Synthesis of Carbosilane Compounds Functionalized with Three or Four β-Cyclodextrin Moieties. Use of a One-Pot Reaction in Liquid Ammonia for Birch Reduction and the Subsequent S_N2 Replacement

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(Received June 22, 1998)

As a basic model reaction for assembling specific functional carbohydrate molecules on a novel core substance by making covalent bonds, an efficient one-pot reaction involving Birch reduction and a subsequent S_N2 replacement was developed, employing trivalent and tetravalent carbosilane bromides as the core and monodeoxy-monomercapto-β-cyclodextrin as the functional carbohydrate. It was confirmed that carbosilane derivatives containing a suitable spacer molecule were of wide applicability as a new core substance for the construction of diverse functional materials.

A variety of approaches towards artificial enzymes or receptor models[1] have utilized the encapsulation ability of cyclodextrins; particularly in recent years, assembling a few pieces of cyclodextrin moieties through covalent bonds is becoming a popular methodology to encapsulate bulkier guest molecules.[2] On the other hand, cyclodextrin-supported polymers, including molecularly imprinted ones, have also been prepared as potential separation materials.[3] Interest in creating a novel type of separation materials led us to consider using carbosilane compounds for supporting cyclodextrin moieties, because such organosilicon molecules possess excellent thermal, chemical, and biological stabilities as well as the ability to grow to globular structures having various degrees of bulkiness.[4] Prior to the construction of macromolecular separation materials, an efficient methodology with general applicability had to be developed for coupling cyclodextrin moieties with the carbosilane component part. The insertion of an appropriate length of spacer molecule between the carbosilane core and the cyclodextrin moieties had also been necessary for assembling such a bulky molecule as cyclodextrin.

This paper deals with introduction of a linear spacer molecule carrying a bromine atom at its ω position into simple trifunctional and tetrafunctional silicon compounds and efficient condensation of the resulting carbosilane bromides with monomercapto derivatives of β-cyclodextrin to prepare **1** and **2**, thus developing an efficient one-pot reaction which involves the Birch reduction and subsequent S_N2 replacement (Fig. 1).

According to the literature,[5,6] trichlorophenylsilane **3** and tetrachlorosilane **4** were treated with allylmagnesium bromide, and the resulting compounds, triallylphenylsilane **5** and tetraallylsilane **6**, underwent hydroboration reactions, giving tris(3-hydroxypropyl)phenylsilane **7**[5] and tetrakis(3-hydroxypropyl)silane **8**,[6] respectively (Scheme 1). Compounds **7** and **8** were the actual starting materials for the synthesis of **1** and **2**, and were first manipulated for coupling with a spacer molecule. The reason why we chose the allyl function for the initial Grignard reaction was that the allyl-bearing compounds, such as **5** and **6**, were reported to readily undergo hydrosilylation reactions,[4—6] giving bulkier homologs of the original **3** and **4**, which we expected to use as the future starting compounds for similar syntheses.

In order to prepare for the coupling with the spacer molecule, compounds **7** and **8** were subjected to a change of their hydroxy groups into amino groups. Thus, direct iodination of the triol **7**[5] was conducted by using modified Vilsmeier–Haack condition,[7] giving triiodide **9** in 88% yield (Scheme 2). All of the iodine atoms were then replaced with azido anions to give a triazide **10** as a colorless liquid in 96% yield. The reduction of the azido groups of **10** to the amines was achieved most effectively by a treatment with H_2S among other tested reagents, such as H_2–Raney Ni or PPh_3. Thus, **10** was treated with H_2S gas in a mixture of pyridine and triethylamine overnight at r.t. to give tris(3-aminopropyl)phenylsilane **11** in almost quantitative yield, which showed a positive ninhydrin test intensively and no absorption at around 2100 cm^{-1} due to the azido functional group, and was immediately used for the next coupling reaction with a spacer molecule without further characterization.

