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The first examples of anthracene capped chiral carbohydrate derived dendrimers: synthesis, fluorescence and chiroptical properties

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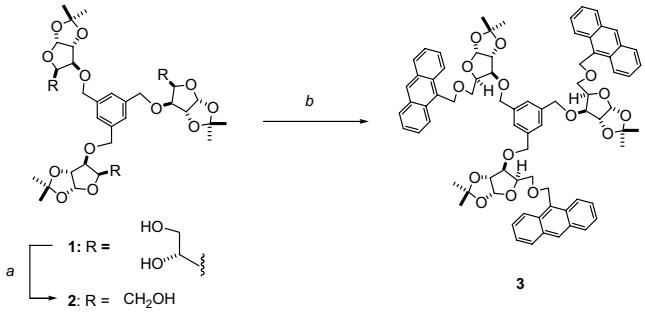
Abstract—The first examples of anthracene capped chiral dendrimers derived from a 1,3,5-trisubstituted aromatic core and carbohydrate units in the interior and periphery are described. Excimer formation was evident from the fluorescence spectrum, and both fluorescence and chiroptical properties indicated that the dendrimer does not undergo aggregation in the ground state.

The chemistry of dendrimers has acquired remarkable significance due to their characteristic hyperbranched structural framework and their potential application as functional devices.[1] The development of strategies for the synthesis of dendrimers based on novel cores and branches continues to be one of the important aspects of dendrimer chemistry. Recently we reported a strategy for the synthesis of dendrimers incorporating carbohydrate skeletons in the interior and periphery.[2] The successful application of these chiral molecules will rest on assembling functional units either in the interior or periphery of the dendrimers. The study of the amplification of the properties associated with these functional units is an essential aspect of dendrimer chemistry. Considering the importance of multichromophoric dendrimers as light harvesting materials, the introduction of photochromic groups in a chiral framework may lead to dendritic molecules having interesting photophysical[3] and chiroptical properties.[4] Herein we disclose a strategy for the synthesis and a preliminary study of the fluorescence and chiroptical properties of the first examples of dendritic molecules incorporating furanoside moieties in the interior and anthracene capped furanoside moieties in the periphery.

The general strategy of the dendritic molecules described herein involves a 1,3,5-trisubstituted benzene core, and is illustrated by the synthesis of a primitive dendron **3** containing three anthracene capped furanoside moieties. As shown in Scheme 1 the synthesis starts with the conversion of the known 1,2-isopropylidene glucose derivative **1**[2] to the triol **2** via $NaIO_4$ induced cleavage to the corresponding trialdehyde followed by reduction with $NaBH_4$. Alkylation of **2** with 9-bromomethylanthracene in the presence of a phase transfer catalyst afforded **3** in 38% overall yield from **1**. The C_3-symmetric nature of **3** was evident from its ^1H NMR spectrum, which exhibited a three-proton singlet at δ 6.88 due to the aromatic protons, and a three-proton doublet



Scheme 1. Synthesis of the dendron **3**. Reagents and conditions: (a) (i) $NaIO_4$, MeOH–H_2O, 0–25 °C, 1 h, 90%; (ii) $NaBH_4$, EtOH, 0–25 °C, 6 h, 85%; (b) 9-bromomethyl anthracene, Bu_4NBr, 50% aq NaOH–CH_2Cl_2, 25 °C, 36 h, 50%.

Keywords: Dendrimer; Carbohydrate; Anthracene; Fluorescence; Chiroptical properties.
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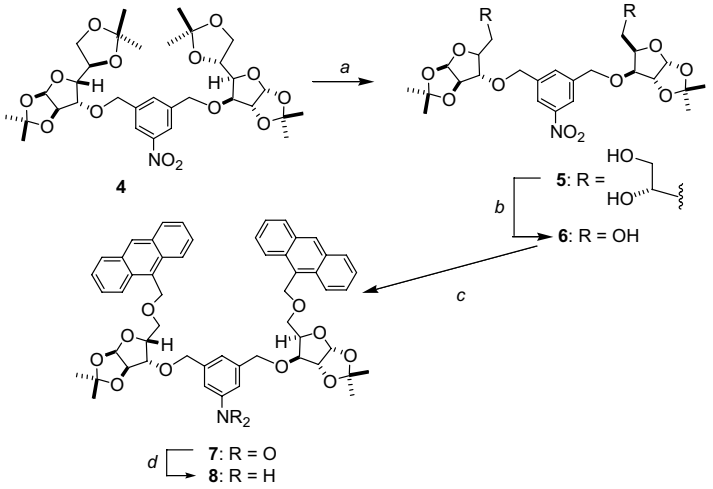


