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A One-Pot Synthesis of a 243-Allyl Dendrimer under Ambient Conditions

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ABSTRACT

Hydrosilylation of a nonaallyl dendritic core using HSi(Me)$_2$Cl followed by reaction with a phenolate dendronic brick bearing three allyl groups, followed by repetition of this sequence of reactions twice, allows a one-pot synthesis of a 243-allyl dendrimer under ambient conditions.

Among branched polymers,[1,2] dendrimers[2,3] occupy a privileged place because they are monodisperse macromolecular compounds. Dendrimer synthesis is based on iterations, and a drawback is that the numerous iterative syntheses may be long and tedious, especially when several dendritic generations are called for. Nevertheless, the potential applications of dendrimers are considerable in biology, medicine, catalysis, and materials nanoscience.[4] Despite the huge amount of publications on dendrimer chemistry, only very few papers are concerned with one-pot syntheses. The preparation of hyperbranched or dendronized polymers is a well-known efficient alternative, although irregular dendrimers or dendritic/dendronized polymers are produced.[1] Reports on genuine iterative one-pot dendrimer syntheses are very rare. Rannard's group has reported one-pot multiple-addition convergent synthesis at 60 °C of polycarbonate dendrimers containing up to 16 isobutyl termini,[5] and Eilbracht and Hagg's group has synthesized amino-functionalized dendritic architectures by hydroformylation−reductive amination sequences of dendritic polyglycerol with 30−40 amino termini at 75−85 °C under 60 atm of CO/H$_2$ pressure.[6]

We have recently designed giant dendrimers[7] far beyond the de Gennes dense-packing limit[8] by iteration of a sequence of reactions involving hydrosilylation of the nonaallyl dendritic core **2**[9a] with HSi(Me)$_2$CH$_2$Cl followed by Williamson reaction with the dendronic phenoltriallyl building block **4**.[9b] The construction involved monitoring each reaction by ^{1}H NMR until completion followed by chromatographic separation for full characterization. The choice of the silane was guided by the absence of dehydrogenation in the course of the Williamson reaction and the formation of C−O bonds.[7]

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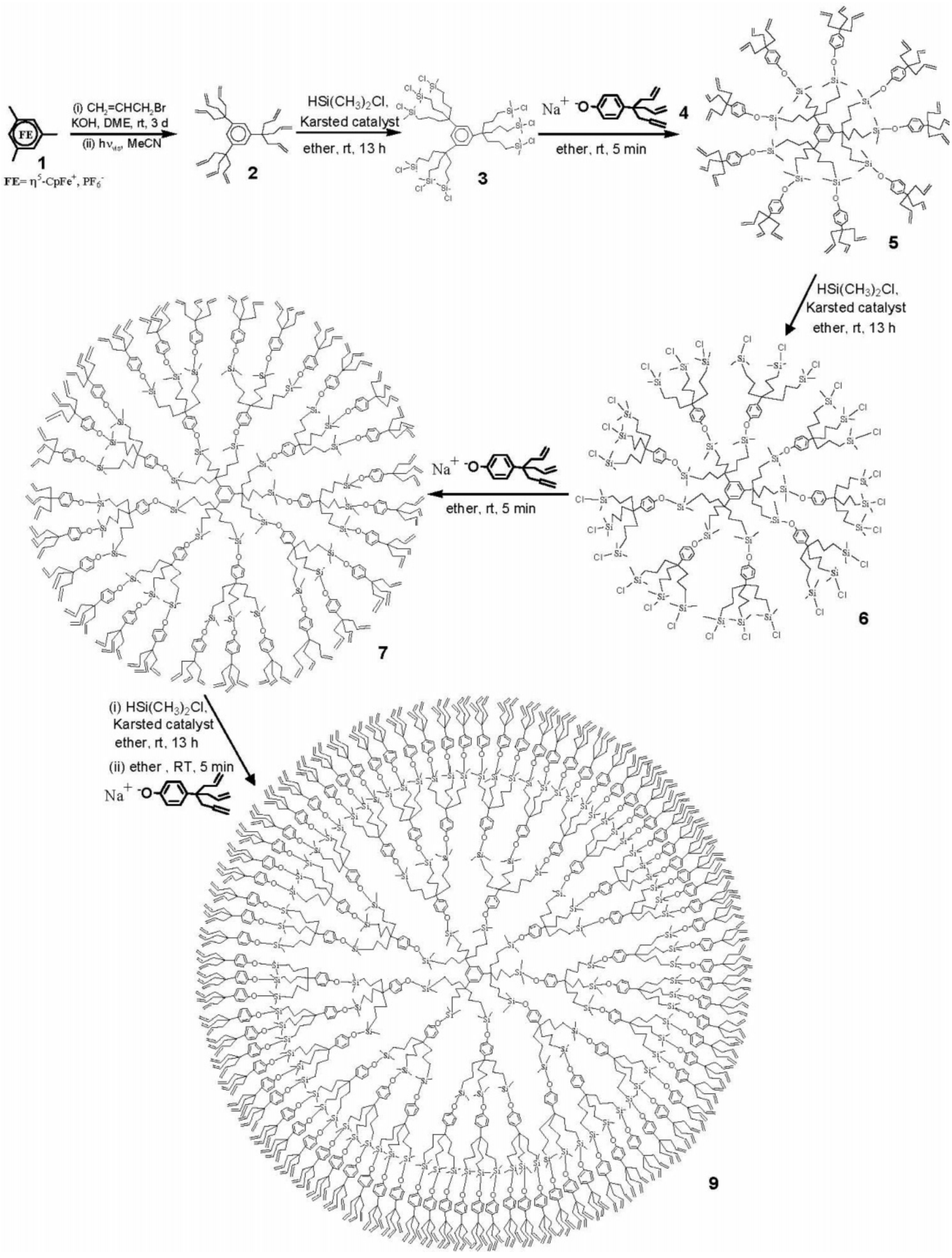
Scheme 1. “One-Pot” Synthesis of the 243-Olefin (G_3) Dendrimer **9**