Conversion of the tetrahydroxy compound **8** into the corresponding tetraamino compound was carried out in a similar

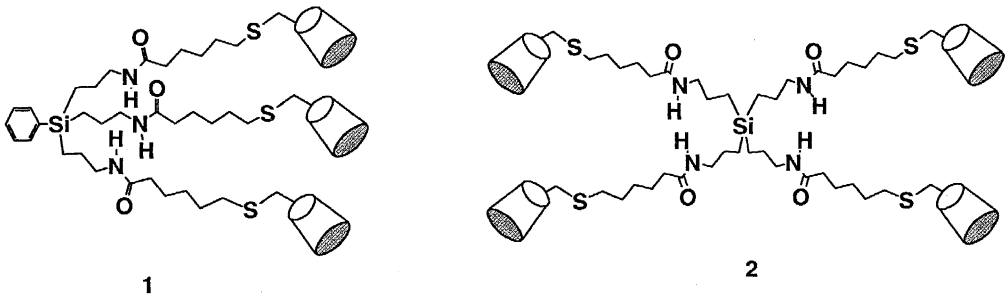
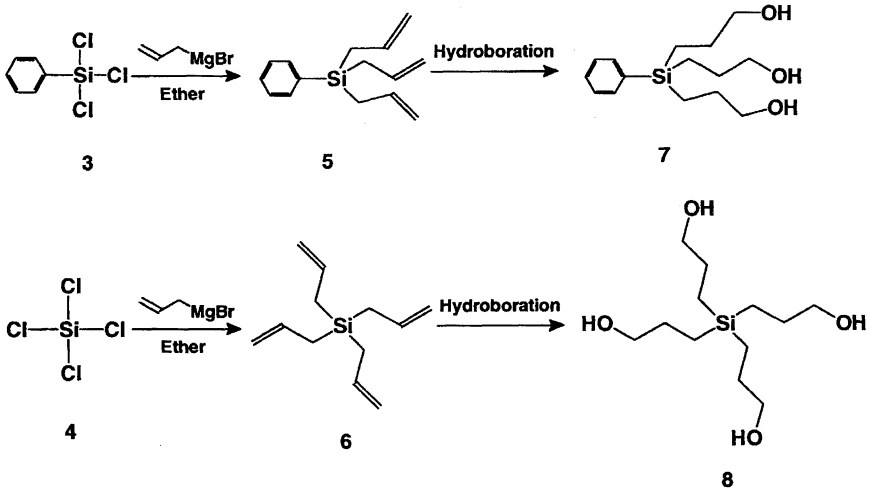
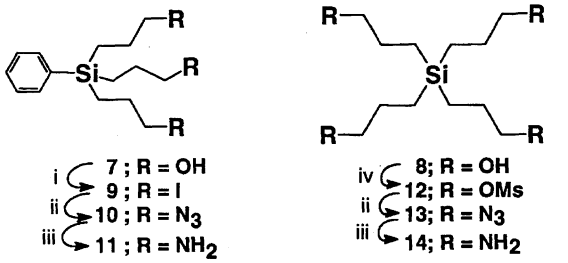


Fig. 1. Structures of carbosilane compounds functionalized with three or four β-cyclodextrin moieties.



Scheme 1. Synthetic route of alcoholic carbosilane compounds.



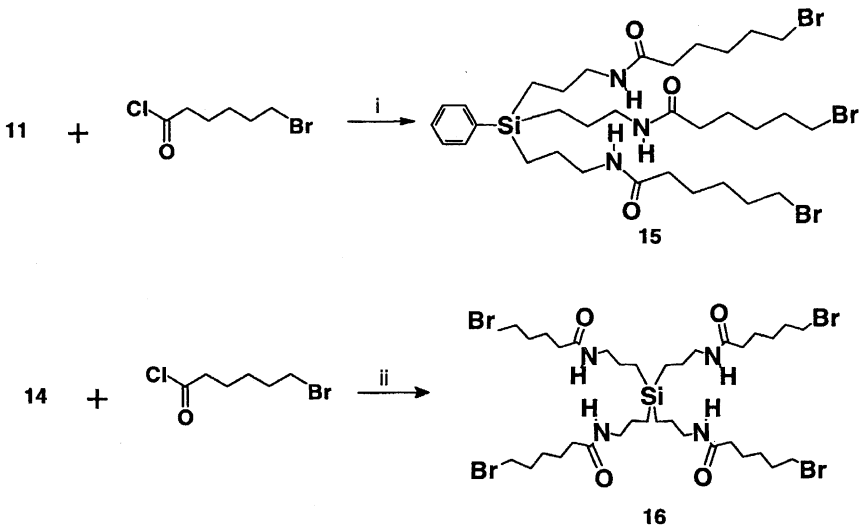
Scheme 2. Reagents and conditions. (i) I_2, PPh_3, DMF, 80 °C, 2.5 h, 88%; (ii) NaN_3, DMF, 80 °C, 3—4 h, 96% for **10**, 82% for **13**; (iii) H_2S, pyridine–triethylamine (7 : 3, v/v), r.t., 1 d, q.y.; (iv) MsCl, pyridine, 0 °C→r.t., 50 min, q.y.

way to the preparation of **11** from **7** with a few modifications. Thus, **8** was methanesulfonylated in the usual way to give the tetramesylate **12** in quantitative yield as a syrup. The mesylate groups of **12** were smoothly replaced with azido anions when heated in DMF, giving tetrakis(3-azidopropyl)silane **13** in 82% yield as a liquid. The subsequent reduction with a H_2S treatment also proceeded smoothly, giving tetrakis(3-aminopropyl)silane **14**, which showed no absorption due to the azido group in the IR spectrum and was soon used for the next coupling reaction.

