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Regio- and Diastereoselective Synthesis of Bis- and Tetrakisadducts of C_{70} by Directed Remote Functionalization Using Tröger Base Tethers

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Abstract: Double Bingel cyclopropanation of C_{70} with bismalonates featuring Tröger base derivatives as chiral spacers afforded bisadducts with almost perfect regio- and stereoselectivity. The excellent directing property of these rigidly folded spacers in the remote functionalization of the higher fullerene was further highlighted by the selective formation of a product with a novel bisaddition pattern involving the C(7)–C(22) and C(33)–C(34) bonds of C_{70}. Enantiomerically pure bisadducts of C_{70} were prepared by highly diastereoselective transformations of bismalonates incorporating optically pure Tröger base tethers. The absolute configuration of these bisadducts was established by comparison of circular dichroism (CD) spectra with data reported in the literature. For the first time, optically active tetrakisadducts of a fullerene were prepared by two sequential chiral-spacer-controlled remote functionalizations.

Keywords: circular dichroism · diastereoselectivity · fullerenes · optical activity · Tröger base

Introduction

Spacer-controlled multiple functionalization has been developing into a tool to prepare regio- and stereospecifically, on a reasonable scale, multiple adducts of fullerenes without tedious purification procedures.[1] A wide variety of tethers, from simple aromatics to porphyrins and crown ethers, have been employed while a number of optically pure spacer groups have led to diastereoselective additions.

Unlike C_{60}, the multiple functionalization of C_{70} has not been widely studied. The chemistry of C_{70} is complicated by the fact that there are eight (only two in the case of C_{60}) distinct bond types (four between two six-membered rings (6–6) and four between a six- and a five-membered ring (6–5)) at which functionalization may occur.[2] The different 6–6 bonds in C_{70} have been classified according to their local curvature as α-, β-, ε-, and κ-type bonds (see Figure 4), with the degree of local curvature decreasing from α bonds located near the poles to κ-type bonds located at the equator of the C-sphere.[3] Earlier studies, using a combination of functionalization experiments and theoretical calculations, have established the relative reactivities of these bonds to Bingel cyclopropanation,[4] with α bonds being the most reactive, followed by β-, ε-, and κ-type bonds.[3,5]

Double Bingel cyclopropanations of C_{70} with diethyl malonate have been shown to occur on opposite hemispheres at the most curved α-type bonds, yielding three constitutional isomers (twelve, two, and five o'clock adducts in Newman-type projections looking down the C_5-symmetry axis of the C_{70} core onto the two polar pentagons, see Figure 1), two of which (two and five o'clock) are pairs of enantiomers due to the inherent chirality of the addition pattern.[3,5] Although there is some degree of regioselectivity in sequential multiple functionalization of C_{70}, due to the different types of 6–6 bonds, isomeric mixtures often obtained are difficult to separate, requiring high-performance liquid chromatography (HPLC) techniques.[5] With the tether-directed remote functionalization strategy,[6] highly regioselective macrocyclizations of C_{70} have been achieved using bismalonates attached to crown ether tethers.[7] However, the stereoselective functionalization of C_{70} leading to optically pure multiple adducts with inherently chiral addition patterns remained unexplored.

Recently, much success has been reported in the regio- and stereoselective double functionalization of C_{60} through the use of bismalonates conjugated to enantiomerically pure derivatives of the Tröger base as rigid spacers.[8,9] The Tröger base is a chiral diamine with two bridgehead nitrogen atoms as stereogenic centers.[10] The rigidity and folded geometry of Tröger base derivatives, in particular those with C_2 symmetry, makes them attractive building blocks in su-

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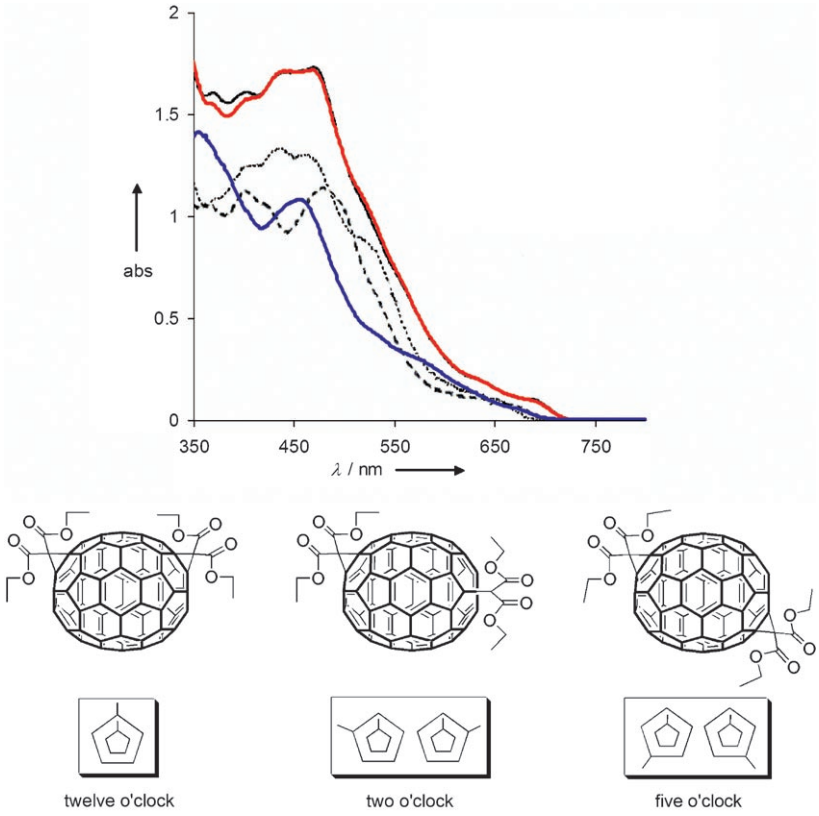
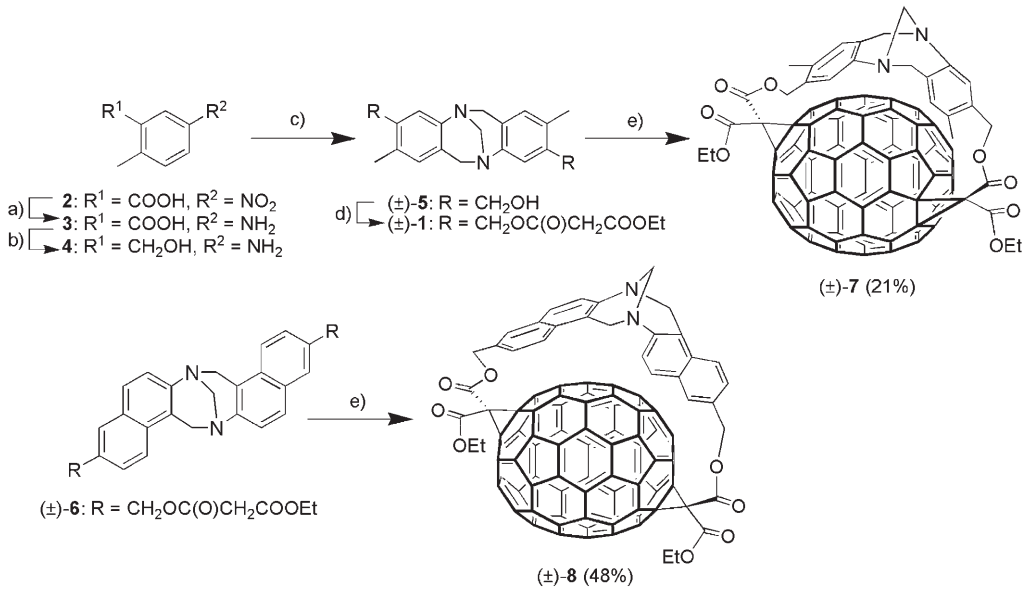