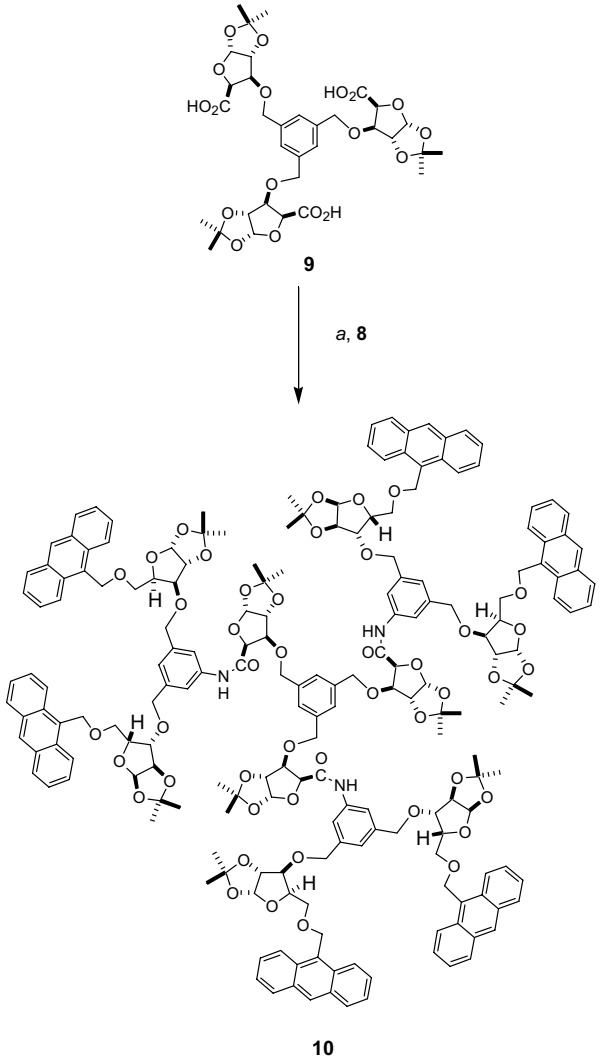
Scheme 2. Synthesis of the branch unit **8**. Reagents and conditions: (a) 75% aq AcOH, 25 °C, 12 h, 96%; (b) (i) $NaIO_4$, MeOH–H_2O, 0–25 °C, 1 h, 97%; (ii) $NaBH_4$, MeOH, 0–25 °C, 6 h, 75%; (c) 9-bromomethyl anthracene, CH_2Cl_2, 50% aq NaOH, Bu_4NBr, 25 °C, 36 h, 80%; (d) $FeSO_4$, NH_4OH, THF–H_2O, reflux, 4 h, 80%.

at δ 5.85 due to the anomeric protons of the furanoside rings.[5]

The branch **8** required for the synthesis of a second generation dendrimer was obtained as shown in Scheme 2 from the earlier reported[2] furanoside-capped nitroaromatic **4** via a sequence, which involved partial deprotection to the bis-diol intermediate **5** and oxidative cleavage of the latter to the corresponding dialdehyde with $NaIO_4$ followed by $NaBH_4$ reduction giving the diol **6**. Alkylation of **6** with 9-bromomethyl anthracene followed by reduction of the nitro group in the resulting **7** with ferrous sulfate and ammonia in THF–water gave the amine **8** in 45% overall yield from **4**.[5]

Towards the synthesis of the second generation dendrimer, the core tricarboxylic acid **9** was prepared according to the literature procedure[2] and was coupled with the amine **8** in the presence of BOP along with DIPEA affording the anthracene-capped dendrimer **10** in 45% yield (Scheme 3). The structure of **10** was established on the basis of NMR and mass spectral analyses. The C_3-symmetric nature of **10** was clearly evident from the ^1H and ^{13}C NMR spectra. The three-proton singlet at δ 7.01 for the core aromatic protons served as the reference for the introduction of the required number of branches. As evident from the structure of **10**, the core aromatic protons (3H singlet at δ 7.01), interior furanoside anomeric protons (3H doublet at δ 6.01), peripheral furanoside anomeric protons (6H doublet at δ 5.84) and one of the two sets of anthracene peri protons (12H doublet at δ 7.86) appeared in the ratio of 1:1:2:4. This rapid check of the correct number of branch units incorporated was a useful feature of the characterization process. The positive-ion ESI mass spectrum of **10** exhibited a strong peak at *m*/2e 1676 due to the doubly charged species $[M + 2Na]^{+2}$.[5]

The UV spectrum of **3**, **8** and **10** exhibited absorption maximum at 366 nm besides bands at 348 and 386 nm.