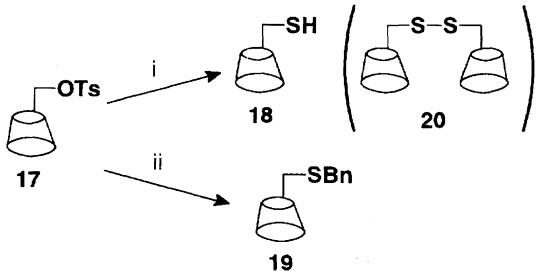
A bifunctional linear compound having an appropriate length was required as a spacer precursor. We chose 6-bromohexanoyl group for that purpose and condensed 6-bromohexanoyl chloride with **11** and **14** under basic conditions, obtaining the triamide **15** and the tetraamide **16** in yields of 94 and 75%, respectively (Scheme 3). The ω-bromoalkyl group was expected to play the role of an electrophile in the coupling reaction with a mercapto group introduced into the cyclodextrin molecule. Namely, we planed to replace the bromine atom with the thiolate anion in S_N2 fashion for connecting those two portions. In order to prevent any undesirable participation of the amide carbonyl groups in **15** and **16** to the S_N2 reaction, the number of carbon units of the spacer had to be longer than 6.

As the other component for the coupling reaction, we initially synthesized mono-6-deoxy-6-mercapto-β-cyclodextrin **18** from the known mono-6-*O*-tosyl derivative **17**[8] according to the literature[9] and tried its condensation with **15** and **16**. Later, in addition to **18**, mono-6-deoxy-6-benzylmercapto-β-cyclodextrin **19**[10] was prepared from **17** as a stable precursor of **18**, since **18** was apt to undergo air oxidation to give a disulfide **20** (Scheme 4). Compound **19** was also used directly for coupling with **15** and **16**, as described in the following.

Combining the carbosilane components with the β-cyclodextrin moiety is the pivotal step in the synthesis of **1** and **2**. Unless the coupling reaction is highly efficient, it may cease without completion, with some of spacer terminals remaining uncharged. Recently, Stoddart et al.[11] reported on a successful S_N2 reaction between per-6-deoxy-6-iodo-β-cyclodextrin and cystein in liquid NH_3 in the presence of Na. The application of this system seemed to be very attractive for the coupling of **18** with **15** and **16**, because the disulfide bond of **20** contaminating **18** could undergo a



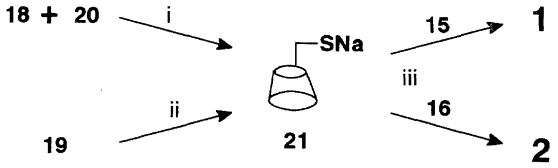
Scheme 3. Reagents and conditions. (i) $Br(CH_2)_5COCl$ (3.3 molar excess), triethylamine (3.3 molar excess), MeOH, 0 °C→r.t., 1 h, 94%; (ii) $Br(CH_2)_5COCl$ (4.4 molar excess), triethylamine (4.4 molar excess), MeOH, 0 °C→r.t., 40 min, 75%.



Scheme 4. Reagents and conditions. (i) Ref. 9; (ii) NaH (5 molar excess), α-toluenethiol (5 molar excess), DMF, r.t.→50 °C, 16.5 h, 86%.

reductive cleavage with Na–liquid NH_3 to give the thiolate anion **21**. Thus, sodium metal was added to a solution of **18** (plus **20**) in liquid NH_3 and, after some time, a methanolic solution of **15** or **16** was added to the mixture. The reaction was carried out at −33 °C overnight, followed by a separation work-up involving evaporation, gel filtration, and so on, to give **1** or **2** in moderate yields (Scheme 5).