Figure 1. UV/Vis spectra of various bisadducts of C_{70} in CH_2Cl_2: ——: (±)-**7**, ——: (±)-**8**. The spectra of the five (——), two (••••), and twelve (-----) o'clock isomers (see the Newman-type projections looking down the C_5-symmetry axis of the C_{70} core onto the two polar pentagons, which show the relative orientations of the addends) are taken from the literature.[5,7]

pramolecular construction and molecular recognition chemistry.[11,12] Here we describe the covalently templated regio- and stereoselective synthesis of enantiomerically pure bis- and tetracyclopropanated derivatives of C_{70} with inherently chiral addition patterns by macrocyclization with bismalonates attached to optically pure Tröger base tethers.

Results and Discussion

Synthesis of racemic bisadducts of C_{70}: For the synthesis of C_{70} bisadducts, bismalonate (±)-**1** was prepared from 2-methyl-5-nitrobenzoic acid (**2**) via **3** → **4** → (±)-**5** → (±)-**1**, while bismalonate (±)-**6** was obtained as previously described (Scheme 1).[8] Macrocyclization of the bismalonates with C_{70} in the presence of iodine and DBU gave the two racemic bisadducts (±)-**7** and (±)-**8** as the only isolated products in 21 and 48% yield, respectively. It should be noted that, apart from (±)-**1** and (±)-**6**, a wider variety of Tröger base-tethered bismalonates[8,12d] were tested in macrocyclizations with C_{70}. In these cases, most of the product obtained was insoluble and soluble fractions gave unassignable complex ^{1}H NMR spectra indicating a mixture of different adducts.



Scheme 1. Synthesis of C_{70} bisadducts (±)-**7** and (±)-**8**. a) Pd/C, H_2, MeOH, 16 h, 83%; b) $LiAlH_4$, THF, Δ, 2 h, 91%; c) H_2CO/H_2O, HCl, EtOH, 20°C, 16 h 37%; d) $EtOOCCH_2COCl$, DMAP, THF, 20°C, 16 h, 25%; e) C_{60}, I_2, DBU, toluene, 0°C, 1 h. THF = tetrahydrofuran, DMAP = 4-(dimethylamino)-pyridine, DBU = 1,8-diazabicyclo[5.4.0]undec-7-ene.

Characterization of racemic bisadducts of C_{70}: Matrix-assisted laser-desorption-ionization (MALDI) mass spectrometry confirmed that (±)-**7** and (±)-**8** are bisadducts of C_{70}. ^{1}H NMR and UV/Vis spectroscopies were initially employed to determine, by comparison with the spectra of reported bisadducts of C_{70},[5,7] which of the three possible constitutionally isomeric bisadducts of C_{70} (twelve, two, and five o'clock) had been isolated.

The UV/Vis spectrum of (±)-**8** was remarkably similar to that of bismalonate adducts with the inherently chiral five o'clock addition pattern, reported in the literature (Figure 1).[5] In fact, the solution of the X-ray crystal structure of a five o'clock bismalonate adduct with a bridging dibenzo[18]crown-6 tether had unequivocally confirmed the earlier, UV/Vis and NMR spectroscopy-based assignments.[7] We therefore can state with confidence that (±)-**8** is also a five o'clock constitutional isomer, resulting from a completely regioselective transformation.

Interestingly, the ^{1}H and ^{13}C NMR spectra of (±)-**8** in $CDCl_3$ indicate a C_1-symmetric molecule (Figure 2). This appears to be contrary to the assignment of the five o'clock constitutional isomer, because both the Tröger base tether and the five o'clock addition pattern of C_{70} have C_2 symmetry. The possibility of having diastereoisomers, resulting from attack of each enantiomer of (±)-**6** at the bonds of both enantiomeric five o'clock addition patterns, could be excluded: bismalonates with optically pure Tröger base tethers undergo the macrocyclization with perfect diastereoselectivity (see below). In theory, the described tether-directed addition can produce various diastereoisomers (*in–in*, *in–out*, and *out–out*) with respect to the relative orientation of the ethoxycarbonyl residues at the two methano-bridge atoms.[13] One possible explanation for the C_1 symmetry observed in the ^{1}H NMR spectra could be that the isolated bisadduct has the *in–out* constitution which, in contrast to *in–in* and *out–out*, would introduce C_1 symmetry. However, molecular mechanics-based modeling suggested the *in–out* (and *in–in*) constitution to be much higher in energy than the *out–out* geometry.[14] At the same time, the modelling studies indicated a plausible explanation of the C_1-symmetric NMR spectra of a macrocyclic five o'clock bisadduct: the C_2 axes of the Tröger base tether and the five o'clock addition pattern cannot align due to the rigidity of the tether and the steric constraints of the molecule (Figure 3). Hence, we can be confident that the bisadduct (±)-**8** is a five o'clock constitutional isomer (as assigned by comparison of UV/Vis spectra) with the malonate addends arranged in the *out–out* geometry.

Bisadduct (±)-**7**, with the shorter Tröger base tether, also has a C_1 symmetry as shown in its ^{1}H NMR spectrum (Figure 2). Intriguingly, the UV/Vis spectrum of (±)-**7** does not match those of the previously reported C_{70} bisadducts[5,7] featuring the twelve, two, or five o'clock addition patterns (Figure 1). This is an indication that a new bisaddition pattern has been obtained. Whereas in the three known constitutional isomers, two of the most reactive, α-type 6–6 bonds

