Molecular Recognition of Pyranosides by a Family of Trimeric, 1,1′-Binaphthalene-Derived Cyclophane Receptors

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Dedicated to Prof. Dr. *Hans Bock* on the occasion of his 70th birthday

The synthesis and carbohydrate-recognition properties of a new family of optically active cyclophane receptors, **1**–**3**, in which three 1,1′-binaphthalene-2,2′-diol spacers are interconnected by three buta-1,3-diynediyl linkers, are described. The macrocycles all contain highly preorganized cavities lined with six convergent OH groups for H-bonding and complementary in size and shape to monosaccharides. Compounds **1**–**3** differ by the functionality attached to the major groove of the 1,1′-binaphthalene-2,2′-diol spacers. The major grooves of the spacers in **2** are unsubstituted, whereas those in **1** bear benzyloxy (BnO) groups in the 7,7′-positions and those in **3** 2-phenylethyl groups in the 6,6′-positions. The preparation of the more planar, D_3-symmetrical receptors (*R*,*R*,*R*)-**1** (*Schemes 1* and *2*), (*S*,*S*,*S*)-**1** (*Scheme 4*), (*S*,*S*,*S*)-**2** (*Scheme 5*), and (*S*,*S*,*S*)-**3** (*Scheme 8*) involved as key step the *Glaser-Hay* cyclotrimerization of the corresponding OH-protected 3,3′-diethynyl-1,1′-binaphthalene-2,2′-diol precursors, which yielded tetrameric and pentameric macrocycles in addition to the desired trimeric compounds. The synthesis of the less planar, C_2-symmetrical receptors (*R*,*R*,*S*)-**2** (*Scheme 6*) and (*S*,*S*,*R*)-**3** (*Scheme 9*) proceeded *via* two *Glaser-Hay* coupling steps. First, two monomeric precursors of identical configuration were oxidatively coupled to give a dimeric intermediate which was then subjected to macrocyclization with a third monomeric 1,1′-binaphthalene precursor of opposite configuration. The 3,3′-dialkynylation of the OH-protected 1,1′-binaphthalene-2,2′-diol precursors for the macrocyclizations was either performed by *Stille* (*Scheme 1*) or by *Sonogashira* (*Schemes 4*, *5*, and *8*) cross-coupling reactions. The flat D_3-symmetrical receptors (*R*,*R*,*R*)-**1** and (*S*,*S*,*S*)-**1** formed 1:1 cavity inclusion complexes with octyl 1-*O*-pyranosides in $CDCl_3$ (300 K) with moderate stability (ΔG^0 *ca.* -3 kcal mol^{-1}) as well as moderate diastereo- ($\Delta(\Delta G^0)$ up to 0.7 kcal mol^{-1}) and enantioselectivity ($\Delta(\Delta G^0) = 0.4$ kcal mol^{-1}) (*Table 1*). Stoichiometric 1:1 complexation by (*S*,*S*,*S*)-**2** and (*S*,*S*,*S*)-**3** could not be investigated by ^{1}H-NMR binding titrations, due to very strong signal broadening. This broadening of the ^{1}H-NMR resonances is presumably indicative of higher-order associations, in which the planar macrocycles sandwich the carbohydrate guests. The less planar C_2-symmetrical receptor (*S*,*S*,*R*)-**3** formed stable 1:1 complexes with binding free enthalpies of up to $\Delta G^0 = -5.0$ kcal mol^{-1} (*Table 2*). With diastereoselectivities up to $\Delta(\Delta G^0) = 1.3$ kcal mol^{-1} and enantioselectivities of $\Delta(\Delta G^0) = 0.9$ kcal mol^{-1}, (*S*,*S*,*R*)-**3** is among the most selective artificial carbohydrate receptors known.

1. Introduction. – Carbohydrate-protein recognition processes are ubiquitous in nature [1–3], and an increasing number of X-ray crystal structures has revealed the highly complex nature of these phenomena [4][5]. It also has become apparent that many of the underlying principles governing protein-carbohydrate interactions cannot be identified or quantified on an atomic scale in biological studies only. Rather, there is increasing consensus that investigations with well-defined synthetic receptors, whose binding properties can be systematically varied and analyzed, could make important contributions to the understanding of carbohydrate-recognition processes in biology.

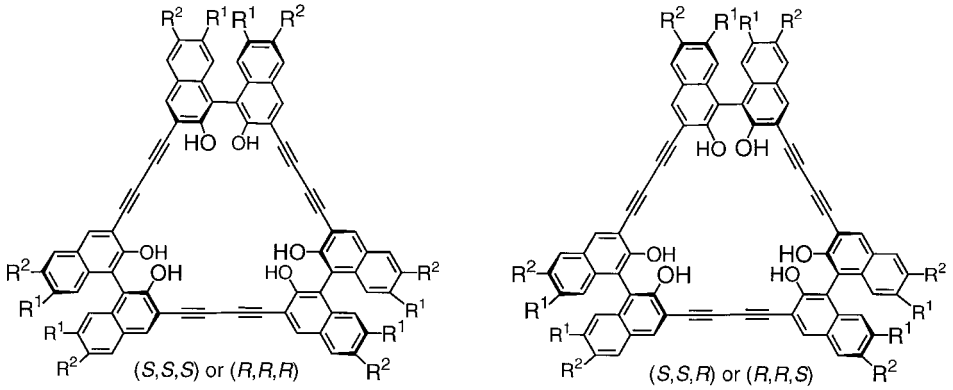
Complexation of carbohydrates by proteins is based on a subtle balance between hydrophobic and hydrophilic interactions [1–4] (for some other recent examples of X-ray crystal structures of protein-carbohydrate complexes, see [5]). Highly directional

H-bonds, many of which are bidentate ionic ones (to the side-chain functionality of aspartic acid (Asp), glutamic acid (Glu), arginine (Arg), asparagine (Asn), and glutamine (Gln) residues) control the binding selectivity, whereas apolar interactions and hydrophobic desolvation provide a large part of the thermodynamic driving force for complexation. Contacts between protein and carbohydrate are frequently mediated by H_2O bridges [1b]. The overall binding picture has been elucidated by X-ray crystallography of biological systems, but there remain many questions, which could be addressed by systematic biomimetic studies [6] with synthetic receptors for example. How many intermolecular host-guest H-bonds are needed to form a stable carbohydrate complex? What is the strength of individual neutral and ionic H-bonds involving sugar OH groups, and which ionic H-bonding residues of proteins (anionic Asp, Glu, phosphate *vs.* cationic Arg, histidine (His)) provide the strongest association [7]? X-Ray structures of protein-carbohydrate complexes display a very large number of H-bonds, yet the binding free enthalpy of such complexes often only amounts to values of $\Delta G^0 = -7$ to -8 kcal mol^{-1} [1b][8]. What is the contribution of cooperativity (*i.e.*, the sugar OH group acts both as a H-bond donor and acceptor) to H-bonding strength [9]? How important are apolar interactions such as *van der Waals* dispersion interactions, hydrophobic desolvation [10], and, in particular, sugar-CH$\cdots$aromatic π-electron interactions [11]? Biological X-ray crystal structures consistently show stacking between aromatic amino-acid side chains, predominantly Tyr and Trp, with the apolar faces of the bound sugars. It is clear that a great variety of medicinal-chemistry programs would benefit from sound answers to these questions [12].

Despite recent significant interest in the development of efficient synthetic carbohydrate receptors, only modest advances have been achieved in this area. This is, at least in part, due to the complex three-dimensional structure of sugars which contain both hydrophilic and hydrophobic domains. Complexation by H-bonding in noncompetitive organic solvent environments is hampered by the fact that some of the strong intramolecular H-bonds within the sugar substrates themselves need to be disrupted [13] (for evaluations of intramolecular H-bonding strengths in sugars, see [14]). Recognition in H_2O requires tight encapsulation of the limited hydrophobic surfaces of the sugars, yet an unfavorable desolvation of their H-bonding sites must be avoided. Furthermore, H_2O competes strongly for the H-bonding sites on the receptor and the sugar OH groups. Nevertheless, a variety of synthetic carbohydrate receptors have been developed.

The majority of the synthetic carbohydrate receptors form complexes in apolar solvents, for example in CCl_4 or $CHCl_3$, taking advantage of H-bonding interactions as the major driving force for association [13][15–26]. In a few cases, optically active receptors were shown to bind octyl glucosides enantioselectively, with differences in stability between diastereoisomeric complexes $\Delta(\Delta G^0)$ ranging between 0.4 [22a,b] and 0.8 kcal mol^{-1} [18b][20]. X-Ray crystal structures of complexes between artificial receptors and carbohydrates have, to the best of our knowledge, not yet been obtained. Carbohydrate complexation by synthetic receptors in more polar solvents, which compete efficiently for the H-bonding sites of the binding partners, is even less developed [11a,b] [22b] [27–31]. A popular and highly efficient strategy to recognize and transport carbohydrates relies on the formation of cyclic boronate esters between boronic acids and sugars in aqueous solutions [32–39]; since this mode of recognition does not primarily involve non-covalent interactions, its biomimetic relevance is rather limited.

We describe here the synthesis and carbohydrate-recognition properties of the new series of optically active cyclophane receptors **1**–**3** in which three 1,1′-binaphthalene-2,2′-diol spacers are interconnected by buta-1,3-diynediyl linkers to form highly pre-organized cavities lined with six convergent OH groups [40]. These cavities mimic the natural carbohydrate-recognition sites by providing a circular array of H-bonding groups for interactions with the substrate. We show that both D_3-symmetrical ((*S*,*S*,*S*)- or (*R*,*R*,*R*)-configured) and C_2-symmetrical ((*S*,*S*,*R*)- or (*R*,*R*,*S*)-configured) artificial binders form complexes with octyl glycosides in $CDCl_3$, with the less symmetrical receptors displaying a much higher overall binding affinity as well as a remarkably enhanced degree of diastereo- and enantioselectivity.



Receptor	R^1	R^2
1	OBn	H
2	H	H
3	H	CH_2CH_2Ph

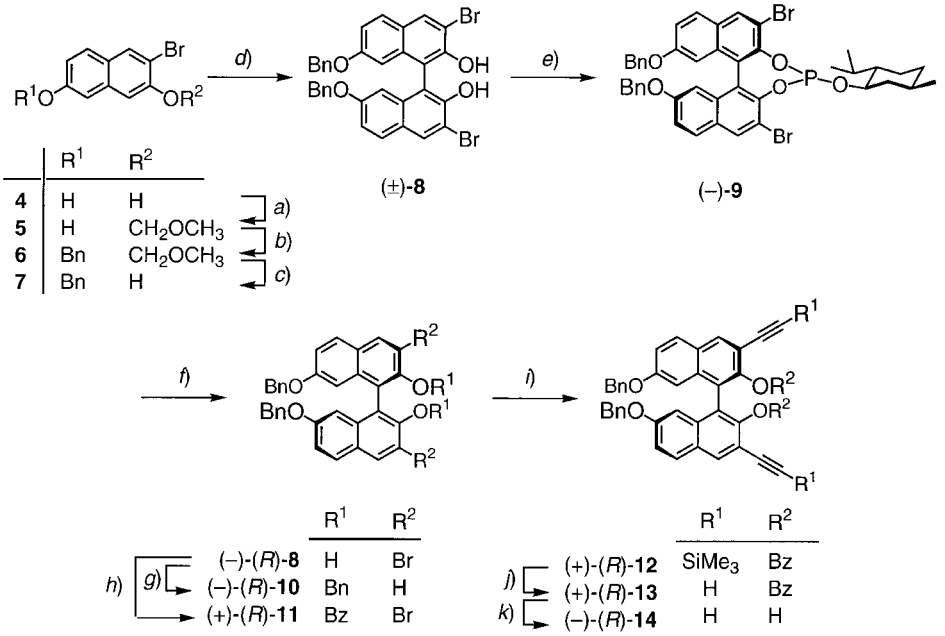
2. Results and Discussion. – 2.1. *Synthesis of the Receptors.* The three receptors **1**–**3** differ in their substituents in the 6,6′- and 7,7′-positions in the major groove of the 1,1′-binaphthalene spacers. The first compounds prepared were D_3-symmetrical (*R*,*R*,*R*)-**1** [22b] and (*S*,*S*,*S*)-**1** with benzyloxy (BnO) groups diverging from the 7,7′-positions to provide solubility in organic solvents. The presence of these substituents, however, caused several synthetic problems resulting in long synthetic routes (*Sect. 2.1.1*). Therefore, we prepared optically pure D_3- and C_2-symmetrical **2** lacking functionality in the major groove of the 1,1′-binaphthalene spacers by a significantly shorter route (*Sect. 2.1.2*). However, C_2-symmetrical **2** was found to be insoluble in $CDCl_3$ and the D_3-symmetrical diastereoisomer presumably formed higher-order complexes with carbohydrate substrates, thereby preventing the analysis of any 1:1 host-guest association. Since the comparison between **1** and **2** clearly demonstrated that major-groove functionality was required to prevent higher-order complexation, we ultimately prepared, by an efficient synthetic route, optically pure D_3- and C_2-symmetrical **3** with 2-phenylethyl substituents in the 6,6′-positions (*Sect. 2.1.3*). In the case of (*S*,*S*,*R*)-**3**, these residues efficiently prevented carbohydrate-induced aggregation of the receptor

and higher-order complexation, and, therefore, first 1:1 host-guest binding studies could be carried out on a C_2-symmetrical trimer.

2.1.1. *Synthesis of the* C_3*-Symmetrical Receptors (*R,R,R*)-***1*** *and (*S,S,S*)-***1***. The preparation of (*R,R,R*)-**1** in an eleven-step sequence (*Schemes 1* and *2*) started from 3-bromonaphthalene-2,7-diol (**4**) [41]. Protection of the HO–C(2) group as methoxymethyl (MOM) ether to give **5** (50%), followed by benzylation [42] of the remaining OH group to afford **6** (94%), and removal of the MOM group [43] led to naphthol **7** (98%). Large-scale (up to 20 g) oxidative homo-coupling of **7** to 1,1′-binaphthalene-2,2′-diol (±)-**8** was best achieved (84%) with stoichiometric amounts of $CuCl_2$ in MeOH in the presence of *t*-$BuNH_2$ [44], whereas coupling with catalytic amounts (1 mol-%) of [CuCl(OH)·TMEDA] (prepared from $CuCl_2$ and *N,N,N′,N′*-tetramethylethylenediamine (TMEDA)) [45] only afforded (±)-**8** in 64% yield. The structure of (±)-**8** was confirmed by single-crystal X-ray diffraction [22b].

The optical resolution of (±)-**8** was performed *via* formation of the two diastereoisomeric cyclic menthyl phosphites [46] (using *in situ*-prepared (1*R*,2*S*,5*R*)-menthyl phosphorodichloridite). The ^{31}P-NMR spectrum of the crude product mixture

Scheme 1. *Synthesis of the Macrocyclization Precursor (*R*)-***13***



	R^1	R^2
4	H	H
5	H	CH_2OCH_3
6	Bn	CH_2OCH_3
7	Bn	H

	R^1	R^2
(–)-(*R*)-**8**	H	Br
(–)-(*R*)-**10**	Bn	H
(+)-(*R*)-**11**	Bz	Br

	R^1	R^2
(+)-(*R*)-**12**	$SiMe_3$	Bz
(+)-(*R*)-**13**	H	Bz
(–)-(*R*)-**14**	H	H

a) $MeOCH_2Cl$, K_2CO_3, MeCN, –18°, 4 h, 50%. *b*) BnCl, K_2CO_3, DMF, 80°, 1 h, 94%. *c*) Cat. conc. aq. HCl soln., THF/MeOH 2:1, 70°, 3 h, 98%. *d*) *t*-$BuNH_2$, $CuCl_2$, MeOH, 80°, 1 h, 84%. *e*) (1*R*,2*S*,5*R*)-Menthyl phosphorodichloridite, Et_3N, THF, –18°, 15 min, then recrystallization (2×) from Et_2O, 37%. *f*) K_2CO_3, $CHCl_3$/MeOH 1:1, 20°, 30 min, 97%. *g*) Pd/C (10%), $HCOONH_4$, MeOH, 60°, 30 min, then BnCl, K_2CO_3, DMF, 80°, 2 h, 15%. *h*) PhCOCl (BzCl), 4-(dimethylamino)pyridine (DMAP), pyridine, CH_2Cl_2, 20°, 2 h, 95%. *i*) $Me_3SiC{\equiv}CSnMe_3$, [$Pd(PPh_3)_4$], 2,6-di(*tert*-butyl)-*p*-cresol, toluene, 100°, Ar, 36 h, 45%. *j*) K_2CO_3, THF/MeOH 1:1, 20°, 2 h, 91%. *k*) KOH, THF, 20°, 1 h, 79%.

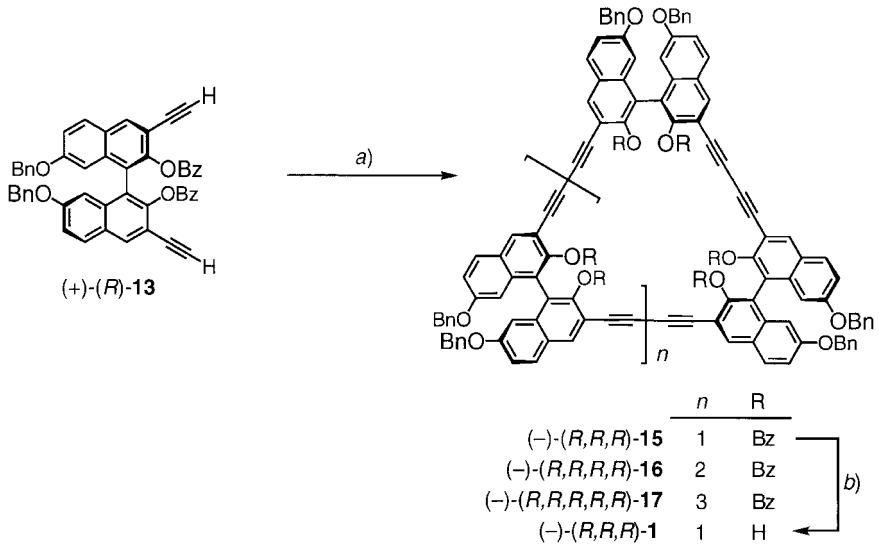
showed two signals of same intensity at 154.8 and 151.4 ppm corresponding to the two diastereoisomers. In contrast to the original procedure [46], where a solution of PCl_3 was added to a solution of (1*R*,2*S*,5*R*)-menthol, we found that inverse addition proved to be crucial in obtaining the desired monomenthyl phosphorodichloridite in high yield. By using the published conditions, significant formation of dimenthyl phosphorochloridite arising from a second substitution of chloride by menthol was observed. It was also of great importance to employ only 0.9 equiv. of menthyl phosphorodichloridite to avoid the formation of products in which the OH groups of (±)-**8** had reacted with 2 equiv. of the reagent. Under these conditions, diastereoisomerically pure (−)-**9** (37%, >99.5% de (= diastereoisomeric excess) [47]) was isolated after repeated recrystallization from Et_2O. The other diastereoisomer failed to crystallize from the filtrate even after concentration.

After isolation, menthyl phosphite (−)-**9** was hydrolyzed with K_2CO_3 in $CHCl_3$/MeOH to afford enantiomerically pure (−)-**8** (97%). To establish the (*R*)-configuration of (−)-**8**, the diol was debrominated and benzylated to give (−)-**10** (15% from (−)-**8**). The optical rotation of (−)-(*R*)-**10** ($[\alpha]_D^{r.t.} = -15.2$ ($c = 0.5$ (CH_2Cl_2))) was then compared with that of (+)-(*S*)-**10** ($[\alpha]_D^{r.t.} = +15.2$ ($c = 0.5$ (CH_2Cl_2))) derived from benzylation of (+)-(*S*)-7,7′-bis(benzyloxy)-1,1′-binaphthalene-2,2′-diol, whose absolute configuration had been previously determined [48]. Benzoylation of (*R*)-**8** to give (*R*)-**11** (95%) was followed by Pd^0-catalyzed *Stille* cross-coupling with 1-(trimethylsilyl)-2-(trimethylstannyl)ethyne [49] to give (*R*)-**12**. The yields for the formation of (*R*)-**12** after two rounds of chromatography (SiO_2-H) proved to be very unreproducible; they could be as high as 45%, but usually less than 25%. Efforts to obtain the desired dialkynylated product by a *Stille* or *Sonogashira* [50] cross-coupling reaction with unprotected (*R*)-**8** failed. Removal of the Me_3Si groups in (*R*)-**12** gave the diethynyl derivative (*R*)-**13** (91%), the direct precursor for the macrocyclization to receptor (*R*,*R*,*R*)-**1**. Benzoyl-ester hydrolysis afforded the dialkynylated 1,1′-binaphthalene-2,2′-diol (*R*)-**14** (69%) whose sugar-binding properties were also investigated for comparison.

Oxidative *Glaser-Hay* coupling [51] of (*R*)-**13** in CH_2Cl_2 proceeded rapidly and afforded a product mixture from which cyclic trimeric (*R*,*R*,*R*)-**15** (20%), tetrameric (*R*,*R*,*R*,*R*)-**16** (20%), and pentameric (*R*,*R*,*R*,*R*,*R*)-**17** (4%) were isolated by careful flash chromatography (*Scheme 2*). Fast-atom-bombardment (FAB) mass spectra with positive-ion detection gave strong molecular ions indicating the size of the oligomers, and the ^{13}C-NMR spectra displayed the required 22 peaks for the D_3-symmetrical cyclic oligomers. Importantly, two signals were observed between 75 and 85 ppm, corresponding to the C-atoms in the buta-1,3-diynediyl linkers. Further confirmation for the formation of these linkers was provided by the IR spectra, which showed both symmetric and antisymmetric stretches in the region between 2100 and 2250 cm^{-1}. The ^{1}H-NMR spectra of the three cyclic oligomers were very similar, except for the aromatic signals corresponding to the benzoyl (Bz) protecting groups; presumably, the observed differences in the positions of the Bz resonances reflect the different degrees of steric crowding in the three cavities.

Benzoyl-ester hydrolysis of (*R*,*R*,*R*)-**15** proceeded smoothly to afford the neutral receptor (*R*,*R*,*R*)-**1** in 90% yield. Attempts to prepare the target molecule by oxidative macrocyclization of the free diol (*R*)-**14** failed. Instead, 5-*endo-dig* cyclization [52] of

Scheme 2. *Synthesis of the Receptor* (R,R,R)-**1**



a) CuCl, TMEDA, O_2, CH_2Cl_2, 20°, 20 min, 20% ((*R*,*R*,*R*)-**15**), 20% ((*R*,*R*,*R*,*R*)-**16**), 4% ((*R*,*R*,*R*,*R*,*R*)-**17**). *b*) KOH, THF, 20°, 30 min, 90%.

the OH groups with the adjacent ethynyl moieties occurred. Formation of products containing naphtho[*b*]furan rings was deduced by the presence of a sharp *singlet* in the ^{1}H-NMR spectrum ($CDCl_3$) at 7.00 ppm for the H–C(3) resonance of the furan ring. An analogous reaction has been utilized for the efficient preparation of 2-substituted benzo[*b*]furans by the reaction of 2-hydroxyaryl halides with a variety of alkynes in the presence of a Pd^0 catalyst and CuCl under mild conditions [53].