A combination of Na and liquid NH_3 reminded us of the Birch reduction, which could cleave the benzyl–S bond, generating a thiolate anion **21**. Consequently, **19** was utilizable instead of **18** (plus **20**) for direct coupling with **16**. Although a larger amount of Na metal was needed, the treatment of the



Scheme 5. Reagents and conditions. (i) Na (8 molar excess), liquid NH_3, −33 °C; (ii) Na (80 molar excess), liquid NH_3, −33 °C, then NH_4Cl (72 molar excess); (iii) **15** (1/6 molar excess) or **16** (1/8 molar excess), liquid NH_3, −33 °C, 26% for **1** based on **15**, 70% for **2** based on **16**.

coupling reaction with **19** was essentially the same as that with **18** (plus **20**), giving **2** in moderate yield. It is noteworthy that this one-pot S_N2 reaction in liquid NH_3 between alkyl halide and α-toluenethiolate has wide applicability, and that the reaction seems to selectively proceed only with such a potent nucleophile as the thiolate anion, but not with the lesspotent alkoxide anion.

The readiness for purification was not the same between **1** and **2**, which reflected their final yields. Since **1** has an aromatic group in the carbosilane core part, gel filtration using Shephadex gels decreased the product yield due to a strong affinity between the gel and the aromatic ring. Furthermore, the separation of **1** from the dimeric compound **20** also encountered difficulty, because **20** behaved similarly to **1** in a column of the gel. Dialysis using the proper membrane (molecular weight cut off of 3500 Da) was of great help for complete separation of those two components, and gave pure **1** as a white powder after lyophilization.

In conclusion, the basic model scheme was established to connect many cyclodextrin moieties with carbosilane cores by developing an efficient one-pot reaction using liquid NH_3 as the solvent. This methodology would be widely applicable to bulkier carbosilane cores carrying many more bromine atoms, and also to varieties of general thio sugars. A diverse combination of such substrates using this methodology has a possibility to afford novel functional materials.

Experimental

Materials and Methods. Unless otherwise stated, all commercially available solvents and reagents were used without further purification. *N,N*-Dimethylformamide (DMF) and pyridine were stored over molecular sieves (MS 4 Å), and methanol (MeOH) was stored over MS 3 Å before use. The optical rotations were determined with a JASCO DIP-1000 digital polarimeter. The ^1H NMR spectra were recorded at 200, 300, or 400 MHz with a Bruker AC-200, AC-300, or AM-400 spectrometer in $CDCl_3$, (dimethyl sulfoxide)-d_6 (DMSO-d_6), or D_2O. The ^{13}C NMR spectra were recorded at 50.3 or 100.6 MHz using the same instruments. Tetramethylsilane,

DMSO (2.5 ppm for ^{1}H), or $CHCl_3$ (7.26 ppm for ^{1}H or 77.0 ppm for ^{13}C) were used as internal standards. Proton assignments in NMR were made by first-order analysis of the spectra, and were supported by homonuclear decoupling experiments. Elemental analyses were performed with a Fisons EA1108 on samples extensively dried at 50—60 °C over phosphorus pentaoxide for 4—5 h in vacuo. Fast-atom bombardment mass spectra were recorded with a JEOL JMS-HX110 spectrometer. The reactions were monitored by thin-layer chromatography (TLC) on a precoated plate of silica gel $60F_{254}$ (layer thickness, 0.25 mm; E. Merck, Darmmstadt, Germany). The solvent systems used were (A) 10 : 1, (B) 4 : 1 (v/v) hexane–EtOAc, (C) 10 : 4 : 1, (D) 5 : 4 : 1 (v/v/v) $CHCl_3$–EtOAc–MeOH, and (E) 5 : 5 : 1, (F) 7 : 14 : 6, (G) 7 : 12 : 6 (v/v/v) $CHCl_3$–MeOH–water. For detecting the intermediates, TLC sheets were dipped with (a) a solution of 85 : 10 : 5 (v/v/v) MeOH–concentrated sulfuric acid–*p*-anisaldehyde and heated for a few minutes (for carbohydrate), (b) an aqueous solution of 5 wt% potassium permanganate and heated similarly (for double bond), or (c) an ethanolic solution of 7% phosphomolybdic acid and heated similarly. Column chromatography was performed on silica gel (Silica Gel 60; 40—63 μm, E. Merck) or (Silica Gel 60, spherical neutral; 40—100 μm, E. Merck). Dialysis was performed against distilled water using a dialysis tubing (molecular cut off, 3500 Da). All of the extractions were concentrated below 45 °C under diminished pressure, unless stated otherwise.

