Amphiphilic Fullerene-Cholesterol Derivatives: Synthesis and Preparation of *Langmuir* and *Langmuir-Blodgett* Films

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Amphiphilic fullerene bis-adducts **11** and **14** containing two and four cholesterol moieties, respectively, were prepared starting from the corresponding bis-malonate derivatives. In a systematic study, their spreading behavior at the air-water interface was compared to that of bis-adduct **6** with no polar head-group. Compared to **6**, for which some three-dimensional aggregation occurs, the polar head-group in **11** and **14** is responsible for an attractive interaction with the aqueous subphase, forcing the molecules towards the water surface into a two-dimensional arrangement. Even if homogeneous *Langmuir* films were obtained with both **11** and **14**, only the films of **14** show a reversible compression/expansion behavior. This suggests that, by increasing the number of cholesterol subunits, the encapsulation of the C-sphere in its addend is more efficient, thus preventing fullerene-fullerene interactions and aggregation phenomena. The *Langmuir* films of **11** and **14** were also efficiently transferred onto hydrophilic quartz slides, yielding *Langmuir-Blodgett* films.

1. Introduction. – Growing attention is currently devoted to fullerene derivatives for applications in supramolecular chemistry and materials science [1]. In this respect, the incorporation of such compounds into thin ordered films appears as an important issue [2][3]. One of the most widely pursued approach towards structurally ordered fullerene assemblies has been the preparation of *Langmuir* films at the air-water interface and their transfer onto solid substrates [2]. However, monolayers of fullerene derivatives are difficult to prepare due to strong fullerene-fullerene interactions and three-dimensional aggregation [2]. Indeed, fullerene derivatives with good spreading characteristics and reversible compression/decompression behavior are quite rare [4][5]. In collaborative work by *Diederich*, *Stoddart*, *Echegoyen*, and *Leblanc*, fullerene derivatives bearing dendritic branches with peripheral acylated glucose units have been investigated [4]. These derivatives are able to form stable ordered monolayers at the air-water interface and show reversible behavior in successive compression/decompression cycles. The dendritic portion is effective in preventing the irreversible aggregation usually observed for amphiphilic fullerene derivatives. We have recently shown that good spreading characteristics and a reversible compression/expansion behavior can also be obtained with amphiphilic cyclic fullerene bis-adducts. In this case, the encapsulation of the C-sphere in a cyclic addend surrounded by long alkyl chains also prevents efficiently the aggregation of the fullerene moieties [5]. As

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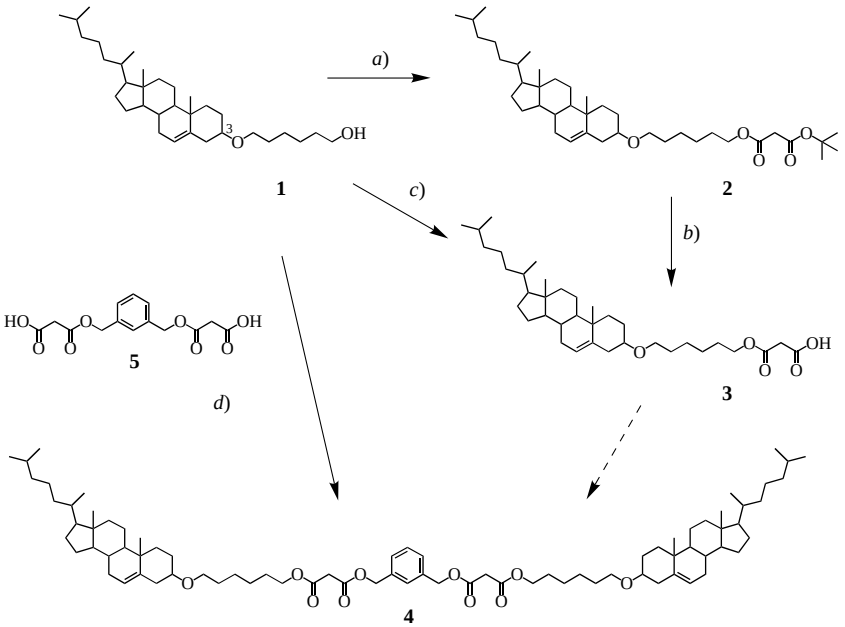
part of this research, we now show that substitution of the amphiphilic cyclic fullerene bis-adduct substructure with cholesterol groups is also a convenient way to prepare suitable derivatives for efficient incorporation into *Langmuir* films.

2. Results and Discussion. – 2.1. *Synthesis.* We planned to attach the cholesterol moieties to the [5,6]fullerene-C_{60}-I_h (C_{60}) core by taking advantage of the versatile regioselective reaction developed in the group of *Diederich* [6], which led to macrocyclic bis-adducts of C_{60} by a macrocyclization reaction at the fullerene sphere with bis-malonate derivatives in a double *Bingel* cyclopropanation [7]. Therefore, we prepared the bis-malonate **4** substituted with two cholesterol residues starting from cholesterol (=(3β)-cholest-5-en-3-ol) (*Scheme 1*). Compound **1** was prepared in two steps from cholesterol as previously described [8]. In this synthetic process, the ether derivative **1** is obtained with the natural (3*S*)-configuration [8]. All efforts to efficiently prepare acid **3** towards formation of the desired bis-malonate **4** were disappointing. The preparation of **3** was initially attempted by heating alcohol **1** with 2,2-dimethyl-1,3-dioxane-4,6-dione (= *Meldrum*'s acid) [9]. Decomposition was observed under these conditions, and compound **3** was thus obtained in low yield. *N*,*N*′-Dicyclohexylcarbodiimide(DCC)-mediated esterification of **1** with *tert*-butyl malonate followed by selective hydrolysis of the *tert*-butyl ester moiety of the resulting **2** under acidic conditions gave **3** in poor yield. Indeed, deprotection of **2** under various conditions led to decomposition, and no further efforts were made to prepare **4** by this route. In

Scheme 1

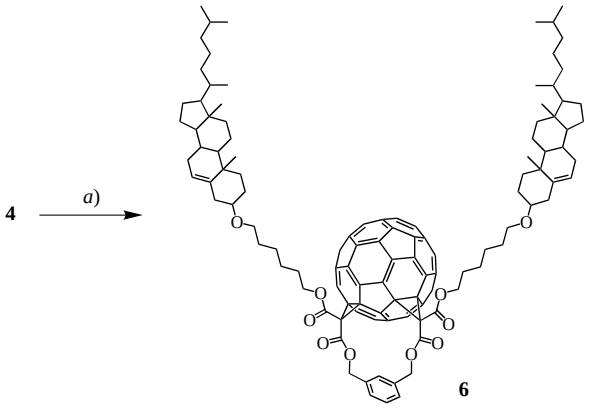


a) *t*-$BuO_2CCH_2CO_2H$, DCC, DMAP, BtOH, CH_2Cl_2, 0° to r.t. (65%). *b*) CF_3CO_2H, CH_2Cl_2, r.t. (non-reproducible yields). *c*) *Meldrum*'s acid, 120° (10–35%). *d*) DCC, DMAP, BtOH, CH_2Cl_2 (93%).

contrast, the reaction of **1** with diacid **5** [10] in CH_2Cl_2 under esterification conditions (DCC, *N*,*N*-dimethylpyridin-4-amine (DMAP), and 1-hydroxy-1*H*-benzotriazole (BtOH)) gave the desired bis-malonate **4** in 74% yield.