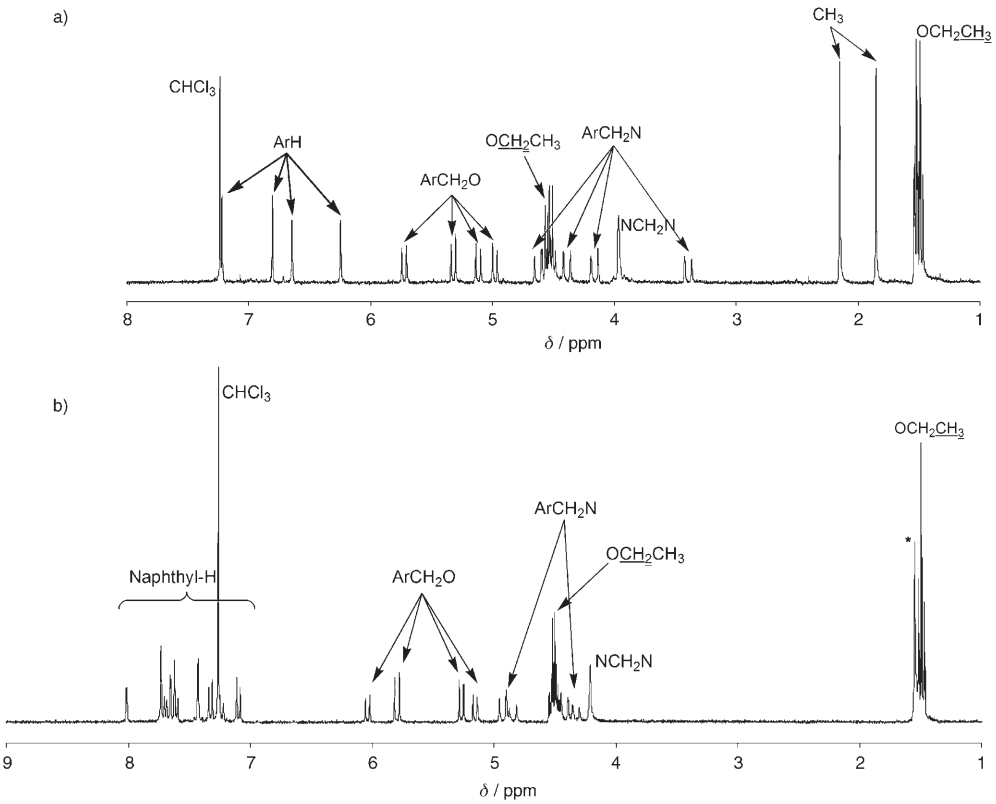


Figure 2. ^{1}H NMR spectra ($CDCl_3$) of a) (±)-**7** and b) (±)-**8**. *Residual water.

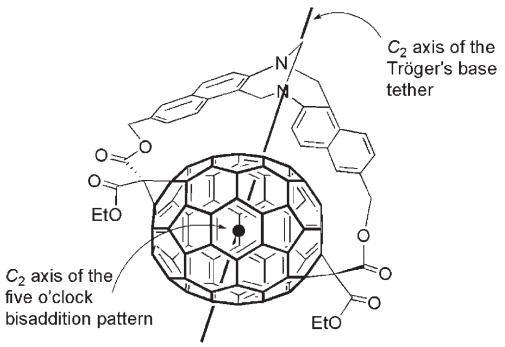


Figure 3. Illustration of the symmetry of bisadduct (±)-**8**.

on opposite poles are bridged, it is likely that the bismalonate tether in (±)-**7** is anchored to two different types of 6–6 bonds on opposite poles, one α and one β (Figure 4). As mentioned in the Introduction, β-type 6–6 bonds are second in reactivity to α-type 6–6 bonds. Molecular modeling indicated that the inherently chiral bisadduct with the cyclopropane rings fused to the C(7)–C(22) and C(33)–C(34) bonds is the most favored one in terms of stability. Without further evidence, this constitutional assignment of (±)-**7** can only be a tentative one. However, it was later confirmed by transforming (±)-**7** into a tetrakisadduct with a known addition pattern (see below). Again, modeling strongly supports the assignment of the *out–out* configuration.

Isolation of enantiomerically pure bisadducts of C_{70}: The enantiomers of the two Tröger base-tethered bismalonates (±)-**1** and (±)-**6** were separated by preparative HPLC on a Regis Whelk-O1 column using mixtures of hexane and ethyl acetate. The absolute configurations of the enantiomerically pure bismalonates were subsequently assigned by comparison of their circular dichroism (CD) spectra with those of literature-known optically pure Tröger base derivatives.[8,15]

Subsequent macrocyclizations (Scheme 1) yielded bisadducts with constitutions as assigned above (MALDI-TOF, ^{1}H and ^{13}C NMR). Starting from (*S*,*S*)-**1**, two diastereoisomeric five o'clock bisadducts, with enantiomeric $^{f,s}A$ and $^{f,s}C$ addition patterns,[16] can in principle be formed. However, only one stereoisomer, enantiomerically pure (*S*,*S*,$^{f,s}C$)-**7** (see Figure 5) is isolated as clearly indicated by the number of resonances in the ^{1}H and ^{13}C NMR spectra (corresponding to one C_1-symmetric structure) as well as the CD spectra (see below). Thus, the macrocyclization to the bisadducts occurs with complete diastereoselectivity. Similarly, the addition of (*R*,*R*)-**1** afforded enantiomerically pure (*R*,*R*,$^{f,s}A$)-**7**. The absolute configurational assignments for the addition patterns are based on molecular mechanics-based calculations of heats of formation for geometry-optimized structures, which suggested that the formation of (*S*,*S*,$^{f,s}C$)-**7** and (*R*,*R*,$^{f,s}A$)-**7** is more favorable (by ~2 kcal mol^{-1}) than the formation of the corresponding diastereoisomers (*S*,*S*,$^{f,s}A$)-**7** and (*R*,*R*,$^{f,s}C$)-**7**. As previously discussed,[8,17] it is assumed that the thermodynamic stability of the bisadduct is reflected in the second cyclopropanation step that leads to macrocyclization and determines the absolute configuration of the addition pattern. These absolute configurational assignments are further supported by CD spectral comparisons shown below. Similarly, complete diastereoselectivity was obtained in the macrocyclization of (*S*,*S*)- and (*R*,*R*)-**6** with the higher fullerene and only one C_1-symmetric product was observed by NMR from each of the enantiomerically pure bismalonate tethers. Based on the modeling, the enantiomerically pure bisadduct structures are assigned to the more stable (by ~2 kcal mol^{-1}) diastereoisomers (*S*,*S*,$^{f,s}A$)-**8** and (*R*,*R*,$^{f,s}C$)-**8** as opposed to diastereoisomers (*S*,*S*,$^{f,s}C$)-**8** and (*R*,*R*,$^{f,s}A$)-**8**.

The CD spectra in CH_2Cl_2 fully confirm the diastereoselectivity of the macrocyclizations and the formation of enantiomerically pure products starting from the optically resolved bismalonates. The CD spectra of enantiomeric (*S*,*S*,$^{f,s}A$)-**8** and (*R*,*R*,$^{f,s}C$)-**8** are shown in Figure 6. The spectra closely resemble those of the enantiomerically pure five o'clock bisadducts of C_{70},[5] (*S*,*S*,*S*,*S*,$^{f,s}C$)-**9** and (*R*,*R*,*R*,*R*,$^{f,s}A$)-**9**, for which absolute configurations had been assigned by calculations of their theoretical CD spectra and comparison with the experimental CD data (Figure 6).[5a,18] This close spectral similarity further corroborates the absolute configurational assignments made in this study based on molecular modeling.