Considering the varying low yields of (*R*)-**12** in the *Stille* coupling and the tedious chromatographic product isolation, we sought to improve the yield and ease of isolation of the dialkynylated 1,1′-binaphthalene precursor using the *Sonogashira* cross-coupling reaction [50]. Since 3,3′-dibrominated 1,1′-binaphthalenes such as (±)-**8** or (±)-**11** were found to be quite unreactive under these conditions, a corresponding 3,3′-diiodo derivative was prepared. For this purpose, **6** was metallated and then reacted with I_2 to give **18** in 97% yield. Deprotection of the OH group at C(2) afforded **19** (97%), which was coupled to give (±)-**20** (63%) (*Scheme 3*). To our disappointment, (±)-**20** did not react with (1*R*,2*S*,5*R*)-menthyl phosphorodichloridite to form two diastereoisomeric cyclic menthyl phosphites, probably as a result of the increased steric hindrance by the bulky I substituents *ortho* to the OH groups at C(2) and C(2′). Furthermore, all other attempts[1]) to resolve (±)-**20** failed. In view of these problems, which are undoubtedly associated with the presence of the I-atoms in (±)-**20**, we decided to introduce these substituents only after optical resolution of the 1,1′-binaphthalene moiety.

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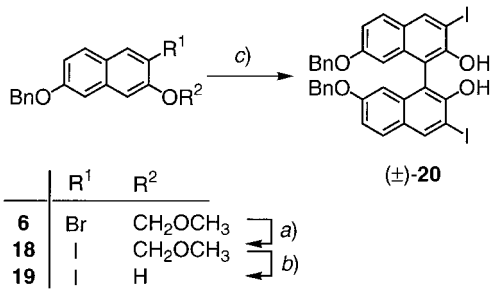
[1]) The optical resolution was attempted by methods reported in [46][54]. For other resolutions of 1,1′-binaphthalene-2,2′-diols, see [55]. For the synthesis of asymmetric 1,1′-binaphthalene-2,2′-diols, see [56].

Scheme 3. *Synthesis of (±)-***20**



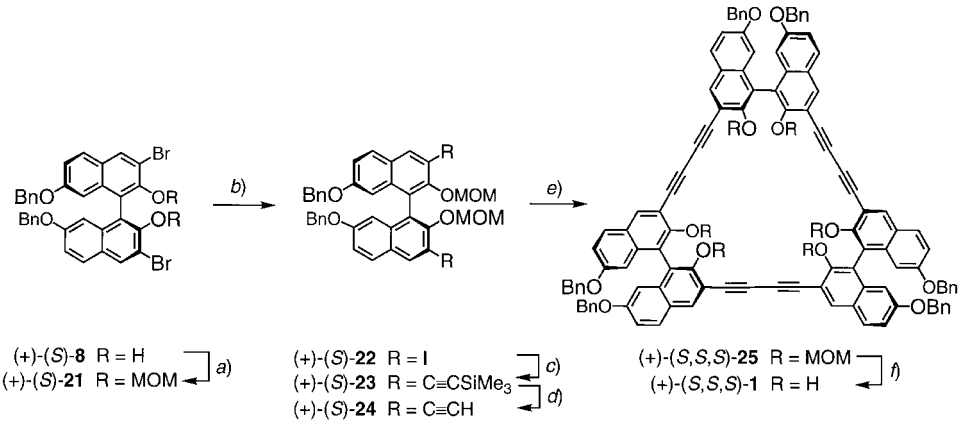
a) *t*-BuLi, THF, −78°, 30 min, then I_2, −78° →20°, 12 h, 97%, *b*) Conc. aq. HCl soln. (cat.), THF/MeOH 2 : 1, 70°, 3 h, 97%. *c*) *t*-$BuNH_2$, $CuCl_2$, MeOH, 80°, 1 h, 65%.

The direct electrophilic iodination [57] of enantiomerically pure 7,7′-bis(benzyloxy)-1,1′-binaphthalene-2,2′-diol [48] or the *ortho*-lithiation of OH-protected derivatives, followed by quenching with I_2 [58], failed to yield enantiomerically pure **20**. Most conversions afforded complex product mixtures containing only traces of the desired diiodinated compound, sometimes accompanied by reduced and higher iodinated derivatives. Therefore, we decided to introduce the I substituents by a halogen-exchange reaction after the optical resolution of (±)-**8**.

In a test run, diol (±)-**8** was transformed into the MOM-protected derivative (±)-**21** which, upon treatment with *t*-BuLi (3 equiv.) in THF at −78° followed by quenching with I_2, afforded (±)-**22** (*Scheme 4*) in 93% yield. Repeating the reaction under exactly the same conditions with the enantiomer (+)-(*S*)-**8** (obtained from menthyl phosphite (+)-**9** prepared with (1*S*,2*R*,5*S*)-menthyl phosphorodichloridite as described above) unfortunately was much less successful and yielded a mixture of the desired product (*S*)-**22** (less than 25%) together with mono- and bis-reduced side-products resulting from Br/H exchange (*ca*. 20% each).

Deuterium isotope studies were performed in an effort to shed light on this considerable difference in behavior between racemic and enantiomerically pure **21**. The enantiomer (*S*)-**21** was dilithiated as described above at −78° and, after 1 h, quenched at this temperature with CD_3OD. The ^{1}H-NMR spectrum of the crude product showed a mixture of 3,3′-di- and 3-mono-deuterated 1,1′-binaphthalene derivatives. Interestingly, one diastereotopic proton (either H_R or H_S) in each of the two benzylic CH_2 groups was also found to be quantitatively substituted by a D-atom, as illustrated by the ^{2}H-NMR spectrum ($CHCl_3$, 46 MHz) of the mixture. However, when racemic (±)-**21** was subjected to the same conditions, the benzylic H/D exchange was insignificant and only deuteration at the 3,3′-positions was observed. These results suggest that the 7,7′-bis(benzyloxy)-1,1′-binaphthalene molecules, with their large *van der Waals* surfaces, aggregate at −78° in THF and that the steric accessibility to the base (*t*-BuLi), and, therefore, the reactivity differs in the aggregates formed by the same enantiomers (self-recognition in the conversion of (*S*)-**21**) and those formed by different enantiomers (non-self-recognition in the conversion of (±)-**21** (for an

Scheme 4. *Synthesis of* (S,S,S)-**1**



a) $MeOCH_2Cl$, K_2CO_3, MeCN, 20°, 15 h, 96%. *b*) BuLi, TMEDA, THF, −78°, 45 min, then I_2, 15 min, 66%. *c*) $Me_3SiC{\equiv}CH$, $[PdCl_2(dppf)]\cdot CH_2Cl_2$, CuI, Et_2NH, toluene, 40°, 4 h, 98%. *d*) K_2CO_3, THF/MeOH 1:1, 20°, 2 h, 93%. *e*) CuCl, TMEDA, O_2, CH_2Cl_2, 20°, 3 h, 25%. *f*) Conc. aq. HCl soln. (cat.), THF/MeOH 1:1, 20°, 12 h, 77%.

example of different aggregations in solutions of racemates (non-self-recognition and enantiomers (self-recognition, see [59]). A co-aggregation of the reagent can also not be excluded. The X-ray crystal-structure analysis obtained for (*S*)-**21** could possibly suggest that coordination of the Li-atom in *t*-BuLi to the MOM moieties directs the base in a proper orientation for intramolecular attack at the benzylic positions. The monoclinic crystals obtained from AcOEt/hexane ($P2_1/n$, $Z=2$) contain (*S*)-**21** arranged in two conformations, one (molecule 1) of which is depicted in *Fig. 1*. Both molecules, in particular the one which is not shown (molecule 2), exhibit severe disorder as a result of the flexible BnO and MOM residues. The torsion angle for rotation about the chirality axis, C(6)−C(1)−C(23)−C(24), in molecule 1 adopts a value of 87°, whereas it is significantly narrowed to 65° in molecule 2, illustrating the well-known conformational flexibility of the 1,1′-binaphthalene moiety [60].

A satisfactory yield of (*S*)-**22** (up to 66%) was finally obtained by treatment of (*S*)-**21** with 5 equiv. of BuLi in the presence of TMEDA in THF at −78°, followed by quenching with I_2 at this temperature (*Scheme 4*). *Sonogashira* coupling [50] with (trimethylsilyl)acetylene to give (*S*)-**23** (98%) followed by alkyne deprotection afforded the cyclization component (*S*)-**24** (93%) in excellent yield. Among various Pd catalysts, commercially available [1,1-bis(diphenylphosphino)ferrocene]dichloropalladium(II)$\cdot CH_2Cl_2$ ($[PdCl_2(dppf)]\cdot CH_2Cl_2$) gave the best yield in the shortest conversion time (4 h) in the cross-coupling step. *Glaser-Hay* coupling of (*S*)-**24** yielded, after gel-permeation chromatography (GPC), trimeric (*S*,*S*,*S*)-**25** (25%), in addition to higher oligomers which were not isolated. Acidic deprotection of (*S*,*S*,*S*)-**25** under very dilute conditions to avoid naphtho[*b*]furan formation finally afforded receptor (*S*,*S*,*S*)-**1** in 77% yield.

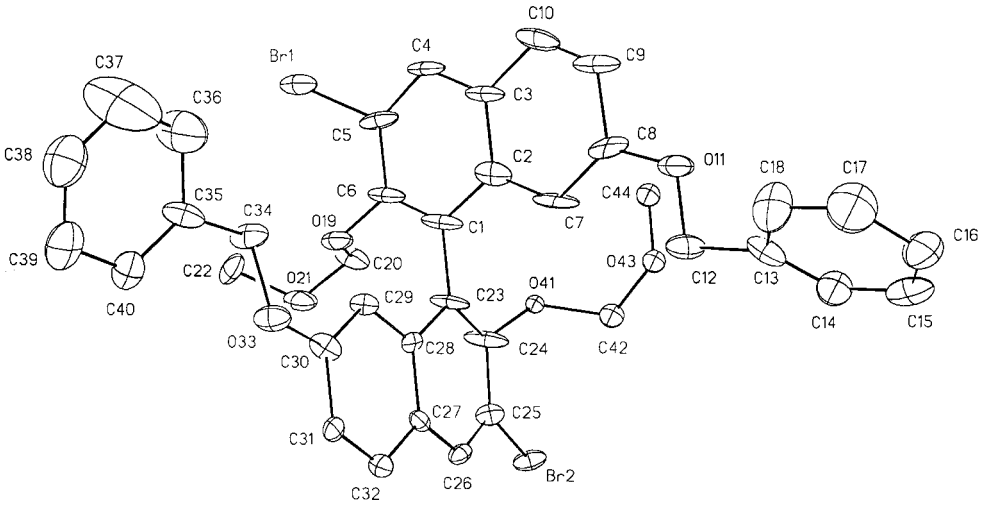


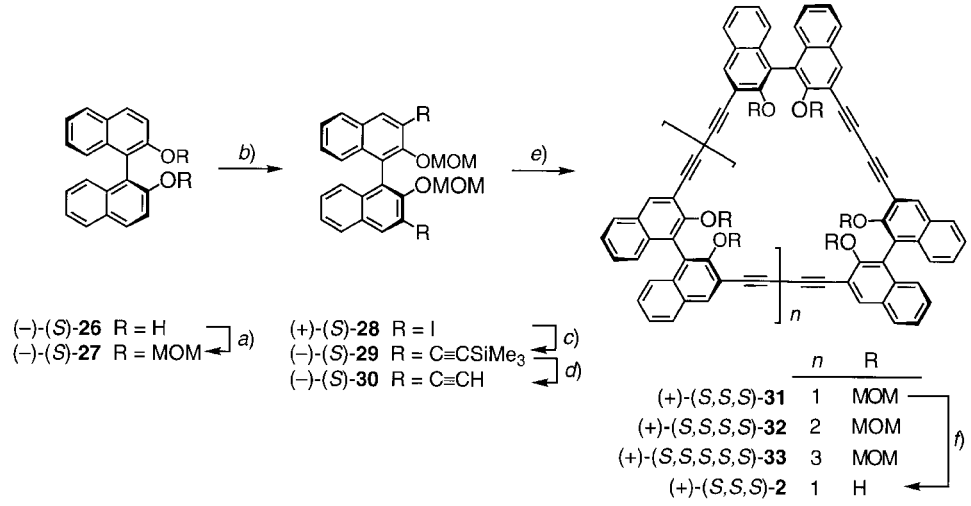
Fig. 1. *X-Ray crystal structure of* (S)-**21**. Only one of the two conformers (molecule 1) in the crystal is shown. The vibrational ellipsoids are shown at the 30% probability level.

2.1.2. *Synthesis of Receptors* (S,S,S)- *and* (R,R,S)-**2**. The synthesis of these receptors was greatly facilitated by starting from readily available, optically pure 1,1′-binaphthalene-2,2′-diol ((*R*)-**26** and (*S*)-**26**, resp.; *Scheme 5*). The resolution of (±)-**26** on a large scale was performed by clathrate formation with *N*-benzylcinchonidinium chloride [55e,g][61], yielding 10–15 g of each enantiomer. After MOM protection of (*S*)-**26** to give (*S*)-**27** (97%) [62], *ortho*-lithiation, followed by quenching with I_2, afforded (*S*)-**28** in 65% yield. The optimal conditions for the iodination of enantiomerically pure material differ from the published ones [58]: the most effective method proved to be lithiation with 3.7 equiv. of BuLi and TMEDA in Et_2O at room temperature over 6.5 h, followed by addition of I_2 in Et_2O at −78°. *Sonogashira* cross-coupling using $[PdCl_2(PPh_3)_2]$ as the catalyst led to (*S*)-**29** (90%), and protodesilylation provided (*S*)-**30** (98%). Oxidative *Glaser-Hay* coupling yielded a mixture of trimeric (*S*,*S*,*S*)-**31** (37%), tetrameric (*S*,*S*,*S*,*S*)-**32** (24%), and pentameric (*S*,*S*,*S*,*S*,*S*)-**33** (5%) which were separated by GPC. MOM Deprotection of the trimeric macrocycle provided the target molecule (*S*,*S*,*S*)-**2** (97%). The overall yield for the formation of (*S*,*S*,*S*)-**2** from (*S*)-**26** was high (20%).

The construction of the macrocyclic skeleton in (*R*,*R*,*S*)-**2** followed a stepwise procedure (*Scheme 6*). The dialkynylated compound (*R*)-**29** was prepared as described above for its enantiomer, and slow mono-deprotection using borax ($Na_2B_4O_7$) in THF/H_2O afforded (*R*)-**34**. When the reaction was quenched after 3.5 h, a mixture of starting material (*R*)-**29** (33%), desired product (*R*)-**34** (42%), and doubly deprotected (*R*)-**30** (13%) was obtained. By repeating the reaction with recovered starting material three times, the overall yield of (*R*)-**34** was improved to 61%. Performing the same reaction for 24 h led to (*R*)-**30** in quantitative yield.

Dimerization of (*R*)-**34** under *Glaser-Hay* conditions afforded (*R*,*R*)-**35** (86%), and alkyne deprotection gave (*R*,*R*)-**36** (81%) which was subjected to a *Glaser-Hay*

Scheme 5. *Synthesis of* (S,S,S)-**2**



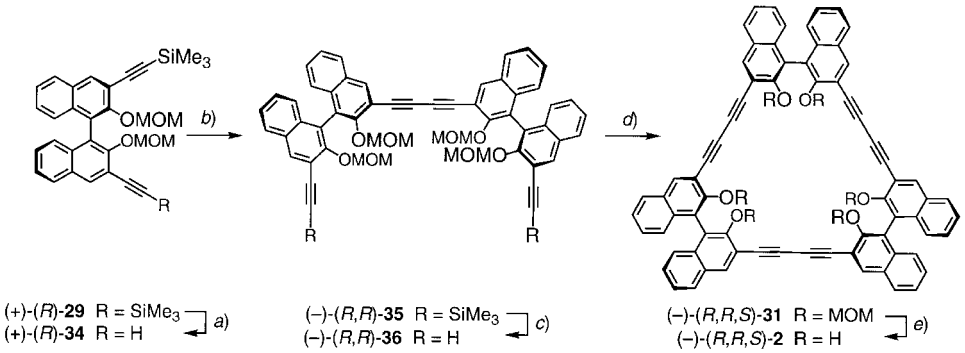
a) $MeOCH_2Cl$, NaH, THF, 20°, 30 min, 97%. *b*) BuLi, TMEDA, Et_2O, 20°, 6.5 h, then I_2, –78°, 2 h, 65%. *c*) $Me_3SiC{\equiv}CH$, $[PdCl_2(PPh_3)_2]$, CuI, Et_3N, 40°, 20 h, 90%. *d*) K_2CO_3, THF/MeOH 1:1, 20°, 3 h, 98%. *e*) CuCl, TMEDA, CH_2Cl_2, O_2, 20°, 2 h, 37% ((*S*,*S*,*S*)-**31**), 24% ((*S*,*S*,*S*,*S*)-**32**), 5% ((*S*,*S*,*S*,*S*,*S*)-**33**). *f*) Conc. aq. HCl soln. (cat.), THF/MeOH 1:1, 20°, 12 h, 97%.

cross-coupling with (*S*)-**30**. Slow addition of a solution of the two cyclization components in CH_2Cl_2 to a solution of CuCl and TMEDA in CH_2Cl_2 under air afforded diastereoisomeric mixtures of trimeric and tetrameric macrocyclic products, from which pure (*R*,*R*,*S*)-**31** (11%) and (*S*,*S*,*S*)-**31** (4%) were isolated by GPC followed by HPLC. The C_2-symmetrical structure of (*R*,*R*,*S*)-**31** was confirmed by its ^{1}H- and ^{13}C-NMR spectra which revealed three sets of naphthalene resonances of equal intensity. Deprotection under mild acidic conditions finally led to the target compound (*R*,*R*,*S*)-**2** (79%).

2.1.3. *Synthesis of Receptors* (S,S,S)- *and* (S,S,R)-**3**. These macrocycles were also synthesized starting from enantiomerically pure 1,1′-binaphthalene-2,2′-diol ((*S*)- or (*R*)-**26**). Bromination of (*S*)-**26** afforded the 6,6′-dibromo derivative (*S*)-**37** (90%) [63], and MOM protection led to (*S*)-**38** (95%) (*Scheme 7*). The 2-phenylethyl groups in (*S*)-**39** were efficiently introduced (94%) by *Suzuki* cross-coupling [64] with *B*-(2-phenylethyl)-9-borabicyclo[3.3.1]nonane (**40**), prepared *in situ* from styrene and 9-borabicyclo[3.3.1]nonane (9-BBN) [65], using $[PdCl_2(dppf)]\cdot CH_2Cl_2$ as catalyst and NaOH as base.

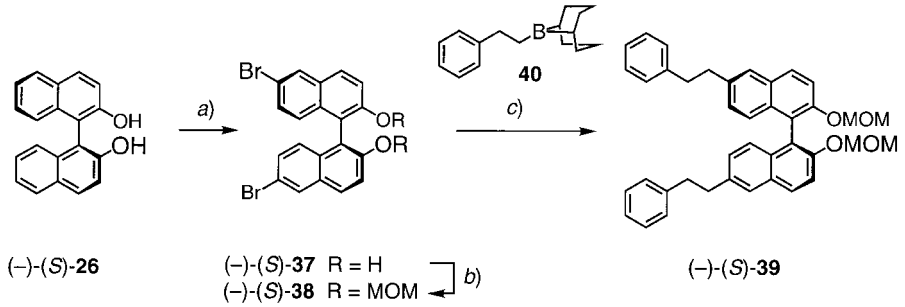
All other reaction steps were adopted from the sequence described above for the preparation of (*S*,*S*,*S*)-**2** and (*R*,*R*,*S*)-**2** (*Sect. 2.1.2*) and proceeded in comparable reaction times and yields. The D_3-symmetrical receptor (*S*,*S*,*S*)-**3** was formed by the sequence (*S*)-**39** → (*S*)-**41** → (*S*)-**42** → (*S*)-**43** → (*S*,*S*,*S*)-**44** (together with tetrameric (*S*,*S*,*S*,*S*)-**45**) → (*S*,*S*,*S*)-**3** (*Scheme 8*) in an overall yield of 13% (eight steps starting from (*S*)-**26**). The C_2-symmetrical counterpart (*S*,*S*,*R*)-**3** was obtained by the sequence

Scheme 6. *Synthesis of* (R,R,S)-**2**



a) Borax, THF/H_2O, 20°, 3.5 h, 42%. *b*) CuCl, TMEDA, CH_2Cl_2, O_2, 20°, 3 h, 86%. *c*) K_2CO_3, THF/MeOH 1:1, 20°, 1.5 h, 81%. *d*) (*S*)-**30**, CuCl, TMEDA, CH_2Cl_2, O_2, 20°, 2 h, 11%. *e*) Conc. aq. HCl soln. (cat.), THF/MeOH 1:1, 20°, 12 h, 79%.

Scheme 7. *Synthesis of* (S)-**39**

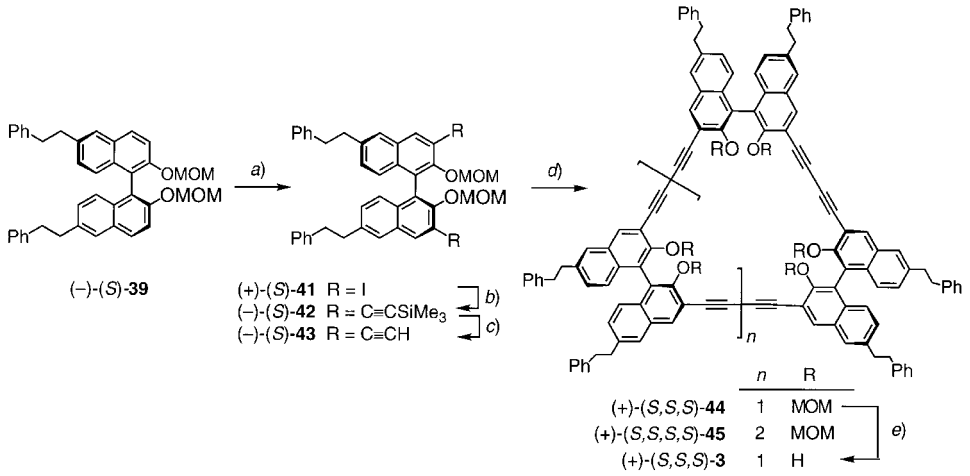


a) Br_2, CH_2Cl_2, –78° →20°, 3 h, 90%. *b*) $MeOCH_2Cl$, K_2CO_3, DMF, 20°, 12 h, 95%. *c*) $[PdCl_2(dppf)]\cdot CH_2Cl_2$, NaOH, THF, 50°, 15 h, 94%.