Treatment of C_{60} with **4**, I_2, and diazabicyclo[5.4.0]undec-7-ene (DBU) in toluene at room temperature afforded the desired cyclization product **6** in 28% yield (*Scheme 2*). It is well-established that the 1,3-phenylenebis(methylene)-tethered bis-malonates produce regioselectively the *cis-2* addition pattern at C_{60} [6][10][11]. All the spectroscopic data obtained for compound **6** are in agreement with such a *cis-2* addition pattern. In particular, the UV/VIS spectra of the bis-cyclopropanated fullerene derivative **6** shows all the characteristic features of a *cis-2* bis-adduct [10].

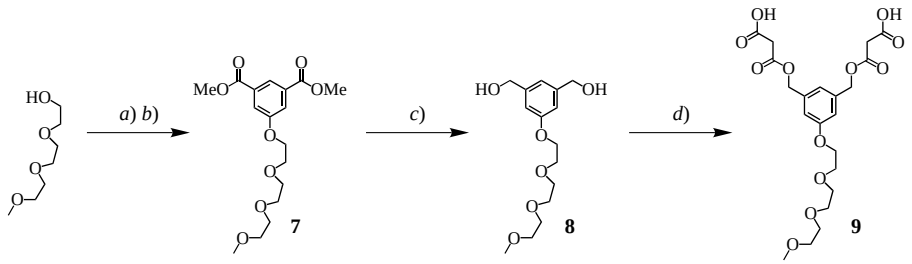
Scheme 2



a) C_{60}, I_2, DBU, toluene, r.t. (28%).

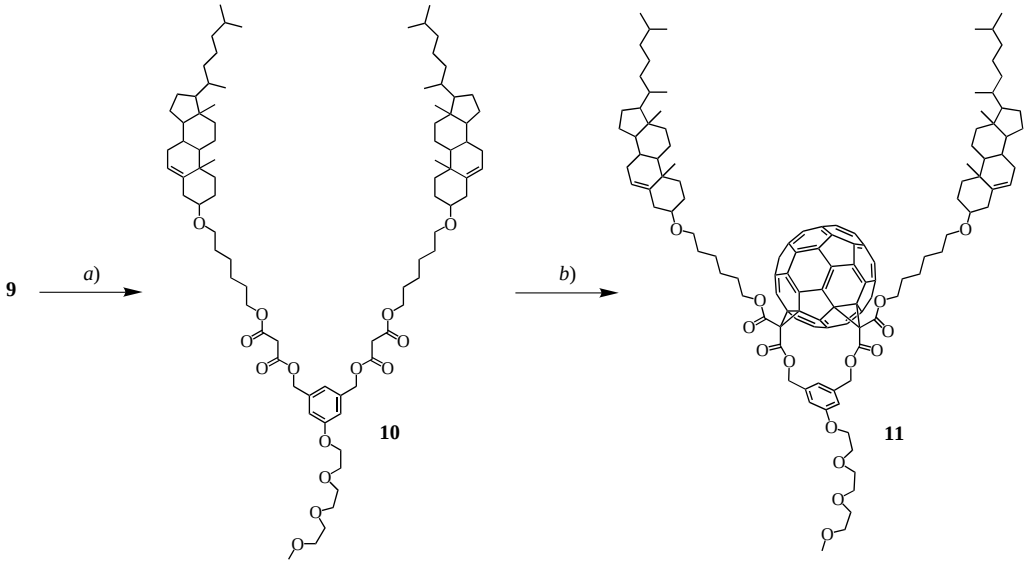
The preparation of the corresponding fullerene derivative bearing a triethylene glycol-type polar head group was achieved by a similar route (*Schemes 3* and *4*). Treatment of triethylene glycol monomethyl ether with *p*-toluene sulfonyl chloride (TsCl) and pyridine, followed by reaction of the resulting tosylate with dimethyl 5-hydroxyisophthalate in the presence of K_2CO_3 in DMF at 70° afforded **7** in 88% yield

Scheme 3



a) TsCl, pyridine, CH_2Cl_2, 0° (69%). *b*) Dimethyl 5-hydroxyisophthalate, K_2CO_3, DMF, 80° (88%). *c*) $LiAlH_4$, THF, 0° to r.t. (88%). *d*) *Meldrum*'s acid, 110° (98%).

Scheme 4



a) **1**, DCC, DMAP, BtOH, CH_2Cl_2 (73%). *b*) C_{60}, I_2, DBU, toluene, r.t. (50%).

(*Scheme 3*). Lithium aluminum hydride ($LiAlH_4$) reduction then gave diol **8**. Subsequent treatment with *Meldrum*'s acid afforded diacid **9** in 98% yield.

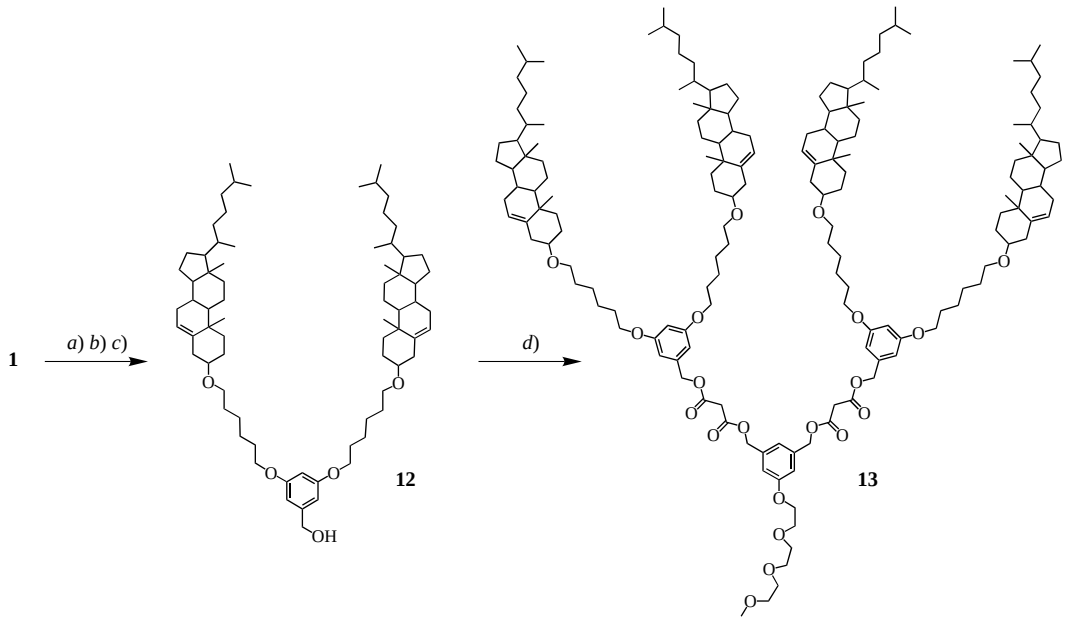
Reaction of alcohol **1** with diacid **9** in CH_2Cl_2 under esterification conditions (DCC, DMAP, and BtOH) gave bis-malonate **10** in 73% yield (*Scheme 4*). Subsequent reaction with C_{60}, I_2, and DBU in toluene at room temperature afforded the *cis-2* bis-adduct **11** in 50% yield.