Similarly, mirror-image CD spectra were also recorded for the pair of enantiomers (*S*,*S*,$^{f,s}C$)-**7** and (*R*,*R*,$^{f,s}A$)-**7** (Figure 7). Again, this means that the macrocyclizations of

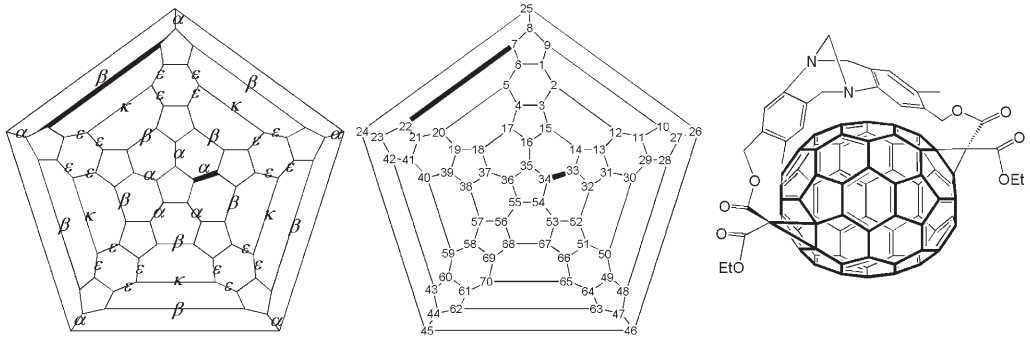


Figure 4. Schlegel diagrams showing the predicted constitution of bisadduct (±)-**7**.

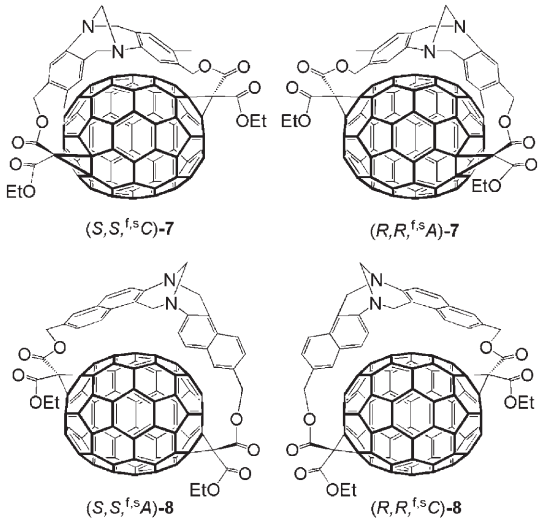


Figure 5. Macrocyclization with optically active bismalonates afforded enantiomerically pure (*S*,*S*,^{f,s}*C*)-**7** and (*R*,*R*,^{f,s}*A*)-**7** (from (*S*,*S*)- and (*R*,*R*)-**1**, respectively) and (*S*,*S*,^{f,s}*A*)-**8** and (*R*,*R*,^{f,s}*C*)-**8** (from (*S*,*S*)- and (*R*,*R*)-**6**, respectively).

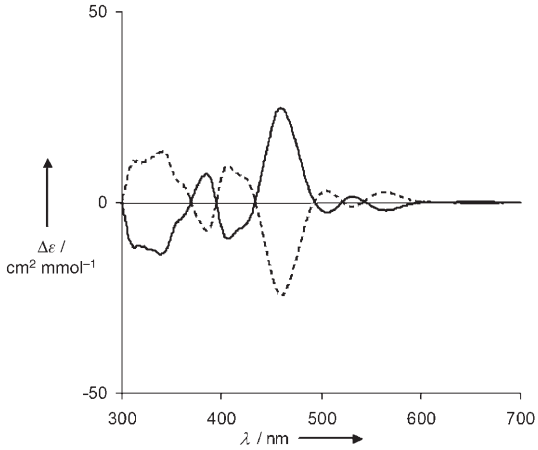


Figure 7. CD spectra of (*S*,*S*,^{f,s}*C*)-**7** (——) and (*R*,*R*,^{f,s}*A*)-**7** (– – –) obtained in CH_2Cl_2.

(*S*,*S*)-**1** and (*R*,*R*)-**1** with C_{70} had proceeded with perfect diastereoselectivity.

Enantiomerically pure tetrakisadducts of C_{70}: Whereas optically active tetrakisadducts of C_{70} are known,[5a,8] the application of two sequential tether-directed remote-functionalizations to the preparation of enantiomerically pure tetrakisadducts of C_{70} has not been reported. In fact, such a sequence remains unknown in the entire field of covalent fullerene chemistry. At the same time, we hoped that the constitution of bisadduct (±)-**7** could be unambiguously identified by transforming it into a tetrakisadduct with a known addition pattern.

When the macrocyclization of bisadduct (±)-**7** with bismalonate (±)-**1** was performed in the presence of iodine and DBU, a single tetrakisadduct (±)-**10** was isolated (Scheme 2). MALDI mass spectra displayed a strong peak