Tris(3-iodopropyl)phenylsilane (9). Iodine (411 mg, 1.62 mmol) was added to a solution of **7**[5] (127 mg, 0.45 mmol) and triphenylphosphine (425 mg, 1.62 mmol) in DMF (5 mL) at 0 °C under a nitrogen atmosphere. The mixture was stirred at 80 °C for 2.5 h, and then evaporated at 70 °C. The residue was diluted with hexane, and the suspension was filtered off to remove precipitates of triphenylphosphine oxide. The filtrate was evaporated, and dissolved in $CHCl_3$. The $CHCl_3$ solution was successively washed with 10 wt% $Na_2S_2O_3$ and brine, dried over anhydrous $MgSO_4$, and evaporated. The resulting residue was suspended with hexane, filtered, and concentrated. The residual syrup was chromatographed on silica gel (ca. 20 g, 2 i.d. × 14 cm) with 1 : 0, then with 5 : 1 (v/v) hexane–EtOAc as the eluent to give **9** as a colorless syrup (242 mg, 88 %): R_F 0.60 (solvent A); IR (neat) 3065 (ν_{C-H}), 2925 (ν_{C-H}), 1426 (ν_{Si-C}), 1202 (ν_{C-I}), 701 (ν_{Si-C}) cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ = 0.93 (m, 6 H, $3CH_2Si$), 1.82 (m, 6 H, $3CH_2$), 3.19 (t, 6 H, J = 6.9 Hz, $3CH_2I$), 7.4 (m, 5 H, Ph); ^{13}C NMR (100.6 MHz, $CDCl_3$) δ = 10.95, 14.16, 28.25, 128.13, 129.56, 133.87, 135.04. Anal. Calcd for $C_{15}H_{23}I_3Si_1$: C, 29.43; H, 3.79%. Found: C, 29.79; H, 3.71%.

Tris(3-azidopropyl)phenylsilane (10). Compound **9** (2.45 g, 4 mmol) was heated with NaN_3 (2.34 g, 36.0 mmol) in DMF (25 mL) at 80 °C for 3.5 h under a nitrogen atmosphere. After evaporation, the resulting syrup was diluted with $CHCl_3$, and the $CHCl_3$ solution was successively washed with water and brine, dried over anhydrous magnesium sulfate, and concentrated. The residue was chromatographed on silica gel (ca. 80 g, 2.5 i.d. × 17 cm) with 20 : 1 (v/v) hexane–EtOAc as the eluent to give **10** (1.37 g, 95.8%) as a colorless liquid: R_F 0.43 (solvent A); IR (neat) 2930 (ν_{C-H}), 2093 ($\nu_{N=N=N}$), 1427 (ν_{Si-C}), 701 (ν_{Si-C}) cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ = 0.88 (m, 6 H, $3CH_2Si$), 1.60 (m, 6 H, $3CH_2$), 3.24 (t, 6 H, J = 6.8 Hz, $3CH_2N_3$), 7.4 (m, 5 H, Ph); ^{13}C NMR (100.6 MHz, $CDCl_3$) δ = 9.21, 23.35, 54.17, 128.00, 129.39, 133.75, 134.99. Anal. Calcd for $C_{15}H_{23}N_9Si_1$: C, 50.40; H, 6.48; N, 35.26%. Found: C, 50.68; H, 6.52; N, 35.49%.

Tris[3-(6-bromohexanoylamino)propyl]phenylsilane (15) via Tris(3-aminopropyl)phenylsilane (11). H_2S gas was bubbled into a solution of **10** (348 mg, 0.973 mmol) in 7 : 3 (v/v) pyridine–triethylamine (30 mL) at r.t. for 40 min. The resulting dark-green solution was allowed to stand in a sealed flask at r.t. for 1 d, and then evaporated. The residual syrup was diluted with MeOH, and then evaporated. These procedures (dilution and evaporation) were repeated twice. A solution of the residue in MeOH (20 mL) was stirred, precipitating sulfur. After filtration, the filtrate was concentrated, giving **11** as a yellow syrup in almost quantitative yield, which was used for the next coupling reaction without further purification: positive ninhydrin test, IR (neat) 3340 (ν_{N-H}), 2945 (ν_{C-H}) 1560 (δ_{N-H}), 1110 (ν_{C-N}) cm^{-1}.