(*S*)-**42** →(*S*)-**46** →(*S,S*)-**47** →(*S,S*)-**48** →(*S,S,R*)-**44** →(*S,S,R*)-**3** (*Scheme 9*). All 2-phenylethyl precursors to (*S,S,S*)-**3** and (*S,S,R*)-**3** are highly viscous oils, which contrasts with the crystallinity of the 1,1′-binaphthalene precursors bearing BnO groups in the 7,7′-positions or lacking functionality in the major groove.

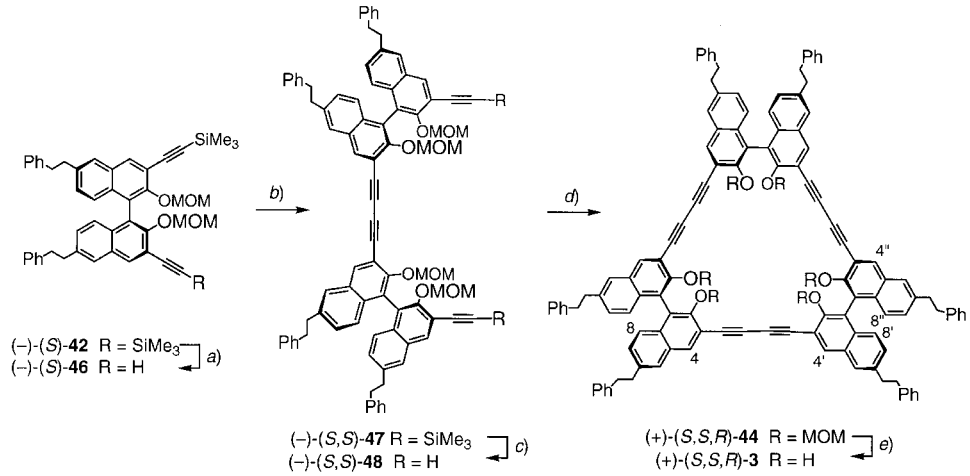
2.2. *Carbohydrate Recognition by the Synthetic Receptors* **1**–**3**. *CPK* (*Corey-Pauling-Koltum*)-model examinations and computer modeling (MacroModel V.5.5 and V.6.0 [66]) suggested that the rigid, preorganized cavities with the six convergent H-bonding sites in receptors **1**–**3** would be complementary in size and shape to a hexopyranose ring. Therefore, the complexation of octyl pyranosides was investigated in the noncompetitive solvent $CDCl_3$. The D_3-symmetrical receptors are rather planar in their overall shape, whereas the C_2-symmetrical counterparts are much more distorted from planarity (*Fig. 2*). Furthermore, the cavity of the latter is significantly

Scheme 8. *Synthesis of* (S,S,S)-**3**



a) BuLi, TMEDA, Et_2O, 20°, 6.5 h, then I_2, −78°, 2 h, 73%. *b*) $Me_3SiC{\equiv}CH$, $[PdCl_2(PPh_3)_2]$, CuI, Et_3N, 50°, 2 h, 93%. *c*) K_2CO_3, THF/MeOH 1:1, 20°, 3 h, 87%. *d*) CuCl, TMEDA, CH_2Cl_2, O_2, 20°, 1 h, 36% ((*S,S,S*)-**44**), 25% ((*S,S,S,S*)-**45**. *e*) Conc. aq. HCl soln. (cat.), THF/MeOH 1:1, 20°, 12 h, 81%.

Scheme 9. *Synthesis of* (S,S,R)-**3**



a) Borax, THF/H_2O, 20°, 3.5 h, 28%. *b*) CuCl, TMEDA, CH_2Cl_2, O_2, 20°, 3 h. *c*) K_2CO_3, THF/MeOH 1:1, 20°, 1.5 h, 76% from (*S*)-**46**. *d*) (*R*)-**43**, CuCl, TMEDA, CH_2Cl_2, O_2, 20°, 1 h, 23%. *e*) Conc. aq. HCl soln. (cat.), THF/MeOH 1:1, 20°, 12 h, 75%.

narrowed. We expected that the reduced symmetry of the binding site and the tighter host-guest fit provided by the C_2-symmetrical receptors would translate into both higher binding strength and enhanced substrate selectivity. As expected, the modeling also showed that the size and shape of the receptor cavities are not affected by the changes in peripheral functionality in **1**–**3**.

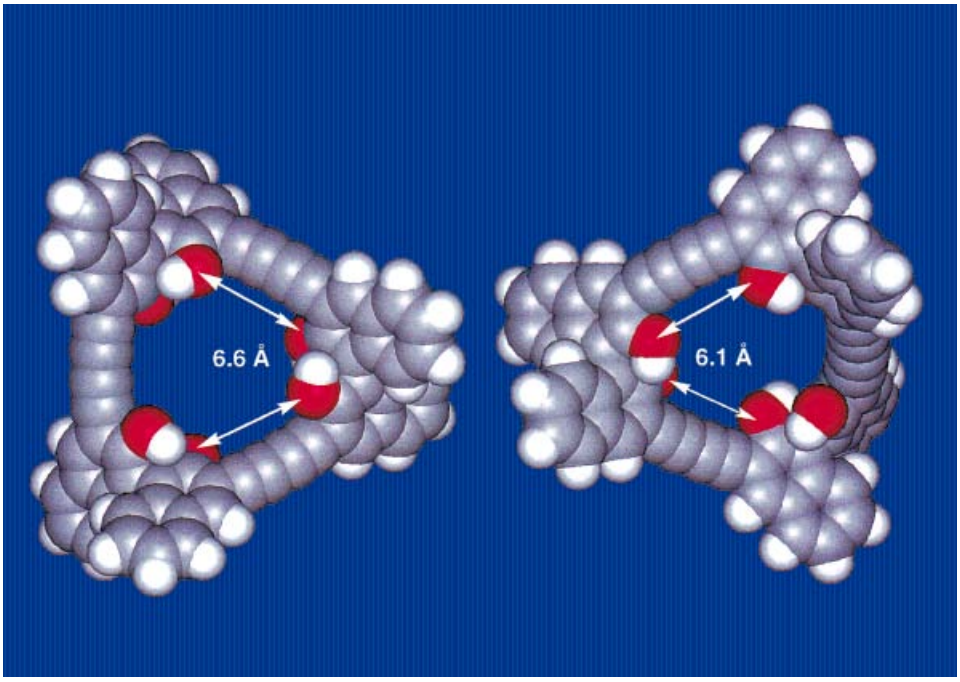
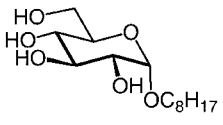


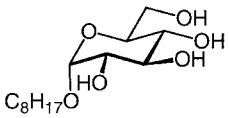
Fig. 2. *Comparison of the energy-minimized structures of (*R,R,R*)*-**2** (left) *and (*S,S,R*)*-**2** (right) (MacroModel V.6.0, AMBER* force field, GB/SA solvation model for $CHCl_3$). Similar binding sites are present in the corresponding receptors **1** and **3**.

2.2.1. *^{1}H-NMR-Spectroscopic Investigations of the Complexation between 1-*O*-Octyl Pyranosides and the* D_3*-Symmetrical Receptors (*R,R,R*)*-**1** *and (*S,S,S*)*-**1**. The trimeric receptors (*R,R,R*)-**1**/(*S,S,S*)-**1** are highly soluble in $CDCl_3$ (up to 20 mM) and do not aggregate appreciably at concentrations below 5 mM, as determined by ^{1}H-NMR dilution experiments. Binding studies with 1-*O*-octyl pyranosides **49**–**52** were carried out at 300 K in dried $CDCl_3$ by 500-MHz ^{1}H-NMR titrations. The complexation-induced downfield shift of the OH protons of the receptor, held at constant concentration, was monitored as a function of the concentration of the guest. It was experimentally impossible to approach the calculated shifts at saturation binding ($\Delta\delta_{sat}$) because of the overlap of the downfield-shifting OH signal with the aromatic receptor resonances at higher degrees of complexation. Nevertheless, the maximum observed degree of saturation ($\Delta\delta_{max\,obs}$ up to 50–60% of $\Delta\delta_{sat}$) proved to be sufficient in most assays for the reproducible determination of association constants K_a [l mol^{-1}] and binding free enthalpies ΔG^0 [kcal mol^{-1}] by nonlinear least-squares curve-fitting of

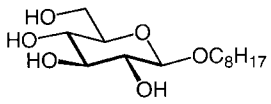
the experimental titration data [67]. Other resonances of the receptors were not affected by the addition of the carbohydrate guests.



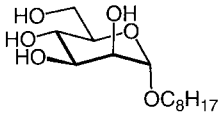
49 Octyl α-D-glucoside



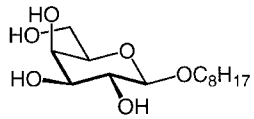
50 Octyl α-L-glucoside



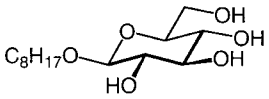
51 Octyl β-D-glucoside



52 Octyl α-D-mannoside



53 Octyl β-D-galactoside



54 Octyl β-L-glucoside

The 1:1 complexes formed between (*R*,*R*,*R*)-**1** or (*S*,*S*,*S*)-**1**, and pyranosides **49**–**51** are of moderate stability, with association constants varying between $K_a = 110$ and 370 l mol^{-1} (*Table 1*). Diastereoselectivities of up to $\Delta(\Delta G^0) = 0.7$ kcal mol^{-1}, and a small enantioselectivity of $\Delta(\Delta G^0) = 0.4$ kcal mol^{-1} was measured for the complexation of octyl α-D- (**49**) and octyl α-L-pyranoside (**50**). Note that the binding free enthalpies determined for the complexes of (*S*,*S*,*S*)-**1** with **49** and **50** are 0.3 kcal mol^{-1} more negative than for the corresponding enantiomeric complexes formed by (*R*,*R*,*R*)-**1**. Such a discrepancy between spectra measured more than three years apart could originate from differences in the experimental titration conditions, such as the presence of different amounts of residual H_2O in the solvent [15][16]. In the titrations with (*R*,*R*,*R*)-**1**, no residual H_2O was present, whereas the ^{1}H-NMR spectra recorded in the titrations with (*S*,*S*,*S*)-**1** displayed a small H_2O peak at 1.54 ppm ($c \approx 0.5$ mM). Most importantly, however, the enantioselectivities determined with the two enantiomeric receptors are in complete agreement.

Table 1. *Association Constants* K_a [l mol^{-1}] *and Complexation Free Enthalpies* ΔG^0 [kcal mol^{-1}] *for 1:1 Complexes of Receptors* (S,S,S)- *and* (R,R,R)-**1** *in* $CDCl_3$ (300 K). Also shown are the calculated and, in parenthesis, the maximum observed complexation-induced upfield shifts $\Delta\delta_{sat}$ and $\Delta\delta_{max\,obs}$, of the receptor OH protons.

Sugar[a])	Receptor	K_a[b]) [l mol^{-1}]	ΔG^0 [kcal mol^{-1}]	$\Delta\delta_{sat}$ ($\Delta\delta_{max\,obs}$)
49	(*R*,*R*,*R*)-**1**	210	−3.2	2.01 (1.15)
50	(*R*,*R*,*R*)-**1**	110[c])	−2.8	2.29 (0.84)
51	(*R*,*R*,*R*)-**1**	370	−3.5	2.48 (1.42)
49	(*S*,*S*,*S*)-**1**	170	−3.1	2.09 (1.05)
50	(*S*,*S*,*S*)-**1**	350	−3.5	1.90 (1.19)
51	(*S*,*S*,*S*)-**1**	240	−3.3	2.03 (1.06)

[a]) Host concentration was constant at 0.5 mM, guest concentration varied between 0.5–6.0 mM. [b]) Association constants determined by nonlinear least-squares curve fitting of 500-MHz ^{1}H-NMR titrations. Uncertainty in K_a estimated at 20%. [c]) Higher uncertainty in K_a since only *ca.* 37% saturation binding reached.

In control runs under the same conditions, no appreciable changes occurred in the ^{1}H-NMR spectra of 1,1′-binaphthalene-2,2′-diol (*R*)-**14** ($c = 0.5$ mM) upon addition of up to 12 equiv. of the pyranosides. This observation confirms that more than two OH groups of the receptors (*R*,*R*,*R*)-**1**/(*S*,*S*,*S*)-**1** contribute to the binding of the substrates in the macrocyclic cavity.

The complexation of (*R*,*R*,*R*)-**1** with α-D-mannoside **52** was also investigated, but a broadening of the receptor OH signal at ambient temperature occurred, indicating an intermediate host-guest exchange rate on the ^{1}H-NMR time scale. This was confirmed by variable-temperature studies. Fast exchange occurred at 330 K, whereas cooling to 240 K led to slow exchange and gave rise to a very complicated spectrum, since the low symmetry of the pyranoside is imposed on the resonances of the receptor, with very broad signals of bound host and guest. This slow host-guest exchange rate contrasts with the rapid kinetics observed previously at similar binding strength for the complexation of octyl pyranosides by open, cleft-type receptors [22a]. It supports a complex geometry in which the sugar substrate fully penetrates into the macrocyclic cavity rather than docking onto one of the two receptor faces.

2.2.2. *^{1}H-NMR-Spectroscopic Investigations into the Sugar-Binding Ability of the* D_3*-Symmetrical Receptors (*S,S,S*)-***2*** *and (*S,S,S*)-***3***. Like receptors (*R*,*R*,*R*)-**1** and (*S*,*S*,*S*)-**1**, the two trimeric macrocycles (*S*,*S*,*S*)-**2** and (*S*,*S*,*S*)-**3** are highly soluble in $CDCl_3$ and, at 300 K, do not aggregate at concentrations below 4 mM. When ^{1}H-NMR titration experiments with these receptors and octyl pyranosides at 300 K were attempted, a strong broadening of all receptor proton signals occurred. This broadening prevented determination of host-guest stoichiometries and association constants; it did, however, provide evidence for sugar-receptor interactions. The OH resonance of the receptors (0.5 mM) showed large downfield shifts upon addition of less than 1 equiv. of carbohydrate. Due to the extreme broadening, however, it was impossible to follow this signal over a meaningful titration range. Upon heating a solution of host and guest ($c =$ 0.5 mM) in $CDCl_2CDCl_2$ to 360 K, sharp signals were recovered; however, complexation had vanished at this temperature. When a solution of (*S*,*S*,*S*)-**3** ($c = 0.5$ mM) and **49** ($c = 0.5$ mM) in $CDCl_3$ was cooled to 250 K, a spectrum at slow host-guest exchange with sharp signals was obtained. Significant changes in the chemical shifts of the aromatic receptor protons were observed, but the complexity of this spectrum prevented the evaluation of the association strength by simple integration of signals of free and bound macrocycle. The symmetry of the complex is reduced by the bound pyranoside. The existence of different, energetically similar complex conformations could further increase the number of resonances. Additionally, the stoichiometry of the formed host-guest associations remained uncertain. Attempts to determine the association strength by other methods (UV/VIS or circular dichroism (CD) titrations) were unsuccessful. Also, the addition of co-solvents did not improve the ^{1}H-NMR titration results.

What causes the drastically different titration behavior of (*S*,*S*,*S*)-**2** and (*S*,*S*,*S*)-**3**, as compared to (*R*,*R*,*R*)-**1** or (*S*,*S*,*S*)-**1** for which the determination of association constants from ^{1}H-NMR binding titrations was quite straightforward (*Sect. 2.2.1*)? All four receptors possess structurally identical cavity binding sites; they only differ by the functionality attached to the major grooves of the 1,1′-binaphthalene spacers. Large differences in the H-bonding donor-acceptor ability of the OH groups at the minor

grooves of the 1,1′-binaphthalene spacers due to the differences in the major groove functionality can be excluded with confidence. We assume that the strong signal broadening observed at 300 K for solutions of receptors (*S*,*S*,*S*)-**2** or (*S*,*S*,*S*)-**3** and octyl pyranosides does not reflect a stronger 1:1 host-guest binding than had been observed for the two D_3-symmetrical enantiomers of **1** (*Table 1*). Rather, we suggest that it originates from carbohydrate-induced aggregation and higher-order complexation. All three D_3-symmetrical receptors **1**–**3** possess a rather flat macrocyclic framework with three OH groups oriented to each face (see *Fig. 2*). A sandwich-type complexation mode is conceivable, by which the sugar interacts with the OH groups on the interior faces of two surrounding receptor molecules, leading to host-guest associations with 2:1 stoichiometry and possibly even to more extended columnar aggregates ··H··G··H··G··H··G··H·· (H = host, G = guest). Apparently, the lateral BnO groups in receptor D_3-**1** are efficient in preventing such higher-order complexation, and formation of cavity inclusion complexes with 1:1 host-guest stoichiometry is observed. In contrast, receptor D_3-**2** lacks any aggregation-preventing lateral functionality and the 2-phenylethyl groups in D_3-**3** do not seem to be effective in preventing sandwich-type complex geometries with higher stoichiometry.

2.2.3. *^{1}H-NMR-Spectroscopic Investigations into the Sugar-Binding Ability of (*R,R,S*)-**2** and (*S,S,R*)-**3***. With their less planar geometries, the C_2-symmetrical receptors were not expected to undergo a sandwiching complexation of sugar substrates, and this was confirmed in the binding studies. However, ^{1}H-NMR titrations with (*R*,*R*,*S*)-**2** turned out to be impossible because of the insolubility of the receptor in $CDCl_3$. In contrast, the macrocycle (*S*,*S*,*R*)-**3**, with its flexible 2-phenylethyl groups at the cavity periphery, proved to be readily soluble, and titrations at 300 K in $CDCl_3$ were not hampered by any signal broadening.

Octyl pyranosides and C_2-symmetrical (*S*,*S*,*R*)-**3** form 1:1 complexes with association constants up to 10-fold higher (*Table 2*) than those measured for the corresponding complexes of D_3-symmetrical (*R*,*R*,*R*)- and (*S*,*S*,*S*)-**1** (*Table 1*). In the binding titrations at constant receptor concentration ($c = 0.5$ mM), the small ($\Delta\delta_{sat} < 0.1$ ppm) but highly reproducible upfield changes in the chemical shift of the sharp aromatic receptor signals of H–C(4), H–C(4′), and H–C(4″) (for numbering, see *Scheme 9*) upon addition of the monosaccharides were evaluated. Since the signals of these three resonances appear at nearly identical chemical shift (*Fig. 3*), their averaged $\Delta\delta$ values were considered. Upon addition of a large excess of carbohydrate, values of the maximum observed upfield shifts ($\Delta\delta_{max\,obs}$) very close to the calculated saturation shifts ($\Delta\delta_{sat}$) were measured. Other aromatic resonances of (*S*,*S*,*R*)-**3** such as H–C(8), H–C(8′), and H–C(8″) also displayed significant complexation-induced changes in chemical shift (*Fig. 3*) which, due to the multiplicity of the resonances, could, however, not be evaluated with the same accuracy. Analysis of the larger complexation-induced downfield shifts of the receptor OH protons ($\Delta\delta_{sat} \gg 1.0$ ppm) was less informative, because of the overlap with the aromatic signals over a significant part of the titration. However, where measurement was possible, comparable association constants to those obtained from the resonances of H–C(4), H–C(4′), and H–C(4″) were obtained.

The selectivity in the complexation of octyl pyranosides by (*S*,*S*,*R*)-**3** is remarkable: diastereoselectivities up to 1.3 kcal mol^{-1} were observed, and the enantioselectivity ($\Delta(\Delta G^0) = 0.9$ kcal mol^{-1}) for the preferred binding of octyl α-L-glucoside (**50**) over

Table 2. *Association Constants* K_a [l mol^{-1}] *and Complexation Free Enthalpies* ΔG^0 [kcal mol^{-1}] *for 1:1 Complexes of Receptor (*S,S,R*)-***3** *in* $CDCl_3$ (300 K). Also shown are the averaged calculated complexation-induced upfield shifts $\Delta\delta_{sat}$ of the aromatic proton H–C(4), H–C(4′), and H–C(4″).

Sugar[a])	K_a[b]) [l mol^{-1}]	ΔG^0 [kcal mol^{-1}]	$\Delta\delta_{sat}$	H_2O [mM]
49	1110	– 4.1	0.049	0
49	1190	– 4.2	0.048	3.0
50	4440	– 5.0	0.036	0
51	3260	– 4.8	0.048	0
51	2950	– 4.7	0.050	1.5
51	3360	– 4.8	0.049	6
53	560	– 3.7	0.051	0

[a]) Host concentration was constant at 0.5 mM, guest concentration varied between 0.5 – 9.0 mM. [b]) Association constants determined by nonlinear least-squares curve fitting of 500-MHz ^{1}H-NMR titrations. Uncertainties in K_a estimated at ±20%.

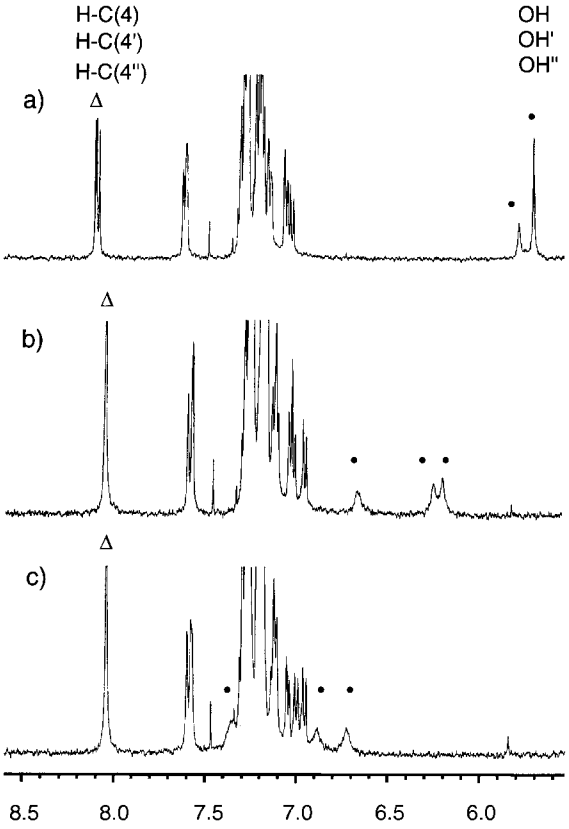


Fig. 3. *Part of the* ^{1}*H-NMR spectrum of (*S,S,R*)-***3** (0.5 mM) *alone* (a), *and in the presence of 1.2 mM of* **50** (b) *and 5.8 mM of* **50** (c)

octyl α-D-glucoside (**49**) is the highest so far observed for carbohydrate recognition with synthetic receptors. When ^{1}H-NMR titration experiments were performed with octyl β-L-glucoside (**54**), the host-guest exchange rate became so slow that sharp signals for unbound and bound receptor were visible at ambient temperature which, in this case, is indicative of a very strong association. Unfortunately, signal assignments in the complex and determination of quantitative binding data were unsuccessful. Nevertheless, it can be stated with confidence that (*S*,*S*,*R*)-**3** has a higher affinity for L-glucosides than for D-glucosides.