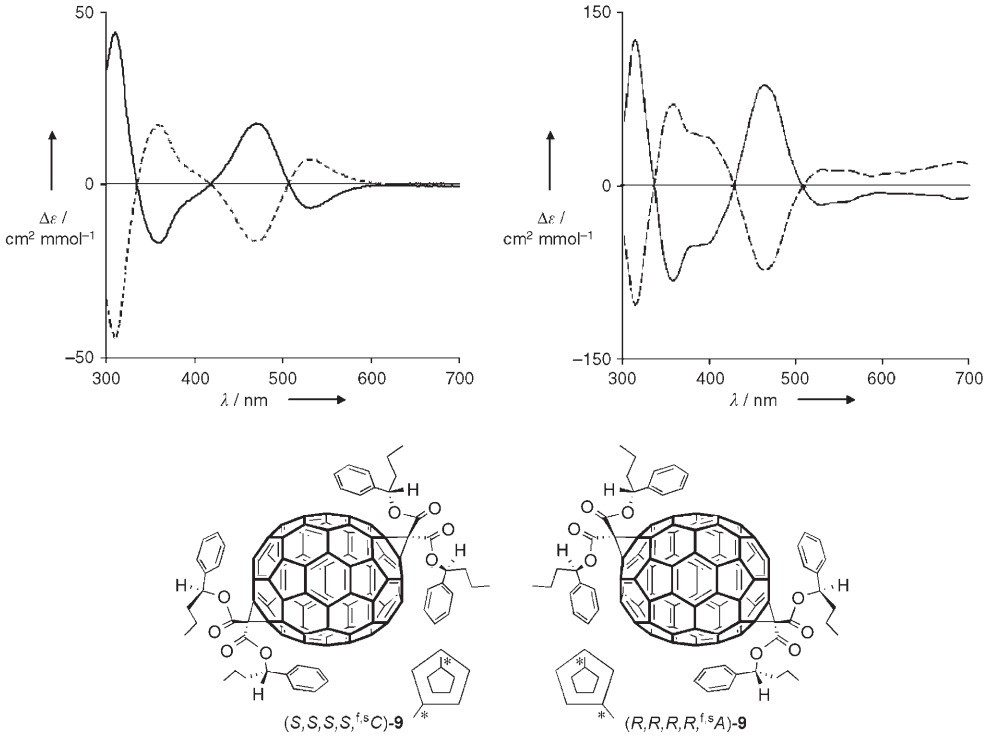
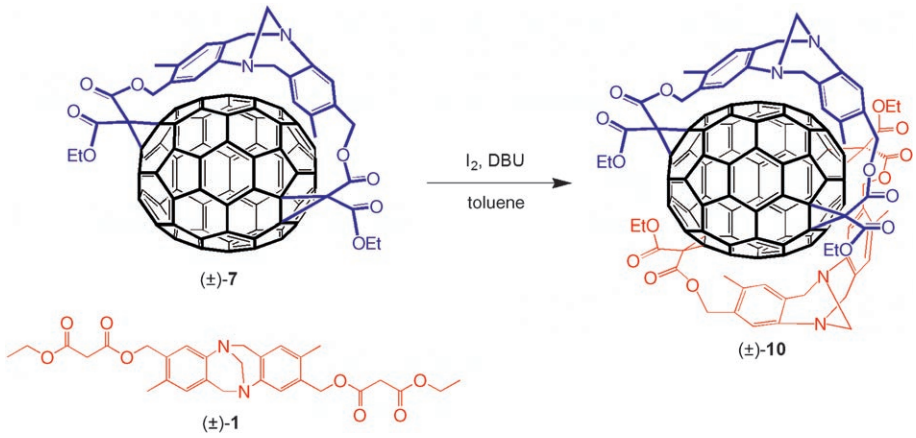


Figure 6. Left: CD spectra of (*S*,*S*,^{f,s}*A*)-**8** (– – –) and (*R*,*R*,^{f,s}*C*)-**8** (——) in CH_2Cl_2. Right: CD spectra of the five o'clock bisadducts (*S*,*S*,*S*,*S*,^{f,s}*C*)-**9** (——) and (*R*,*R*,*R*,*R*,^{f,s}*A*)-**9** (– – –).[5a]



Scheme 2. Synthesis of tetrakisadduct (±)-**10**.

corresponding to the parent ion of tetrakisadduct (±)-**10**, while no higher adducts were observed.

The UV/Vis spectrum of (±)-**10** in CH_2Cl_2 is in good agreement with that of the previously reported tetrakisadduct (±)-**11** (Figure 8),[5] suggesting identical addition patterns. With this assumption, the proposed addition pattern of (±)-**7** could be definitively confirmed.

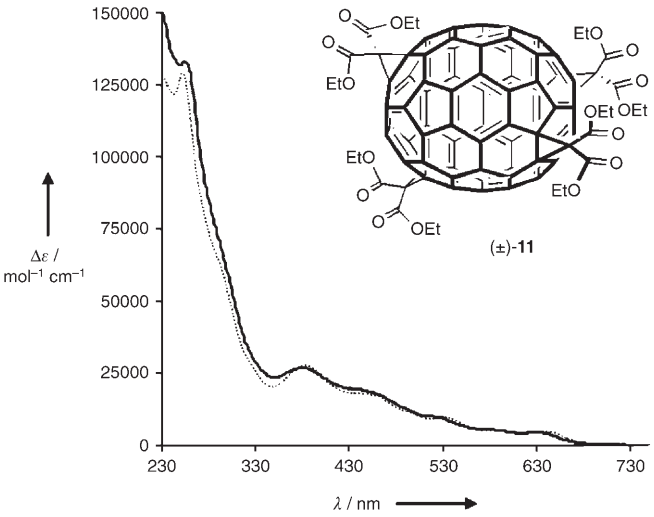


Figure 8. UV/Vis spectra of tetrakisadduct (±)-**10** (——) and the previously reported tetrakisadduct (±)-**11** (•••••) in CH_2Cl_2.

Only four inherently chiral bisaddition patterns are possible for (±)-**7** in order to produce the tetrakisaddition pattern of (±)-**10** (see Schlegel diagram in Figure 9). Bisaddition patterns of (±)-**7** with functionalization at the 6–6 bonds **A** & **B** (or **C** & **D**) and **B** & **D** are unlikely because the tethered bismalonate (±)-**1** is too large to fit between the selected anchor points. Functionalization at bonds **A** & **C** corresponds to the two o'clock bisadduct of C_{70}, and it is known from the UV/Vis spectrum (Figure 1) that (±)-**7** is not a two o'clock bisadduct. This leaves cyclopropanation at bonds **A** & **D** (or **B** & **C**), corresponding to fusion of the cyclopropane rings to the C(7)–C(22) and C(33)–C(34) bonds, as the only way to produce a precursor to (±)-**10**, in agreement with the modeling discussed earlier.

Enantiomerically pure tetrakisadducts were synthesized by macrocyclization of bismalonates (*S*,*S*)-**1** and (*R*,*R*)-**1** with the optically pure bisadducts (*S*,*S*,^{f,s}*C*)-**7** and (*R*,*R*,^{f,s}*A*)-**7**, respectively, in the presence of iodine and DBU. Again, also the second spacer-controlled

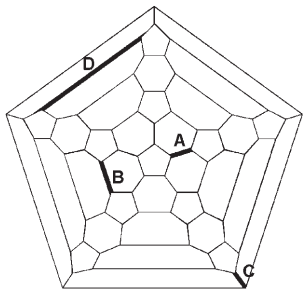


Figure 9. Schlegel diagrams showing the addition patterns of tetrakisadduct (±)-**10** and (±)-**11**. The four cyclopropanated bonds are labeled **A**, **B**, **C**, and **D**.

bisfunctionalization proceeded with complete diastereoselectivity and the CD spectra of the isolated enantiomerically pure tetrakisadducts (*S*,*S*,*S*,*S*,^{f,s}*A*)-**10** and (*R*,*R*,*R*,*R*,^{f,s}*C*)-**10** are shown in Figure 10. Their absolute configuration was assigned by comparison with the CD spectra of literature-known tetrakisadducts (*R*,*R*,*R*,*R*,^{f,s}*A*)-**12** and (*S*,*S*,*S*,*S*,^{f,s}*C*)-**12**.[5a]

Conclusion

The first diastereoselective synthesis of enantiomeric bisadducts of C_{70} with inherently chiral addition patterns by tether-directed remote functionalization is reported. As already seen in the preparation of optically pure bisadducts of C_{60}, Tröger base derivatives are also extremely efficient optically active tethers in the Bingel macrocyclization reaction with C_{70}. The rigid, folded shape of Tröger base derivatives imposes severe steric constraints on the transition state of the second cyclopropanation step: accordingly, a nearly perfect fit between tether length and the distance between the two reacting fullerene bonds is required for the macrocyclization to occur. As a result, the regio- and stereoselectivity of these macrocyclizations are unprecedented. Thus, an appropriate Tröger base tether enabled the synthesis of a C_{70} bisadduct with a previously unknown addition pattern. Also