Scheme 3. Synthesis of the dendrimer **10**. Reagents and conditions: (a) BOP, DIPEA, CH_2Cl_2, 25 °C, 72 h, 45%.

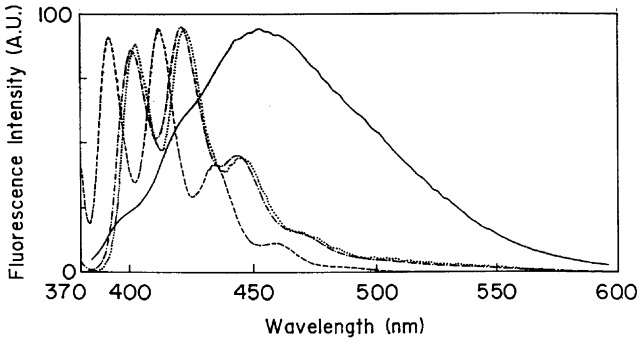


Figure 1. Fluorescence spectra ($\lambda_{ex} = 366$ nm) of anthracene (5×10^{-6} M in CH_2Cl_2) (---) and the dendrimer **10** (5×10^{-6} M in THF) (·-·-·), **10** (5×10^{-6} M in CH_2Cl_2) (···) and **10** (2 mM in aqueous SDS) (—).

The absorption of **10** having six anthracene units was almost three times that of the dendron **8** with two anthracene units, which is a desirable feature from the standpoint of amplification of photophysical properties. The fluorescence emission spectrum of **10** was obtained after excitation at the 366 nm band and had maxima centred around 414 nm in CH_2Cl_2 (Fig. 1). The peaks for **10** as well as **3** and **8** were 12–14 nm red shifted compared to anthracene itself. The shift may be caused by the stabilization of the excited states due to π–π stacking interactions. A notable feature of the fluorescence spectrum of **10** was the presence of a shoulder at 466 nm, ascribable to excimer formation. The excimer fluorescence peak was also present in the fluorescence spectra of **3** and **8**. The concentration independence of the excimer emission band at 466 nm between 10^{-7} and 10^{-5} M ruled out any aggregation in the ground state of the dendrimer (Fig. 2). Although **10** incorporates amide moieties capable of intermolecular H-bonding, they are probably shielded by the peripheral anthracene and furanoside units thus preventing any aggregation.

Apart from CH_2Cl_2, the fluorescence of **10** was also measured in $CHCl_3$ and THF. Although there was no dramatic change in the fluorescence pattern, a red shift of 2–3 nm was observed for each change in solvent (THF–CH_2Cl_2–$CHCl_3$).

It was of interest to study the effect of micelles on the fluorescence emission of **10**, which has a unique environment created by the presence of the furanoside, amide and anthracene moieties. A significant change in the emission pattern of **10** occurred in aqueous sodium dodecyl sulfate (SDS) micellar solution[6] after excitation at 366 nm, and the emission was featured by a hump centred at 453 nm, which is 40 nm red shifted compared to that observed in organic solvents. A similar effect has also been observed in the case of Fréchet-type dendrimers capped with naphthalene units.[7] The dendrimer can reside near the surface of the micelle or inside the micelle. As a result an overlay of two different fluorescence spectra is obtained (Fig. 1). The excimer emission in this case is enhanced, and inside the micellar cavity the excimer formation is encouraged not by aggregation, but by stacking interaction between the anthracene units.

The chiral dendrimer **10** incorporates both carbohydrate derived units and efficient chromophores in the form of anthracene units. Although **10** possesses nine furanoside units, it is still possible that **10** can possess an achiral or a weakly chiral conformation. It is not unusual that the conformation of a dendritic structure due to its globular shape can have a resultant achiral conformation, which may be evident from the absence of any circular dichroism.[4] It was indeed gratifying to see that **10** exhibited a strong negative Cotton effect peak at 367 nm and another similar peak at 391 nm with lower intensity in its CD spectrum in $CHCl_3$ (Fig. 3). The nature of the peaks indicated the absence of any aggregation in the ground state. This observation is commensurate with a strong chirality associated with the conformation of **10**. In contrast, the smaller dendron **3** exhibited only very weak CD, which points to the fact that the amplification of chirality in these furanoside based dendritic species is indeed possible.