The observation of upfield shifts for several aromatic protons of (*S*,*S*,*R*)-**3** indicates that the receptor undergoes substrate-induced structural changes. This contrasts with the results for (*R*,*R*,*R*)-**1** and (*S*,*S*,*S*)-**1**, where only changes in the chemical shifts of the OH protons were observed. Structural analysis by computer modeling indicated that receptor (*S*,*S*,*R*)-**3** not only contains a cavity with a smaller diameter (*Fig. 2*) than the D_3-symmetrical counterpart, but that the binding site is also more flexible. Monte Carlo conformational searches (MacroModel V.6.0 [66], 4000 steps, AMBER*, GB/SA solvation model for $CHCl_3$) revealed for (*S*,*S*,*R*)-**2** (as model for (*S*,*S*,*R*)-**3**) a total of six conformers with 5 kcal mol^{-1} above the calculated global minimum structure, whereas for (*R*,*R*,*R*)-**2** only two conformers were found in this energy range.

The energy-minimized structure of the stable complex formed between (*S*,*S*,*R*)-**2** and octyl α-L-glucoside (**50**) is depicted in *Fig. 4*. It shows clearly the tight host-guest fit

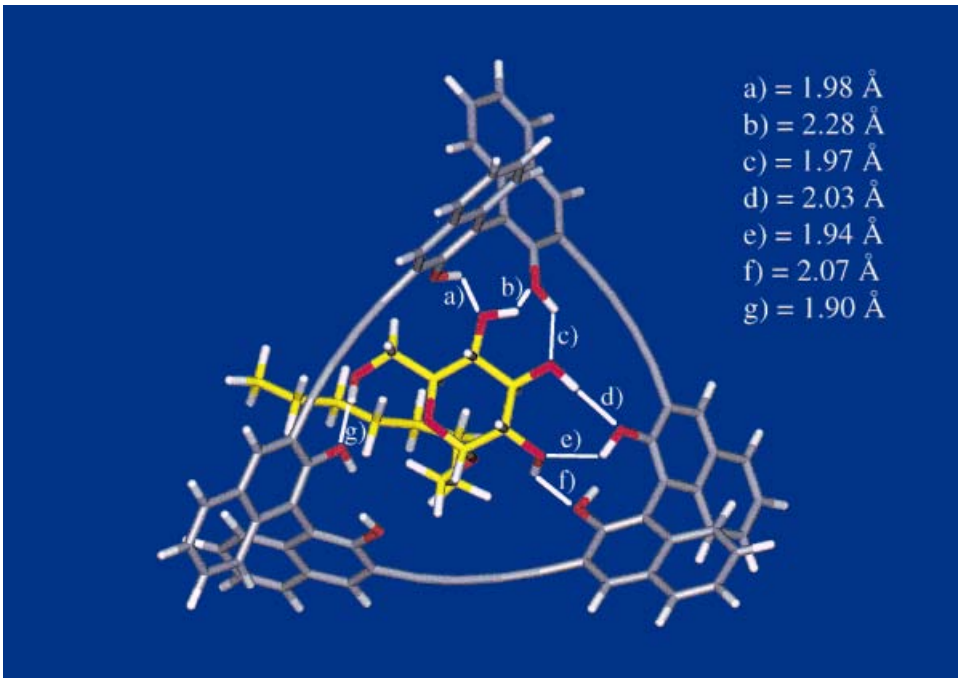


Fig. 4. *The energy-minimized structure of the complex formed between (*S,S,R*)-***2*** (as a model for (*S*,*S*,*R*)-***3***) and octyl α-L-glucoside* (**50**) (MacroModel V.6.0, AMBER* force field, GB/SA solvation model for $CHCl_3$). Shown are the intermolecular H···O H-bonding distances in the complex.

in the inclusion complex with several short intermolecular H-bonds in which the sugar OH groups participate cooperatively both as H-bond donors and acceptors. Experimental evidence for such a tight fit was not only obtained by the large association constants measured but also by the invariance of the complexation strength with respect to small amounts of H_2O in the titration solutions (*Table 2*). *Bonar-Law* and *Sanders* [15] had observed higher binding strength when small amounts of H_2O or MeOH were added to solutions of carbohydrates and synthetic receptors in $CDCl_3$. Their receptors were too large to provide a tight fit to the substrate, and the co-solvents were proposed to act as mortar and to enhance the associations by bridging the binding partners *via* H-bonding. In our study, small amounts of H_2O did not at all affect the binding of pyranosides to (*S*,*S*,*R*)-**3** (*Table 2*). The host-guest fit is already very tight in the narrow cavity binding site, and there is no space to accommodate extra H_2O molecules.

3. Conclusions. – Remarkable differences in the carbohydrate recognition properties were observed in the series of optically active D_3-symmetrical ((*S*,*S*,*S*) and (*R*,*R*,*R*)) and C_2-symmetrical ((*S*,*S*,*R*) and (*R*,*R*,*S*)) macrocycles **1**–**3**. They all possess a cavity lined with six convergent OH groups for H-bonding recognition and complementary in size and shape to a monosaccharide. Whereas the D_3-symmetrical receptors possess, on average, quite planar geometries, the C_2-symmetrical counterparts are much less planar. The recognition sites in the latter are also smaller and more flexible, thereby providing a better fit to a complexed sugar guest.

The major difference in the series **1**–**3** consists in the functional groups attached to the periphery of the macrocycles. The BnO (in **1**) and 2-phenylethyl (in **3**) groups were initially introduced to solubilize the receptors in the concentration ranges needed for ^{1}H-NMR titrations in the noncompetitive solvent $CDCl_3$. Whereas the solubility properties of **1** and **3** were satisfactory, macrocycle (*R*,*R*,*S*)-**2**, lacking peripheral functionality, was indeed found to be too insoluble for binding studies. An unexpected advantage of the BnO groups in the 7,7′-positions of the 1,1′-binaphthalene spacers in **1** over the 2-phenylethyl groups in the corresponding 6,6′-positions in **3** only became clear during the binding titrations. The flat D_3-symmetrical macrocycle (*S*,*S*,*S*)-**3** (as well as (*S*,*S*,*S*)-**2** without major-groove functionality) displayed a strong tendency to form higher order, presumably sandwich-type complexes with the octyl pyranoside substrates, and the determination of 1:1 host-guest association strength was, therefore, not possible. In contrast, the 7,7′-BnO groups in (*S*,*S*,*S*)-**1** and (*R*,*R*,*R*)-**1** apparently prevent this higher-order complexation mode effectively, and stoichiometric 1:1 complexation could be investigated. No such higher-order complexation, which is indicated by a very strong peak broadening in the ^{1}H-NMR spectra, was observed with the less planar macrocycle (*S*,*S*,*R*)-**3**. These findings underline in an impressive way the relevance of a proper design of structural details not directly associated with the binding interaction but ensuring solubility and preventing aggregation of a receptor.

The flat D_3-symmetrical receptors (*S*,*S*,*S*)-**1** and (*R*,*R*,*R*)-**1** displayed only moderate binding affinities and selectivities, whereas (*S*,*S*,*R*)-**3** showed remarkable association strength and selectivity. Aromatic OH groups are not the most efficient H-bond donor and acceptor groups, yet the concerted binding of the sugar by a cyclic array of these groups provides complex stabilities around $\Delta G^0 = -5.0$ kcal mol^{-1}.

With diastereoselectivities up to $\Delta(\Delta G^0) = 1.3$ kcal mol^{-1} and enantioselectivities of $\Delta(\Delta G^0) = 0.9$ kcal mol^{-1}, (*S,S,R*)-**3** is among the most selective artificial carbohydrate receptors known. Complexation occurs at present only in noncompetitive solvents such as $CDCl_3$. In future work, we hope to provide the necessary hydrophobic desolvation, dispersion interactions, and C–H$\cdots\pi$ interactions by attaching aromatic caps to the receptor, to sandwich the saccharide guest bound to the cyclic array of OH groups in the cavity. This may be a way to achieve complexation in competive protic solvents and, ultimately, in H_2O.

Experimental Part

General. All reactions were carried out under N_2. Solvents and reagents were reagent-grade and commercially available and used without further purification unless otherwise stated. THF and Et_2O were freshly distilled from sodium benzophenone ketyl. Evaporation *in vacuo* was conducted at H_2O aspirator pressure. Column chromatography (CC): SiO_2 *60* (230–400 mesh, 0.040–0.063 mm) from *E. Merck* (for products containing MOM-protecting groups) or *Fluka*; visualization by UV light. M.p.: *Büchi SMP-20*; uncorrected. IR Spectra (cm^{-1}): *Perkin-Elmer 1600-FT IR*. NMR Spectra: *Bruker AMX 500* or *AMX 400*, and *Varian Gemini 300* or *200* at 296 or 300 K, with solvent peak as reference. MS (*m*/*z* (%)): EI: *VG TRIBRID* spectrometer at 70 eV; FAB: *VG ZAB2-SEQ* spectrometer with 3-nitrobenzyl alcohol (NOBA) as matrix; MALDI-TOF-MS: *Bruker Reflex* spectrometer with 2-(4-hydroxyphenylazo)benzoic acid (HABA), α-cyano-4-hydroxycinnamic acid (CCA), 2,4,6-trihydroxyacetophenone/diammonium citrate (THA/citrate) 2:1, or 1,8,9-trihydroxyanthracene (dithranol) as matrix; positive-ion mode. Prep. gel-permeation chromatography (GPC): *Biobeads SX-1* or *SX-3* from *Biorad*, eluent toluene or CH_2Cl_2; detection at 300 nm by UV detector from *Knauer*. Elemental analyses were performed by the Mikrolabor at the Laboratorium für Organische Chemie, ETH-Zürich.

Computer Modeling. For the simulations of receptors and host-guest complexes, Version 6.0 of Macro-Model [66] was applied (Monte Carlo simulation, 4000 steps, AMBER* force field, GB/SA solvation model for $CHCl_3$). The AMBER* force field was modified to include buta-1,3-diyne parameters. For this purpose, an X-ray crystal structure of 1,4-diphenylbuta-1,3-diyne [68] provided values for the bond distances and angles, whereas stretching and bending force field constants adapted from AMBER* supplied C(sp^2)–C≡C parameters.

^{1}H-NMR Binding Titrations. Quantitative binding data (K_a, ΔG^0, $\Delta\delta_{sat}$) were determined by nonlinear least-squares curve fitting of ^{1}H-NMR titration data (500 MHz, 300 K) in dry $CDCl_3$ using the program Associate V.1.6 [67]. Commercially available guests were used without further treatment. Pyranosides **50** [69] and **54** [70] were prepared according to published procedures. The host concentration was kept constant at 0.5 mM, and a soln. of guest (and 0.5 mM host) was added in portions *via* microsyringe to the septum-capped NMR tube containing the host and freshly activated, powdered 4-Å molecular sieves. After each addition, a ^{1}H-NMR spectrum was taken. To obtain reproducible binding results, the solvent was carefully dried. Therefore, $CDCl_3$ was first allowed to stand over anh. K_2CO_3 and molecular sieves (4 Å) for at least 24 h prior to the titration experiment. This served to both deacidify the $CDCl_3$ and partially dry it. The remaining traces of H_2O (*ca*. 3 mM according to the ^{1}H-NMR spectrum) in the decanted solvent were removed by the addition of just enough freshly activated, powdered 4-Å molecular sieves to the NMR tube containing the titration soln., to cause, in most cases, the disappearance of the H_2O peak at 1.54 ppm (there should be no excess of sieves present). *Bonar-Law* and *Sanders* had previously shown that these experimental conditions do not affect the complexation of pyranosides [15].

6-Bromo-7-(methoxymethoxy)naphthalen-2-ol (**5**). To a degassed mixture of *3-bromonaphthalene-2,7-diol* (**4**) [41] (15.0 g, 62.7 mmol) and K_2CO_3 (7.5 g, 54.3 mmol) in dry MeCN (300 ml), $MeOCH_2Cl$ (MOMCl) (6.5 ml, 6.9 g, 85.7 mmol) was added at −18° over 2 h *via* syringe pump. After stirring for 2 h, 0.1M aq. HCl soln. (150 ml) was added, and the product extracted with AcOEt. The org. phase was washed with sat. aq. NaCl soln., dried (Na_2SO_4), and evaporated *in vacuo*. CC (hexane/AcOEt 5:1 with 0.5% Et_3N) afforded **5** (8.9 g, 50%). White solid. M.p. 107–108°. IR ($CHCl_3$): 3324*s* (br.), 2942*w*, 1624*m*, 1592*w*, 1501*m*, 1455*w*, 1437*w*, 1369*m*, 1200*s*, 1146*s*, 1078*m*, 1005*m*, 968*m*. ^{1}H-NMR (300 MHz, $CDCl_3$): 3.56 (*s*, 3 H); 5.13 (*s*, 1 H); 5.35 (*s*, 2 H); 6.99 (*dd*, *J* = 8.7, 2.5, 1 H); 7.03 (*d*, *J* = 2.5, 1 H); 7.31 (*s*, 1 H); 7.59 (*d*, *J* = 8.7, 1 H); 7.98 (*s*, 1 H). ^{13}C-NMR (50 MHz, $(CD_3)_2CO$): 56.23; 95.48; 108.83; 110.06; 110.33; 117.92; 125.63; 129.05; 132.42; 135.89; 152.02; 156.82. EI-MS:

282 (35, M^+, $^{79}BrC_{12}H_{11}O_3$), 45 ($[CH_3OCH_2]^+$). Anal. calc. for $C_{12}H_{11}BrO_3$ (283.12): C 50.91, H 3.92, Br 28.22; found: C 50.97, H 3.99, Br 28.37.

6-(Benzyloxy)-2-bromo-3-(methoxymethoxy)naphthalene (**6**). To a degassed mixture of **5** (4.0 g, 14.1 mmol) and K_2CO_3 (4.0 g, 28.9 mmol) in dry DMF (40 ml), BnCl (2.0 ml, 2.2 g, 17.4 mmol) was added, and the mixture was stirred at 80° for 1 h. The salts were removed by filtration through *Celite*. Evaporation *in vacuo* afforded **6** (5.0 g, 94%). White solid (toluene). M.p. 114–115°. IR ($CHCl_3$): 3010*m*, 2935*w*, 1627*s*, 1594*m*, 1503*s*, 1454*m*, 1391*m*, 1244*m*, 1227*m*, 1152*s*, 1086*m*, 1015*s*, 976*m*, 884*m*. ^{1}H-NMR (300 MHz, $CDCl_3$): 3.57 (*s*, 3 H); 5.16 (*s*, 2 H); 5.36 (*s*, 2 H); 7.11–7.15 (*m*, 2 H); 7.35–7.49 (*m*, 6 H); 7.61 (*d*, *J* = 9.7, 1 H); 7.98 (*s*, 1 H). ^{13}C-NMR (75 MHz, $CDCl_3$): 56.43; 70.03; 95.14; 106.48; 110.25; 110.93; 118.10; 125.64; 127.56; 128.10; 128.28; 128.68; 131.95; 134.72; 136.72; 151.74; 157.29. EI-MS: 374 (38, M^+, $^{79}BrC_{19}H_{17}O_3$), 91 (100, $[C_7H_7]^+$). Anal. calc. for $C_{19}H_{17}BrO_3$ (373.25): C 61.14, H 4.59, Br 21.41; found: C 61.08, H 4.68, Br 21.18.

7-(Benzyloxy)-3-bromonaphthalen-2-ol (**7**). A soln. of **6** (5.0 g, 13.4 mmol) and conc. aq. HCl soln. (37%, 5 ml) in THF/MeOH 2:1 (100 ml) was heated to reflux for 3 h. After cooling to r.t., the mixture was quenched with H_2O (50 ml), extracted with CH_2Cl_2, and the org. phase washed with sat. aq. NaCl soln. Evaporation *in vacuo* gave **7** (4.3 g, 98%). White solid (toluene). M.p. 153–154°. IR ($CHCl_3$): 3521*s* (br.), 3010*w*, 1630*s*, 1604*m*, 1505*s*, 1454*m*, 1439*m*, 1394*m*, 1267*s*, 1228*m*, 1199*s*, 1155*m*, 1011*m*, 882*m*. ^{1}H-NMR (300 MHz, $(CD_3)_2CO$): 5.17 (*s*, 2 H); 7.07 (*dd*, *J* = 9.0, 2.7, 1 H); 7.21 (*d*, *J* = 2.7, 1 H); 7.31–7.56 (*m*, 6 H); 7.68 (*d*, *J* = 9.0, 1 H); 8.03 (*s*, 1 H); 9.24 (*s*, 1 H). ^{13}C-NMR (75 MHz, $(CD_3)_2CO$): 70.51; 106.58; 110.29; 110.59; 117.92; 125.78; 128.56; 128.72; 129.14; 129.32; 132.68; 136.38; 138.20; 152.97; 158.50. EI-MS: 330 (19, M^+, $^{79}BrC_{17}H_{13}O_2$), 91 (100, $[C_7H_7]^+$). Anal. calc. for $C_{17}H_{13}BrO_2$ (329.20): C 62.03, H 3.98, O 9.72, Br 24.27; found: C 62.11, H 3.97, O 9.81, Br 24.32.

(±)-7,7′-Bis(benzyloxy)-3,3′-dibromo-1,1′-binaphthalene-2,2′-diol ((±)-**8**). *Method A:* A soln. of **7** (15 g, 46 mmol) and $CuCl_2$ (12.6 g, 94 mmol) in MeOH (1.5 l) was degassed, saturated with Ar, and *t*-BuNH_2 (21.0 ml, 14.6 g, 200 mmol) in MeOH (150 ml) was added slowly. The mixture was heated to reflux for 1 h, then cooled to 0°, and quenched with 6M aq. HCl soln. (600 ml) to yield a yellow precipitate which was filtered and redissolved in $CHCl_3$. The org. phase was washed with H_2O until neutral and evaporated *in vacuo* to afford (±)-**8** (12.5 g, 84%). White powder (toluene).

Method B: To a soln. of CuCl(OH)·TMEDA [45] (56 mg, 2 mol-%) in CH_2Cl_2 (200 ml), **7** (3.8 g, 11.5 mmol) was added at 0°. The mixture was stirred for 46 h at r.t., and then washed with 0.1M aq. NH_3 soln. and sat. aq. NaCl soln. Evaporation *in vacuo* gave (±)-**8** (2.4 g, 64%). White crystalline solid (toluene). M.p. 207–208°. IR ($CHCl_3$): 3511*m*, 3022*w*, 1622*s*, 1494*m*, 1450*w*, 1378*m*, 1267*m*, 1194*s*, 1072*w*, 1028*w*. ^{1}H-NMR (300 MHz, $CDCl_3$): 4.72 (*d*, *AB*, *J* = 12.3, 2 H); 4.79 (*d*, *AB*, *J* = 12.3, 2 H); 5.45 (*s*, 2 H); 6.38 (*d*, *J* = 2.4, 2 H); 7.10–7.27 (*m*, 12 H); 7.72 (*d*, *J* = 9.0, 2 H); 8.15 (*s*, 2 H). ^{13}C-NMR (75 MHz, $CDCl_3$): 69.9; 104.8; 109.2; 113.6; 117.8; 125.3; 127.5; 127.9; 128.5; 129.0; 132.4; 134.1; 136.1; 136.3; 148.5; 158.0. FAB-MS: 656 (100, M^+). Anal. calc. for $C_{34}H_{24}Br_2O_4$ (656.38): C 62.22, H 3.69, O 9.75, Br 24.35; found: C 62.32, H 3.97, O 9.55, Br 24.30.

*Optical Resolution of (±)-***8**. *(−)-[(*R*)-7,7′-Bis(benzyloxy)-3,3′-dibromo-1,1′-binaphthalene-2,2′-diyl] [(1*R*,2*S*,5*R*)-5-Methyl-2-(1-methylethyl)cyclohexyl] Phosphite* ((−)-**9**). To PCl_3 (1.12 ml, 1.76 g, 12.8 mmol) in dry THF (15 ml) was added over 30 min at 0° a soln. of (−)-(1*R*,2*S*,5*R*)-menthol (2.97 g, 19.0 mmol) in THF (15 ml). The mixture was cooled to −18°, and dry Et_3N (5.35 ml, 3.89 g, 38.4 mmol) was added. After stirring for 15 min, a portion of this suspension (27 ml, 9.47 mmol) was added to (±)-**8** (6.87 g, 10.47 mmol) in dry THF (15 ml) at −18°. The instantaneous disappearance of (±)-**8** was monitored by TLC (toluene). The white insoluble Et_3NHCl was removed by filtration through *Celite*, and Et_2O (200 ml) was added to the filtrate, and the soln. evaporated *in vacuo*. Pure (−)-**9** (3.23 g, 37%) was obtained by two recrystallizations at −18° from Et_2O. M.p. 181–182°. $[\alpha]_D^{rt.} = -394.5$ (*c* = 1.0, CH_2Cl_2). IR ($CHCl_3$): 2956*m*, 2922*m*, 2867*m*, 1622*s*, 1578*w*, 1500*s*, 1450*m*, 1383*s*, 1317*w*, 1217*s*, 978*s*, 883*m*, 844*s*. ^{1}H-NMR (500 MHz, $CDCl_3$): 0.83–2.39 (*m*, 18 H); 4.20–4.35 (*m*, 1 H); 4.53 (*d*, *AB*, *J* = 11.8, 2 H); 4.60 (*d*, *AB*, *J* = 11.8, 2 H); 6.55 (*d*, *J* = 2.4, 1 H); 6.57 (*d*, *J* = 2.4, 1 H); 7.00–7.24 (*m*, 12 H); 7.71 (*d*, *J* = 6.2, 1 H); 7.73 (*d*, *J* = 6.2, 1 H); 8.13 (*s*, 1 H); 8.16 (*s*, 1 H). ^{13}C-NMR (125 MHz, $CDCl_3$): 15.59; 15.62; 21.00; 22.07; 22.72; 24.96; 31.89; 34.03; 44.11; 44.14; 48.51; 48.53; 69.93; 78.22; 78.39; 106.89; 107.09; 113.24; 113.34; 119.12; 119.35; 123.17; 124.76; 124.80; 126.98; 127.17; 127.22; 127.41; 127.93; 127.95; 128.48; 128.82; 128.98; 132.21; 132.41; 132.47; 132.65; 136.26; 136.33; 144.89; 145.66; 157.22; 157.29 (There should be a total of 40 ^{13}C resonances; extra signals are caused by $J(^{31}P,^{13}C)$ of 3 Hz.) ^{31}P-NMR (121.5 MHz, $CDCl_3$): 155.1. FAB-MS: 841 (21, M^+), 703 (100, $[M - C_{10}H_{19}]^+$). Anal. calc. for $C_{44}H_{41}Br_2O_5P$ (840.60): C 62.87, H 4.92, O 9.52, Br 19.01, P 3.68; found: C 62.97, H 4.97, O 9.44, Br 18.84, P 3.59.