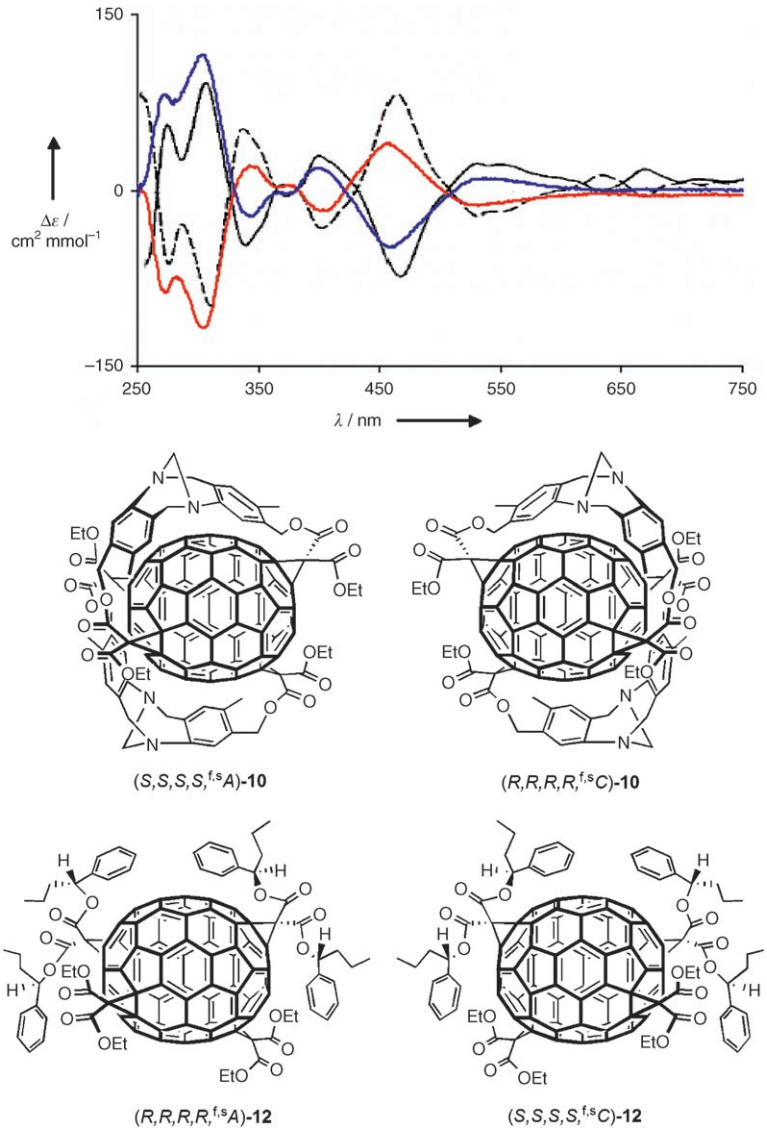


Figure 10. CD spectra of tetrakisadducts (*S*,*S*,*S*,*S*,^{f,s}*A*)-**10** (——), (*R*,*R*,*R*,*R*,^{f,s}*C*)-**10** (——), (*R*,*R*,*R*,*R*,^{f,s}*A*)-**12** (-----), and (*R*,*R*,*R*,*R*,^{f,s}*C*)-**12** (——).

for the first time, enantiomerically pure tetrakisadducts of a fullerene were prepared by two sequential bisadditions directed by covalent Tröger base templates. In view of these results, it is not surprising that the current interest in Tröger base as chiral module in supramolecular construction and asymmetric synthesis is growing rapidly.

Experimental Section

General methods: The syntheses of (±)-**5**[19] and (±)-**6**[8] have been reported previously. All other chemicals and solvents were obtained from commercial sources (Fluka, Aldrich, Merck) and used without further purification unless stated otherwise. Technical grade solvents were distilled before use. THF was distilled over sodium/benzophenone. DMF was stored over flame-dried molecular sieves 4 Å). Reactions were carried out under dry N_2 or Ar. TLC: pre-coated silica gel plates Alugram UV254 (Macherey-Nagel). Column chromatography: Kieselgel 60 (Fluka, particle size 0.040–0.063 mm). HPLC: Merck-Hitachi L-6250 Intelligent Pump, L-4000 A UVdetector, and D-2500 Chromato-Integrator. NMR: Varian Gemini 300 and Bruker AMX 500 spectrometer; chemical shifts (δ) are given in ppm relative to TMS; coupling constants (J) are given in Hz; solvent signals were used as internal references; all spectra were obtained at 20 °C. EI-MS (70 eV): Micromass Auto-Spec Ultima mass spectrometer; ESI-MS (solvent CH_2Cl_2/CH_3OH) and MALDI-MS (2-[(2*E*)-3-(4-*tert*-butylphenyl)-2-methylprop-2-enylidene]malononitrile (DCTB) matrix): Ion Spec 4.7 Ultima mass spectrometer. UV/Vis spectra: Varian CARY 500 spectrophotometer. Circular dichroism (CD) spectra: Jasco J 715 spectropolarimeter. Optical rotations: Perkin–Elmer 241 polarimeter; $[\alpha]_D$ values are given in 10^{-1} deg cm^2 g^{-1}. Melting points: Büchi B-540 instrument in open capillaries.

(±)-1,1′-Diethyl 3,3′-(2,8-dimethyl-6*H*,12*H*-5,11-Methanodibenzo[*b*,*f*]-[1,5]diazocine-3,9-diyl)dimethylene dimalonate [(±)-1]: A solution of (±)-**5**[19] (310 mg, 1 mmol) and DMAP (366 mg, 3 mmol) in dry THF (50 mL) was treated dropwise at 0 °C with ethyl 3-chloro-3-oxopropionate (0.38 mL, 3 mmol). The mixture was stirred for 24 h at 20 °C, concentrated, and the residue purified by column chromatography (silica gel; CH_2Cl_2/AcOEt 1:1) to afford (±)-**1** (135 mg, 25 %) as a colorless oil. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.08 (s, 2H, ArH), 6.73 (s, 2H, ArH), 5.09 (s, 4H, CH_2OCO), 4.62 (d, J = 16.8 Hz, 2H, $ArCH_2N$), 4.26 (s, 2H, NCH_2N), 4.18 (*q*, J = 7.2 Hz, 4H, OCH_2Me), 4.11 (d, J = 16.8 Hz, 2H, $ArCH_2N$), 3.39 (s, 4H, CH_2CO), 2.20 (s, 6H, Ar-CH_3), 1.24 (t, J = 7.2 Hz, 6H, OCH_2Me); ^{13}C NMR (75 MHz, $(CD_3)_2SO$): δ = 166.25 (C=O), 145.79, 132.51, 132.37, 128.64, 128.07, 125.88, 67.02 (NCH_2N), 65.50, 61.63, 58.47, 41.64 (CH_2CO), 18.38 (Ar-CH_3), 14.19 (OCH_2Me); ESI-MS: m/z: 539 $[M+H]^+$.