In conclusion, a novel anthracene capped chiral dendrimer has been synthesized via a convergent approach, which will be suitable for anchoring other useful functionalities. The absence of aggregation of the dendrimer

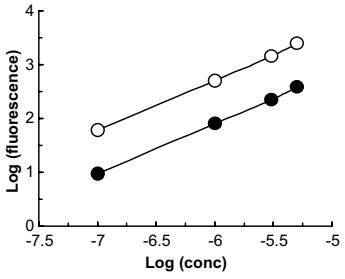


Figure 2. Concentration dependence of the fluorescence of **10** in $CHCl_3$. Open circles—fluorescence intensity of the 416 nm band. Solid circles—excimer fluorescence of the 466 nm band.

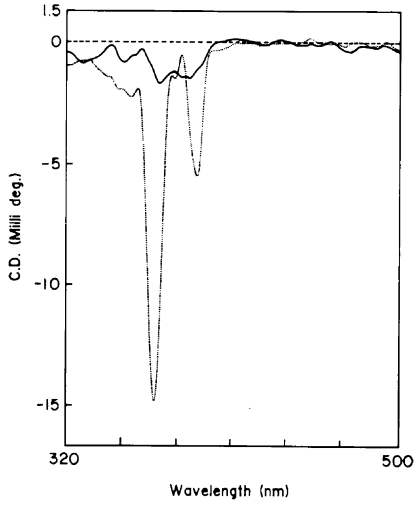


Figure 3. CD spectra of **3** (—) and **10** (···); concentration 1×10^{-4} M in $CHCl_3$.

in organic solvents is favourable for the amplification of photophysical and chiroptical properties. The synthesis of other differently capped dendrimers of similar structures is underway.

