Detection and Functionalization of Dendrimers Possessing Free Carboxylic Acid Moieties[1]

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ABSTRACT: 9-Anthryldiazomethane (**2**) was used to detect the presence of unreacted internal carboxylic acid moieties in amide-based dendrimers. This esterification procedure is a simple method to qualitatively analyze the dendritic homogeneous and heterogeneous structural integrity.

Introduction

In the preparation of dendritic macromolecules, the continued inability to ascertain the absolute homogeneity of the resultant structures has led many to claim the monodisperse character of their products. At times, the inability to effect chromatographic separation of the macromolecular components, coupled with the general lack of resolution of spectral analysis associated with current instrumentation, have led to a quest for chemical methods to circumvent this quandary. Since we, and others, have prepared various dendritic families[2] based on diverse molecular building blocks,[3] we herein start to probe the ability to quantify the presence of unreacted termini within the dendrimer's infrastructure. In that most divergent procedures are two-step coupling−deprotection sequences, it should be feasible to analyze for those uncoupled termini or "loose ends".

Figure 1 illustrates the introduction of faults during the creation[4] of a dendritic polyamido-based family, namely,[5] *Z*-Cascade:methane[4]:(3-oxo-6-oxa-2-azaheptylidene):(3-oxo-2-azapentylidyne)^n:propanoic acid. This series is formed by repetitive treatment of a polycarboxylic acid with "Behera's Amine",[6] by a peptide coupling procedure,[7] followed by quantitative hydrolysis with formic acid to afford higher generations. The purity, or monodisperse character, of each resultant (macro)molecule was monitored by normal spectroscopic and analytical procedures; however, beyond the third generation, these analytical tools are less definative as to the monodisperse, and in particular "unimolecular", character of the larger products. A *monomolecular* dendrimer is defined as a perfectly defined structure of known composition, possessing no detectable faults, whereas a *monodisperse* dendrimer is defined as a mixture of closely related macromolecules within a given family, thus possessing faults, albeit to a minimum degree.[8] This general observation is consistent with all current divergent procedures. In order to circumvent these limitations, we recently reported[9] the creation of bis-dendrimers, which were assembled by the coupling of two totally characterized halves, via metal ion connectivity, then the presence of the metal's content and oxidation state was ascertained electrochemically. We herein describe an attractive application of traditional qualitative analysis procedures[10] to evaluate the presence of *residual* terminal carboxylic acid centers, which failed to react during the coupling procedure. To test this basic concept, we utilized 9-anthryldiazomethane (**2**), which has been previously recommended[11] for the characterization of carboxylic acids; the inherent highly fluorescent property[12,13] of the anthracene moiety and high-performance liquid chromatography (HPLC) procedures for derivative purification, support its viability in this application.

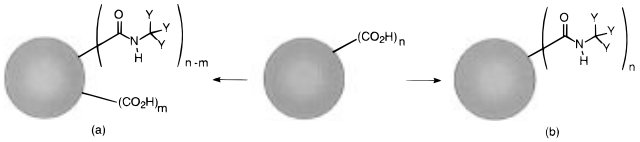
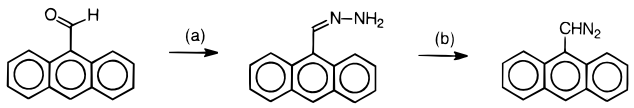


Figure 1. General faulted and idealized divergent growth pattern to monodisperse (a) and monomolecular (b) dendrimers, respectively.

Scheme 1[a]



[a] $H_2NNH_2 \cdot H_2O$/EtOH/25 °C/ 3h. (b) Na_2SO_4/Et_2O/EtOH/KOH/HgO (yellow)/5 h.

Results and Discusson

Although commercially available,[14] the synthesis (Scheme 1) of 9-anthryldiazomethane (**2**) from 9-anthraldehyde[15] followed a very simple two-step procedure.[11] Aldehyde **1**, upon treatment with hydrazine hydrate in absolute ethanol, was converted (>90%) into the corresponding reddish-yellow crystalline hydrazone, which was oxidized with mercuric oxide to give (ca. 50%) the red crystalline diazomethane **2**. In spite of the fact that upon warming to ca 60 °C, **2** lost nitrogen and was reported[11] to initiate the radical polymerization of methyl methacrylate; at diminished temperatures, **2** was stable and showed a characteristic diazo band (IR) at 2080 cm^{-1} as well as a definitive spike (^{1}H NMR) at 5.70 ppm for the RC*H*N_2.