(*S*,*S*)-**1** and (*R*,*R*)-**1** were obtained by optical resolution of (±)-**1** using preparative HPLC on a Regis (*S*,*S*)-Whelk-O1 column (250 × 10 mm, hexane/AcOEt 70:30, flow rate 7 mL min^{-1}, detection at 290 nm). (*S*,*S*)-**1**: t_R = 16 min; $[\alpha]_D$ = 300 (c = 0.50, chloroform); (*R*,*R*)-**1**: t_R = 18 min; $[\alpha]_D$ = −280 (c = 0.50, chloroform).

(*S*,*S*)-**6** and (*R*,*R*)-**6** were obtained by optical resolution of (±)-**6**[8a] using preparative HPLC on a Regis (*S*,*S*)-Whelk-O1 column (250 × 10 mm, hexane/AcOEt 65:35, flow rate 7 mL min^{-1}, detection at 290 nm). (*S*,*S*)-**6**: t_R = 16 min; $[\alpha]_D$ = 510 (c = 0.50, chloroform). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.67–7.61 (m, 6H, ArH), 7.08 (d, J = 8.7 Hz, 2H, ArH), 6.73 (d, J = 8.7 Hz, 2H, ArH), 5.25 (s, 4H, CH_2OCO), 5.03 (d, J = 16.8 Hz, 2H, NCH_2Ar), 4.74 (d, J = 16.8 Hz, 2H, NCH_2Ar), 4.49 (s, 2H, NCH_2N), 4.18 (q, J = 7.2 Hz, 4H, OCH_2Me), 3.37 (s, 4H, CH_2CO), 1.20 (t, J = 7.2 Hz, 6H, OCH_2Me); ESI-MS: m/z: 611 $[M+H]^+$; (*R*,*R*)-**6**: t_R = 19 min; $[\alpha]_D$ = −476 (c = 0.50, chloroform).

(±)-*out*,*out*-3′,3″-Diethyl 3′,3″-(2,8-dimethyl-6*H*,12*H*-5,11-methanodibenzo[*b*,*f*][1,5]diazocine-3,9-diyldimethylene)-3′*H*,3″*H*-dicyclopropa[7,22:33,34](C$_{70}$-*D*$_{5h(6)}$)[5,6]fullerene-3′,3′,3″,3″-tetracarboxylate [(±)-7]: A well-degassed solution of (±)-**1** (91 mg, 0.17 mmol) and C_{70} (130 mg, 0.16 mmol) in toluene (100 mL) was treated at 0 °C with a solution of I_2 (100 mg, 0.4 mmol) in toluene (5 mL) and then with DBU (0.15 mL, 1 mmol). The resulting mixture was stirred for 1 h at 0 °C, then filtered. Column chromatography (silica gel; CH_2Cl_2/AcOEt 10:1) afforded (±)-**7** (50 mg, 21 %) as a dark solid. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.22 (s, 1H; Ar-H), 6.81 (s, 1H; Ar-H), 6.65 (s, 1H; Ar-H), 6.25 (s, 1H; Ar-H), 5.74 (d, J = 11.4 Hz, 1H; OCH_2Ar), 5.34 (d, J = 11.4 Hz, 1H; OCH_2Ar), 5.14 (d, J = 11.1 Hz, 1H; OCH_2Ar), 5.00 (d, J = 11.1 Hz, 1H; OCH_2Ar), 4.66 (d, J = 18.9 Hz, 1H; NCH_2Ar), 4.57–4.48 (m, 4H; CH_2CH_3), 4.42 (d, J = 17.1 Hz, 1H; NCH_2Ar), 4.19 (d, J = 17.7 Hz, 1H; NCH_2Ar), 3.97 (s, 2H; NCH_2N), 3.42 (d, J = 16.8 Hz, 1H; NCH_2Ar), 2.15 (s, 3H; Ar-CH_3), 1.85 (s, 3H; Ar-CH_3), 1.50 (m, 6H; CH_2CH_3); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 164.22, 163.80, 163.60 and 162.98 (C=O), 155.59, 153.30, 152.97, 152.55, 151.89, 151.32, 149.63, 149.21, 149.03, 148.92, 148.57, 148.05, 147.92, 147.54, 147.40, 146.83, 146.57, 146.46, 146.20, 145.94, 145.78, 145.54, 145.39, 144.83, 144.41, 144.31, 144.17, 144.04, 143.85, 142.73, 142.62, 142.24, 141.51, 140.87, 139.99, 139.77, 139.23, 139.14, 130.03, 138.66, 138.16, 138.09, 136.99, 134.40, 134.11, 133.67, 133.31, 133.17, 131.84, 131.54, 130.86, 130.32, 129.13, 129.05, 128.90, 128.58, 128.42, 67.25, 66.97, 66.30, 65.69, 63.68, 63.60, 60.43, 57.19, 57.03, 38.17, 37.73, 21.16, 19.46, 19.14, 14.42; UV/Vis (CH_2Cl_2): $\lambda_{max}(\varepsilon)$ = 454 (21 640), 530 (sh, 8630), 575 (sh, 6000), 671 (sh, 1200); HR-MALDI-MS: m/z: calcd for $C_{99}H_{30}N_2O_8$: 1375.20; found 1376.2073 $[M]^+$.

(*R*,*R*,^{f,s}*A*)-7 and (*S*,*S*,^{f,s}*C*)-7: Prepared as described for (±)-**7** from (*R*,*R*)-**1** (30 mg, 0.06 mmol) and (*S*,*S*)-**1** (20 mg, 0.04 mmol), respectively. (*R*,*R*,^{f,s}*A*)-**7**: Yield = 20 mg, 26 %. (*S*,*S*,^{f,s}*C*)-**7**: Yield = 10 mg, 20 %. CD spectra, see Figure 7.