Compound (+)-**9** (679 mg, 24%) was obtained following the same procedure, starting with (+)-(1*S*,2*R*,5*S*)-menthol and (±)-**8** (2.20 g, 3.35 mmol). $[\alpha]_D^{rt.} = +394.5$ (*c* = 1.0, CH_2Cl_2). ^{31}P-NMR (121.5 MHz, $CDCl_3$): 155.3.

*Hydrolysis of (−)-***9**. Compound (−)-**9** (2.0 g, 2.4 mmol) was stirred with K_2CO_3 (2.0 g, 14.5 mmol) in $CHCl_3$/MeOH 1:1 (200 ml) for 30 min. The reaction was quenched with H_2O (100 ml), and the product

extracted with $CHCl_3$. Evaporation *in vacuo* yielded (−)-(*R*)-**8** (1.5 g, 97%) which was further converted without purification. A small amount was recrystallized from toluene to give a white solid with spectroscopic data identical to those of the racemic material (±)-**8** and $[\alpha]_D^{r.t.} = -79.4$ ($c = 1.0$, CH_2Cl_2).

Compound (+)-**9** was converted to (+)-(*S*)-**8** ($[\alpha]_D^{r.t.} = +79.4$ ($c = 1.0$, CH_2Cl_2)) in the same way.

*(−)-(*R*)-2,2′,7,7′-Tetrakis(benzyloxy)-1,1′-binaphthalene* ((−)-(*R*)-**10**). A soln. of (*R*)-**8** (50 mg, 76 μmol), ammonium formate (167 mg, 2.6 mmol), and Pd/C (10%, 36 mg) in MeOH (5 ml) was heated to reflux. After 30 min, the mixture was filtered through *Celite* and evaporated *in vacuo*. The crude product was treated with BnCl (100 μl, 110 mg, 0.87 mmol) and K_2CO_3 (0.48 g, 3.5 mmol) in DMF (10 ml) at 80° for 2 h, DMF was removed, the product was purified by CC (hexane/AcOEt 4:1), and then recrystallized from CH_2Cl_2 with layered addition of hexane to afford (*R*)-**10** (8 mg, 15%). $[\alpha]_D^{r.t.} = -15.2$ ($c = 0.5$, CH_2Cl_2). ^{1}H-NMR (300 MHz, $CDCl_3$): 4.65 (*d*, *AB*, $J = 11.7$, 2 H); 4.71 (*d*, *AB*, $J = 11.7$, 2 H); 4.91 (*d*, *AB*, $J = 12.6$, 2 H); 4.98 (*d*, *AB*, $J = 12.6$, 2 H); 6.90–7.30 (*m*, 24 H); 6.52 (*d*, $J = 2.4$, 2 H); 7.79 (*d*, $J = 9.0$, 2 H); 7.84 (*d*, $J = 8.7$, 2 H). ^{13}C-NMR (75 MHz, $CDCl_3$): 69.6; 71.0; 105.4; 113.6; 116.8; 119.9; 125.1; 126.7; 127.2; 127.5; 127.7; 128.1; 128.4; 128.8; 129.4; 135.3; 136.8; 137.7; 154.6; 157.1. FAB-MS: 678 (22, M^+), 91 (100, $[C_7H_7]^+$).

*(+)-(*R*)-7,7′-Bis(benzyloxy)-3,3′-dibromo-1,1′-binaphthalene-2,2′-diyl Dibenzoate* ((+)-(*R*)-**11**). To a soln. of (*R*)-**8** (1.30 g, 2.0 mmol) in CH_2Cl_2 (100 ml), pyridine (0.33 ml, 0.32 g, 4.0 mmol), DMAP (0.49 g, 4.0 mmol), and BzCl (0.58 ml, 0.64 g, 5.0 mmol) were added at 0°. The mixture was stirred at r.t. for 2 h and then washed with 0.02M aq. $CuSO_4$ soln., 20% aq. $NaHCO_3$ soln., and H_2O. Evaporation *in vacuo* and purification by CC (hexane/AcOEt 5:1) afforded (*R*)-**11** (1.64 g, 95%). White solid. M.p. 146–148°. $[\alpha]_D^{r.t.} = +8.0$ ($c = 1.0$, CH_2Cl_2). IR ($CHCl_3$): 3181*w*, 3149*w*, 1742*s*, 1622*m*, 1584*w*, 1499*m*, 1452*m*, 1384*m*, 1260*s*, 1224*s*, 1178*m*, 1150*w*, 1078*m*, 1059*m*, 1039*m*, 930*m*. ^{1}H-NMR (200 MHz, $CDCl_3$): 4.71 (*d*, *AB*, $J = 12.0$, 2 H); 4.89 (*d*, *AB*, $J = 12.0$, 2 H); 6.60 (br. *s*, 2 H); 7.10–7.60 (*m*, 18 H); 7.67 (*d*, $J = 9.1$, 2 H); 7.81 (br. *s*, 4 H); 8.10 (*s*, 2 H). ^{13}C-NMR (75 MHz, $CDCl_3$): 69.95; 106.17; 112.87; 120.38; 125.14; 127.62; 127.90; 127.97; 128.42 (2×); 128.64; 128.77; 130.08; 132.52; 133.49 (2×); 136.42; 145.11; 157.51; 163.81. FAB-MS: 864 (12, M^+), 105 (100, $[C_7H_5O]^+$). Anal. calc. for $C_{48}H_{32}Br_2O_6$ (864.59): C 66.68, H 3.73, O 11.10, Br 18.48; found: C 66.52, H 3.88, Br 18.29.

*(+)-(*R*)-7,7′-Bis(benzyloxy)-3,3′-bis[(trimethylsilyl)ethynyl]-1,1′-binaphthalene-2,2′-diyl Dibenzoate* ((+)-(*R*)-**12**). 1-(Trimethylsilyl)-2-(trimethylstannyl)ethyne (1.5 ml, 1.8 g, 6.7 mmol) [49], (*R*)-**11** (2.0 g, 2.3 mmol), $[Pd(PPh_3)_4]$ (10 mol-%, 267 mg), and 2,6-di-(*tert*-butyl)-*p*-cresol (200 mg, 10% by weight) were added to dry toluene (20 ml). The mixture was heated to 100° under Ar for 36 h. The black precipitate was removed by filtration through *Celite*, and the soln. washed with H_2O. CC (*Fluka* SiO_2-*H*; hexane/AcOEt 99.5:0.5 → 99:1), followed by recrystallization from CH_2Cl_2 with layered addition of pentane, afforded (*R*)-**12** (932 mg, 45%). M.p. 170–172°. $[\alpha]_D^{r.t.} = +1.6$ ($c = 1.0$, CH_2Cl_2). IR (CCl_4): 3066*w*, 2960*m*, 2898*w*, 2155*m*, 1744*s*, 1621*s*, 1495*m*, 1452*m*, 1410*w*, 1389*m*, 1314*w*. ^{1}H-NMR (300 MHz, $CDCl_3$): −0.06 (*s*, 18 H); 4.75 (*d*, *AB*, $J = 12.0$, 2 H); 4.92 (*d*, *AB*, $J = 12.0$, 2 H); 6.69 (*s*, 2 H); 7.55–7.71 (*m*, 18 H); 7.72 (*d*, $J = 9.0$, 2 H); 7.86 (*m*, 4 H); 8.08 (*s*, 2 H). ^{13}C-NMR (75 MHz, $CDCl_3$): −0.51; 69.87; 99.03; 100.62; 106.13; 114.18; 119.72; 123.37; 126.53; 127.79 (2×); 128.19; 128.37; 129.42; 129.48; 130.14; 133.08; 133.58; 134.54; 136.47; 148.28; 157.96; 164.16. FAB-MS: 899 (24, M^+), 105 (100, $[C_7H_5O]^+$). Anal. calc. for $C_{58}H_{50}O_6Si_2$ (899.21): C 77.47, H 5.60; found: C 77.30, H 5.82.

*(+)-(*R*)-7,7′-Bis(benzyloxy)-3,3′-diethynyl-1,1′-binaphthalene-2,2′-diyl Dibenzoate* ((+)-(*R*)-**13**). To a soln. of (*R*)-**12** (310 mg, 0.35 mmol) in THF/MeOH 1:1 (64 ml), K_2CO_3 (320 mg, 2.32 mmol) was added, and the mixture was stirred at r.t. for 2 h. CH_2Cl_2 (160 ml) was added, the org. phase washed with H_2O, and concentrated to yield (*R*)-**13** (237 mg, 91%). White powder (CH_2Cl_2/hexane). M.p. 95–97°. $[\alpha]_D^{r.t.} = +26.6$ ($c = 1.0$, CH_2Cl_2). IR (CCl_4): 3312*m*, 3066*w*, 2957*w*, 2110*w*, 1742*s*, 1622*m*, 1495*m*, 1452*m*, 1387*m*, 1260*m*, 1262*s*, 1071*m*. ^{1}H-NMR (300 MHz, $CDCl_3$): 3.12 (*s*, 2 H); 4.75 (*d*, *AB*, $J = 12.0$, 2 H); 4.92 (*d*, *AB*, $J = 12.0$, 2 H); 6.67 (br. *s*, 2 H); 7.10–7.60 (*m*, 18 H); 7.73 (*d*, $J = 9.0$, 2 H); 7.80–7.85 (*m*, 4 H); 8.10 (*s*, 2 H). ^{13}C-NMR (75 MHz, $CDCl_3$): 69.92; 79.50; 81.28; 106.01; 113.30; 119.94; 123.48; 126.54; 127.69; 127.84; 128.27; 128.38; 129.15; 129.42; 129.98; 133.18; 134.30; 134.58; 136.39; 147.98; 158.12; 164.22. FAB-MS: 755 (27, M^+), 105 (100, $[C_7H_5O]^+$). Anal. calc. for $C_{52}H_{34}O_6$ (754.85): C 82.74, H 4.54; found: C 82.94, H 4.73.

*(−)-(*R*)-7,7′-Bis(benzyloxy)-3,3′-diethynyl-1,1′-binaphthalene-2,2′-diol* ((−)-(*R*)-**14**). To a soln. of (*R*)-**13** (70 mg, 9.3 μmol) in THF (40 ml), KOH (1.9M soln. in MeOH, 50 μl, 95 μmol) was added, and the mixture was stirred for 1 h at r.t. The soln. was poured into Et_2O (40 ml), washed with H_2O (3 × 100 ml), dried (Mg_2SO_4), and evaporated to afford (*R*)-**14** (40 mg, 79%). Cream-colored solid. M.p. 174–176°. $[\alpha]_D^{r.t.} = -50$ ($c = 1.0$, CH_2Cl_2). IR (CCl_4): 3528*m*, 3307*m*, 2100*w*, 1625*s*, 1497*m*, 1453*w*, 1380*w*, 1264*m*, 1220*s*, 1141*m*, 1020*w*. ^{1}H-NMR (300 MHz, $CDCl_3$): 3.49 (*s*, 2 H); 4.72 (*d*, *AB*, $J = 12.0$, 2 H); 4.80 (*d*, *AB*, $J = 12.0$, 2 H); 5.60 (*s*, 2 H); 6.40 (*d*, $J = 9.0$, 2 H); 7.08–7.23 (*m*, 12 H); 7.75 (*d*, $J = 9.0$, 2 H); 8.09 (*s*, 2 H). ^{13}C-NMR (75 MHz, $CDCl_3$): 69.8; 79.1; 83.2; 104.8; 108.3; 112.2; 117.5; 124.0; 127.6; 127.9; 128.5; 129.9; 134.1; 135.4; 136.3; 152.0; 158.6. FAB-MS: 546 (51, M^+), 91 (100, $[C_7H_7]^+$). Anal. calc. for $C_{38}H_{26}O_4$ (546.63): C 83.50, H 4.79; found: C 83.27, H 4.97.

Glaser-Hay *Cyclization of (+)-(*R*)-***13***.* A soln. of CuCl (2.71 g, 27 mmol) and (*R*)-**13** (150 mg, 0.2 mmol) in CH_2Cl_2 (1 l) was stirred for 10 min under dry air, then TMEDA (4.21 ml, 3.24 g, 28 mmol) was added. After 20 min, the reaction was quenched with H_2O (1 l), the org. phase washed with H_2O, and concentrated. The above procedure was repeated, and the cyclic oligomers were then isolated by CC (cyclohexane →cyclohexane/AcOEt 4:1) to afford (*R*,*R*,*R*)-**15** (62 mg, 20%), in addition to tetramer (*R*,*R*,*R*,*R*)-**16** (62 mg, 20%), and pentamer (*R*,*R*,*R*,*R*,*R*)-**17** (5 mg, 4%).

*(−)-(*R,R,R*)-Tris[2,2′-bis(benzoyloxy)-7,7′-bis(benzyloxy)-1,1′-binaphthalene-3,3′-diylbis(ethynyl)]* ((−)-(*R*,*R*,*R*)-**15**). M.p. 168–172°. $[\alpha]_D^{r.t.} = -869.5$ ($c = 1.0$, CH_2Cl_2). IR ($CHCl_3$): 3066*w*, 3033*w*, 2214*m*, 2144*w*, 1745*s*, 1620*s*, 1495*m*, 1451*m*, 1391*m*, 1237*s*, 1208*m*, 1140*m*, 1080*m*. ^{1}H-NMR (300 MHz, $CDCl_3$): 4.54 (*d*, *AB*, $J =$ 12.1, 6 H); 4.78 (*d*, *AB*, $J = 12.1$, 6 H); 6.58 (*d*, $J = 2.4$, 6 H); 6.78–6.90 (*m*, 18 H); 7.12–7.24 (*m*, 36 H); 7.61 (*d*, $J = 9.0$, 6 H); 7.85 (*dd*, $J = 8.4$, 1.2, 12 H); 7.93 (*s*, 6 H). ^{13}C-NMR (75 MHz, (D_8)THF): 70.54; 78.31; 79.19; 106.90; 114.09; 120.77; 124.60; 127.60; 128.24; 128.43 (2×); 128.98; 129.06; 129.76; 130.62; 134.03; 134.66; 135.39; 137.69; 150.05; 159.61; 164.91. FAB-MS: 2258 (100, M^+). Anal. calc. for $C_{156}H_{96}O_{18}$ (2258.49): C 82.96, H 4.28; found: C 83.23, H 4.31.

*(−)-(*R,R,R,R*)-Tetrakis[2,2′-bis(benzoyloxy)-7,7′-bis(benzyloxy)-1,1′-binaphthalene-3,3′-diylbis(ethynyl)]* ((−)-(*R*,*R*,*R*,*R*)-**16**). M.p. 185–188°. $[\alpha]_D^{r.t.} = -855.6$ ($c = 1.0$, CH_2Cl_2). IR ($CHCl_3$): 3066*m*, 2213*w*, 2144*w*, 1744*s*, 1620*s*, 1494*m*, 1451*m*, 1390*m*, 1238*s*, 1206*m*, 1178*m*, 1139*w*, 1055*m*, 1023*m*, 892*w*. ^{1}H-NMR (300 MHz, $CDCl_3$): 4.69 (*d*, *AB*, $J = 12.0$, 8 H); 4.89 (*d*, *AB*, $J = 12.0$, 8 H); 6.60 (*d*, $J = 2.1$, 8 H); 7.10–7.30 (*m*, 72 H); 7.65 (*d*, $J = 9.3$, 8 H); 7.71 (*m*, 16 H); 7.93 (*s*, 8 H). ^{13}C-NMR (75 MHz, $CDCl_3$): 69.9; 77.8; 77.9; 106.2; 113.0; 120.1; 123.4; 126.5; 127.6; 127.9; 128.2; 128.4; 129.0; 129.5; 130.0; 133.1; 134.6; 134.8; 136.3; 148.3; 158.4; 164.4. FAB-MS: 3011 (100, M^+). Anal. calc. for $C_{208}H_{128}O_{24}$ (3011.32): C 82.96, H 4.28; found: C 83.23, H 4.39.

*(−)-(*R,R,R,R,R*)-Pentakis[2,2′-bis(benzoyloxy)-7,7′-bis(benzyloxy)-1,1′-binaphthalene-3,3′-diylbis(ethynyl)]* ((−)-(*R*,*R*,*R*,*R*,*R*)-**17**). M.p. 205–210. $[\alpha]_D^{r.t.} = -838.8$ ($c = 0.5$, CH_2Cl_2). IR ($CHCl_3$): 3060*m*, 2216*w*, 2143*w*, 1740*s*, 1619*s*, 1494*m*, 1451*m*, 1387*m*, 1315*w*, 1242*s*. ^{1}H-NMR (200 MHz, $CDCl_3$): 4.74 (*d*, *AB*, $J = 12.0$, 10 H); 4.92 (*d*, *AB*, $J = 12.0$, 10 H); 6.59 (*d*, $J = 2.4$, 10 H); 7.10–7.50 (*m*, 90 H); 7.64 (*m*, 30 H); 7.93 (*s*, 10 H). ^{13}C-NMR (75 MHz, $CDCl_3$): 70.0; 77.8; 78.1; 106.0; 113.1; 120.1; 123.4; 126.5; 127.6; 127.9; 128.2; 128.4; 129.0; 129.4; 129.9; 133.1; 134.6; 135.0; 136.3; 148.0; 158.4; 164.2. FAB-MS: 3764 (100, M^+). Anal. calc. for $C_{260}H_{160}O_{30}$ (3764.16): C 82.96, H 4.28; found: C 82.82, H 4.17.

*(−)-(*R,R,R*)-Tris[7,7′-bis(benzyloxy)-2,2′-dihydroxy-1,1′-binaphthalene-3,3′-diylbis(ethynyl)]* ((−)-(*R*,*R*,*R*)-**1**). Compound (*R*,*R*,*R*)-**15** (10 mg, 4.4 μmol) was dissolved in THF (20 ml), and the soln. degassed and saturated with N_2. After the addition of KOH (1.9M soln. in MeOH, 40 μl, 76 μmol), the mixture was stirred at r.t. for 30 min, then AcOEt (20 ml) was added, the org. phase washed with H_2O and evaporated *in vacuo*. The above procedure was repeated four times, and the combined products were recrystallized from CH_2Cl_2 with layered addition of hexane to yield (*R*,*R*,*R*)-**1** (26 mg, 90%). Yellow solid. M.p. 205° (dec.). $[\alpha]_D^{r.t.} = -1114$ ($c =$ 1.0, CH_2Cl_2). IR ($CHCl_3$): 3520*s*, 3066*m*, 2928*s*, 2855*m*, 2203*m*, 2129*m*. ^{1}H-NMR (300 MHz, $CDCl_3$): 4.63 (*d*, *AB*, $J = 12.0$, 6 H); 4.73 (*d*, *AB*, $J = 12.0$, 6 H); 5.75 (*s*, 6 H); 6.41 (*d*, $J = 2.4$, 6 H); 7.07–7.23 (*m*, 36 H); 7.75 (*d*, $J = 9.3$, 6 H); 8.08 (*s*, 6 H). ^{13}C-NMR (75 MHz, (D_8)THF): 70.24; 79.15; 80.61; 105.98; 111.19; 114.05; 117.50; 124.83; 128.25; 128.37; 128.98; 130.60; 134.39; 137.15; 137.95; 156.28; 159.48. FAB-MS: 1633 (6, M^+), 91 (100, $[C_7H_7]^+$). Anal. calc. for $C_{114}H_{72}O_{12}$ (1633.84): C 83.81, H 4.44; found: C 84.11, H 4.69.

6-(Benzyloxy)-2-iodo-3-(methoxymethoxy)naphthalene (**18**). To a soln. of **6** (2.0 g, 5.4 mmol) in dry THF (40 ml) at −78°, *t*-BuLi (1.7M soln. in pentane, 4.8 ml, 7.5 mmol) was added, and the mixture was stirred for 30 min. A soln. of I_2 (1.9 g, 8.2 mmol) in dry THF (10 ml) was added, and the mixture was left to warm to r.t., then stirred for 12 h. After hydrolysis with H_2O (20 ml), the product was extracted with CH_2Cl_2, and the org. phase was washed with 10% aq. $Na_2S_2O_5$ soln. and H_2O. Evaporation *in vacuo* afforded **18** (2.19 g, 97%). White crystals (hexane). M.p. 93–95°. IR (KBr): 1624*s*, 1583*m*, 1500*s*, 1452*s*, 1424*m*, 1390*s*, 1366*s*, 1302*m*, 1272*w*, 1244*m*, 1217*s*, 1204*s*, 1151*s*, 1133*m*, 1086*m*, 1012*s*. ^{1}H-NMR (300 MHz, $CDCl_3$): 3.55 (*s*, 3 H); 5.16 (*s*, 2 H); 5.34 (*s*, 2 H); 7.08–7.12 (*m*, 2 H); 7.30 (*s*, 1 H); 7.35–7.49 (*m*, 5 H); 7.58 (*d*, $J = 9.7$, 1 H); 8.23 (*s*, 1 H). ^{13}C-NMR (75 MHz, $CDCl_3$): 56.55; 70.17; 85.16; 95.21; 106.68; 109.16; 118.09; 126.86; 127.78; 128.34; 128.39; 128.91; 135.75; 136.98; 139.03; 153.66; 157.98. EI-MS: 420 (100, M^+); 91 (58, $[C_7H_7]^+$). Anal. calc. for $C_{19}H_{17}O_3I$ (420.25): C 54.30, H 4.08, I 30.20; found: C 54.46, H 3.88, I 29.95.

7-(Benzyloxy)-3-iodonaphthalen-2-ol (**19**). A soln. of **18** (3.0 g, 7.1 mmol) and conc. aq. HCl soln. (37%, 2.7 ml) in THF/MeOH 2:1 (60 ml) was heated to reflux for 3 h. After cooling to r.t., the mixture was quenched with H_2O (30 ml), the product extracted in CH_2Cl_2, the org. phase washed with sat. aq. NaCl soln. and evaporated *in vacuo*. The residue was suspended in hexane, filtered, and dried to give **19** (2.6 g, 97%). White crystalline solid. M.p. 169–170°. IR (KBr): 3393*m*, 1622*s*, 1588*s*, 1512*m*, 1472*w*, 1454*m*, 1420*s*, 1394*m*, 1372*s*, 1328*w*, 1289*w*, 1270*w*, 1217*s*, 1200*s*, 1161*m*, 1134*m*, 1078*w*, 1005*s*. ^{1}H-NMR (300 MHz, $CDCl_3$): 5.16 (*s*, 2 H); 5.38

(*s*, 1 H); 7.25 (*s*, 1 H); 7.06–7.10 (*m*, 2 H); 7.35–7.50 (*m*, 5 H); 7.58 (*d*, *J* = 8.7, 1 H); 8.15 (*s*, 1 H). ^{13}C-NMR (50 MHz, $CDCl_3$): 67.64; 82.43; 103.41; 106.46; 115.32; 123.76; 125.28; 125.79; 125.89; 126.33; 133.82; 134.36; 135.63; 149.69; 155.56. EI-MS: 376 (10, M^+), 91 (100, $[C_7H_7]^+$). Anal. calc. for $C_{17}H_{13}IO_2$ (376.20): C 54.28, H 3.48; found: C 54.33, H 3.63.