A series of polyacids were initially utilized to test the viability of the trapping procedure. Although the triacid **8** (Figure 2) was readily available,[6] since it is the precursor to the molecular building block "Behera's Amine", the preparation (Scheme 2) of triacid **5** was undertaken to evaluate the differences in the steric

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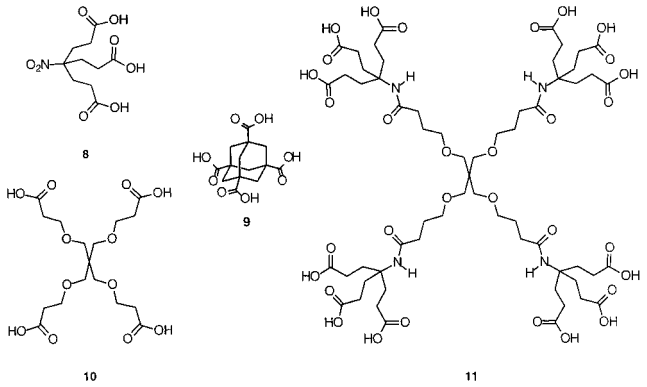
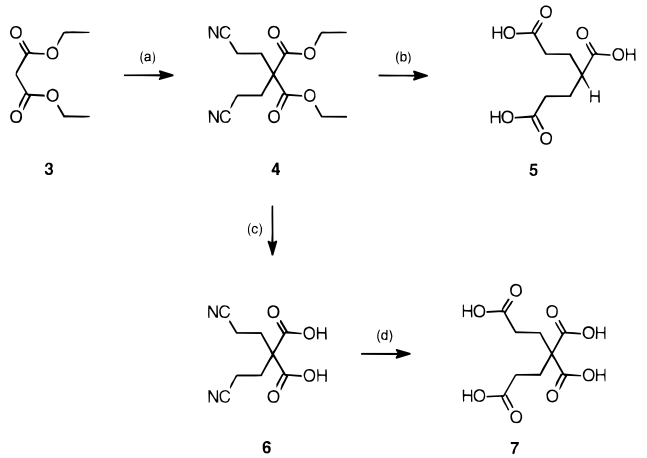


Figure 2. Representative polyacid building blocks and cores.

Scheme 2[a]



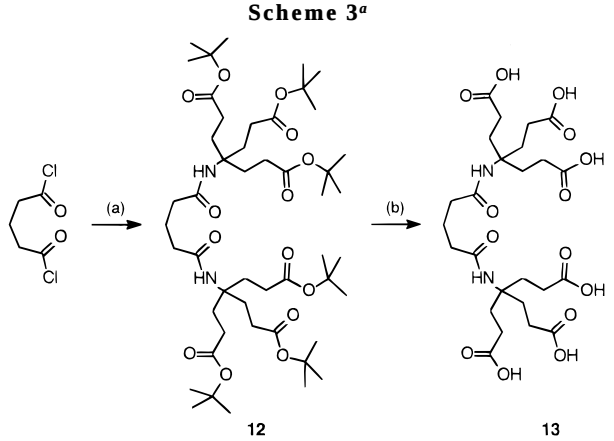
[a] $CH_2{=}HCO_2H/NH_3$ (liq). (b) HCl/Δ. (c) KOH/EtOH/25 °C. (d) KOH/EtOH/H_2O_2/60−70 °C.

environment in the trapping step. Diethyl malonate (**3**) was allowed to react with 2 equiv of acrylonitrile[16] in anhydrous liquid ammonia to give (75%) the bis-Michael addition product **4**, which when refluxed in concentrated hydrochloric acid gave (46%) the desired colorless triacid **5**, whose structure was easily determined (^{13}C NMR) by the peaks at 174.7 and 176.9 ppm for the two different carboxyl groups. Interestingly, saponification of **4** at 25 °C afforded (ca. 60%) the moderately stable diacid **6**, which was further hydrolyzed to the pentane-1,3,3,5-tetracarboxylic acid (**7**) using an ethanolic KOH solution containing 30% hydrogen peroxide. The related four-directional tetracarboxylic acids **9**[17] and **10**[6] have been previously described.

The white crystalline hexacarboxylate **12** was prepared (97%) from glutaroyl chloride with 2 equiv of "Behera's Amine" (Scheme 3). The structure **12** was established by the first-order NMR patterns and was readily converted to the corresponding "arboric acid" (**13**). Again the NMR data for **13** fully support the structural assignments. The preparation and structural characterization of the dodecacarboxylic acid **11** as well as other members in this *Z*-Cascade:methane[4]:(3-oxo-6-oxa-2-azaheptylidene):(3-oxo-2-azapentylidene)^n:propanoic acid family have been reported[4] elsewhere.