The synthesis of the fullerene derivative bearing four cholesterol subunits is shown in *Schemes 5* and *6*. Treatment of **1** with TsCl and pyridine, followed by reaction of the resulting tosylate with KBr in refluxing acetone and subsequent treatment of the resulting bromide with 5-(hydroxymethyl)benzene-1,3-diol in the presence of K_2CO_3 in DMF at 70° afforded **12** (*Scheme 5*). Reaction of alcohol **12** with diacid **9** in CH_2Cl_2 under esterification conditions (DCC, DMAP, and BtOH) gave bis-malonate **13** in 85% yield. Reaction of **13** with C_{60}, I_2, and DBU in toluene at room temperature afforded the *cis-2* bis-adduct **14** in 44% yield (*Scheme 6*).

Whereas liquid-crystalline properties were observed for some of the cholesterol precursors (see the *Table* in the *Exper. Part*), no mesomorphic behavior was detected for the three cholesterol-fullerene derivatives **6**, **11**, and **14**. Actually, they are amorphous glassy compounds at room temperature. Decomposition was observed at *ca.* 150° for compound **6**. In contrast, differential scanning calorimetry (DSC) analysis of **11** and **14** revealed glass transitions at 67° and 35°, respectively. In both cases, an isotropic liquid was obtained after the glass transition.

2.2. Langmuir *Films at the Air-Water Interface.* In spite of the lack of a polar head group, compound **6** is apparently able to form *Langmuir* films at the air-water interface: well-defined isotherms with a rather high collapse pressure (40 mN/m) were recorded

Scheme 5



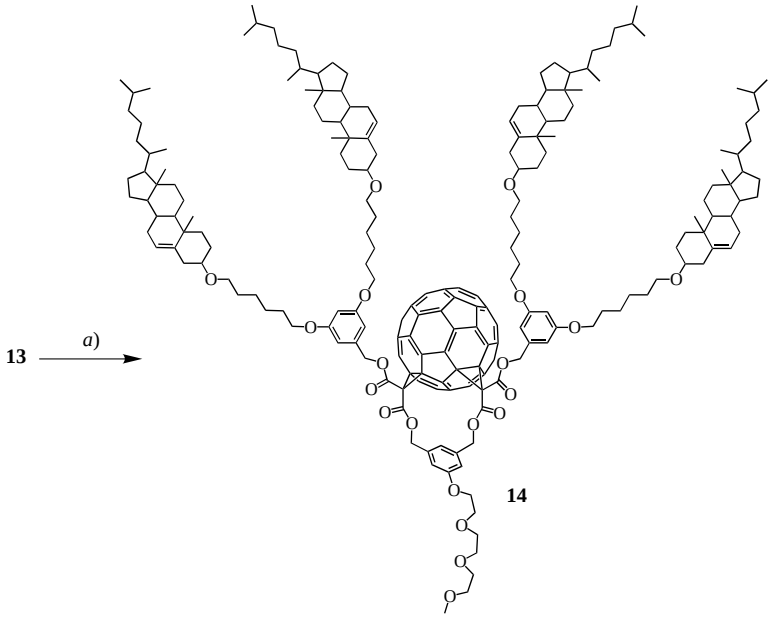
a) TsCl, pyridine, 0° (85%). *b*) KBr, acetone, DMF, Δ (90%). *c*) 5-(Hydroxymethyl)benzene-1,3-diol, K_2CO_3, DMF, 80° (75%). *d*) **9**, DCC, DMAP, BtOH, 0° to r.t. (85%).

(*Fig. 1*). However, these isotherms are not reversible. Furthermore, the molecular area, extrapolated to zero surface pressure, is 73 ± 3 Å^2 for compound **6**, which is obviously too small for such a molecule. One must then conclude that some three-dimensional aggregation occurs, and the film is at least partly multilayered.

Brewster angle microscopy (BAM) observations gave clear evidence for imperfect films in the case of **6** (*Fig. 2*). The pictures taken at different values of the molecular areas reveal that the molecules form aggregates. It should be noted that some large domains appeared birefringent, implying the presence of some degree of molecular alignment. However, since the formation of such domains could not be controlled, no further studies on this particular behavior were attempted.

Comparison of the pressure-area isotherm for compound **11** (*Fig. 3*) with that of **6** reveals that, apparently, the presence of the polar head group in **11** does not change the general shape of the isotherm. However, the molecular area, extrapolated to zero surface pressure, for compound **11** is 170 ± 5 Å^2, and is in good agreement with the value estimated by molecular modeling. This observation suggests that a monomolecular film was obtained. The polar head group in **11** is responsible for a strong attractive interaction with the aqueous subphase, forcing the molecules towards a two-dimensional arrangement on the water surface. Unfortunately, the isotherm still shows poor reversibility, even when the highest pressure is kept below the collapse value (*Fig. 4*).

Scheme 6



a) C_{60}, I_2, DBU, toluene, r.t. (44%).

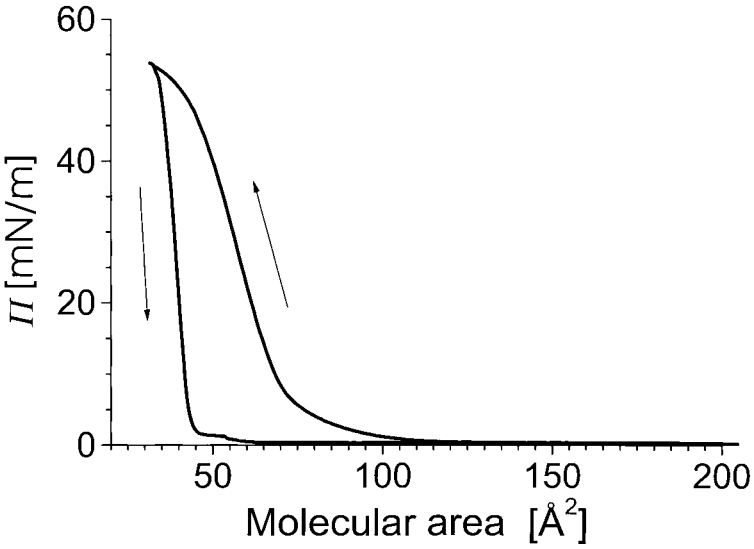


Fig. 1. *Pressure-area isotherm for* **6**

BAM Images show that the *Langmuir* film obtained with compound **11** is homogeneous at the end of the compression (*Fig. 5*). In addition to the observation of the expected molecular area for **11**, the high-quality film observed by BAM clearly