(±)-7,7′-Bis(benzyloxy)-3,3′-diiodo-1,1′-binaphthalene-2,2′-diol ((±)-**20**). Compound (±)-**20** (2.0 g, 65%) was prepared from **19** (3.1 g, 8.2 mmol) using $CuCl_2$ (2.2 g, 16.4 mmol) and *t*-$BuNH_2$ (3.6 ml, 2.5 g, 34.3 mmol) by *Method A*, described above for the synthesis of (±)-**8**. M.p. 197°. IR (KBr): 3444*m*, 1620*s*, 1578*w*, 1499*s*, 1449*m*, 1368*s*, 1217*s*, 1200*s*, 1161*s*, 1074*m*. ^{1}H-NMR (300 MHz, $CDCl_3$): 4.73 (*d*, *AB*, *J* = 12.2, 2 H); 4.78(*d*, *AB*, *J* = 12.2, 2 H); 5.35 (*s*, 2 H); 6.35 (*d*, *J* = 2.2, 2 H); 7.08–7.23 (*m*, 12 H); 7.70 (*d*, *J* = 8.7, 2 H); 8.40 (*s*, 2 H). ^{13}C-NMR (75 MHz, $CDCl_3$): 158.56; 150.96; 140.14; 136.50; 134.85; 129.17; 128.75; 128.21; 127.75; 126.56; 117.88; 111.94; 104.82; 82.88; 70.02. FAB-MS: 750 (100, M^+). Anal. calc. for $C_{34}H_{24}O_4I_2$ (750.38): C 54.42, H 3.22, I 33.82; found: C 54.22, H 3.04, I 33.66.

(+)-(S)-7,7′-Bis(benzyloxy)-2,2′-bis(methoxymethoxy)-3,3′-dibromo-1,1′-binaphthalene ((+)-(*S*)-**21**). To a degassed mixture of (*S*)-**8** (1.30 g, 2.0 mmol) and K_2CO_3 (1.7 g, 12.3 mmol) in dry MeCN (50 ml), MOMCl (0.61 ml, 0.65 g, 8.0 mmol) was added at 0°. The mixture was stirred for 15 h at r.t., then the salts were removed by filtration through *Celite*. Evaporation *in vacuo* gave (*S*)-**21** (1.43 g, 96%). White crystalline solid (hexane). M.p. 112°. $[\alpha]_D^{r.t.} = +155.4$ (*c* = 1.0, $CHCl_3$). IR (KBr): 3485*m* (br.), 2944*w*, 2889*w*, 1620*s*, 1496*s*, 1453*m*, 1380*s*, 1228*s*, 1205*s*, 1155*s*, 1088*w*, 1029*m*, 930*s*. ^{1}H-NMR (300 MHz, $CDCl_3$): 2.63 (*s*, 6 H); 4.49 (*d*, *AB*, *J* = 5.4, 2 H); 4.66 (*d*, *AB*, *J* = 12.6, 2 H); 4.69 (*d*, *AB*, *J* = 5.4, 2 H); 4.70 (*d*, *AB*, *J* = 12.6, 2 H); 6.40 (*d*, *J* = 2.2, 2 H); 7.02–7.05 (*m*, 4 H); 7.16–7.20 (*m*, 8 H); 7.72 (*d*, *J* = 8.7, 2 H); 8.16 (*s*, 2 H). ^{13}C-NMR (300 MHz, $CDCl_3$): 56.34; 69.82; 77.21; 98.87; 106.48; 114.66; 119.39; 126.34; 127.10; 127.28; 127.90; 128.54; 132.54; 134.25; 136.47; 150.43; 157.32. FAB-MS: 744 (100, M^+). Anal. calc. for $C_{38}H_{32}O_6Br_2$ (744.48): C 61.32, H 4.33, Br 21.47; found: C 61.34, H 4.24, Br 21.22.

(±)-7,7′-Bis(benzyloxy)-2,2′-bis(methoxymethoxy)-3,3′-diiodo-1,1′-binaphthalene ((±)-**22**). To a soln. of (±)-**21** (1.07 g, 1.4 mmol) in dry THF (25 ml), *t*-BuLi (1.7M soln. in pentane, 2.5 ml, 4.3 mmol) was added at −78°. The mixture was stirred for 30 min, and a soln. of I_2 (1.10 g, 4.3 mmol) in dry THF (4.5 ml) was added. After stirring at −78° for 2.5 h, the reaction was quenched with H_2O (4 ml), the product extracted with CH_2Cl_2, and the org. phase washed with 10% aq. $Na_2S_2O_5$ soln. and H_2O. Evaporation *in vacuo* gave (±)-**22** (1.13 g, 93%). White crystals (CH_2Cl_2/hexane). M.p. 132°. ^{1}H-NMR (300 MHz, $CDCl_3$): 2.65 (*s*, 6 H); 4.32 (*d*, *AB*, *J* = 5.3, 2 H); 4.63 (*d*, *AB*, *J* = 5.3, 2 H); 4.63 (*d*, *AB*, *J* = 12.4, 2 H); 4.70 (*d*, *AB*, *J* = 12.4, 2 H); 6.38 (*d*, *J* = 2.5, 2 H); 7.00–7.20 (*m*, 12 H); 7.69 (*d*, *J* = 9.0, 2 H); 8.41 (*s*, 2 H). ^{13}C-NMR (50 MHz, $CDCl_3$): 54.18; 67.48; 86.75; 96.65; 104.11; 116.78; 122.84; 124.81; 125.50; 125.57; 125.98; 126.17; 132.65; 134.08; 137.00; 150.07; 155.09. FAB-MS: 838 (100, M^+). Anal. calc. for $C_{38}H_{32}O_6I_2$ (838.48): C 54.43, H 3.85, O 11.45; found: C 54.24, H 3.80, O 11.56.

(+)-(S)-7,7′-Bis(benzyloxy)-2,2′-bis(methoxymethoxy)-3,3′-diiodo-1,1′-binaphthalene ((+)-(*S*)-**22**). To a soln. of (*S*)-**21** (500 mg, 0.7 mmol) in dry THF (40 ml), TMEDA (0.51 ml, 390 mg, 3.4 mmol) and BuLi (1.6M soln. in hexane, 2.10 ml, 3.4 mmol) were added at −78°. The mixture was stirred for 45 min, and a soln. of I_2 (792 mg, 3.1 mmol) in dry THF (10 ml) was added. After 15 min, the reaction was quenched with 10% aq. $Na_2S_2O_5$ soln., the product extracted with CH_2Cl_2, the org. phase washed with H_2O, and dried (Na_2SO_4). Evaporation *in vacuo* gave the crude product which was purified by CC (hexane/AcOEt 3 : 1 containing 0.5% Et_3N) to give (*S*)-**22** (369 mg, 66%). White powder with spectroscopic data identical to those of the racemic material (±)-**22** and $[\alpha]_D^{r.t.} = +91.6$ (*c* = 1.0, $CHCl_3$).

(+)-(S)-7,7′-Bis(benzyloxy)-2,2′-bis(methoxymethoxy)-3,3′-bis[(trimethylsilyl)ethynyl]-1,1′-binaphthalene ((+)-(*S*)-**23**). To a degassed soln. of (*S*)-**22** (559 mg, 0.67 mmol) in dry Et_2NH (13 ml) and dry toluene (13 ml), CuI (56 mg, 0.29 mmol), $[PdCl_2(dppf)]\cdot CH_2Cl_2$ (22 mg, 4 mol-%), and (trimethylsilyl)acetylene (0.3 ml, 209 mg, 2.16 mmol) were added, and the mixture stirred at 40° for 4 h. After evaporation of the solvent, the residue was dissolved in CH_2Cl_2, the org. phase washed with sat. aq. NH_4Cl soln. and H_2O, dried (Na_2SO_4), and evaporated *in vacuo*. CC (hexane/AcOEt 7 : 5 containing 0.5% Et_3N) afforded (*S*)-**23** (509 mg, 98%). White solid. M.p. 156–158°. $[\alpha]_D^{r.t.} = +43.1$ (*c* = 1.0, $CHCl_3$). IR (KBr): 3480*s* (br.), 2956*w*, 2891*w*, 2154*m*, 1618*s*, 1492*m*, 1376*m*, 1245*s*, 1221*m*, 1160*m*, 1071*w*, 983*m*, 950*m*, 888*w*, 843*s*, 759*w*. ^{1}H-NMR (300 MHz, $CDCl_3$): 0.26 (*s*, 18 H); 2.51 (*s*, 6 H); 4.62 (*d*, *AB*, *J* = 12.1, 2 H); 4.68 (*d*, *AB*, *J* = 12.1, 2 H); 4.80 (*d*, *AB*, *J* = 5.9, 2 H); 4.94 (*d*, *AB*, *J* = 5.9, 2 H); 6.40 (*d*, *J* = 2.5, 2 H); 7.04–7.07 (*m*, 4 H); 7.13 (*dd*, *J* = 9.0, 2.5, 2 H); 7.17–7.20 (*m*, 6 H); 7.71 (*d*, *J* = 9.0, 2 H); 8.07 (*s*, 2 H). ^{13}C-NMR (75 MHz, $CDCl_3$): −0.08; 56.16; 69.86; 98.33; 98.75; 102.44; 106.60; 114.77; 119.03; 124.90; 125.88; 127.55; 127.99; 128.65; 129.35; 134.70; 135.38; 136.71; 154.15; 158.00. FAB-MS: 779 (65, M^+); 91 (100, $[C_7H_7]^+$). Anal. calc. for $C_{48}H_{50}O_6Si_2$ (779.10): C 74.00, H 6.47; found: C 74.23, H 6.31.

(+)-(S)-7,7′-Bis(benzyloxy)-2,2′-bis(methoxymethoxy)-3,3′-diethynyl-1,1′-binaphthalene ((+)-(*S*)-**24**). To a soln. of (*S*)-**23** (330 mg, 0.42 mmol) in THF/MeOH 1:1 (70 ml), K_2CO_3 (385 mg, 2.79 mmol) was added, and the mixture was stirred at r.t. for 2 h. After the addition of CH_2Cl_2 (160 ml), the org. phase was washed with H_2O and dried (Na_2SO_4). Evaporation *in vacuo* and CC (hexane/AcOEt 5:1, 0.5% Et_3N) afforded (*S*)-**24** (249 mg, 93%). White powder. M.p. 160–162°. $[\alpha]_D^{r.t.} = +71.4$ ($c = 1.0$, $CHCl_3$). IR (KBr): 3279*m*, 3233*m*, 2821*w*, 2822*w*, 2089*w*, 1619*s*, 1493*s*, 1448*m*, 1379*s*, 1241*s*, 1220*s*, 1158*s*, 1099*w*, 1068*m*, 1026*m*, 940*s* (br.), 851*w*, 812*w*, 736*m*. ^{1}H-NMR (500 MHz, $CDCl_3$): 2.60 (*s*, 6 H); 3.30 (*s*, 2 H); 4.66 (*d*, *AB*, $J = 12.1$, 2 H); 4.70 (*d*, *AB*, $J = 12.1$, 2 H); 4.81 (*d*, *AB*, $J = 5.7$, 2 H); 4.84 (*d*, *AB*, $J = 5.7$, 2 H); 6.43 (*d*, $J = 2.5$, 2 H); 7.05–7.07 (*m*, 4 H); 7.14–7.19 (*m*, 8 H); 7.74 (*d*, $J = 9.0$, 2 H); 8.10 (*s*, 2 H). ^{13}C-NMR (75 MHz, $CDCl_3$): 56.13; 69.82; 80.81; 98.68; 106.37; 111.58; 113.74; 118.87; 124.65; 125.63; 127.28; 127.79; 128.41; 129.18; 134.73; 135.25; 136.34; 153.81; 157.85. FAB-MS: 634 (100, M^+). Anal. calc. for $C_{42}H_{34}O_6$ (634.74): C 79.48, H 5.40; found: C 79.24, H 5.29.

(+)-(S,S,S)-Tris[7,7′-bis(benzyloxy)-2,2′-bis(methoxymethoxy)-1,1′-binaphthalene-3,3′-diylbis(ethynyl)] ((+)-(*S,S,S*)-**25**). A mixture of (*S*)-**24** (100 mg, 0.16 mmol) and CuCl (1.35 g, 14 mmol) in CH_2Cl_2 (500 ml) was stirred for 10 min under dry air, then TMEDA (2.1 ml, 1.62 g, 14 mmol) was added. After 3 h, the reaction was quenched with H_2O (500 ml), the org. phase washed (H_2O), and concentrated. CC (cyclohexane/AcOEt 4:1) yielded a mixture of cyclic oligomers, and separation by GPC (toluene) afforded (*S,S,S*)-**25** (25 mg, 25%). M.p. 272°. $[\alpha]_D^{r.t.} = +445.2$ ($c = 0.5$, $CHCl_3$). IR (KBr): 3059*m*, 2929*m*, 2200*w*, 2133*w*, 1617*s*, 1494*m*, 1450*m*, 1378*m*, 1261*m*, 1217*s*, 1156*m*, 1017*m*. ^{1}H-NMR (200 MHz, $CDCl_3$): 2.68 (*s*, 18 H); 4.62 (*d*, *AB*, $J = 12.0$, 6 H); 4.71 (*d*, *AB*, $J = 12.0$, 6 H); 4.77 (*d*, *AB*, $J = 5.6$, 6 H); 4.87 (*d*, *AB*, $J = 5.6$, 6 H); 6.52 (*d*, $J = 2.4$, 6 H); 7.05–7.24 (*m*, 36 H); 7.76 (*d*, $J = 9.0$, 6 H); 8.09 (*s*, 6 H). ^{13}C-NMR (50 MHz, $CDCl_3$): 53.89; 67.45; 75.80; 77.61; 96.68; 104.02; 111.44; 116.59; 122.17; 123.25; 124.93; 125.54; 126.11; 127.25; 131.66; 133.03; 134.04; 153.25; 155.85. MALDI-TOF-MS (dithranol): 1920 ($[M + Na]^+$), 1936 ($[M + K]^+$). Anal. calc. for $C_{126}H_{96}O_{18}$ (1898.16): C 79.73, H 5.10; found: C 79.86, H 5.31.

(+)-(S,S,S)-Tris[7,7′-bis(benzyloxy)-2,2′-dihydroxy-1,1′-binaphthalene-3,3′-diylbis(ethynyl)] ((+)-(*S,S,S*)-**1**). To a soln. of (*S,S,S*)-**25** (18 mg, 9.5 μmol) in THF/MeOH 1:1 (6 ml), conc. aq. HCl soln. (37%, 0.3 ml) was added. After stirring for 12 h, the solid was filtered and dried to give (*S,S,S*)-**1** (12 mg, 77%) with anal. data identical to those of (*R,R,R*)-**1** and $[\alpha]_D^{r.t.} = +554.3$ ($c = 0.5$, $CHCl_3$).

(+)-(S)-2,2′-Bis(methoxymethoxy)-3,3′-diiodo-1,1′-binaphthalene ((+)-(*S*)-**28**). To a soln. of (*S*)-**27** [62] (1.60 g, 4.3 mmol) in dry Et_2O (80 ml), TMEDA (2.39 ml, 1.85 g, 15.9 mmol) and BuLi (1.6M soln. in hexane, 9.8 ml, 15.7 mmol) were added at r.t. After stirring for 6.5 h, a soln. of I_2 (5.09 g, 20.1 mmol) in Et_2O (40 ml) was slowly added at −78°. The mixture was stirred for 2 h, then warmed to r.t., and quenched with 10% aq. $Na_2S_2O_5$ soln. (15 ml). The product was extracted with AcOEt, the org. phase washed with H_2O, and evaporated *in vacuo*. CC (hexane/AcOEt 9:1 containing 0.5% Et_3N) afforded (*S*)-**28** (1.75 g, 65%). White crystals. M.p. 92°. $[\alpha]_D^{r.t.} = +8.7$ ($c = 1.0$, THF). IR (KBr): 2922*w*, 2356*w*, 1383*m*, 1344*m*, 1180*s*, 994*s*, 956*s*. ^{1}H-NMR (200 MHz, $CDCl_3$): 2.63 (*s*, 6 H); 4.72 (*d*, *AB*, $J = 5.4$, 2 H); 4.83 (*d*, *AB*, $J = 5.4$, 2 H); 7.18–7.22 (*dd*, $J = 8.3$, 0.8, 2 H); 7.29–7.33 (*m*, 2 H); 7.36–7.49 (*m*, 2 H); 7.80 (*d*, $J = 7.9$, 2 H); 8.57 (*s*, 2 H). ^{13}C-NMR (50 MHz, $CDCl_3$): 54.09; 90.09; 97.03; 123.54; 123.92; 124.20; 124.43; 124.81; 129.92; 131.57; 137.73; 149.91. FAB-MS: 626 (16, M^+), 468 (100, $[M - I - MeO]^+$). Anal. calc. for $C_{24}H_{20}O_4I_2$ (626.23): C 46.03, H 3.22; found: C 45.85, H 3.09.

Compound (−)-(*R*)-**28** ($[\alpha]_D^{r.t.} = -7.4$ ($c = 1.0$, THF)) was prepared in the same manner.

(−)-(S)-2,2′-Bis(methoxymethoxy)-3,3′-bis[(trimethylsilyl)ethynyl]-1,1′-binaphthalene ((−)-(*S*)-**29**). To a degassed soln. of (*S*)-**28** (1.06 g, 1.7 mmol) in dry Et_3N (29 ml), $[PdCl_2(PPh_3)_2]$ (58 mg, 5 mol-%), CuI (17 mg, 5 mol-%), and (trimethylsilyl)acetylene (1.0 ml, 0.69 g, 7.5 mmol) were added, and the mixture was stirred for 20 h at 40°. The reaction was quenched with sat. aq. NaCl soln. (20 ml), the mixture filtered through *Celite*, and the soln. extracted with CH_2Cl_2. The org. phase was washed with sat. aq. $NaHCO_3$ soln., dried (Na_2SO_4), and concentrated. CC (hexane/AcOEt 5:1 containing 0.5% Et_3N) afforded (*S*)-**29** (0.86 g, 90%). White crystals (hexane). M.p. 170°. $[\alpha]_D^{r.t.} = -34.7$ ($c = 0.1.0$, THF). IR (KBr): 2956*m*, 2155*m*, 1426*m*, 1244*s*, 1158*s*, 1068*s*, 978*s*, 911*m*, 844*s*, 759*m*. ^{1}H-NMR (300 MHz, $CDCl_3$): 0.27 (*s*, 18 H); 2.44 (*d*, $J = 0.6$, 6 H); 4.87 (*dd*, *AB*, $J = 6.2$, 0.6, 2 H); 5.18 (*dd*, *AB*, $J = 6.2$, 0.6, 2 H); 7.15–7.18 (*d*, $J = 8.7$, 2 H); 7.25–7.30 (*m*, 2 H); 7.38–7.43 (*m*, 2 H); 7.81 (*d*, $J = 8.1$, 2 H); 8.17 (*s*, 2 H). ^{13}C-NMR (75 MHz, $CDCl_3$): −0.13; 56.06; 98.88; 99.29; 102.09; 117.26; 125.27; 126.01; 126.79; 127.50; 127.75; 130.38; 134.14; 135.15; 153.66. FAB-MS: 566 (63, M^+), 391 (100). Anal. calc. for $C_{34}H_{38}O_4Si_2$ (566.85): C 72.04, H 6.76; found: C 72.00, H 6.55.

Compound (+)-(*R*)-**29** ($[\alpha]_D^{r.t.} = +35.4$ ($c = 1.0$, THF)) was prepared in the same manner.

(−)-(S)-2,2′-Bis(methoxymethoxy)-3-3′-diethynyl-1,1′-binaphthalene ((−)-(*S*)-**30**). A soln. of (*S*)-**29** (0.70 g, 1.2 mmol) and K_2CO_3 (1.17 g, 8.5 mmol) in MeOH/THF 1:1 (120 ml) was stirred at r.t. for 3 h. After addition of CH_2Cl_2 (500 ml), the org. phase was washed with H_2O, dried (Na_2SO_4), and concentrated. CC (hexane/AcOEt 5:1 containing 0.5% Et_3N) afforded (*S*)-**30** (0.51 g, 98%). White powder. M.p. 42°. $[\alpha]_D^{r.t.} =$

– 83.0 ($c = 1.0$, THF). IR (KBr): 3280*s*, 2925*m*, 2100*w*, 1617*w*, 1490*m*, 1425*m*, 1392*m*, 1353*m*, 1240*s*, 1156*s*, 1064*s*, 9173*s*, 751*s*. ^{1}H-NMR (500 MHz, $CDCl_3$): 2.53 (*s*, 6 H); 3.33 (*s*, 2 H); 4.89 (*d*, *AB*, $J = 6.0$, 2 H); 5.08 (*d*, *AB*, $J =$ 6.0, 2 H); 7.19–7.21 (*m*, 2 H); 7.29–7.32 (*m*, 2 H); 7.41–7.44 (*m*, 2 H); 7.82–7.84 (*m*, 2 H); 8.20 (*s*, 2 H). ^{13}C-NMR (125 MHz, $CDCl_3$): 56.05; 80.60; 81.52; 98.87; 116.24; 125.46; 125.59; 125.76; 127.49; 127.57; 130.11; 133.97; 135.23; 153.37. FAB-MS: 422 (36, M^+), 391 (100, $[M - MeO]^+$). Anal. calc. for $C_{28}H_{22}O_4 \cdot 0.5\ H_2O$ (431.48): C 77.94, H 5.37; found: C 77.95, H 5.56.

Compound (+)-(*R*)-**30** ($[\alpha]_D^{r.t.} = +81.8$ ($c = 1.0$, THF)) was prepared in the same manner.

Glaser-Hay *Cyclization of* (S)-**30**. A soln. of (*S*)-**30** (150 mg, 0.35 mmol) and CuCl (4.0 g, 40 mmol) in CH_2Cl_2 (1.8 l) was stirred for 15 min, then TMEDA (6.0 ml, 4.6 g, 40 mmol) was added. The mixture was stirred for 2 h under dry air, then quenched with H_2O. The org. phase was washed (H_2O), dried (Na_2SO_4), and concentrated. Separation by GPC (toluene) afforded (*S*,*S*,*S*)-**31** (55 mg, 37%) in addition to tetramer (*S*,*S*,*S*,*S*)-**32** (36 mg, 24%) and pentamer (*S*,*S*,*S*,*S*,*S*)-**33** (8 mg, 5%).