(±)-*out*,*out*-3′,3″-Diethyl 3′,3″-(8*H*,16*H*-7,15-methanodinaphtho[2,1-*b*,2′,1′-*f*,1,5]diazocin-3,11-diyldimethylene)-3′*H*,3″*H*-dicyclopropa[8,25:53,54](C$_{70}$-*D*$_{5h(6)}$)[5,6]fullerene-3′,3′,3″,3″-tetracarboxylate [(±)-8]: Prepared as described for (±)-**7** from (±)-**6** (100 mg, 0.17 mmol). Yield = 100 mg, 48 %; dark solid. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.99 (s, 1H; Ar-H), 7.71–7.57 (m, 4H; Ar-H), 7.41 (s, 2H; Ar-H), 7.31 (d, J = 8.7 Hz, 1H; Ar-H), 7.22 (d, J = 9.3 Hz, 1H; Ar-H), 7.08 (d, J = 8.7 Hz, 1H; Ar-H), 6.03 (d, J = 10.8 Hz, 1H; OCH_2Ar), 5.79 (d, J = 10.8 Hz, 1H; OCH_2Ar), 5.26 (d, J = 10.8 Hz, 1H; OCH_2Ar), 5.15 (d, J = 10.8 Hz, 1H; OCH_2Ar), 4.93 (d, J = 16.8 Hz, 1H; NCH_2Ar), 4.84 (d, J = 16.5 Hz, 1H; NCH_2Ar), 4.50 (m, 4H; CH_2CH_3), 4.42 (d, J = 17.1 Hz, 1H; NCH_2Ar), 4.33 (d, J = 17.1 Hz, 1H; NCH_2Ar), 4.18 (s, 2H; NCH_2N), 1.46 (m, 6H; CH_2CH_3); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 163.26 and 162.51 (C=O), 155.93, 155.86, 154.78, 154.60, 151.58, 150.69, 150.59, 149.91, 149.71, 148.20, 147.88, 147.67, 147.30, 147.06, 146.65, 146.57, 146.40, 146.20, 144.08, 143.66, 142.78, 142.43, 141.51, 141.44, 141.00, 140.28, 139.35, 138.99, 138.31, 137.75, 137.31, 136.90, 136.31, 135.99, 135.79, 133.18, 132.33, 132.07, 131.62, 131.27, 131.12, 130.99, 130.76, 130.63, 130.45, 130.37, 130.26, 129.60, 128.65, 128.30, 127.64, 125.23, 124.83, 121.32, 120.90, 120.43, 120.22, 69.29, 68.85, 67.21, 67.05, 66.37, 66.06, 65.85, 63.62, 60.04, 55.02, 54.81, 54.44, 36.08, 35.88, 21.15, 14.37; UV/Vis (CH_2Cl_2): $\lambda_{max}(\varepsilon)$ = 404 (sh, 9780), 436 (10 600), 469 (10 650), 523 (sh, 6550), 558 (sh, 4220), 637 (sh, 1200), 690 (sh, 580); HR-MALDI-MS: m/z: calcd for $C_{105}H_{30}N_2O_8$: 1447.2090; found 1447.2090 $[M]^+$.

(*R*,*R*,^{f,s}*C*)-8 and (*S*,*S*,^{f,s}*A*)-8: Prepared as described for (±)-**8** from (*R*,*R*)-**6** (36 mg, 0.06 mmol) and (*S*,*S*)-**6** (36 mg, 0.06 mmol), respectively. (*R*,*R*,^{f,s}*C*)-**8**: Yield = 41 mg, 48 %. (*S*,*S*,^{f,s}*A*)-**8**: Yield = 40 mg, 46 %. CD spectra, see Figure 6.

(±)-*out*,*out*,*out*,*out*-3′,3″,3‴,3⁗-Tetraethyl 3′,3″,3‴,3⁗-bis(2,8-dimethyl-6*H*,12*H*-5,11-methanodibenzo[*b*,*f*][1,5]diazocine-3,9-diyldimethylene)-3′*H*,3″*H*,3‴*H*,3⁗*H*-tetracyclopropa[7,22:14,15:46,47:55,56](C$_{70}$-*D*$_{5h(6)}$)-[5,6]fullerene-3′,3′,3″,3″,3‴,3‴,3⁗,3⁗-octacarboxylate [(±)-10]: Bisadduct (±)-**7** (20 mg, 0.015 mmol) and bismalonate (±)-**1** (8 mg, 0.015 mmol) were dissolved in toluene (10 mL), and the solution was thoroughly degassed and cooled to 0 °C. Iodine (10 mg, 0.04 mmol) in toluene (1 mL) was added, followed by DBU (0.015 mL, 0.1 mmol). The mixture was stirred at 0 °C under nitrogen, and the reaction was monitored by TLC. The transformation was complete (approx. 1 h) when all of (±)-**7** had been consumed (it may be necessary to add more bismalonate tether (±)-**1**, iodine, and DBU). The mixture was filtered through a plug of Celite and the solvent evaporated. The brown residue was purified by column chromatography (silica gel; CH_2Cl_2/AcOEt 4:1, R_f = 0.2) to give (±)-**10** as a brown solid (10 mg, 36 %). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.09 (s, 2H; Ar-H), 6.87 (s, 1H; Ar-H), 6.66 (m, 2H; Ar-H), 6.62 (s, 2H; Ar-H), 6.27 (s, 1H; Ar-H), 5.80–5.50 (m, 4H; OCH_2Ar), 5.14–4.94 (m, 4H; OCH_2Ar), 4.63–4.01 (m, 14H; NCH_2Ar, CH_2CH_3), 3.95 (s, 4H; NCH_2N), 3.39 (m, 2H; NCH_2Ar), 2.17 (m, 6H; Ar-CH_3), 1.87 (m, 6H; Ar-CH_3), 1.51 (m, 12H; CH_2CH_3); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 166.39, 164.58, 163.79, 162.83, 156.14, 152.09, 151.75, 148.65, 146.85, 146.40, 146.12, 145.59, 144.92, 144.52, 144.06, 143.10, 142.70, 142.48, 140.93, 140.68, 140.12, 139.57, 139.33, 137.89, 136.91, 136.27, 135.68, 134.68, 134.43, 133.57, 131.56, 131.12, 129.21, 129.04, 128.83, 128.08, 126.81, 67.02, 65.97, 65.63, 63.49, 58.46, 56.93, 41.53, 29.68, 19.48, 19.23, 19.01, 18.46, 14.31, 14.22; UV/Vis (CH_2Cl_2): $\lambda_{max}(\varepsilon)$ = 256 (133 000), 380 (26 900), 449 (sh, 18 800), 528 (sh, 9690), 634 (4560); HR-MALDI-MS: m/z: calcd for $C_{128}H_{60}N_4O_{16}$: 1909.40; found 1909.41 $[M]^+$.

(*R*,*R*,*R*,*R*,^{f,s}*C*)-10 and (*S*,*S*,*S*,*S*,^{f,s}*A*)-10: (*R*,*R*,*R*,*R*,^{f,s}*C*)-**10** was prepared as described for (±)-**10** from (*R*,*R*,^{f,s}*A*)-**7** (5 mg, 0.004 mmol) and (*R*,*R*)-**1** (2 mg, 0.004 mmol). Yield = 2.0 mg, 29 %. (*S*,*S*,*S*,*S*,^{f,s}*A*)-**10** was prepared as described for (±)-**10** from (*S*,*S*,^{f,s}*C*)-**7** (5 mg, 0.004 mmol) and (*S*,*S*)-**1** (2 mg, 0.004 mmol). Yield = 2.5 mg, 36 %. CD-spectra, see Figure 10.

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