In order to ascertain the ability of diazomethane **2** to detect internally terminated carboxylic acids even in the presence of other hydrogen bonding moieties, the treatment of the tetraacyl chloride **14** with the extended building block **15** afforded dendrimer **16**, which upon deprotection and treatment with "Behera's Amine" using DCC and 1-HOBT conditions afforded the 36-

Scheme 3[a]



[a] $H_2NC(CH_2CH_2CO_2$-*tert*-$Bu)_3/NEt_3$/THF/50 °C/1 h. (b) HCO_2H/25 °C/24 h.

dendrimer **17**, contaminated with **17***, which, as ascertained by MALDI-TOF MS data [$(M + Na)^+ - NHC(CH_2CH_2CO_2C(CH_3)_3$; *m/z* 6553.1] possesses one residual, internal-terminated carboxylic acid moiety resulting from incomplete amidation (Scheme 4). Realizing the presence of **17***, the mixture can be readily driven to complete conversion under the above conditions.

Treatment of a carboxylic acid moiety with 9-anthryldiazomethane (**2**) in anhydrous diethyl ether afforded a high yield of the corresponding acetate. Simply, when acetic acid was subjected to **2**, the 9-anthrylmethyl acetate was generated in 100% yield. In general, the polyacids were treated with 9-anthryldiazomethane (**2**) under similar conditions in ether or THF to give the corresponding polyester (see Table 1). All new compounds were fully characterized by their spectral and analytical data. Limited solubility of the larger polyacids in these ethereal solvents was not problematic due to the increasing solubility of the esterified intermediates and products as the reactions proceeded.

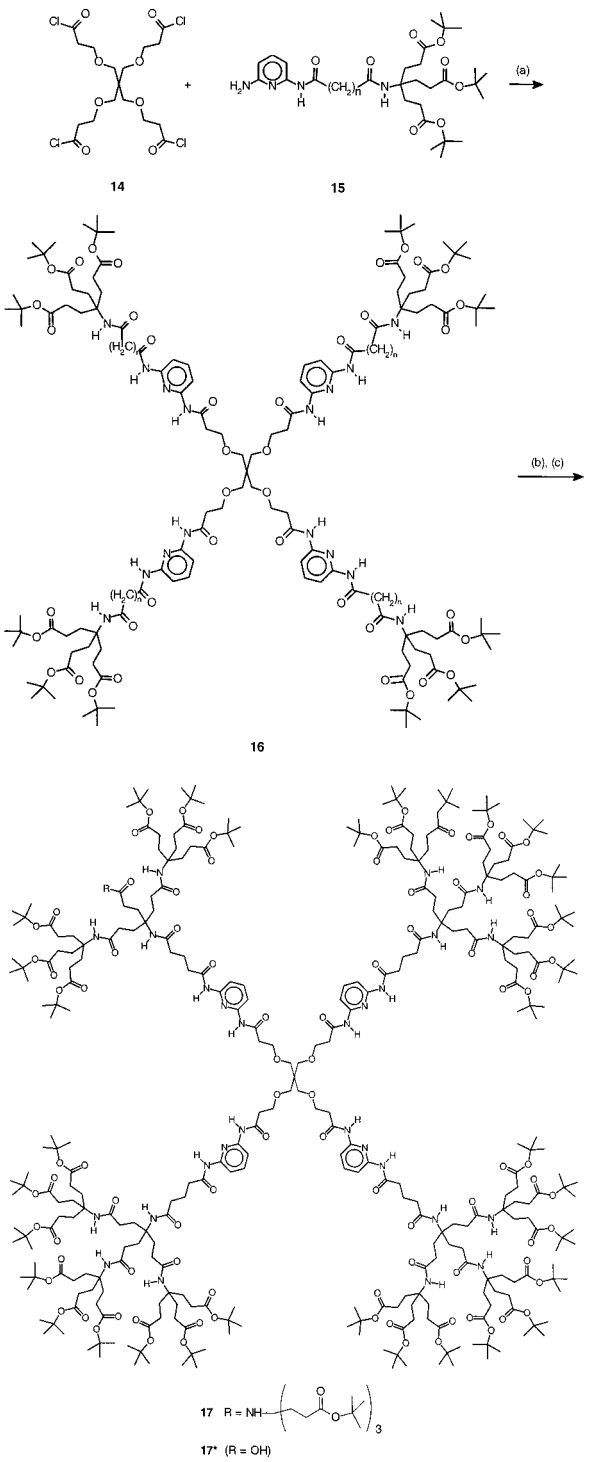
When the corresponding, fully substituted "monomolecular" dendrimers were treated with diazoanthracene **2**, no fluorescence spectrum for the anthracene moiety was detected; however use of the "monodisperse" sample, shown by MS to be less than perfect, such as **17***, afforded a notable fluorescence (Figure 3). Thus, this simple esterification analysis (e.g., of the 36- and 108-Cascade ester families[4]) can be readily used to detect the presence of traces (<1%) of imperfection within a given sample even when standard analytical methods, such as NMR, fail; lacking any detectable fluorescence, after treatment with anthracene **2**, supports the monomolecular nature of the samples.