*(+)-(*S,S,S*)-Tris[2,2′-bis(methoxymethoxy)-1,1′-binaphthalene-3,3′-diylbis(ethynyl)]* ((+)-(*S*,*S*,*S*)-**31**). M.p. > 300°. $[\alpha]_D^{r.t.} = +1287.8$ ($c = 1.0$, THF). IR (KBr): 2928*m*, 2202*w*, 2134*w*, 1618*m*, 1584*m*, 1490*m*, 1448*m*, 1426*m*, 1388*m*, 1349*m*, 1238*m*, 1200*m*, 1152*s*, 1067*s*, 969*s*, 914*m*. ^{1}H-NMR (500 MHz, $CDCl_3$): 2.59 (*s*, 18 H); 4.83 (*d*, *AB*, $J = 6.4$, 6 H); 5.05 (*d*, *AB*, $J = 6.4$, 6 H); 7.24 (*d*, $J = 8.7$, 6 H); 7.30–7.33 (*m*, 6 H); 7.42–7.45 (*m*, 6 H); 7.84 (*d*, $J = 8.1$, 6 H); 8.18 (*s*, 6 H). ^{13}C-NMR (125 MHz, $CDCl_3$): 56.23; 78.60; 79.95; 99.20; 116.25; 125.60; 125.63; 126.47; 127.79; 127.94; 130.08; 134.14; 134.46; 154.86. MALDI-TOF-MS (dithranol): 1284 ($[M + Na]^+$), 1303 ($[M + K]^+$). Anal. calc. for $C_{84}H_{60}O_{12}$ (1261.41): C 79.98, H 4.79; found: C 79.73, H 4.77.

*(+)-(*S,S,S,S*)-Tetrakis[2,2′-bis(methoxymethoxy)-1,1′-binaphthalene-3,3′-diylbis(ethynyl)]* ((+)-(*S*,*S*,*S*,*S*)-**32**). M.p. > 300°. $[\alpha]_D^{r.t.} = +992.0$ ($c = 1.0$, THF). IR (KBr): 2950*m*, 2211*w*, 2138*w*, 1725*m*, 1616*m*, 1583*m*, 1489*m*, 1446*m*, 1428*m*, 1390*m*, 1353*m*, 1240*m*, 1155*s*, 1071*m*, 968*s*, 907*m*. ^{1}H-NMR (300 MHz, $CDCl_3$): 2.58 (*s*, 24 H); 4.90 (*d*, *AB*, $J = 6.3$, 8 H); 5.13 (*d*, *AB*, $J = 6.3$, 8 H); 7.20 (*d*, $J = 8.4$, 8 H); 7.30–7.35 (*m*, 8 H); 7.41–7.46 (*m*, 8 H); 7.85 (*d*, $J = 8.1$, 8 H); 8.24 (*s*, 8 H). ^{13}C-NMR (125 MHz, $CDCl_3$): 56.37; 78.29; 79.47; 99.40; 116.29; 125.97; 126.03; 126.76; 128.00; 128.08; 130.37; 134.48; 135.98; 154.26. MALDI-TOF-MS (HABA): 1705 ($[M + Na]^+$). Anal. calc. for $C_{112}H_{80}O_{16} \cdot 3\ H_2O$ (1735.92): C 77.49, H 4.99; found: C 77.38, H 5.22.

*(+)-(*S,S,S,S,S*)-Pentakis[2,2′-bis(methoxymethoxy)-1,1′-binaphthalene-3,3′-diylbis(ethynyl)]* ((+)-(*S*,*S*,*S*,*S*,*S*)-**33**). M.p. > 300°. $[\alpha]_D^{r.t.} = +339.8$ ($c = 1.0$, THF). IR (KBr): 2956*m*, 2207*w*, 2131*w*, 1731*w*, 1621*m*, 1586*m*, 1490*m*, 1446*m*, 1424*m*, 1394*m*, 1350*m*, 1258*m*, 1153*s*, 1079*m*, 969*s*, 912*m*. ^{1}H-NMR (500 MHz, $CDCl_3$): 2.60 (*s*, 30 H); 4.90 (*d*, *AB*, $J = 6.3$, 10 H); 5.12 (*d*, *AB*, $J = 6.3$, 10 H); 7.20 (*d*, $J = 8.7$, 10 H); 7.30–7.35 (*m*, 10 H); 7.42–7.47 (*m*, 10 H); 7.85 (*d*, $J = 8.1$, 10 H); 8.23 (*s*, 10 H). ^{13}C-NMR (125 MHz, $CDCl_3$): 56.38; 78.32; 79.62; 99.39; 116.27; 126.01 (2×); 126.74; 127.97; 128.12; 130.40; 134.39; 136.19; 154.02. MALDI-TOF-MS (HABA): 2126 ($[M + Na]^+$).

*(+)-(*S,S,S*)-Tris[2,2′-dihydroxy-1,1′-binaphthalene-3,3′-diylbis(ethynyl)]* ((+)-(*S*,*S*,*S*)-**2**). To a soln. of (*S*,*S*,*S*)-**31** (22 mg, 1.7 μmol) in THF/MeOH 1:1 (6 ml) was added conc. aq. HCl soln. (37%, 0.4 ml), and the mixture was stirred for 12 h. After addition of H_2O (35 ml), the precipitate was filtered and dried to afford (*S*,*S*,*S*)-**2** (17 mg, 97%). M.p. 260° (dec.). $[\alpha]_D^{r.t.} = +1663.5$ ($c = 1.0$ THF). IR (KBr): 3508*s*, 3056*w*, 2200*w*, 2140*w*, 1619*s*, 1494*m*, 1455*m*, 1430*m*, 1392*m*, 1349*m*, 1264*s*, 1240*s*, 1150*s*, 1097*w*, 889*m*. ^{1}H-NMR (200 MHz, $CDCl_3$): 5.75 (*s*, 6 H); 6.97 (*d*, $J = 8.3$, 6 H); 7.13–7.20 (*m*, 6 H); 7.31–7.35 (*m*, 6 H); 7.82–7.86 (*d*, $J = 7.9$, 6 H); 8.14 (*s*, 6 H). ^{13}C-NMR (50 MHz, $CDCl_3$): 76.43; 77.45; 108.55; 111.00; 122.05; 122.90; 125.89; 126.14; 126.24; 131.95; 132.14; 149.91. FAB-MS: 997 (100, M^+). Anal. calc. for $C_{72}H_{36}O_6 \cdot 2.5\ H_2O$ (1042.17): C 82.98, H 3.97; found: C 82.81, H 4.25.

*(+)-(*R*)-2,2′-Bis(methoxymethoxy)-3-ethynyl-3′-[(trimethylsilyl)ethynyl]-1,1′-binaphthalene* ((+)-(*R*)-**34**). A soln. of (*R*)-**29** (535 mg, 0.94 mmol) and borax (1.45 g, 9.4 mmol) in THF (500 ml) and H_2O (380 ml) was stirred at r.t. for 3.5 h. After addition of H_2O (380 ml), the mixture was extracted with CH_2Cl_2. The org. phase was washed with sat. aq. NaCl soln., dried (Na_2SO_4), and concentrated. CC (hexane/AcOEt 7:1 containing 0.5% Et_3N) afforded (*R*)-**34** (196 mg, 42%). M.p. 122°. $[\alpha]_D^{r.t.} = +63.3$ ($c = 1.0$, THF). IR (KBr): 3245*s*, 2955*m*, 2155*m*, 1426*m*, 1241*s*, 1159*s*, 1069*s*, 975*s*, 914*s*, 843*s*, 756*s*. ^{1}H-NMR (200 MHz, $CDCl_3$): 0.29 (*s*, 9 H); 2.49 (*s*, 3 H); 2.54 (*s*, 3 H); 3.35 (*s*, 1 H); 4.88 (*d*, *AB*, $J = 6.0$, 1 H); 4.92 (*d*, *AB*, $J = 6.2$, 1 H); 5.11 (*d*, *AB*, $J = 6.0$, 1 H); 5.19 (*d*, *AB*, $J = 6.2$, 1 H); 7.18–7.22 (*m*, 2 H); 7.27–7.36 (*m*, 2 H); 7.39–7.49 (*m*, 2 H); 7.82–7.88 (*m*, 2 H); 8.19 (*s*, 1 H); 8.22 (*s*, 1 H). ^{13}C-NMR (75 MHz, $CDCl_3$): – 0.14; 56.01; 56.21; 80.78; 81.65; 98.85; 99.08; 99.35; 102.05; 116.45; 117.29; 125.72; 125.80; 126.19 (2×); 126.69; 126.77; 127.57; 127.66; 127.78 (2×); 130.37 (2×); 134.07; 134.30; 135.20; 135.39; 153.63; 153.68. FAB-MS: 494 (23, M^+), 419 (100, $[M - C_3H_8O_2]^+$). Anal. calc. for $C_{31}H_{30}O_4Si$ (494.67): C 75.27, H 6.11; found: C 75.35, H 6.20.

*(–)-(*R,R*)-3,3′-(Buta-1,3-diynediyl)bis{2,2′-bis(methoxymethoxy)-3′-[(trimethylsilyl)ethynyl]-1,1′-binaphthalene}* ((–)-(*R*,*R*)-**35**). A soln. of (*R*)-**34** (132 mg, 0.27 mmol) and CuCl (1.00 g, 10 mmol) in CH_2Cl_2 (440 ml)

was stirred for 15 min, then TMEDA (1.5 ml, 1.16 g, 10 mmol) was added, and stirring was continued for 3 h under dry air. After addition of H_2O, the org. phase was washed (H_2O), dried (Na_2SO_4), and concentrated. CC (hexane/AcOEt 5:1 containing 0.5% Et_3N) afforded (*R*,*R*)-**35** (113 mg, 86%). M.p. 83°. $[\alpha]_D^{r.t.} = -125.1$ ($c = 1.0$, THF). IR (KBr): 2956*m*, 2144*w*, 1244*m*, 1158*s*, 1072*m*, 973*s*, 844*s*, 744*m*. ^{1}H-NMR (200 MHz, $CDCl_3$): 0.30 (*s*, 18 H); 2.52 (*s*, 6 H); 2.66 (*s*, 6 H); 4.90 (*d*, *AB*, $J = 6.2$, 2 H); 4.95 (*d*, *AB*, $J = 6.2$, 2 H); 5.12 (*d*, *AB*, $J = 6.2$, 2 H); 5.22 (*d*, *AB*, $J = 6.2$, 2 H); 7.20–7.50 (*m*, 12 H); 7.85 (*d*, $J = 7.9$, 2 H); 7.88 (*d*, $J = 7.9$, 2 H); 8.21 (*s*, 2 H); 8.28 (*s*, 2 H). ^{13}C-NMR (50 MHz, $CDCl_3$): −2.64; 53.55; 53.86; 75.73; 77.23; 96.37; 96.75; 96.91; 99.48; 113.76; 114.78; 123.09; 123.22; 123.41; 123.79; 124.08; 124.30; 125.09; 125.28; 125.34; 125.47; 127.85; 128.55; 131.44; 131.98; 132.74; 133.50; 151.12; 151.34. EI-MS: 987 (18, M^+), 149 (100). Anal. calc. for $C_{62}H_{58}O_8Si_2 \cdot 0.5\ H_2O$ (996.23): C 74.74, H 5.97; found: C 74.82, H 5.91.

*(−)-(*R,R*)-3,3′-(Buta-1,3-diynediyl)bis[2,2′-bis(methoxymethoxy)-3′-ethynyl-1,1′-binaphthalene]* ((−)-(*R*,*R*)-**36**). A soln. of (*R*,*R*)-**35** (215 mg, 0.22 mmol) and K_2CO_3 (208 mg, 1.50 mmol) in MeOH/THF 1:1 (40 ml) was stirred at r.t. for 1.5 h. After addition of CH_2Cl_2 (250 ml), the org. phase was washed (H_2O), dried (Na_2SO_4), and concentrated. CC (hexane/AcOEt 3:2 containing 0.5% Et_3N) afforded (*R*,*R*)-**36** (148 mg, 81%). M.p. 82°. $[\alpha]_D^{r.t.} = -28.7$ ($c = 1.0$, THF). IR (KBr): 3278*m*, 2922*w*, 2143*w*, 2109*w*, 1240*m*, 1158*s*, 971*s*, 751*m*. ^{1}H-NMR (200 MHz, $CDCl_3$): 2.55 (*s*, 6 H); 2.64 (*s*, 6 H); 3.34 (*s*, 2 H); 4.89 (*d*, *AB*, $J = 6.2$, 2 H); 4.90 (*d*, *AB*, $J = 5.8$, 2 H); 5.08 (*d*, *AB*, $J = 5.8$, 2 H); 5.10 (*d*, *AB*, $J = 6.2$, 2 H); 7.20 (*d*, $J = 8.7$, 4 H); 7.28–7.48 (*m*, 8 H); 7.85 (*d*, $J = 7.9$, 4 H); 8.21 (*s*, 2 H); 8.28 (*s*, 2 H). ^{13}C-NMR (50 MHz, $CDCl_3$): 56.21; 56.37; 78.26; 79.70; 80.70; 81.79; 99.13; 99.29; 116.29; 116.45; 125.84; 125.90; 126.01; 126.16; 126.64; 126.77; 127.83; 127.87; 127.94; 128.10; 130.40 (2×); 134.15; 134.46; 135.59; 136.16; 153.68; 153.94. MALDI-TOF-MS (THA/citrate): 866 ([$M + Na$]$^+$). Anal. calc. for $C_{56}H_{42}O_8 \cdot 0.5\ H_2O$ (851.95): C 78.95, H 5.09; found: C 79.00, H 5.31.

*(−)-(*R,R,S*)-Tris[2,2′-bis(methoxymethoxy)-1,1′-binaphthalene-3,3′-diylbis(ethynyl)]* ((−)-(*R*,*R*,*S*)-**31**). A soln. of CuCl (1.35 g, 14 mmol) in CH_2Cl_2 (600 ml) was stirred for 15 min under dry air, then TMEDA (2.09 ml, 1.62 g, 14 mmol) was added. A soln. of (*S*)-**30** (50 mg, 11.6 μmol) and (*R*,*R*)-**36** (100 mg, 11.6 μmol) in CH_2Cl_2 (250 ml) was slowly added *via* syringe pump over 3 h. The mixture was stirred at r.t. for 24 h, then warmed to 30° for 2 h. The same workup as described for the synthesis of (*S*,*S*,*S*)-**31** yielded a diastereoisomer mixture of (*R*,*R*,*S*)-**31** (16 mg, 11%) and (*S*,*S*,*S*)-**31** (6 mg, 4%), which was separated by HPLC (*Spherisorb SW*, 5 μm; toluene/AcOEt 99:1). M.p. 254° (dec.). $[\alpha]_D^{r.t.} = -210.5$ ($c = 1.0$, THF). ^{1}H-NMR (500 MHz, $CDCl_3$): 2.54 (*s*, 6 H); 2.60 (*s*, 6 H); 2.61 (*s*, 6 H); 4.73 (*d*, *AB*, $J = 6.2$, 2 H); 4.77 (*d*, *AB*, $J = 6.2$, 2 H); 4.85 (*d*, *AB*, $J = 6.2$, 2 H); 4.98 (*d*, *AB*, $J = 6.2$, 2 H); 4.99 (*d*, *AB*, $J = 6.2$, 2 H); 5.11 (*d*, *AB*, $J = 6.2$, 2 H); 7.22–7.48 (*m*, 18 H); 7.85–7.91 (*m*, 6 H); 8.20 (*s*, 6 H). ^{13}C-NMR (125 MHz, $CDCl_3$): 56.16; 56.20; 56.29; 78.71; 78.74; 78.97; 80.08; 80.35; 80.49; 98.91; 99.18; 99.23; 116.11; 116.30; 116.33; 125.48; 125.55; 125.60; 126.42 (2×); 126.55; 127.78; 127.90; 127.95; 128.20 (3×); 129.03 (3×); 130.07 (2×); 130.15; 134.02; 134.05 (2×), 134.10; 134.46; 134.62; 154.40; 154.81; 154.86.

Compound (−)-(*R*,*R*,*S*)-**2** (18 mg, 79%) was prepared in the same manner as described for (*S*,*S*,*S*)-**2** starting from (*R*,*R*,*S*)-**31** (29 mg, 1.7 μmol) and conc. aq. HCl soln. (37%, 0.15 ml) in THF/MeOH 3:2 (10 ml). M.p. >300°. $[\alpha]_D^{r.t.} = -611.1$ ($c = 1.0$, THF). ^{1}H-NMR (200 MHz, (D_8)THF): 6.99–7.09 (*m*, 6 H); 7.15–7.34 (*m*, 12 H); 7.80–7.87 (*m*, 6 H); 8.11 (*s*, 2 H); 8.14 (*s*, 4 H). ^{13}C-NMR (50 MHz, (D_8)THF): 78.43 (2×); 78.85; 79.64; 79.75; 80.02; 112.53; 112.64; 112.71; 113.98 (3×); 123.16; 123.28; 123.37; 124.71 (3×); 127.08; 127.19 (2×); 127.68; 127.79 (2×); 128.20; 128.27; 128.36; 133.22; 133.30; 133.66; 134.61; 134.71 (2×); 154.17; 154.42 (2×).

*(−)-(*S*)-2,2′-Bis(methoxymethoxy)-6,6′-dibromo-1,1′-binaphthalene* ((−)-(*S*)-**38**). To a degassed soln. of (*S*)-**37** [63] (2.5 g, 5.6 mmol), MOMCl (1.7 ml, 1.80 g, 22.4 mmol) and K_2CO_3 (4.67 g, 33.8 mmol) were added in DMF (50 ml) at 0°, and the mixture was stirred at r.t. for 12 h. The salts were removed by filtration through *Celite*, and evaporation *in vacuo* gave (*S*)-**38** (2.8 g, 95%). White powder (cyclohexane). M.p. 125°. $[\alpha]_D^{r.t.} = -16.3$ ($c = 1.0$, $CHCl_3$). IR (KBr): 2957*m*, 2898*m*, 1586*s*, 1492*s*, 1344*m*, 1237*s*, 1188*m*, 1147*m*, 1077*m*, 1065*m*, 1019*s*, 954*w*, 917*m*, 896*w*, 863*w*, 806*m*. ^{1}H-NMR (300 MHz, $CDCl_3$): 3.16 (*s*, 6 H); 4.98 (*d*, *AB*, $J = 6.9$, 2 H); 5.09 (*d*, *AB*, $J = 6.9$, 2 H); 6.98 (*d*, $J = 9.0$, 2 H); 7.29 (*dd*, $J = 9.0$, 2.1, 2 H); 7.60 (*d*, $J = 9.0$, 2 H); 7.87 (*d*, $J = 9.0$, 2 H); 8.03 (*d*, $J = 9.02$, 2 H). ^{13}C-NMR (100 MHz, (D_8)THF): 55.93; 95.60; 118.28; 118.75; 121.27; 128.07; 129.36; 130.15; 130.71; 131.90; 133.45; 154.34. EI-MS: 532 (62, M^+), 456 ([$M - C_3H_8O_2$]$^+$). Anal. calc. for $C_{24}H_{20}Br_2O_4$ (532.23): C 54.16, H 3.79; found: C 53.89, H 3.85.

Compound (+)-(*R*)-**38** ($[\alpha]_D^{r.t.} = +19.7$ ($c = 1.0$, $CHCl_3$)) was prepared in the same manner.

*(−)-(*S*)-2,2′-Bis(methoxymethoxy)-6,6′-bis(2-phenylethyl)-1,1′-binaphthalene* ((−)-(*S*)-**39**). A soln. of styrene (1.72 ml, 1.56 g, 15.0 mmol) in THF (10 ml) was slowly added to 9-BBN (0.5M soln. in THF, 30 ml, 15.0 mmol), and the mixture was heated to 60° for 5 h. This soln. (40 ml, 15.0 mmol) was then added to a degassed soln. of (*S*)-**38** (2.70 g, 5.1 mmol), [$PdCl_2$(dppf)] · CH_2Cl_2 (135 mg, 3 mol-%), and 3M NaOH (10.0 ml, 30.0 mmol) in THF (100 ml), and the resulting mixture was warmed to 50° for 15 h. After filtration through

Celite, H_2O (300 ml) was added and the product extracted with CH_2Cl_2. The org. phase was stirred with 5% aq. H_2O_2/NaOH soln. (200 ml) for 3 h and then washed (H_2O and sat. aq. NaCl soln.). Evaporation *in vacuo* and CC (hexane/AcOEt 5:1 containing 0.5% Et_3N) afforded (*S*)-**39** (2.80 g, 94%). Highly viscous oil. $[\alpha]_D^{r.t.} = -2.7$ ($c = 1.0$, $CHCl_3$). IR (neat): 2924*s*, 2853*w*, 1597*m*, 1497*m*, 1451*w*, 1355*w*, 1238*m*, 1197*w*, 1147*m*, 1070*m*, 1020*s*, 917*w*, 816*w*. ^{1}H-NMR (200 MHz, $CDCl_3$): 2.97–3.05 (*m*, 8 H); 3.17 (*s*, 6 H); 4.99 (*d*, *AB*, $J = 6.6$, 2 H); 5.10 (*d*, *AB*, $J = 6.6$, 2 H); 7.10–7.32 (*m*, 14 H); 7.60 (*d*, $J = 9.0$, 2 H); 7.97 (*s*, 2 H); 7.90 (*d*, $J = 9.0$, 2 H). ^{13}C-NMR (100 MHz, $CDCl_3$): 37.65; 37.72; 55.75; 95.36; 117.54; 121.45; 125.63; 125.86; 126.35; 127.73; 128.29; 128.39; 128.81; 130.05; 132.56; 137.38; 141.77; 152.20. EI-MS: 582 (100, M^+). HR-EI-MS: 582.2759 (M^+, $C_{40}H_{38}O_4$; calc. 582.2770).

Compound (+)-(*R*)-**39** ($[\alpha]_D^{r.t.} = +3.4$ ($c = 1.0$, $CHCl_3$)) was prepared in the same manner.

*(+)-(*S*)-2,2′-Bis(methoxymethoxy)-6,6′-bis(2-phenylethyl)-6,6′-diiodo-1,1′-binaphthalene* ((+)-(*S*)-**41**). Compound (*S*)-**41** (2.30 g, 73%) was prepared from (*S*)-**39** (2.20 g, 3.8 mmol) in Et_2O (70 ml) using BuLi (1.6M soln. in hexane, 9.5 ml, 15.2 mmol), TMEDA (2.29 ml, 1.77 g, 15.2 mmol), and I_2 (4.80 g, 18.9 mmol, soln. in 20 ml Et_2O) and following the same procedure as described for the synthesis of (*S*)-**28**. Highly viscous oil. $[\alpha]_D^{r.t.} = +12.2$ ($c = 1.0$, $CHCl_3$). IR (neat): 2921*s*, 2849*w*, 1736*m*, 1602*w*, 1562*w*, 1491*m*, 1453*m*, 1372*m*, 1233*m*, 1195*w*, 1159*s*, 1083*m*, 996*m*, 962*m*, 935*m*, 820*w*. ^{1}H-NMR (200 MHz, $CDCl_3$): 2.62 (*s*, 6 H); 2.97–3.06 (*m*, 8 H); 4.69 (*d*, *AB*, $J = 5.6$, 2 H); 4.84 (*d*, *AB*, $J = 5.6$, 2 H); 7.13–7.30 (*m*, 14 H); 7.52 (*s*, 2 H); 8.45 (*s*, 2 H). ^{13}C-NMR (100 MHz, $CDCl_3$): 35.01; 35.26; 54.12; 90.21; 97.06; 123.03; 123.79; 123.95; 124.30; 126.11 (2×); 126.17; 126.36; 130.14; 137.06; 137.22; 139.12; 149.37. EI-MS: 834 (17, M^+), 45 (100, $[C_2H_5O]^+$). HR-EI-MS: 834.0685 (M^+, $C_{40}H_{36}O_4I_2$; calc. 834.0707).