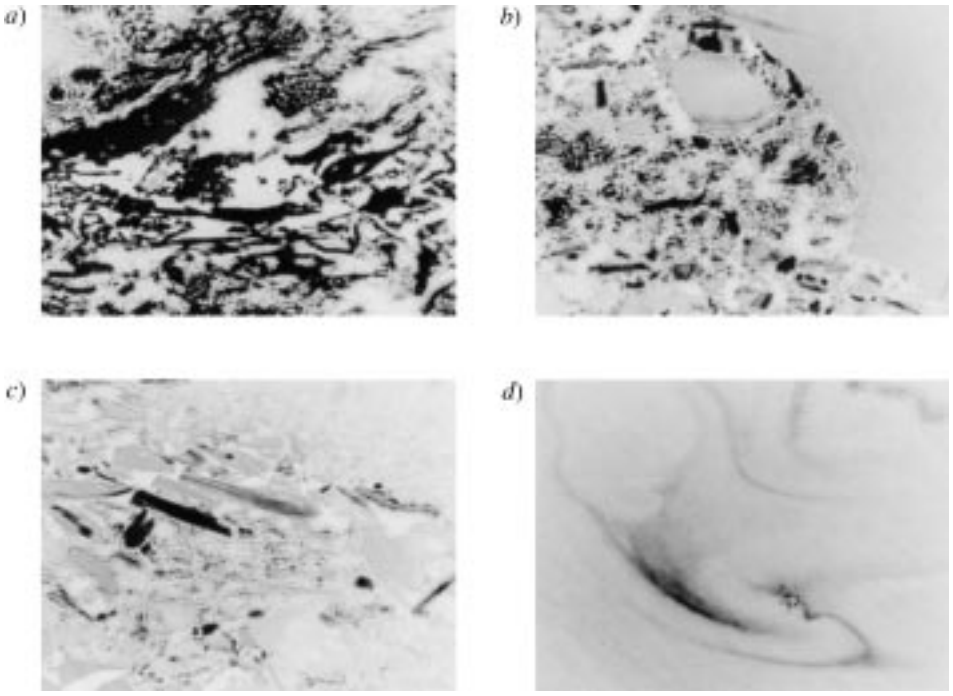


Fig. 2. Brewster *angle microscopy images for* **6** *at* a) A = *95 Å*^{2}, b) A = *94 Å*^{2}, c) A = *74 Å*^{2}, *and* d) A = *67 Å*^{2}

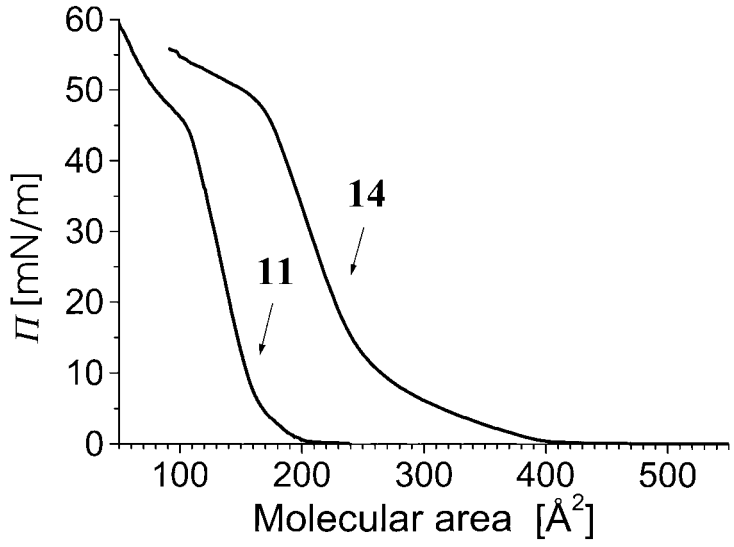


Fig. 3. *Pressure-area isotherms for* **11** *and* **14**

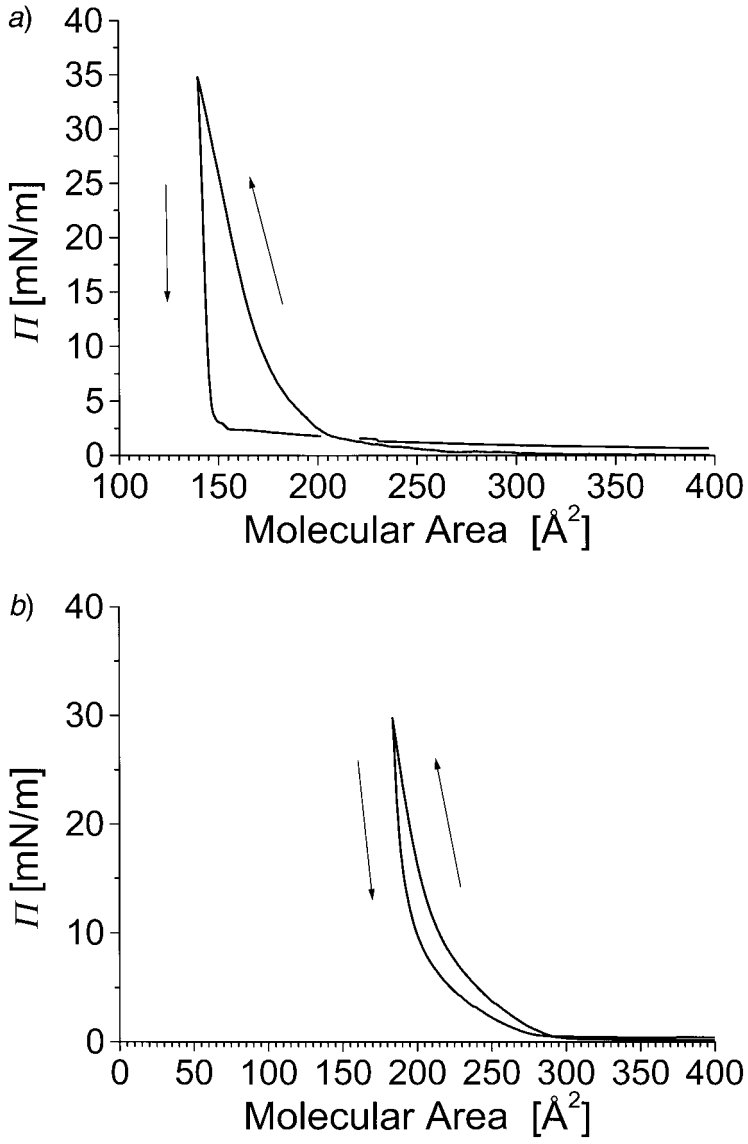


Fig. 4. *Hysteresis curves showing the reversibility of the isotherm* a) *of* **11** *and* b) *of* **14**

indicates the formation of a homogeneous monomolecular layer. As shown in *Fig. 5*, during decompression, the film broke, hence the lack of reversibility of the isotherms.

The pressure-area isotherm for compound **14** is depicted in *Fig. 3*. Films of good quality were obtained, and the BAM picture of the film at the end of the compression looks like the picture shown in *Fig. 5*,*c* for **11** (not shown here). When compared to **11**,