On the basis of the analyses of the fluorescence data (Table 2) of the above series of polyacids, there does not appear to be any linear relationship between ϵ_{max} values and the number of anthryl moieties in a given molecule. For example, comparison of the ϵ values of the excitation spectra of **18** ($\epsilon = 3124$) possessing only a single anthryl unit with that of **23** ($\epsilon = 11\,090$) having four such substituents indicates that a quantitative analysis is not guaranteed; thus, this simple procedure is only a qualitative tool to evaluate the monomolecular vs mono-(poly)disperse nature of the dendritic material.

Conclusions

The use of reagents such as 9-anthryldiazomethane to detect unreacted carboxylic acid loci within macromolecules prepared by the divergent process offers direct, rapid qualitative insight into the monomolecular

Scheme 4[a]



[a] NEt_3/THF/25 °C/1 h; then 50 °C/1 h. (b) HCO_2H/25 °C/24 h. (c) $H_2NC(CH_2CH_2CO_2$-*tert*-$Bu)_3/NEt_3$/THF/50 °C/1 h.

vs monodisperse character of the reaction product. The procedure is cheaper and easier than mass spectral analyses, which may or may not be used as an analytical tool in the quantification of these macromolecules. In the quest of pure, homogeneous dendrimers, as well as in the analysis of heterogeneous dendrimers and hyperbranched polymers, 9-anthryldiazomethane and other functional group sensitive reagents (e.g., fluorescenethioisocyanate for the detection of internal terminated amino moieties) will be useful to probe the structural integrity of the assigned structures. It remains to be proven what will be the effect of the limiting growth factors, e.g., steric crowding, on the use of traditional

Table 1. Melting Points and Yields for Various 9-Anthrylmethyl Esters

acid	ester (R = 9-anthrylmethyl)	mp (°C)	yield (%)
CH_3CO_2H	CH_3CO_2R (**18**)	116[a]	100
8	$O_2NC(CH_2CH_2CO_2R)_3$ (**19**)	180−182	87
6	$(NCCH_2CH_2)_2C(CO_2R)_2$ (**20**)	163−164	77
5	$RO_2CCH(CH_2CH_2CO_2R)_2$ (**21**)	145 (dec)	25
7	$(RO_2C)_2C(CH_2CH_2CO_2R)_2$ (**22**)	105−115	37
9	$C_{10}H_{12}(CO_2R)_4$ (**23**)	ca. 100	79
13	$CH_2(CH_2CONHC(CH_2CH_2CO_2R)_3)_2$ (**24**)	106−120	41
10	$C(CH_2OCH_2CH_2CO_2R)_4$ (**25**)	95−105	92
11	$C[CH_2OCH_2CH_2CONHC(CH_2CH_2CO_2R)_3]_4$ (**26**)	110−115	60

[a] Lit.[3] mp 111−112 °C.

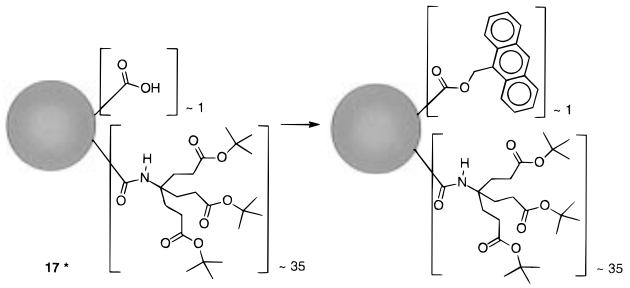


Figure 3. Pictorial representation of the detection procedure using 9-anthryldiazomethane for free carboxyl moieties within a spherical dendrimer.

Table 2. Fluorescence Emission and Excitation Maxima, nm

	excitation 272 nm (intensities)[a]	emission 419 nm (intensities)[a]
18	262.0 (1.76), 272 (3.40), 328 (3.49), 339.5 (3.47), 358 (3.35), 378 (3.43)	399.5 (3.23), 416 (3.48), 440.5 (3.16), 544 (1.66)
23	275 (3.98), 324 (4.04), 339 (3.96), 358 (3.78)	419.5 (3.97), 441 (3.69)

[a] Uncorrected relative fluorescence intensities (log).

qualitative organic techniques in the analysis of such macromolecules. Further, the use of imperfect or monodisperse dendritic species as an actual macromolecular host for internal low concentrations of fluorescent and related chromophores[18] is envisioned by application of this tagging procedure.