Compound (−)-(*R*)-**41** ($[\alpha]_D^{r.t.} = -11.3$ ($c = 1.0$, $CHCl_3$)) was prepared in the same manner.

*(−)-(*S*)-2,2′-Bis(methoxymethoxy)-6,6′-bis(2-phenylethyl)-3,3′-bis[(trimethylsilyl)ethynyl]-1,1′-binaphthalene* ((−)-(*S*)-**42**). To a suspension of (*S*)-**41** (2.30 g, 2.8 mmol) in Et_3N (40 ml), $[PdCl_2(PPh_3)_2]$ (100 mg, 5 mol-%), CuI (27 mg, 5 mol-%), and (trimethylsilyl)acetylene (0.78 g, 1.12 ml, 8.4 mmol) were added, and the mixture was heated to 50° for 2 h. After addition of sat. aq. NaCl soln. (30 ml) and filtration over *Celite*, the product was extracted with CH_2Cl_2 and the solvent removed *in vacuo*. CC (hexane/AcOEt 12:1 containing 0.5% Et_3N) afforded (*S*)-**42** (2.00 g, 93%). Highly viscous oil. $[\alpha]_D^{r.t.} = -35.8$ ($c = 1.0$, $CHCl_3$). IR (neat): 2956*m*, 2144*m*, 1591*w*, 1493*m*, 1250*m*, 1429*m*, 1243*s*, 1205*m*, 1154*m*, 1070*m*, 977*m*, 846*m*. ^{1}H-NMR (200 MHz, $CDCl_3$): 0.27 (*s*, 18 H); 2.44 (*s*, 6 H); 3.00–3.06 (*m*, 8 H); 4.87 (*d*, *AB*, $J = 6.2$, 2 H); 5.18 (*d*, *AB*, $J = 6.2$, 2 H); 7.13–7.32 (*m*, 14 H); 7.55 (*s*, 2 H); 8.08 (*s*, 2 H). ^{13}C-NMR (75 MHz, $CDCl_3$): −2.64; 34.95; 35.20; 53.51; 96.30; 96.52; 99.70; 114.62; 123.38; 123.66; 123.73; 124.27; 126.01; 126.14; 126.43; 127.95; 130.14; 132.04; 136.49; 139.19; 150.58. EI-MS: 774 (9, M^+), 73 (100, $[Me_3Si]^+$). HR-EI-MS: 774.3582 (M^+, $C_{50}H_{54}O_4Si_2$; calc. 774.3560).

Compound (+)-(*R*)-**42** ($[\alpha]_D^{r.t.} = +32.0$ ($c = 1.0$, $CHCl_3$)) was prepared in the same manner.

*(−)-(*S*)-2,2′-Bis(methoxymethoxy)-6,6′-bis(2-phenylethyl)-3,3′-diethynyl-1,1′-binaphthalene* ((−)-(*S*)-**43**). Compound (*S*)-**43** was prepared from (*S*)-**42** (895 mg, 1.2 mmol) using K_2CO_3 (1.16 g, 8.4 mmol) in THF/MeOH 1:1 (140 ml) and following the same procedure as described for (*S*)-**30**. CC (hexane/AcOEt 9:1 containing 0.5% Et_3N) afforded (*S*)-**43** (630 mg, 87%). M.p. 45°. $[\alpha]_D^{r.t.} = -36.0$ ($c = 1.0$, $CHCl_3$). IR (KBr): 2920*s* (br.), 2107*w*, 1731*w*, 1590*m*, 1492*m*, 1448*m*, 1430*m*, 1395*w*, 1373*w*, 1355*w*, 1236*m*, 1250*m*, 1156*s*, 1068*m*, 1011*w*, 966*s*, 905*m*, 816*w*. ^{1}H-NMR (300 MHz, $CDCl_3$): 2.53 (*s*, 6 H); 2.95–3.12 (*m*, 8 H); 3.33 (*s*, 2 H); 4.89 (*d*, *AB*, $J = 5.7$, 2 H); 5.08 (*d*, *AB*, $J = 5.7$, 2 H); 7.12–7.32 (*m*, 14 H); 7.58 (*s*, 2 H); 8.11 (*s*, 2 H). ^{13}C-NMR (100 MHz, $CDCl_3$): 37.55; 37.76; 56.17; 80.89; 81.59; 99.06; 116.42; 125.98; 126.27; 126.40; 126.77; 128.62; 128.72; 129.28; 130.54; 132.80; 134.98; 139.30; 141.74; 153.18. EI-MS: 630 (58, M^+), 45 (100, $[C_2H_5O]^+$). Anal. calc. for $C_{44}H_{38}O_4$ (630.79): C 83.78, H 6.07; found: C 83.80, H 6.20.

Compound (+)-(*R*)-**43** ($[\alpha]_D^{r.t.} = +36.2$ ($c = 1.0$, $CHCl_3$)) was prepared in the same manner.

Glaser-Hay *Cyclization of* (*S*)-**43**. A soln. of (*S*)-**43** (240 mg, 0.38 mmol) and CuCl (3.5 g, 35 mmol) in CH_2Cl_2 (1.2 l) was stirred for 10 min. After addition of TMEDA (5.3 ml, 4.1 g, 35 mmol) and stirring for 1 h under dry air, H_2O (400 ml) was added, the org. phase washed (H_2O), dried (Na_2SO_4), and concentrated. CC (hexane/AcOEt 3:1 → 1:1, containing 0.5% Et_3N) and separation by GPC (CH_2Cl_2) afforded (*S*,*S*,*S*)-**44** (85 mg, 36%), in addition to tetramer (*S*,*S*,*S*,*S*)-**45** (59 mg, 25%).

*(+)-(*S*,*S*,*S*)-Tris[2,2′-bis(methoxymethoxy)-6,6′-bis(2-phenylethyl)-1,1′-binaphthalene-3,3′-diylbis(ethynyl)]* ((+)-(*S*,*S*,*S*)-**44**). M.p. 172°. $[\alpha]_D^{r.t.} = +792.3$ ($c = 1.0$, $CHCl_3$). IR (KBr): 2920*m*, 2854*w*, 2206*w*, 2132*w*, 1585*m*, 1491*m*, 1446*m*, 1434*m*, 1368*w*, 1233*w*, 1200*w*, 1155*s*, 1069*m*, 971*s*, 922*m*, 898*m*, 816*m*. ^{1}H-NMR (200 MHz, $CDCl_3$): 2.61 (*s*, 18 H); 2.98–3.08 (*m*, 24 H); 4.95 (*d*, *AB*, $J = 6.3$, 6 H); 5.07 (*d*, *AB*, $J = 6.3$, 6 H); 7.15–7.32 (*m*, 42 H); 7.60 (*s*, 6 H); 8.10 (*s*, 6 H). ^{13}C-NMR (50 MHz, $CDCl_3$): 35.04; 35.23; 53.80; 76.18; 77.70; 96.84; 113.86; 123.28; 123.73; 124.20 (2×); 126.08; 126.17; 127.03; 127.92; 130.39; 131.63; 136.71; 139.12; 152.10. MALDI-TOF-MS (HABA): 1910 ($[M + Na]^+$). Anal. calc. for $C_{132}H_{108}O_{12}$ (1886.33): C 84.05, H 5.77; found: C 83.92, H 5.93.

*(+)-(*S,S,S,S*)-Tetrakis[2,2′-bis(methoxymethoxy)-6,6′-bis(2-phenylethyl)-1,1′-binaphthalene-3,3′-diylbis-(ethynyl)]* ((+)-(*S,S,S,S*)-**45**). M.p. 195–197°. $[\alpha]_D^{r.t.} = +595.1$ ($c = 1.0$, $CHCl_3$). IR (KBr): 2926*m*, 2232*w*, 2161*w*, 1587*m*, 1492*m*, 1445*m*, 1427*m*, 1372*w*, 1239*w*, 1204*w*, 1157*s*, 1071*m*, 968*s*, 929*m*, 908*m*, 817*m*. ^{1}H-NMR (300 MHz, $CDCl_3$): 2.59 (*s*, 24 H); 2.95–3.09 (*m*, 32 H); 4.89 (*d*, *AB*, $J = 6.3$, 8 H); 5.12 (*d*, *AB*, $J = 6.3$, 8 H); 7.11–7.32 (*m*, 56 H); 7.58 (*s*, 8 H); 8.13 (*s*, 8 H). ^{13}C-NMR (75 MHz, $CDCl_3$): 37.54; 37.76; 56.37; 78.24; 79.60; 99.39; 116.27; 125.98; 126.29; 126.54; 126.81; 128.62; 128.72; 129.61; 130.54; 133.05; 135.41; 139.39; 141.69; 153.79. MALDI-TOF-MS (HABA): 2539 ($[M + Na]^+$). Anal. calc. for $C_{176}H_{144}O_{16} \cdot 2\,H_2O$ (2551.13): C 82.86, H 5.85; found: C 82.99, H 5.85.

*(+)-(*S,S,S*)-Tris[6,6′-bis(2-phenylethyl)-2,2′-dihydroxy-1,1′-binaphthalene-3,3′-diylbis(ethynyl)]* ((+)-(*S,S,S*)-**3**). A soln. of (*S,S,S*)-**44** (70 mg, 3.7 μmol) and conc. aq. HCl soln. (37%, 0.35 ml) in THF/MeOH 3:2 (25 ml) was stirred at r.t. for 12 h. After concentration to 1/3 of the volume, reprecipitation with hexane (20 ml), filtration, and drying afforded (*S,S,S*)-**3** (45 mg, 75%). Yellow powder. M.p. >250°. $[\alpha]_D^{r.t.} = +1278.3$ ($c = 1.0$, $CHCl_3$). IR (KBr): 3502*s* (br.), 3027*w*, 2921*m*, 2853*w*, 2202*w*, 2132*w*, 1598*m*, 1492*w*, 1439*m*, 1376*w*, 1259*m*, 901*m*, 814*m*. ^{1}H-NMR (400 MHz, $CDCl_3$): 2.90–2.97 (*m*, 24 H); 5.69 (br. *s*, 6 H); 6.90 (*d*, $J = 8.5$, 6 H); 7.01 (*d*, $J = 8.5$, 6 H); 7.16–7.29 (*m*, 30 H); 7.58 (*s*, 6 H); 8.06 (*s*, 6 H). ^{13}C-NMR (100 MHz, $CDCl_3$): 37.57; 37.61; 78.90; 79.86; 110.85; 113.23; 125.37; 126.02; 126.96; 128.41; 128.44; 128.56; 129.55; 132.73; 133.93; 137.71; 141.58; 151.69. MALDI-TOF-MS (HABA): 1645 ($[M + Na]^+$). Anal. calc. for $C_{120}H_{84}O_6 \cdot H_2O$ (1640.02): C 87.89, H 5.29; found: C 87.83, H 5.21.

*(−)-(*S*)-2,2′-Bis(methoxymethoxy)-6,6′-bis(2-phenylethyl)-3-ethynyl-3′-[(trimethylsilyl)ethynyl]-1,1′-bi-naphthalene* ((−)-(*S*)-**46**). Compound (*S*)-**46** was prepared from (*S*)-**42** (2.0 g, 2.6 mmol) using borax (4.0 g, 26.0 mmol) in THF/H_2O 4:3 (1.4 l), following the same procedure as described for the synthesis of (*R*)-**34**. CC (hexane/AcOEt 12:1 containing 0.5% Et_3N) afforded (*S*)-**46** (520 mg, 28%) as a viscous oil besides starting material ((*S*)-**42**) (1.11 g, 55%) and (*S*)-**43** (90 mg, 6%). $[\alpha]_D^{r.t.} = -45.1$ ($c = 1.0$, $CHCl_3$). IR (KBr): 2922*s* (br.), 2148*m*, 1590*w*, 1494*w*, 1445*w*, 1428*w*, 1239*m*, 1203*w*, 1155*s*, 1067*m*, 970*s*, 843*s*. ^{1}H-NMR (500 MHz, $CDCl_3$): 0.27 (*s*, 9 H); 2.46 (*s*, 3 H); 2.50 (*s*, 3 H); 2.97–3.06 (*m*, 8 H); 3.32 (*s*, 2 H); 4.84 (*d*, *AB*, $J = 6.1$, 1 H); 4.88 (*d*, *AB*, $J = 6.2$, 1 H); 5.07 (*d*, *AB*, $J = 6.1$, 1 H); 5.15 (*d*, *AB*, $J = 6.2$, 1 H); 7.10–7.26 (*m*, 14 H); 7.53 (*d*, $J = 1.2$, 1 H); 7.56 (*d*, $J = 1.2$, 1 H); 8.06 (*s*, 1 H); 8.09 (*s*, 1 H). ^{13}C-NMR (125 MHz, $CDCl_3$): −0.13; 37.41; 37.45; 37.63; 37.65; 55.90; 56.10; 80.78; 81.31; 98.64; 98.86; 98.95; 102.05; 116.18; 117.02; 125.51; 125.88; 125.99 (2×); 126.09; 126.11; 126.50; 126.58; 128.33; 128.34; 128.45 (2×); 128.83; 128.93; 130.28 (2×); 132.40; 132.63; 134.42; 134.60; 138.84; 138.96; 141.46 (2×); 152.83; 152.88. EI-MS: 702 (15, M^+), 91 (100, $[C_7H_7]^+$). Anal. calc. for $C_{47}H_{46}O_4Si$ (702.97): C 80.31, H 6.60; found: C 80.52, H 6.60.

*(−)-(*S,S*)-3,3′-(Buta-1,3-diynediyl)bis[2,2′-bis(methoxymethoxy)-6,6′-bis(2-phenylethyl)-3′-ethynyl-1,1′-bi-naphthalene]* ((−)-(*S,S*)-**48**). Compound (*S,S*)-**47** was prepared from (*S*)-**46** (590 mg, 0.84 mmol) using CuCl (1.00 g, 10 mmol) and TMEDA (1.5 ml, 1.16 g, 10.0 mmol) in CH_2Cl_2 (600 ml) and following the same procedure as described for the synthesis of (*R,R*)-**35**. The crude product was directly dissolved in THF/MeOH 1:1 (140 ml) and converted to (*S,S*)-**48** in the same manner as described for (*R,R*)-**36**, using K_2CO_3 (0.58 g, 4.2 mmol). CC (hexane/AcOEt 9:1 containing 0.5% Et_3N) afforded (*S,S*)-**48** (400 mg, 76% from (*S*)-**46**). M.p. 75°. $[\alpha]_D^{r.t.} = -59.7$ ($c = 1.0$, $CHCl_3$). IR (KBr): 2927*s*, 2855*m*, 2155*w*, 2112*w*, 1726*s*, 1588*w*, 1490*w*, 1450*m*, 1428*w*, 1369*w*, 1272*m*, 1236*m*, 1200*w*, 1156*s*, 1120*w*, 1066*m*, 968*s*, 816*w*. ^{1}H-NMR (300 MHz, $CDCl_3$): 2.55 (*s*, 6 H); 2.64 (*s*, 6 H); 2.99–3.10 (*m*, 16 H); 3.35 (*s*, 2 H); 4.89 (*d*, *AB*, $J = 6.2$, 2 H); 4.92 (*d*, *AB*, $J = 6.2$, 2 H); 5.09 (*d*, *AB*, $J = 6.2$, 2 H); 5.10 (*d*, *AB*, $J = 6.2$, 2 H); 7.15–7.35 (*m*, 28 H); 7.59 (*s*, 4 H); 8.12 (*s*, 2 H); 8.16 (*s*, 2 H). ^{13}C-NMR (125 MHz, $CDCl_3$): 37.44; 37.66; 56.08; 56.23; 77.20; 78.04; 79.65; 80.67; 81.45; 98.90; 99.07; 116.03; 116.17; 125.54; 125.84; 126.00; 126.01; 126.17; 126.23; 126.45; 126.56; 128.35 (2×); 128.45 (2×); 129.07; 129.34; 130.28; 130.31; 132.46; 132.48; 132.76; 134.77; 135.32; 139.05; 139.16; 141.40; 141.44; 152.86; 153.14. MALDI-TOF-MS (HABA): 1283 ($[M + Na]^+$). Anal. calc. for $C_{88}H_{74}O_8$ (1259.57): C 83.92, H 5.92; found: C 83.81, H 6.02.

*(+)-(*S,S,R*)-Tris[2,2′-bis(methoxymethoxy)-6,6′-bis(2-phenylethyl)-1,1′-binaphthalene-3,3′-diylbis(ethyn-yl)]* ((+)-(*S,S,R*)-**44**). A soln. of (*R*)-**43** (75 mg, 0.12 mmol), (*S,S*)-**48** (150 mg, 0.12 mmol), and CuCl (3.2 g, 32 mmol) in CH_2Cl_2 (1.2 l) was stirred for 15 min. After addition of TMEDA (4.8 ml, 3.7 g, 32 mmol) and stirring for 1 h under dry air, H_2O (400 ml) was added, the org. phase washed (H_2O), dried (Na_2SO_4), and concentrated. CC (hexane/AcOEt 3:1→1:1 containing 0.5% Et_3N) and GPC (CH_2Cl_2) afforded a diastereoisomer mixture of trimers (68 mg, 3.6 μmol, 30%). (*S,S,R*)-**44** (52 mg, 2.8 μmol, 23%) was separated from (*S,S,S*)-**44** by HPLC (*Spherisorb SW*, 5 μm; toluene→toluene/AcOEt 95:5). M.p. 175°. $[\alpha]_D^{r.t.} = +241.9$ ($c = 1.0$, $CHCl_3$). ^{1}H-NMR (500 MHz, $CDCl_3$): 2.51 (*s*, 6 H); 2.57 (*s*, 6 H); 2.59 (*s*, 6 H); 2.95–3.08 (*m*, 24 H); 4.69 (*d*, *AB*, $J = 6.2$, 2 H); 4.73 (*d*, *AB*, $J = 6.5$, 2 H); 4.82 (*d*, *AB*, $J = 6.5$, 2 H); 4.95 (*d*, *AB*, $J = 6.5$, 2 H); 4.96 (*d*, *AB*, $J = 6.2$, 2 H); 5.08 (*d*, *AB*, $J = 6.5$, 2 H); 7.12–7.30 (*m*, 42 H); 7.57 (*s*, 4 H); 7.60 (*s*, 2 H); 8.07 (*s*, 2 H); 8.08 (*s*, 4 H). ^{13}C-NMR (125 MHz, $CDCl_3$): 37.45 (2×); 37.49; 37.66 (2×); 37.69; 56.18; 56.22; 56.32; 78.68;

78.73; 78.94; 80.27; 80.55; 80.69; 98.02; 99.17; 99.22; 116.17; 116.34; 116.37; 125.28; 125.31 (2×); 125.44; 125.50; 125.60; 126.03 (2×); 126.05; 126.46; 126.49; 126.60; 128.36 (2×); 128.38; 128.46; 128.47; 128.48; 129.29 (2×); 129.32; 130.27; 130.28; 130.35; 132.66; 132.68; 132.73; 133.57; 133.89; 134.06; 139.00 (2×); 139.04; 141.42; 141.43; 141.44; 153.98; 154.39; 154.43.

Compound (+)-(*S*,*S*,*R*)-**3** (35 mg, 81%) was prepared in the same manner as described for (*S*,*S*,*S*)-**3**, starting from (*S*,*S*,*R*)-**44** (50 mg, 2.7 μmol) and conc. aq. HCl soln. (37 %, 0.23 ml) in THF/MeOH 3 :2 (15 ml). M.p. >250°. $[\alpha]_D^{rt.} = +381.7$ ($c = 1.0$, $CHCl_3$). ^{1}H-NMR (400 MHz, $CDCl_3$): 2.94–3.04 (*m*, 24 H); 5.80 (br. *s*, 6 H); 6.99 (*d*, $J = 8.7$, 6 H); 7.04 (*d*, $J = 8.7$, 6 H); 7.10–7.31 (*m*, 30 H); 7.58 (*s*, 4 H); 7.60 (*s*, 2 H); 8.06 (*s*, 2 H); 8.08 (*s*, 4 H). ^{13}C-NMR (100 MHz, $CDCl_3$): 37.58 (3×); 37.61 (3×); 77.22 (3×); 79.38; 79.48; 79.92; 80.07 (3×); 110.83; 111.05 (2×); 113.25; 113.27; 113.40; 125.34; 126.03 (2×); 126.95; 127.00; 127.08; 128.40 (2×); 128.42; 128.46 (2×); 128.48; 128.71; 128.77; 128.80; 129.86; 129.90; 129.99; 132.75; 132.77; 132.94; 133.54; 133.67; 133.94; 137.96; 137.99 (2×); 141.50; 141.53 (2×); 151.45; 151.61; 151.79.

X-Ray Crystal Structure of (S)-**21**. Crystal data at 95 K for $2(C_{38}H_{32}O_6Br_2)$ (M_r 1488.91): monoclinic, space group $P2_1$ (No. 4), $\rho_{calc.} = 1.488$ g cm^{-3}, $Z = 2$, $a = 15.175(5)$ Å, $b = 10.348(5)$ Å, $c = 21.456(5)$ Å, $\beta = 99.41(2)°$, $V = 3324(2)$ Å^3. *Nonius CAD4* diffractometer, MoK_α radiation, $\lambda = 0.7107$ Å. Single crystals were obtained by diffusion of hexane to a AcOEt soln. The structure was solved by direct methods (SHELXS-86) and refined by full-matrix least-squares analysis (SHELXL-93), using an isotropic extinction correction and $w = 1/[\sigma^2(F_o^2) + (0.111P)^2 + 15.51P]$, where $P = (F_o^2 + 2F_c^2)/3$. Both (independent) molecules, in particular molecule 2 (primed (′) atom labels) exhibit sever disorder, and as a result, the derived molecular geometry is not reliable. For some atoms, the disorder could be resolved. For Br(2′), two sets of atomic parameters were refined anisotropically with weights of 0.65 and 0.35, respectively. Three benzene rings (C(13) to C(18), C(13′) to C(18′), C(35′) to C(40′)) could be refined only by restraining the C–C distances to *ca*. 1.39 Å. In addition, for the benzene ring C(13′) to C(18′) and the fragment O(41)–C(42)–O(43)–C(44), two different orientations were located and refined isotropically with weights of 0.5 (for clarity, only one orientation is shown in *Fig. 1*). All other heavy atoms were refined anisotropically (H-atoms neglected). Final $R(F) = 0.058$, $wR(F^2) = 0.150$ for 798 parameters, 37 restraints, and 3703 reflections with $I > 2\sigma(I)$ and $\theta < 24°$. Further details of the structure analysis are available on request from the *Cambridge Crystallographic Data Centre*, 12 Union Road, Cambridge CB12 1EZ (UK), on quoting the full journal citation.

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