 (m, 2 H, Ar-4-*H*, Ar-6-*H*), 7.34 (t, *J* = 7.9 Hz, 1 H, Ar-5-*H*), 7.19 (t, *J* = 8.3 Hz, 1 H, 4′′-*H*), 7.18 (d, *J* = 7.7 Hz, 1 H, 3-*H*), 7.17 (d, *J* = 7.7 Hz, 1 H, 5-*H*), 7.17–7.15 (m, 1 H, Ar-2-*H*), 6.63 (s, 2 H, 3′-*H*, 5′-*H*), 6.55 (d, *J* = 8.3 Hz, 2 H, 3′′-*H*, 5′′-*H*), 5.08 (s, 2 H, ArO-C*H*$_2$), 3.91 (s, 3 H, Ar-COOC*H*$_3$), 4.04–3.95, 3.90–3.81 (2 m, 8 H, OC*H*$_2$), 1.59–1.50 (m, 8 H, OCH$_2$C*H*$_2$), 1.36–1.07 (m, 24 H, C*H*$_2$) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 166.9 (s, Ar*C*OOCH$_3$), 158.6 (Ar-C-3), 157.9 (s, C-2′, C-6′), 157.8 (s, C-2′′, C-6′′), 154.4 (s, C-2), 154.0 (s, C-6), 137.5 (s, C-4′), 134.5 (d, C-4), 131.4 (s, Ar-C-1), 129.4 (d, Ar-C-5), 128.8 (d, C-4′′), 123.8, 123.7 (2 d, C-3, C-5), 122.2 (d, Ar-C-6), 120.8 (s, C-1′′), 120.5 (s, C-1′), 120.2 (d, Ar-C-2), 115.2 (d, Ar-C-4), 104.9 (d, C-3′′, C-5′′), 103.9 (d, C-3′, C-5′), 70.6 (t, ArO-*C*H$_2$-), 68.6, 68.5 (2 t, O*C*H$_2$), 52.2 (q, Ar-COO*C*H$_3$), 28.0, 27.9, 26.9, 26.8, 25.7, 25.6, 24.4, 24.3 (8 t, *C*H$_2$) ppm. IR (KBr): $\tilde{\nu}$ = 2922, 2867, 1721, 1582, 1455, 1435, 1290, 1279, 1116, 1103 cm^{-1}. MS (ESI): *m*/*z* (%) = 736 (100) $[M + H]^+$. $C_{46}H_{57}NO_7$ (735.95): calcd. C 75.07, H 7.81, N 1.90; found C 75.01, H 7.96, N 2.01.

Acknowledgments

The support of this work by the Schwerpunktsprogramm der Deutschen Forschungsgemeinschaft SPP 1179 is gratefully acknowledged.

[1] V. E. Anderson, M. W. Ruszczycky, M. E. Harris, *Chem. Rev.* **2006**, *106*, 3236–3251.
[2] For a recent example of bifunctional acid–base catalysis and corresponding references, see: J. D. Bass, A. Solovyov, A. J. Pascall, A. Katz, *J. Am. Chem. Soc.* **2006**, *128*, 3737–3747.
[3] For a theoretical and experimental study, see: L.-H. Wang, H. Zipse, *Liebigs Ann.* **1996**, 1501–1509.
[4] U. Lüning "Concave Reagents" in *Encyclopedia of Supramolecular Chemistry* (Eds.: J. L. Atwood, J. W. Steed), Marcel Dekker, New York, **2004**, pp. 311–318.
[5] U. Lüning, *Liebigs Ann. Chem.* **1987**, 949–955.
[6] U. Lüning, R. Baumstark, K. Peters, H. G. v. Schnering, *Liebigs Ann. Chem.* **1990**, 129–143.
[7] H. Ross, U. Lüning, *Angew. Chem.* **1995**, *107*, 2723–2725; *Angew. Chem. Int. Ed. Engl.* **1995**, *34*, 2555–2557.
[8] H. Ross, U. Lüning, *Liebigs Ann.* **1996**, 1367–1373.
[9] S. Konrad, C. Näther, U. Lüning, *Eur. J. Org. Chem.* **2005**, 2330–2337, and refs. cited.
[10] U. Lüning, R. Baumstark, W. Schyja, *Tetrahedron Lett.* **1993**, *34*, 5063–5066.
[11] U. Lüning, F. Fahrenkrug, *Eur. J. Org. Chem.* **2004**, 3119–3127.
[12] U. Lüning, M. Abbass, F. Fahrenkrug, *Eur. J. Org. Chem.* **2002**, 3294–3303.
[13] Single hydrogen bonds are weak interactions, the typical bond energy is 10 to 30 kJ/mol. Therefore, at room temperature in solution, only a fraction of hydrogen-bond donor and acceptors will exist in the hydrogen bonded state. In contrast to the intermolecular formation of a single hydrogen bond, intramolecular hydrogen bonds are formed to a much larger extent due to the vicinity of hydrogen-bond donor and hydrogen-bond acceptor. The "effective concentration" of both centers is high in the intramolecular case.
[14] C. Reichardt, *Solvents and Solvent Effects in Organic Chemistry*, 2nd ed., VCH, Weinheim, **1988**. See especially Table 4–1, p. 83.
[15] K. Izutsu, *Acid-Base Dissociation Constants in Dipolar Aprotic Solvents*, *Chemical Data Series No. 35*, Blackwell Scientific Publications, Oxford, **1990**.
[16] See ref.[6] and cited references.
[17] U. Lüning, H. Baumgartner, C. Wangnick, *Tetrahedron* **1996**, *52*, 599–604.
[18] J. R. Cannon, T. M. Cresp, B. W. Metcalf, M. V. Sargent, G. Vinciguerra, *J. Chem. Soc., C* **1971**, 3495–3499.

Received: September 26, 2006
Published Online: December 12, 2006