6-Bromohexanoyl chloride (0.45 mL, 2.92 mmol) was added dropwise to a solution of freshly prepared **11** (ca. 272 mg, ca. 0.973 mmol) and triethylamine (0.41 mL, 2.92 mmol) in MeOH (10 mL) at 0 °C. The reaction mixture was stirred at r.t. for 1 h, cooled to 0 °C, diluted with water (10 mL), and extracted with $CHCl_3$. The extract was washed with brine, dried over anhydrous $MgSO_4$, and evaporated. The residue was chromatographed on silica gel (ca. 25 g, 2 i.d. × 15 cm) with 50 : 1 (v/v) $CHCl_3$–MeOH as the eluent to give **15** as a lightyellow syrup (741 mg, 93.9%): R_F 0.41 (solvent C); IR (neat) 3294 (ν_{N-H}), 2930 (ν_{C-H}), 1644 ($\nu_{C=O}$), 1556 (δ_{N-H}), 1428 (ν_{Si-C}), 1261 (ν_{C-N}), 701 (ν_{Si-C}) cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ = 0.78 (m, 6 H, $3CH_2Si$), 1.5 (m, 18 H, $9CH_2$), 1.86 (dt, 6 H, J = 7.0 Hz, $3CH_2CH_2Br$), 2.18 (t, 6 H, J = 7.3 Hz, $3CH_2CO$), 3.20 (br q, 6 H, J = 6.7 Hz, $3CH_2N$), 3.39 (t, 6 H, J = 6.7 Hz, $3CH_2Br$), 6.15 (t, 3 H, J = 5.6 Hz, 3NH), 7.4 (m, 5 H, Ph); ^{13}C NMR (50.3 MHz, $CDCl_3$) δ = 9.23, 23.85, 24.77, 27.71, 32.35, 33.62, 36.32, 42.40, 127.97, 129.27, 133.81, 135.96, 172.92. Anal. Calcd for $C_{33}H_{56}Br_3N_3O_3Si_1$: C, 48.90; H, 6.96; N, 5.18%. Found: C, 49.03; H, 6.99; N, 5.12%.

Tetrakis[3-(methylsulfonyloxy)propyl]silane (12). Methanesulfonyl chloride (88 μL, 1.13 mmol) was added dropwise to a solution of **8**[6] (50 mg, 0.189 mmol) in pyridine (1 mL) at 0 °C, and the reaction mixture was stirred at 0 °C for 50 min. Water (1 mL) was added to the mixture, and the solution was then diluted with $CHCl_3$. After the addition of ice-cold 1 M aqueous sulfuric acid (1 M = 1 mol dm^{-3}), the organic layer was separated, successively washed with ice-cold aqueous saturated $NaHCO_3$ and brine, dried over anhydrous $MgSO_4$, and concentrated, to give **12** as a syrup in almost quantitative yield, which was directly used for the next step without further purification: R_F 0.42 (solvent D); IR (neat) 2940 (ν_{C-H}), 1415 (ν_{Si-C}), 1347 ($\nu_{O=S=O}$), 1171 ($\nu_{O=S=O}$), 814 (ν_{Si-C}) cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ = 0.67 (m, 8 H, $4CH_2Si$), 1.74 (m, 8 H, $4CH_2CH_2Si$), 3.03 (s, 12 H, $4CH_3$), 4.18 (t, 8 H, J = 6.4 Hz, $4CH_2O$); ^{13}C NMR (100.6 MHz, $CDCl_3$) δ = 7.45, 23.71, 37.44, 71.91.

Tetrakis(3-azidopropyl)silane (13). NaN_3 (0.15 g, 2.27 mmol) was added to a solution of **12** (87 mg, 0.151 mmol) in DMF (5 mL) at 0 °C; the mixture was then heated at 80 °C for 4 h with stirring. After evaporation, the residue was diluted with $CHCl_3$ and filtered for the removal of salts. The filtrate was washed with brine, dried over anhydrous $MgSO_4$, and evaporated. The residual syrup was chromatographed on silica gel (ca. 9 g, 1.5 i.d. × 10 cm) with 10 : 1 (v/v) hexane–EtOAc as the eluent to give **13** (45 mg, 81.8%) as a colorless liquid: R_F 0.46 (solvent B); IR (neat) 2931 (ν_{C-H}), 2093 ($\nu_{N=N=N}$), 832 (ν_{Si-C}) cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ = 0.63 (m, 8 H, $4CH_2Si$), 1.58 (m, 8 H, $4CH_2$), 3.27 (t, 8 H, J = 6.8 Hz, $4CH_2N_3$); ^{13}C NMR (100.6 MHz, $CDCl_3$) δ = 9.24, 23.52, 54.38. Anal. Calcd for $C_{12}H_{24}N_{12}Si_1$: C, 39.54; H, 6.63; N, 46.11%. Found: C, 39.92; H, 6.65; N, 45.80%.