Experimental Section

General Comments. All melting points were taken in open capillary tubes and are uncorrected. The ^1H and ^{13}C NMR spectra were recorded at 80.06 and 20.08 MHz, respectively, in $DCCl_3$ solutions, except where noted. Deuterated solvent residues were used as internal solvents [$CHCl_3$, 7.27 (^1H) and 77.0 (^{13}C) ppm; Me_2SO, 2.49 (^1H) and 39.5 (^{13}C) ppm], and chemical shift values (δ) are reported in ppm downfield from tetramethylsilane. Infrared spectra (IR) were recorded on an IBM IR/38 Fourier transform infrared spectrophotometer. Quartz cuvettes were used for the UV (λ_{max}, ϵ) and the fluorescence spectra (L = 1 cm) run in CH_2Cl_2 having a molarity of 200 μmol at 22.5 °C. The UV spectrophotometer was from UVIKON-KONTRON, Zurich, Switzerland. Elemental analyses were conducted by M-H-W Laboratories (Phoenix, AZ). Unless otherwise noted, all reagents and solvents utilized were of reagent grade and no further purification was undertaken.

Reagents. (a) 9-Anthryldiazomethane (2) was prepared from 9-anthrylmethanol by the procedure of Nakaya et al.[11]

(b) 1,5-Dicyano-3,3′-bis(ethoxycarbonyl)pentane (4). To a stirred solution of diethyl malonate (**3**; 32 g, 200 mmol) in liquid NH_3 (300 mL) was added acrylonitrile (21.2 g, 400 mmol) at −55 to −60 °C over 10 min. The temperature was

maintained for 30 min and then allowed to increase to 25 °C. The resultant white crystals were recrystallized (EtOH, 50 mL) to give (75%) the desired diester **4**: 40 g; mp 62 °C (lit.[19] mp 62 °C); ^{1}H NMR δ 1.29 (t, J = 7 Hz, 6H, CH_3), 2.24 (t, J = 7 Hz, CH_2CN, 4H), 2.46 (t, J = 4 Hz, CH_2CH_2CN, 4H), 4.25 (q, J = 7 Hz, CH_3CH_2, 4H); ^{13}C NMR δ 12.78 (CH_2CH_2CN), 13.68 (CH_2CH_3), 29.20 (CH_2CH_2CN), 55.36 (4*C*), 62.15 (OCH_2), 118.45 (*C*N), 168.91 (CO_2).

(c) 1,5-Dicyano-3,3-dicarboxypentane (6). A solution of 1,5-dicyano-3,3′-bis(ethoxycarbonyl)pentane (**4**; 5.32 g, 20 mmol) with KOH (1.15 g, 20 mmol) in EtOH (60 mL) and water (15 mL) was stirred at 25 °C for 24 h. The solution was concentrated in vacuo, then water (150 mL) was added and the solution was extracted with ether (2 × 30 mL). The aqueous solution was acidified with HCl and extracted with ether. The solvent was dried ($MgSO_4$) and concentrated in vacuo to afford (57%) the desired diacid **6**, as colorless crystals: 2.4 g; mp 152 °C; ^{1}H NMR (DMSO-d_6) δ 2.07 (t, J = 8 Hz, CH_2CN, 4H); 2.46 (t, J = 8 Hz, CH_2CH_2, 4H), 12.0 (br, CO_2H, 2H); ^{13}C NMR (DMSO-d_6) δ 12.44 (*C*H_2CN), 27.66 (*C*H_2-CH_2CN), 55.45 (4*C*), 120.19 (*C*N), 171.25 (CO_2).

(d) 1,3,5-Pentanetricarboxylic Acid (5). A suspension of 1,5-dicyano-3,3′-bis(ethoxycarbonyl)pentane in concentrated HCl (50 mL) was refluxed for 48 h. The solution was concentrated in vacuo then diluted with water (50 mL) and reconcentrated in vacuo to give a solid, which was recrystallized (MeCN) to give (46%) this triacid, as a colorless solid: 1.42 g; mp 115−116 °C; ^{13}C NMR (DMSO-d_6) δ 27.3 (*C*H_2-CO_2H), 32.0 (CH_2*C*H_2CO_2H), 43.9 (4*C*), 174.7 (*C*H_2CO_2OH), 176.9 (CO_2H). *Anal.* Calcd for $C_8H_{12}O_6$: C, 47.05, H, 5.82. Found: C, 47.06, H, 5.92.