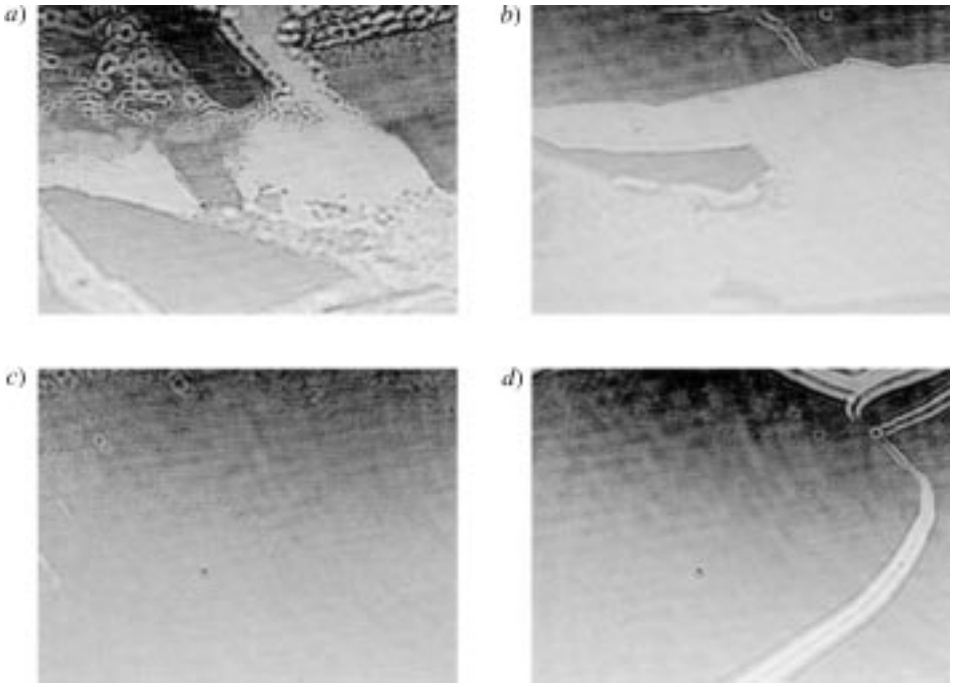


Fig. 5. Brewster *angle microscopy images for* **11** *at* a) A = *300 Å*^{2}, b) A = *200 Å*^{2}, c) A = *162 Å*^{2}, *and* d) *during the decompression*

one immediately sees (*Fig. 3*) that the additional two cholesterol moieties increase the molecular area, which becomes 270 ± 10 Å^2. It can also be noticed that the shape of the isotherm is different; the surface pressure starts to increase slowly at a molecular area of 400 Å^2, before rising in a steeper way at *ca.* 250 Å^2. This liquid-expanded phase between 400 and 250 Å^2, not observed with compound **11**, is indicative for long-range intermolecular interactions in the *Langmuir* film. Extra evidence of better film cohesion is confirmed by the hysteresis curve, which shows a better reversibility of the isotherm (*Fig. 4*). By increasing the number of cholesterol subunits, the encapsulation of the C-sphere in its addend is more effective, thus limiting fullerene-fullerene interactions and aggregation phenomena.

2.3. Langmuir-Blodgett *Films.* It was possible to transfer the *Langmuir* films of **11** onto hydrophilic quartz slides. The transfer ratio was 1 ± 0.1, and Y-type multilayers were assembled. The deposition occurred regularly, as shown by the plot of the absorbance at 260 nm obtained from the UV/VIS spectra of the *LB* films as a function of the number of layers (*Fig. 6*). A straight line was obtained, indicating efficient stacking of the layers.

The *Langmuir* films of **14** were also efficiently transferred onto hydrophilic quartz slides with a transfer ratio of 1 ± 0.1, and Y-type *LB* films were obtained. As for the *LB* films prepared with **11**, absorbance measurements indicate that the film obtained from **14** grows regularly.

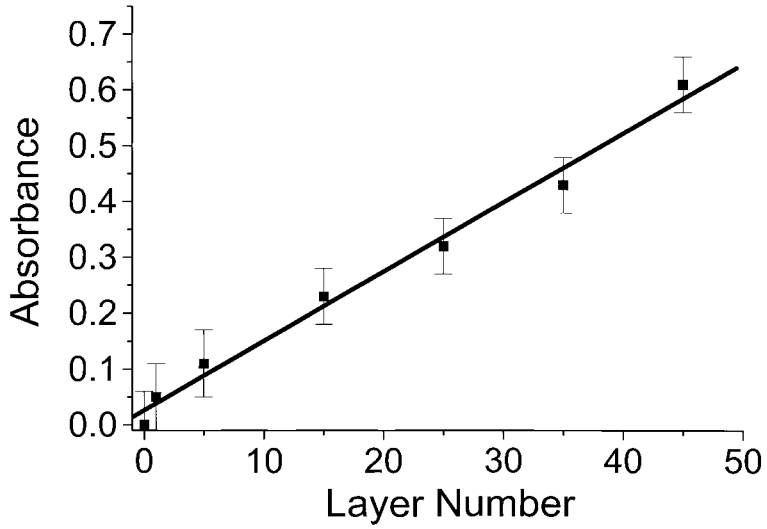


Fig. 6. *Plot of the absorbance at 260 nm against the layer number for* Langmuir-Blodgett *films of* **11**

3. Conclusions. – The amphiphilic fullerene bis-adducts **11** and **14**, containing two and four cholesterol residues, respectively, were prepared. Their spreading behavior was compared to that of bis-adduct **6** with no polar head-group. For **6**, some three-dimensional aggregation occurred, whereas, in the case of **11** and **14**, the polar head-group was responsible for an attractive interaction with the aqueous subphase, forcing the molecules towards the water surface into a two-dimensional arrangement. Homogeneous *Langmuir* films were obtained for both **11** and **14**, but only the films obtained with **14** showed a reversible compression/expansion behavior. This suggests that, by increasing the number of cholesterol subunits, the encapsulation of the C-sphere in its addend is more efficient, thus limiting fullerene-fullerene interactions and aggregation phenomena. We also showed that the *Langmuir* films of **11** and **14** can be efficiently transfered onto solid substrates. Therefore, **11** and **14** appear to be interesting compounds for future applications in materials science. Having already shown that the functionalization of the fullerene sphere with cholesterol subunits is an efficient way to produce C_{60} derivatives with liquid-crystalline properties [12], we have now established that related derivatives can be efficiently incorporated into thin ordered films.

Experimental Part

General. Reagents and solvents were purchased as reagent grade and used without further purification. Compounds **1** [8] and **5** [10], triethylene glycol monomethyl ether tosylate [13] and (3β)-cholest-5-en-3-yl 6-bromohexyl ether [8] were prepared according to the literature. All reactions were performed in standard glassware under Ar. Evaporation and concentration were done at water-aspirator pressure and drying *in vacuo* at 10^{-2} Torr. Column chromatography (CC): silica gel *60* (230–400 mesh, 0.040–0.063 mm) from *E. Merck*. TLC: glass sheets coated with silica gel *60* F_{254} from *E. Merck*; visualization by UV light. UV/VIS Spectra (λ_{max} in nm (ε)): *Hitachi-U-3000* spectrophotometer. IR Spectra (cm^{-1}): *ATI-Mattson-Genesis* instrument, series FTIR. NMR Spectra: *Bruker AC-200* (200 MHz) or *Bruker AM-400* (400 MHz); solvent peaks as reference; δ in

ppm; *J* in Hz. Elemental analysis were performed by the analytical service at the Institut Charles Sadron, Strasbourg, France.

Phase Behavior. Liquid-crystalline properties were observed for compound **10** and **12**. They were deduced from the observation of the compounds by polarized optical microscopy and confirmed by X-ray analysis. Details on the equipment used for X-ray investigations were recently reported [14]. The phase transition and the melting points were determined by DSC analyses *Perkin-Elmer DSC-7* apparatus, scan rate 10° min^{-1}). Results: *Table*.