Tetrakis[3-(6-bromohexanoylamino)propyl]silane (16) via Tetrakis(3-aminopropyl)silane (14). Compound **13** (43 mg,

0.118 mmol) was treated with H_2S gas as described for the preparation of **11**; a subsequent work-up gave **14** (30 mg, 99%) as a lightyellow syrup, which was directly used for the next coupling reaction without further purification: positive ninhydrin test, IR (neat) 3340 (ν_{N-H}), 2922 (ν_{C-H}) 1591 (δ_{N-H}), 1127 (ν_{C-N}) cm^{-1}.

6-Bromohexanoyl chloride (79 μL, 0.519 mmol) was added dropwise to a solution of **14** (30 mg, 0.118 mmol) and triethylamine (72 μL, 0.519 mmol) in MeOH (1 mL) at 0 °C, and the reaction mixture was stirred at r.t. for 40 min, then cooled, diluted with water (1 mL), and extracted with $CHCl_3$. The extract was successively washed with aqueous saturated $NaHCO_3$ and brine, dried over anhydrous $MgSO_4$, and evaporated. The residue was chromatographed on silica gel (ca. 10 g, 1.5 i.d. × 13 cm) with 15 : 1 (v/v) $CHCl_3$–MeOH as the eluent to give **16** (85 mg, 74.6%) as a yellow syrup: R_F 0.46 (solvent C); IR (neat) 3303 (ν_{N-H}), 2932 (ν_{C-H}), 1651 ($\nu_{C=O}$), 1544 (δ_{N-H}), 1434 (ν_{Si-C}), 1274 (ν_{C-N}), 735 (ν_{Si-C}) cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ = 0.49 (m, 8 H, $4SiCH_2$), 1.45 (m, 16 H, $8CH_2$), 1.67 (dt, 8 H, J = 7.5 & 15.4 Hz, $4CH_2CH_2CO$), 1.88 (dt, 8 H, J = 6.9 & 14.8 Hz, $4CH_2CH_2Br$), 2.21 (t, 8 H, J = 7.5 Hz, $4CH_2CO$), 3.17 (br q, 8 H, J = 6.7 Hz, $4CH_2N$), 3.42 (t, 8 H, J = 6.7 Hz, $4CH_2Br$), 6.51 (t, 4 H, J = 5.8 Hz, 4 × NH); ^{13}C NMR (50.3 MHz, $CDCl_3$) δ = 9.42, 24.09, 24.81, 27.74, 32.37, 33.70, 36.33, 42.58. Anal. Calcd for $C_{36}H_{68}Br_4N_4O_4Si_1$: C, 44.64; H, 7.08; N, 5.78%. Found: C, 44.78; H, 7.10; N, 5.74%.

Mono-6-Deoxy-6-Benzylmercapto-β-Cyclodextrin (19). After α-toluenethiol (1.90 mL, 16.2 mmol) was added dropwise to a suspension of NaH (60%, 0.48 g, 12.0 mmol, washed with hexane) in DMF (20 mL) at 0 °C, the mixture was stirred for 35 min. A solution of **17**[8] (4.13 g, 3.20 mmol) in DMF (80 mL) was added dropwise to the mixture at 0 °C, and the whole mixture was stirred at r.t. for 23 h. The whole mixture was then poured into acetone (200 mL), giving white precipitates, which were filtered off and washed with acetone to give a slightly yellow powder. Recrystallization from distilled water gave **19** (2.54 g, 63.8%) as an amorphous powder: R_F 0.24 (solvent E); $[\alpha]_D^{28}$ 135° (*c* 0.94, DMF); IR (KBr) 3396 (ν_{O-H}), 1029 (ν_{C-O}) cm^{-1}, and the absorption at around 1360 cm^{-1} due to $\nu_{O=S=O}$ was not detectable; ^1H NMR (400 MHz, DMSO-d_6) δ = 4.5 (m, 6 H, OH-6), 4.8 (m, 7 H, H-1), 5.7 (m, 14 H, OH-2 & -3), 7.3 (m, 5 H, Ph), and the peak of the methyl group due to the tosyl group was not detectable. FAB MS Calcd for [M+H$^+$]: 1241.40. Found: *m/z* 1241.37. Anal. Calcd for $C_{49}H_{76}O_{34}S_1 \cdot 6H_2O$: C, 43.62; H, 6.57%. Found: C, 43.46; H, 6.56%.