(e) 1,3,3,5-Pentanetetracarboxylic Acid (7). To a solution of 1,5-dicyano-3,3′-bis(ethoxycarbonyl)pentane (**4**; 4.0 g, 15 mmol) in a mixture of EtOH (150 mL), water (50 mL), and KOH (18 g, 320 mmol), H_2O_2 (45 mL, 30%) was slowly added at 10−20 °C, and then stirred for 45 min at 25 °C. The temperature was then increased to 60−70 °C for 20 h. After the solvent was distilled in vacuo, and concentrated HCl was added to attain the pH = 1, the solution was continuously extracted with ether for 7 h. Concentration of the extract in vacuo furnished an oil, which crystallized (MeCN) on standing to afford (76%) the desired tetraacid **7**: 2.71 g; mp 168−171 °C (dec.); ^{13}C NMR (DMSO-d_6) δ 27.59 (*C*H_2CO_2H), 29.48 (*C*H_2-CH_2CO_2H), 55.93 (4*C*), 172,84 (*C*COOH), 174.28 (CH_2*C*O_2H). *Anal.* Calcd for $C_9H_{12}O_8$: C, 43.55; H, 4.87. Found: C, 43.80; H, 4.51.

(f) 1,3,5,7-Adamantanetetracarboxylic acid (9) was prepared according to the literature[17a] or by a more novel route from adamantanecarboxylic acid.[17b]

***tert*-Butyl 4,4,12,12-Tetrakis(*β*-carboxyethyl)-5,11-diaza-6,10-diketopentadecanoate (12).** A solution of di-*tert*-butyl 4-amino-4-[(2-*tert*-butoxycarbonyl)ethyl]-1,7-heptanedioate[6] (4.14 g, 10 mmol) and Et_3N (1.1g, 10 mmol) in THF (40 mL) was added drop wise to a stirred solution of glutaryl chloride (845 mg, 5 mmol) in THF (50 mL) at 50 °C over a period of 30 min and maintained at 50 °C for 1 h. Stirring at 25 °C was continued for 24 h, then Et_3N·HCl was filtered and the THF removed in vacuo. The residue was dissolved in ether (150 mL), washed with a $NaHCO_3$ solution (5%, 20 mL) and then water (20 mL), and dried (Na_2SO_4). Distillation of the solvent gave (97%) the desired product **12**, which was recrystallized from cyclohexane (40 mL) affording white crystals: 4.51 g; mp 116−118 °C; ^{1}H NMR δ 1.43 [s, C(*C*H_3)$_3$, 54H], 1.95 (m, CH_2-CH_2CH_2, CH_2CH_2CO, 14H), 2.18 (m, $CH_2CH_2CH_2$, CH_2CH_2-CO, 16H), 6.15 (br, N*H*); ^{13}C NMR δ 21.60 ($CH_2CH_2CH_2$), 28.24 [(CH_3)$_3$], 29.87 ($O_2CCH_2CH_2$), 30.10 ($O_2CCH_2CH_2$), 35.84 ($NHCOCH_2CH_2$), 57.74 (CNHCO), 80.79 (COCO), 172.18 (NH*C*O), 172.96 (CO_2).

(h) 4,4,12,12-Tetrakis(*β*-carboxyethyl)-5,11-diaza-6,10-diketopentadecanoic Acid (13). A solution of hexaester **12** (3.46 g, 373 mmol) in formic acid (25 mL) was allowed to stand at 25 °C for 24 h, then the volatile products were distilled in vacuo. Water (25 mL) was added to the residue and distilled from the solution. This procedure was repeated twice yielding (95.8%) **13**, as a white amorphous solid: 2.11 g; mp slow decomposition above 90 °C; ^{1}H NMR (DMSO-d_6) δ 2.24 (d, J = 7 Hz, 14H, $CH_2CH_2CH_2$, $CH_2CH_2CO_2$H), 2.49 (m, CH_2CH_2-CH_2, $CH_2CH_2CO_2$H,16H), 7.56 (s, 2H, NH), 12.49 (s, br, 6H, CO_2H); ^{13}C NMR (DMSO-d_6) δ 22.30 ($CH_2CH_2CH_2$), 28.30 ($CH_2CH_2CO_2$H), 29.32 ($CH_2CH_2CO_2$H), 35.83 ($NHCOCH_2$), 56.55 (*C*═), 172.02 (NH*C*O), 174.74 (*C*O_2H).

General Esterification Procedure. Tris(9-anthrylmethyl)-4-[1-(2-carboxyethyl)]-4-nitroheptanedicarboxylate (19). A solution of 9-anthryldiazomethane (**2**); 500 mg, 2.2 mmol) in ether (30 mL) was added to a slurry of 4-[1-(2-carboxyethyl)]-4-nitroheptanedioic acid[20] (138.5 mg, 0.5 mmol) in ether (50 mL). After the mixture was allowed to stand at 25 °C for 48 h, the solvent was removed by distillation, and the residue was crystallized from $CHCl_3$ yielding the triester **19**, as yellow needles: 370 mg; UV 388.5 (3.321), 367.0 (3.728); ^{1}H NMR δ 2.20 (d, J = 5 Hz, 12 H, CH_2CH_2), 6.07 (s, CH_2, 6H), 7.26−8.44 (m, Ar*H*, 27H); ^{13}C NMR δ 28.50 (*C*$H_2CH_2CO_2$), 30.09 (CH_2*C*H_2CO_2), 59.24 (Anth*C*H_2), 91.64 (*C*NO_2), 123.72, 125.04, 125.65, 126.67, 129.02, 129.26, 130.90, 131.24 (Anth*C*), 171.76 (CO_2). *Anal.* Calcd for $C_{55}H_{45}NO_8$ (M = 847.918): C, 77.90; H, 5.35; N, 1.65. Found: C, 77.82; H, 5.42; N, 1.67.