Table. *Phase Behavior of Compounds* **10** *and* **12**. Chol. = cholesteric; SmA = smectic A; SmC* = chiral smectic C; I = isotrope. In the case of a smectic type arrangement, the layer thickness obtained from the X-ray patterns is indicated in parenthesis

Transitions	
10	Glass – 20° SmA (60 Å at 25°) 69° Chol 77° I
12	SmC* (51 Å at 25°) 104° I

Langmuir *and* Langmuir-Blodgett *Films*. Spreading solns. were prepared by dissolving the compounds in $CHCl_3$ (analysis grade, from *Carlo Erba*) at 1.0–3.0 mg/ml concentrations. For a typical experiment, the fresh soln. (50 µl) was spread on the water surface with a microsyringe, and the film was then left 15–20 min to equilibrate before the compression started. Data were collected with a *KSV-LB5000* system (*KSV Instruments*, Helsinki, Finland) in a symmetrical compression *Teflon* trough equipped with hydrophilic barriers in a dust-free environment. The whole setup was in a *Plexiglas* enclosure resting on a vibration-free table, and the trough temp. was controlled to ±0.1°. All isotherms were taken at 20°. Ultra pure water ($\rho = 18.2\ M\Omega \cdot cm$) obtained from a *Milli-RO3-Plus* system combined with a *Milli-Q185-Ultra-Purification* system from *Millipore* was used for the subphase. Surface pressure was measured with the *Wilhelmy* plate method. The monolayers were compressed with speeds ranging from 2.5 to 10 $Å^2$/(molecule · min), with almost no incidence of the barrier velocity on the observed behavior. *Brewster*-angle microscopy (BAM) was performed with a *BAM 2 plus* setup from *Nanofilm Technologies GmbH*. Illumination came from an Ar laser, images were recorded on a *CCD* camera; field: 620 µm width × 500 µm height. *Langmuir-Blodgett* (*LB*) films were obtained by transfer onto quartz slides. Dipping parameters were not very stringent, and usually a dipping speed $V_{dip} \approx 2$ mm/min was used. Transfers were performed at a surface pressure of 25 mN/m and 40 mN/m for **11** and **14**, resp. In both cases, the transfer ratios were 1 ± 0.1, and Y-type multilayer films were obtained.

Propanedioic Acid 1,3-Phenylenebis(methylene) Bis[6-[(3β)-cholest-5-en-3-yloxy]hexyl] Ester (**4**). DCC (1.06 g, 5.13 mmol) was added to a stirred soln. of DMAP (0.10 g, 0.82 mmol), HOBt (cat. amount), propanedioic acid 1,3-phenylenebis(methylene) (**5**; 0.64 g, 2.05 mmol), and 6-[(3β)-cholest-5-en-3-yloxy]hexanol (**1**; 2.50 g, 5.13 mmol) in CH_2Cl_2 (100 ml) at 0°. After 1 h, the mixture was allowed to slowly warm to r.t. (within 1 h), then stirred for 15 h, filtered, and evaporated. CC (SiO_2, 2% MeOH/CH_2Cl_2) yielded **4** (2.40 g, 93%). Colorless solid. M.p. 78°: IR (CH_2Cl_2): 1747 (C=O). ^{1}H-NMR ($CDCl_3$, 200 MHz): 0.70 (*s*, 6 H); 0.70–2.42 (*m*, 96 H); 3.14 (*m*, 2 H); 3.42 (*t*, *J* = 6, 4 H); 3.45 (*s*, 4 H); 4.15 (*t*, *J* = 6, 4 H); 5.20 (*s*, 4 H); 5.36 (*m*, 2 H); 7.48 (*m*, 4 H). ^{13}C-NMR ($CDCl_3$, 50 MHz): 11.85; 18.72; 19.36; 21.05; 22.55; 22.81; 23.82; 24.27; 25.64; 25.84; 27.98; 28.23; 28.39; 28.45; 30.05; 31.87; 31.93; 35.77; 36.18; 36.88; 37.27; 39.18; 39.50; 39.77; 41.51; 41.89; 42.30; 50.19; 56.15; 56.76; 65.63; 65.78; 67.83; 78.96; 121.42; 127.96; 128.20; 128.89; 135.75; 141.05; 166.34; 166.39. Anal. calc. for $C_{80}H_{126}O_{10} \cdot 1/2\ H_2O$ (1265.87): C 76.45, H 10.18; found: C 76.21, H 10.11.

4″,15″-Dioxo-3′,3″-(methanoxymethano[1,3]benzenomethanoxymethano)-3′,3″-dicyclopropa[1,9:3,15][5,6]-fullerene-C_{60}-I_h-3′,3″-dicarboxylic Acid Bis[6-[(3β)-cholest-5-en-3-yloxy]hexyl] Ester (**6**). DBU (0.41 ml, 2.77 mmol) was added at r.t. to a stirred solution of C_{60} (400 mg, 0.55 mmol), I_2 (352 mg, 1.38 mmol), and **4** (727 mg, 0.58 mmol) in toluene (800 ml). The soln. was stirred for 6 h. The crude material was filtered through a short plug of SiO_2, eluting first with toluene (to remove unreacted C_{60}) and then with CH_2Cl_2. CC (SiO_2, CH_2Cl_2) yielded **6** (304 mg, 28%). Dark orange glassy product. IR (CH_2Cl_2): 1748 (C=O). ^{1}H-NMR ($CDCl_3$, 200 MHz): 0.70 (*s*, 6 H); 0.90–2.42 (*m*, 96 H); 3.14 (*m*, 2 H); 3.45 (*t*, *J* = 6, 4 H); 4.35 (*t*, *J* = 6, 4 H); 5.15 (*d*, *J* = 12, 2 H); 5.34 (*m*, 2 H); 5.90 (*d*, *J* = 12, 2 H); 7.20–7.52 (*m*, 4 H). ^{13}C-NMR ($CDCl_3$, 50 MHz): 11.85; 18.71; 19.39; 21.05; 22.55; 22.82; 23.82; 24.29; 25.74; 25.79; 28.00; 28.23; 28.43; 28.48; 30.11; 31.87; 31.96; 35.77; 36.17; 36.88; 37.27; 39.20; 39.49; 39.78; 42.30; 49.35; 50.17; 56.14; 56.76; 67.03; 67.17; 67.39; 67.83; 70.71; 78.97; 121.49; 123.63; 126.60; 128.67; 134.80; 135.88; 136.27; 136.62; 137.64; 139.97; 141.03; 141.31; 142.36; 143.06; 143.29; 143.61; 143.80; 143.99; 144.21; 144.28; 144.40; 144.63; 145.08; 145.23; 145.40; 145.68; 145.78; 146.10; 146.16;

147.34; 147.55; 148.75; 162.85; 162.95 UV/VIS (CH_2Cl_2): 259 (119210), 320 (sh, 33015), 437 (2885), 469 (2610). Anal. calc. for $C_{140}H_{122}O_{10} \cdot CH_2Cl_2$ (2049.42). C 82.66, H 6.11; found: C 83.20, H 6.04.

5-{2-[2-(2-Methoxyethoxy)ethoxy]ethoxy}benzene-1,3-dicarboxylic Acid Dimethyl Ester (**7**). A soln. of triethylene glycol monomethyl ether tosylate (5.00 g, 16.53 mmol), dimethyl 5-hydroxyisophthalate (2.90 g, 13.78 mmol), and K_2CO_3 (9.52 g, 68.90 mmol) in DMF (200 ml) was stirred at 80° for 48 h. The mixture was evaporated and the crude product dissolved in CH_2Cl_2 (100 ml) and then filtered (*Celite*). CC (SiO_2, Et_2O/acetone 7:3) yielded **7** (4.35 g, 88%). Colorless oil. ^{1}H-NMR ($CDCl_3$, 200 MHz): 3.37 (*s*, 3 H); 3.53–3.90 (*m*, 10 H); 3.92 (*s*, 6 H); 4.16 (*t*, *J* = 6, 2 H); 7.75 (*d*, *J* = 2, 2 H); 8.26 (*t*, *J* = 2, 1 H). ^{13}C-NMR ($CDCl_3$, 50 MHz): 52.11; 58.72; 67.77; 69.24; 70.30; 70.38; 70.62; 71.64; 119.61; 122.77; 131.42; 158.61; 165.73. Anal. calc. for $C_{17}H_{24}O_8$ (356.36): C 57.29, H 6.78; found: C 56.99, H 6.86.