Carbosilane Compound Carrying Three β-Cyclodextrin Moieties (1). Na (33 mg, 1.31 mmol) was added to a solution of **18** contaminated with **20** (2.00 g, 1.74 mmol) in liquid NH_3 (100 mL) at −33 °C; after the blue color disappeared, a solution of **15** (231 mg, 0.29 mmol) in MeOH (1.5 mL) was added dropwise to the reaction mixture. The whole mixture was kept at −33 °C overnight with stirring, evaporated, and neutralized with 1 M aqueous HCl. The solution was chromatographed several times on Sephadex G-50 (ca. 50 g, 3 i.d. × 72 cm) with 5% aqueous AcOH as the eluent to give crude **1**, which was further chromatographed on Sephadex G-25 (ca. 40 g, 2.7 i.d. × 35 cm) with 5% aqueous AcOH as the eluent. Dialysis gave **1** (300 mg, 25.6% based on **15**) as a white powder after lyophilization: R_F 0.54 (solvent F); IR (KBr) 3391 (ν_{O-H}), 2921 (ν_{C-H}), 1631 ($\nu_{C=O}$), 1546 (δ_{N-H}), 1414 (ν_{Si-C}), 1154 (ν_{C-O}), 1079 (ν_{C-O-C}), 1033 (ν_{C-O-C}), 702 (ν_{Si-C}) cm^{-1}; ^1H NMR (400 MHz, DMSO-d_6) δ = 0.72 (br s, 6 H, $3CH_2Si$), 1.3 (m, 24 H, $12CH_2$), 2.01 (t, 6 H, J = 6.8 Hz, $3CH_2CO$), 2.7—3.8 (m, 138 H, $4CH_2N$, $4CH_2S$, & sugar ring protons), 4.47 (s, 18 H, OH-6), 4.82 (21 H, s, H-1), 5.7 (m, 42 H, OH-2 & -3), 7.4 (m, 5 H, Ph), 7.76 (br t, 3 H, 3NH). FAB MS Calcd for [M+H$^+$]: 4021.4. Found: *m/z* 4021.0.

Carbosilane Compound Carrying Four β-Cyclodextrin Moieties (2). Method A: Compound **16** (85 mg, 87.8 μmol) was treated with Na (17mg, 739 μmol) and **18** (808 mg, 702 μmol) in liquid NH_3 similarly to the procedure described for the preparation of **1**. After evaporation of liquid NH_3, the residue was dissolved in 5% aqueous AcOH (10 ml) and chromatographed on Sephadex G-50 (ca. 50 g, 3 i.d. × 72 cm) with 5% aqueous AcOH as the eluent. The chromatography was repeated using Sephadex G-25 (ca. 50 g, 2.7 i.d. × 45 cm) with 5 % aqueous AcOH as the eluent to give **2** (321 mg, 69.6% based on **16**) as a white powder after lyophilization: R_F 0.42 (solvent G); IR (KBr) 3392 (ν_{O-H}), 2927 (ν_{C-H}), 1636 ($\nu_{C=O}$), 1557 (δ_{N-H}), 1410 (ν_{Si-C}), 1156 (ν_{C-O}), 1079 (ν_{C-O-C}), 1032 (ν_{C-O-C}) cm^{-1}; ^1H NMR (DMSO-d_6) δ = 0.40 (br s, 8 H, $4SiCH_2$), 4.5 (br s, 24 H, OH-6), 4.82 (s, 28 H, H-1), 5.7 (br s, 56 H, OH-2 and -3), 7.83 (br s, 4 H, 4NH). FAB MS Calcd for [M+H$^+$]: 5249.9. Found: *m/z* 5250.0.

Method B: After Na (95 mg, 4.13 mmol) was added to a solution of **19** (513 mg, 0.413 mmol) in liquid NH_3 (50 mL) at −33 °C, the mixture was stirred for 40 min at −33 °C. NH_4Cl (199 mg, 3.72 mmol) was added to the mixture, giving a colorless solution. A solution of bromide **16** (50 mg, 51.6 μmol) in MeOH (1 mL) was added dropwise to the solution, and the reaction mixture was kept at −33 °C overnight, evaporated, and diluted with 5% aqueous AcOH (5 mL). The solution was purified by repeated gel filtrations, as described for method A to give **2** (140 mg, 51.7%) as a white powder.

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