The related esters were purified by chromatography on silica or aluminum oxide, byproducts extracted with toluene/EtOAc, and the desired product obtained by washing the column with a mixture of CH_2Cl_2/EtOAc/MeOH. The melting points and yields are presented in Table 1.

9-Anthrylmethyl Acetate (18) was prepared (100%) from acetic acid according to the literature[11] as yellow needles: UV 348.5 (2.071), 366.5 (2.966), 386.5 (2.676); ^{1}H NMR δ 1.56 (s, CH_3, 3H), 6.16 (s, CH_2, 2H), 7.49−8.53 (m, Ar*H*, 9H); ^{13}C NMR δ 21.24 (*C*H_3), 59.05 (*C*H_2), 124.14, 125.34, 126.43, 126.89, 129.35, 129.43, 131.27, 131.62 (Ar*C*), 171.53 (*C*O_2).

9-Anthrylmethyl 1,5-Dicyano-3,3-pentanedicarboxylate (20): UV 388.0 (2.727), 368.0 (3.087), 350.0 (2.197); ^{1}H NMR δ 2.02 (t, J = 5 Hz, CH_2CH_2, 8H), 6.02 (s, CH_2 ,4H), 7.27−8.44 (m, Ar*H* 18H); ^{13}C NMR δ 12.49 (*C*H_2CN), 29.31 (*C*H_2CH_2CN), 55.80 (4*C*), 60.75 (Anth*C*H_2), 118.10 (*C*N), 123.29, 124.65, 125.15, 126.87, 129.12, 129.71, 130.67, 131,10 (9-Anth*C*), 168.87 (CO_2). *Anal.* Calcd for $C_{39}H_{30}N_2O_4$ (M = 590.64): C, 79.30; H, 5.12; N, 4.74. Found: C, 79.23; H, 4.40; N, 4.70.

9-Anthrylmethyl 1,3,5-Pentanetricarboxylate (21): UV 387.0 (3.215), 366.0 (3.660), 349.0 (3.42); ^{1}H NMR δ 1.59−2.17 (m, CH_2CH_2, CH, 9H); 6.02 (s, 6H, CH_2), 7.25−8.46 (m, Ar*H*, 27H); ^{13}C NMR δ 26.80 (*C*$H_2CH_2CO_2$), 31.52 (*C*H_2CO_2), 43.79 (H*C*═), 58.66, 58.94 (Anth*C*H_2), 172.75 (*C*O_2), 174.81 (*C*O_2). *Anal.* Calcd for $C_{53}H_{42}O_6$ (M = 774.86): C, 82.14; H, 5.46. Found: C, 82.05; H, 5.39.

9-Anthrylmethyl 1,3,3,5-Tetrapentanetetracarboxylate (22): UV 386.0 (3.300), 369.0 (3.880), 350.0 (3.850); ^{1}H NMR δ 1.86−2.03 (m, CH_2CH_2, 8H), 5.80 (s, AnthCH_2, 4H), 5.89 (s, AnthCH_2, 4H), 7.24−8.15 (m, ArH, 36H); ^{13}C NMR δ 28.40 (*C*$H_2CH_2CO_2$), 28.92 (*C*H_2CO_2), 56.22 (4*C*), 58.63 (Anth*C*H_2), 59.73 (Anth*C*H_2), 170.41, 172.34 (*C*O_2). *Anal.* Calcd for $C_{68}H_{52}O_8$ (M = 997.096): C, 81.90; H, 5.26. Found: C, 81.71; H, 5.10.

9-Anthrylmethyl 1,3,5,7-Adamantanetetracarboxylate (23): UV 387.0 (3.190), 367.0 (3.546), 349.0 (3.312); ^{1}H NMR δ 1.98 (s, CH_2, 12H), 6.04 (s, CH_2, 8H), 7.39−8.39 (m, Ar*H*, 36H); ^{13}C NMR δ 38.96 (*C*), 42,78 (*C*H_2), 60.21 (*C*H_2anth), 123.84, 125.02, 125.93, 126.65, 128.90, 129.12, 130.94, 131.21 (anth), 175.38 (*C*O_2). *Anal.* Calcd for $C_{74}H_{54}O_8$ (M = 1071.17): C, 82.97; H, 5.08. Found: 82.80; H, 5.15.