5-{2-[2-(2-Methoxyethoxy)ethoxy]ethoxy}benzene-1,3-dimethanol (**8**). A soln. of **7** (4.00 g, 11.22 mmol) in dry THF (100 ml) was added dropwise within 1 h to a suspension of $LiAlH_4$ (596 mg, 15.71 mmol) in dry THF (50 ml) at 0°. The resulting mixture was stirred for 7 h at r.t., and a few drops of MeOH were carefully added, and then 10 ml of MeOH. The resulting mixture was filtered (*Celite*) and evaporated. CC (SiO_2, 10% MeOH/CH_2Cl_2) yielded **8** (3.0 g, 88%). Colorless oil. ^{1}H-NMR ($CDCl_3$, 200 MHz): 2.77 (*t*, *J* = 5, 2 H); 3.36 (*s*, 3 H); 3.50–3.90 (*m*, 10 H); 4.09 (*t*, *J* = 6, 2 H); 4.56 (*d*, *J* = 5, 4 H); 6.79 (*d*, *J* = 2, 2 H); 6.87 (*t*, *J* = 2, 1 H). ^{13}C-NMR ($CDCl_3$, 50 MHz): 58.93; 64.80; 67.38; 69.72; 70.42; 70.57; 70.70; 71.82; 102.07; 117.59; 142.81; 159.06. Anal. calc. for $C_{15}H_{24}O_6$ (300.35): C 59.98, H 8.05; found: C 59.58, H 8.15.

Propanedioic Acid {5-{2-[2-(2-Methoxyethoxy)ethoxy]ethoxy}-1,3-phenylene}bis(methylene) Ester (**9**). A mixture of *Meldrum*'s acid (2.78 g, 19.31 mmol) and **8** (2.90 g, 9.65 mmol) was heated for 6 h at 110°. After cooling to r.t., drying (10^{-2} Torr, 24 h) provided **9** (4.47 g, 98%). Pale yellow oil. IR (CH_2Cl_2): 1754 (C=O). ^{1}H-NMR ($CDCl_3$, 200 MHz): 3.36 (*s*, 3 H); 3.47 (*s*, 4 H); 3.54–3.86 (*m*, 10 H); 4.12 (*t*, *J* = 6, 2 H); 5.15 (*s*, 4 H); 6.84 (*d*, *J* = 2, 2 H); 6.92 (*t*, *J* = 2, 1 H). ^{13}C-NMR ($CDCl_3$, 50 MHz): 40.97; 58.68; 66.57; 67.24; 69.37; 70.08; 70.31; 70.46; 71.57; 113.79; 119.31; 136.97; 158.85; 166.30;169.94. Anal. calc. for $C_{21}H_{28}O_{12}$ (300.35): C 53.39, H 5.97; found: C 53.40, H 6.13.

Propanedioic Acid {5-{2-[2-(2-Methoxyethoxy)ethoxy]ethoxy}-1,3-phenylene}bis(methylene) Bis{6-[(3β)-cholest-5-en-3-yloxy]hexyl} Ester (**10**). As described for **4**, with DCC (1.09 g, 5.29 mmol), DMAP (103 mg, 0.85 mmol), HOBt (cat. amount), **9** (2.57 g, 5.29 mmol), **1** (1.00 g, 2.11 mmol), and CH_2Cl_2 (50 ml) (stirring for 24 h). CC (SiO_2, CH_2Cl_2/AcOEt 5:3) yielded **10** (2.20 g, 73%). Colorless compound. See *Table*. IR (CH_2Cl_2): 1751 (C=O). ^{1}H-NMR ($CDCl_3$, 200 MHz): 0.67 (*s*, 6 H); 0.85–2.36 (*m*, 96 H); 3.12 (*m*, 2 H); 3.38 (*s*, 3 H); 3.43 (*t*, *J* = 6, 4 H); 3.44 (*s*, 4 H); 3.47–3.88 (*m*, 10 H); 4.14 (*m*, 6 H); 5.13 (*s*, 4 H); 5.35 (*m*, 2 H); 6.88 (*d*, *J* = 2, 2 H); 6.91 (*t*, *J* = 2, 1 H). ^{13}C-NMR ($CDCl_3$, 50 MHz): 11.76; 18.63; 19.29; 20.97; 22.48; 22.74; 23.74; 24.20; 24.59; 25.35; 25.58; 25.77; 27.91; 28.15; 28.30; 28.38; 29.98; 31.81; 34.82; 35.70; 36.10; 36.78; 37.19; 39.10; 39.42; 39.69; 41.38; 42.21; 50.09; 56.06; 57.67; 58.93; 65.54; 66.58; 67.45; 67.75; 69.53; 70.49; 70.56; 70.74; 71.83; 78.88; 114.12; 119.92; 121.33; 137.03; 140.98; 159.09; 166.24; 166.33. Anal. calc. for $C_{87}H_{140}O_{14}$ (1410.06): C 74.11, H 10.01; found: C 74.73, H 10.27.

11″-{2-[2-(2-Methoxyethoxy)ethoxy]ethoxy}-4″,15″-dioxo-3′,3″-(methoxymethano[1,3]benzenomethanoxymethano)-3′,3″-dicyclopropa[1,9:3,15][5,6]fullerene-C_{60}-I_h-3′,3″-dicarboxylic Acid Bis{6-[(3β)-cholest-5-en-3-yloxy]hexyl} Ester (**11**). As described for **6**, with DBU C_{60}, I_2, **10** (822 mg, 0.58 mmol), and toluene. (SiO_2-plug elution with toluene with CH_2Cl_2/AcOEt 1:1). CC (SiO_2, CH_2Cl_2/AcOEt 8:2) yielded **11** (600 mg, 50%). Dark orange glassy product. UV/VIS (CH_2Cl_2): 258 (100460), 320 (sh, 27815), 436 (2760), 471 (2345). IR (CH_2Cl_2): 1747 (C=O). ^{1}H-NMR ($CDCl_3$, 200 MHz): 0.67 (*s*, 6 H); 0.80–2.41 (*m*, 96 H); 3.15 (*m*, 2 H); 3.40 (*s*, 6 H); 3.42 (*t*, *J* = 6, 4 H); 3.52–3.90 (*m*, 10 H); 4.19 (*t*, *J* = 6, 2 H); 4.35 (*t*, *J* = 6, 4 H); 5.14 (*d*, *J* = 14, 2 H); 5.35 (*m*, 2 H); 5.80 (*d*, *J* = 14, 2 H); 6.81 (br. *s*, 2 H); 7.14 (br. *s*, 1 H). ^{13}C-NMR ($CDCl_3$, 50 MHz): 11.79; 18.65; 19.33; 20.99; 22.51; 22.77; 23.76; 24.23; 25.68; 25.73; 27.94; 28.17; 28.37; 28.41; 29.63; 30.04; 31.81; 35.71; 36.11; 36.81; 37.20; 39.13; 39.43; 39.71; 42.24; 49.26; 50.09; 56.08; 56.69; 58.99; 66.92; 67.11; 67.19; 67.55; 67.76; 69.57; 70.52; 70.61; 70.79; 71.86; 78.89; 112.36; 115.11; 121.43; 134.67; 135.79; 136.14; 137.61; 137.99; 139.95; 140.95; 141.22; 142.27; 143.03; 143.22; 143.54; 143.71; 143.93; 144.12; 144.21; 144.34; 144.53; 145.01; 145.14; 145.33; 145.59; 145.71; 146.03; 146.10; 147.27; 147.46; 148.63; 158.80; 162.76. Anal. calc. for $C_{147}H_{136}O_{14}$ (2126.69): C 83.02, H 6.45; found: C 82.54, H 6.45.