Acknowledgements

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5. Spectral data: Compound **3**: $[\alpha]_D^{25}$ −25.5 (*c* 0.55, $CHCl_3$); IR (KBr, cm^{-1}): 2983, 2929, 1625; MS (FAB): *m/z* 1255 (M + H), 1063 (M−CH_2Anthracene); ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.36 (s, 3H), 8.33 (d, 6H, $J = 9.5$ Hz), 7.91 (d, 6H, $J = 9.4$ Hz), 7.42–7.35 (m, 12H), 6.88 (s, 3H), 5.85 (d, 3H, $J = 3.7$ Hz), 5.54 (d, 3H, $J = 11.5$ Hz), 5.45 (d, 3H, $J = 11.5$ Hz), 4.49 (d, 3H, $J = 3.7$ Hz), 4.43–4.38 (m, 3H), 4.35 (d, 3H, $J = 12.1$ Hz), 4.21 (d, 3H, $J = 12.1$ Hz), 3.96 (d, 6H, $J = 6.1$ Hz), 3.86 (d, 3H, $J = 3.0$ Hz), 1.42 (s, 9H), 1.25 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 138.1 (q), 131.4 (q), 131.0 (q), 129.0 (CH), 128.5 (q), 128.4 (CH), 126.2 (CH), 125.1 (CH), 124.9 (CH), 124.3 (CH), 111.7 (q), 105.0 (CH), 82.4 (CH), 81.9 (CH), 79.3 (CH), 71.5 (CH_2), 67.3 (CH_2), 65.5 (CH_2), 26.7 (CH_3), 26.3 (CH_3). Anal. Calcd for $C_{78}H_{78}O_{15}$: C, 74.62; H, 6.26. Found: C, 74.47; H, 6.05. Compound **7**: $[\alpha]_D^{25}$ −37.2 (*c* 0.57, $CHCl_3$); IR (KBr, cm^{-1}): 2984, 2929, 1625, 1533, 1453; MS (FAB): *m/z* 930 (M+Na), 908 (M+H), 716 (M−CH_2Anthracene); ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.36 (d, 4H, $J = 8.8$ Hz), 8.28 (s, 2H), 7.88 (d, 4H, $J = 8.0$ Hz), 7.69 (s, 2H), 7.48–7.36 (m, 8H), 6.85 (s, 1H), 5.87 (d, 2H, $J = 3.7$ Hz), 5.60 (d, 2H, $J = 12.0$ Hz), 5.51 (d, 2H, $J = 11.9$ Hz), 4.47 (d, 2H, $J = 3.7$ Hz), 4.45–4.40 (m, 2H), 4.27 (d, 2H, $J = 12.6$ Hz), 4.01 (d, 2H, $J = 12.6$ Hz), 3.97–3.87 (m, 4H), 3.81 (d, 2H, $J = 3.0$ Hz), 1.47 (s, 6H), 1.29 (s, 6H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 148.1 (q), 139.7 (q), 131.3 (q), 131.0 (q), 130.3 (CH), 129.0 (CH), 128.4 (CH), 128.3 (q), 126.2 (CH), 124.9 (CH), 124.1 (CH), 120.4 (CH), 111.8 (q), 104.9 (CH), 82.4 (CH), 82.1 (CH), 78.9 (CH), 70.3 (CH_2), 66.6 (CH_2), 65.3 (CH_2), 26.7 (CH_3), 26.3 (CH_3). Anal. Calcd for $C_{54}H_{53}NO_{12}$: C, 71.43; H, 5.88; N, 1.54. Found: C, 71.29; H, 5.98; N, 1.35. Compound **8**: $[\alpha]_D^{25}$ −23.4 (*c* 0.46, $CHCl_3$); IR (KBr, cm^{-1}): 3463, 3373, 1616; MS (FAB): *m/z* 878 (M + H); 686 (M−CH_2Anthracene), ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.42 (s, 2H), 8.38 (d, 4H, $J = 8.4$ Hz), 7.97 (d, 4H, $J = 8.2$ Hz), 7.49–7.36 (m, 8H), 6.33 (s, 1H), 6.26 (s, 2H), 5.90 (d, 2H, $J = 3.7$ Hz), 5.58 (d, 2H, $J = 11.6$ Hz), 5.49 (d, 2H, $J = 11.6$ Hz), 4.51 (d, 2H, $J = 3.7$ Hz), 4.42–4.37 (m, 2H), 4.35 (d, 2H, $J = 12.0$ Hz), 4.18 (d, 2H, $J = 12.2$ Hz), 3.98–3.88 (m, 4H), 3.83 (d, 2H, $J = 3.0$ Hz), 3.35 (br s, 2H), 1.43 (s, 6H), 1.27 (s, 6H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 146.5 (q), 138.8 (q), 131.3 (q), 131.0 (q), 128.9 (CH), 128.5 (q), 128.4 (CH), 126.1 (CH), 124.9 (CH), 124.3 (CH), 116.1 (CH), 113.0 (CH), 111.6 (q), 105.0 (CH), 82.3 (CH), 81.4 (CH), 79.3 (CH), 71.5 (CH_2), 67.4 (CH_2), 65.4 (CH_2), 26.7 (CH_3), 26.2 (CH_3). Anal. Calcd for $C_{54}H_{55}NO_{10}$: C, 73.87; H, 6.31; N, 1.60. Found: C, 73.57; H, 6.52; N, 1.45. Compound **10**: $[\alpha]_D^{25}$ −54.2 (*c* 0.21, $CHCl_3$); IR (KBr, cm^{-1}): 3396, 1692, 1611; MS (Positive ion electrospray): *m*/2e 1676 $(M + 2Na)^{+2}$; ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.31–8.29 (m, 21H), 7.86 (d, 12H, $J = 7.8$ Hz), 7.40–7.31 (m, 30H), 7.01 (s, 3H), 6.70 (s, 3H), 6.01 (d, 3H, $J = 3.1$ Hz), 5.84 (d, 6H, $J = 3.6$ Hz), 5.49 (d, 6H, $J = 11.4$ Hz), 5.41 (d, 6H, $J = 11.5$ Hz), 4.79 (d, 3H, $J = 2.9$ Hz), 4.47 (d, 6H, $J = 3.3$ Hz), 4.40–4.15 (m, 27H), 4.24 (d, 3H, $J = 3.0$ Hz), 3.95–3.93 (m, 12H), 3.80 (d, 6H, $J = 2.6$ Hz), 1.42 (s, 9H), 1.39 (s, 18H), 1.25 (s, 9H), 1.21 (s, 18H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 165.8 (q), 139.0 (q), 137.8 (q), 137.5 (q), 134.1 (CH), 131.3 (q), 131.0 (q), 128.9 (CH), 128.5 (q), 128.3 (CH), 127.2 (CH), 126.1 (CH), 124.9 (CH), 124.3 (CH), 117.4 (CH), 112.9 (q), 111.6 (q), 105.6 (CH), 105.0 (CH), 82.3 (CH), 82.1 (CH), 81.3 (CH), 79.4 (CH), 79.3 (CH), 77.2 (CH), 72.2 (CH_2), 71.4 (CH_2), 67.4 (CH_2), 65.4 (CH_2), 27.0 (CH_3), 26.7 (CH_3), 26.4 (CH_3), 26.3 (CH_3). Anal. Calcd for $C_{195}H_{201}N_3O_{45}$: C, 70.83; H, 6.13; N, 1.27. Found: C, 70.56; H, 6.28; N, 1.12.
6. The micellar solution was prepared by sonicating a mixture of 0.1 mL of a solution of **10** in THF (2×10^{-3} M) and 10 mL of an aqueous solution of SDS (2 mM) for 2 h and keeping it in the dark overnight prior to use.
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