Hexakis(9-anthrylmethyl) 4,4′,12,12′-Tetrakis(*β*-carboxyethyl)-5,11-diaza-6,10-diketopentadecanoate (24): UV 364.0 (3.813); ^{1}H NMR δ 1.23−1.63 (m, $CH_2CH_2CH_2$, CH_2-CH_2CO, 30H), 4.93 (s, NH, 2H), 5.96 (s, AnthCH_2,12H), 7.28−8.20 (m, ArH, 54H); ^{13}C NMR δ 21.62 ($CH_2CH_2CH_2$), 28.02 ($CH_2CH_2CO_2$), 28.83 ($CH_2CH_2CO_2$), 33.60 ($COCH_2CH_2CH_2$), 57.23 (═CNHCO), 59.11 (AnthCH_2), 123.96, 125.26, 126.00, 126.96, 129.33, 129.55, 131.10, 131.39 (Anth*C*), 171.51 (NH*C*O), 173.09 (*C*O_2). *Anal.* Calcd for $C_{115}H_{98}N_2O_{14}$ (M = 1731.95): C, 79.74; H, 5.70; N, 1.61. Found: C, 79.70; H, 5.73; N, 1.53.

9-Anthrylmethyl 6,6-bis(carboxy-9-anthrylmethyl-2-oxabutyl)-4,8-dioxaundecane-1,11-dicarboxylate (25) was prepared from the corresponding tetraacid (**10**):[6] UV 388.5

(3.321), 367.0 (3.728); ^{1}H NMR δ 2.22 (t, J = 7.2 Hz, CH_2CO_2, 8H), 3.34 (s, CH_2O, 8H), 3.67 (t, J = 5.7 Hz, OCH_2, 8H), 6.10 (s, AnthCH_2, 8H), 7.39−8.31 (m, ArH, 36H); ^{13}C NMR δ 34.93 (CH_2CO), 44.75 (4C), 58.66 (AnthCH_2), 66.47 (CH_2O), 69.77 (OCH_2), 123.83, 124.93, 126.08, 126.47, 128.91, 128.99, 130.83, 131.16 (Anth$C$), 171.86 (CO_2). *Anal.* Calcd for $C_{77}H_{68}O_{12}$ (M = 1185): C, 78.01; H, 5.74. Found: C, 78.16; H, 5.62.

12-Cascade:methane[4]:(3-oxo-6-oxa-2-azaheptylidene): 9-anthrylmethyl propanoate (26): UV 330.5 (4.000); ^{1}H NMR δ 1.96 (t, J = 7.2 Hz, $CH_2CH_2CO_2$, 24H), 2.22 (t, J = 7.2 Hz, CH_2CO_2, 24H), 2.38 (t, J = 5.7 Hz, CH_2CONH, 8H), 3.34 (s, CHO, 8H), 3.67 (t, J = 5.7 Hz, OCH, 8H), 5.10 (s, AnthCH_2), 24Hz), 7.39−8.31 (ArH, 108H); ^{13}C NMR δ 28.16 (=CH_2CH_2), 29.25 ($CH_2CH_2CO_2$), 36.71 (CH_2CONH), 44.37 (4C), 56.86 (HNC=), 58.72 (AnthCH_2), 66.78 (CH_2O), 67.52 (OCH_2), 123.73, 124.87, 125.93, 126.45, 128.82, 128.96, 130.73, 131.05, 170.63 (CONH), 173.13 (CO_2). *Anal.* Calcd for $C_{237}H_{208}N_4O_{32}$ (M = 3624.066): C, 78.54; H, 5.78; N, 1.55. Found: C, 78.50; H, 5.74; N, 1.53.

Analysis of the Imperfect Dendrimer 17*. To a solution of **17*** (200 mg, 3.05×10^{-5} mol) in anhydrous diethyl ether (50 mL) was added a solution of **2** (150 mg, 6.88×10^{-4} mol) in ether (20 mL). After the mixture was allowed to stand at 20 °C for 24 h, the solvent was removed in vacuo and the residue chromatographed on silica eluting with EtOAc/MeOH (1:1) to give 160 mg of the labeled ester: ^{13}C NMR δ 27.96 (CH_3), 29.69, 31.37(CH_2CH_2), 57.32 (NHC≡), 58.80 (CH_2anth), 80.47 (CCH_3), 109.40, 109.73 (pyr-C3), 123.89, 125.03, 126.05, 126.62, 126.87, 129.11, 130.90, 131.22 (anth$C$), 140.22 (pyr-C4), 149.59, 149.91 (pyr-C2), 170.64, 171.81 (CONH), 172.66 (CO_2t-bu), 172.90 (CO_2CH_2anth).

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