3,5-Bis{{6-[(3β)-cholest-5-en-3-yloxy]hexyl}oxy}benzenemethanol (**12**). A soln. of 5-(hydroxymethyl)benzene-1,3-diol (24 mg, 0.17 mmol), K_2CO_3 (100 mg, 7.27 mmol), and (3β)-cholest-5-en-3-yl 6-bromohexyl ether (200 mg, 0.36 mmol) in DMF (20 ml) was stirred at 80° for 24 h. The mixture was then cooled to r.t. and evaporated. The crude product was dissolved in Et_2O/H_2O and the org. layer washed with brine, dried ($MgSO_4$), and evaporated. CC (SiO_2, CH_2Cl_2) yielded **12** (0.140 g, 75%). Colorless compound. See *Table*. ^{1}H-NMR ($CDCl_3$, 200 MHz): 0.81 (*s*, 6 H); 0.92–2.40 (*m*, 96 H); 3.05 (*m*, 2 H); 3.40 (*t*, *J* = 6, 4 H); 3.83 (*t*, *J* = 6, 4 H);

4.54 (*s*, 2 H); 5.25 (*m*, 2 H); 6.28 (*t*, *J* = 2, 1 H); 6.41 (*d*, *J* = 2, 2 H). ^{13}C-NMR ($CDCl_3$, 50 MHz): 12.12; 18.98; 19.66; 21.33; 22.83; 23.10; 24.09; 24.56; 25.91; 2620; 28.28; 28.51; 28.75; 29.14; 29.46; 30.40; 32.15; 36.06; 36.46; 37.17; 37.55; 39.46; 39.78; 40.04; 42.59; 50.46; 56.43; 57.05; 65.70; 68.17; 79.26; 100.78; 105.31; 121.72; 141.40; 141.90; 160.76.

Propanedioic Acid {5-{2-[2-(2-Methoxyethoxy)ethoxy]ethoxy}-1,3-phenylene}bis(methylene) Bis{{3,5-bis{{6-[(3β)-cholest-5-en-3-yloxy]hexyl}oxy}phenyl}methyl} Ester (**13**). As described for **4**, with DCC (153 mg, 0.74 mmol), DMAP (14 mg, 0.12 mmol), HOBt (cat. amount), **9** (140 mg, 0.29 mmol), **12** (800 mg, 0.742 mmol), and CH_2Cl_2 (20 ml) (stirring for 24 h). CC (SiO_2, CH_2Cl_2/AcOEt 5 :3) yielded **12** (650 mg, 85%), which was used in the next step without further purifications. Colorless glassy solid. ^{1}H-NMR ($CDCl_3$, 200 MHz): 0.68 (*s*, 12 H); 0.85 – 2.34 (*m*, 192 H); 3.13 (*m*, 4 H); 3.43 (*s*, 3 H); 3.46 (*t*, *J* = 6, 8 H); 3.49 (*s*, 4 H); 3.52 – 3.88 (*m*, 10 H); 3.91 (*t*, *J* = 6, 8 H); 4.09 (*t*, *J* = 6, 2 H); 5.09 (*s*, 4 H); 5.13 (*s*, 4 H); 5.34 (*m*, 4 H); 6.39 (*t*, *J* = 2, 2 H); 6.46 (*d*, *J* = 2, 4 H); 6.87 (br. *s*, 2 H); 6.90 (br. *s*, 1 H).

11″-{2-[2-(2-Methoxyethoxy)ethoxy]ethoxy}-4″,15″-dioxo-3′,3″-(methoxymethano[1,3]benzenomethanoxymethano)-3′,3″-dicyclopropa[1,9 :3,15][5,6]fullerene-C_{60}-Ih-3′,3″-dicarboxylic Acid Bis {{3,5-bis{{6-[(3β)-cholest-5-en-3-yloxy]hexyl}oxy}phenyl}methyl} Ester (**14**). As described for **6**, with DBU (0.16 ml, 1.10 mmol), C_{60} (158 mg, 0.22 mmol), I_2 (140 mg, 0.55 mmol), **13** (600 mg, 0.23 mmol), and toluene (500 ml) (SiO_2-plug elution with toluene CH_2Cl_2/AcOEt 1 :1). CC (SiO_2, CH_2Cl_2/AcOEt 8 :2) yielded **14** (320 mg, 44%). Dark orange glassy product. IR (CH_2Cl_2): 1749 (C=O). ^{1}H-NMR ($CDCl_3$, 200 MHz): 0.67 (*s*, 12 H); 0.80 – 2.43 (*m*, 192 H); 3.14 (*m*, 4 H); 3.41 (*s*, 3 H); 3.45 (*t*, *J* = 6, 8 H); 3.52 – 4.15 (*m*, 10 H); 4.05 (*t*, *J* = 6, 8 H); 4.15 (*m*, 2 H); 5.05 (*d*, *J* = 12, 2 H); 5.15 (*d*, *J* = 12, 2 H); 5.33 (*m*, 4 H); 5.45 (*d*, *J* = 12, 2 H); 5.75 (*d*, *J* = 12, 2 H); 6.33 (br. *s*, 2 H); 6.48 (br. *s*, 4 H); 6.80 (br. *s*, 2 H); 7.05 (br. *s*, 1 H). ^{13}C-NMR ($CDCl_3$, 50 MHz): 11.79; 18.65; 19.32; 20.98; 22.51; 22.76; 23.76; 24.21; 24.87; 25.56; 25.77; 25.90; 27.59; 27.91; 28.16; 28.40; 28.98; 29.15; 29.63; 30.07; 31.81; 31.85; 33.85; 35.70; 36.11; 36.81; 37.21; 39.12; 39.42; 39.71; 42.23; 48.94; 50.10; 56.08; 56.68; 58.96; 65.28; 66.78; 67.18; 67.50; 67.85; 68.60; 69.56; 70.50; 70.58; 70.77; 71.85; 77.21; 78.88; 101.54; 107.04; 112.41; 121.36; 135.92; 136.02; 136.46; 138.06; 139.97; 140.96; 142.21; 142.65; 142.86; 143.06; 143.48; 143.64; 143.87; 144.06; 144.24; 144.50; 144.88; 145.08; 145.26; 145.48; 145.68; 145.97; 147.22; 147.37; 148.53; 158.76; 160.25; 162.47. UV/VIS (CH_2Cl_2): 258 (82770), 320 (sh, 22175), 437 (2215), 464 (2020). Anal. calc. for $C_{227}H_{260}O_{20}$ (3308.35): C 82.41, H 7.92; found: C 82.64, H 7.98.

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