The Williamson reaction used in this dendrimer required heating for 2 days at 80 °C in DMF, however, which did not allow one-pot synthesis of the dendrimer series. We now report *a one-pot* construction of dendrimers under ambient conditions in which NaCl is the only byproduct using a similar procedure with **2**, **4**, and the silane $HSi(Me)_2Cl$ (Scheme 1). The use of this silane in a seminal efficient dendrimer synthesis was first carried out by van Leeuwen's group.[10] The formation of the Si−O bonds provides a large driving force for the reaction, so that this reaction now only takes 5 min at room temperature. The one-pot synthesis of dendrimers is all the more useful as the multiplication of the number of branches by three brings about the construction of large dendrimers with 3^{n+2} allyl branches at the periphery in only a few iteration sequences (*n*, generation number).[11] The advantage is of course that, once it is well delineated, the one-pot dendrimer synthesis allows a direct, fast synthesis without the need to isolate any intermediate. This requires molecular engineering in order to design a system in which all the reagents and catalysts used in the successive reactions of the iteration sequences are compatible with one another and with the intermediate dendritic functionalities formed along the synthetic route. Thus, we have now used Scheme 1 that takes this requirement into account. The hydrosilylation step is catalyzed by the Karsted catalyst whose presence does not interfere with the other step, the phenolate condensation reaction. In turn, the latter produces NaCl that does not interfere with the hydrosilylation. The NMR spectra represented in the Supporting Information clearly show that each synthetic step is completed before the next one proceeds. If the nonaallyl core **2** is G_0, the first set of these two reactions produces **5**, the first-generation 27-allyl dendrimer (G_1) that was characterized by its molecular peak at 3079.06 (MNa^+) in the MALDI TOF mass spectrum (calcd for $C_{198}H_{282}Si_9O_9$ 3059.12), by size-exclusion chromatography (SEC) and ^{1}H, ^{13}C, and ^{29}Si NMR. The one-pot dendrimer construction was carried out to form **7**, the 81-allyl G_2 dendrimer and **9**, the 243-allyl G_3 dendrimer that were characterized by SEC and ^{1}H, ^{13}C, and ^{29}Si NMR. Typically, the reaction starts with 0.025 g (0.052 mmol) of **2** (whose yield from **1** is 70%) and finally gives 1.77 g of 243-allyl dendrimer **9** (quantitative yield). The reactions are conveniently monitored by ^{1}H NMR allowing to observe the disappearance of the olefin signals at 4.46 and 5.52 ppm vs TMS in $CDCl_3$ upon hydrosilylation. ^{29}Si NMR was a useful technique that allowed confirming completion of the reactions (Figure 1, right). For the Si−Cl dendrimers, the ^{29}Si−Cl signal appears at 32 ppm vs TMS in $CDCl_3$, whereas after reaction with the phenolate dendron, the Si−O signal appears at 18 ppm. Hydrosilylation of the 81-allyl G_2 dendrimer **7** leads to the observation of both the signal of the 27 inner Si−O and of the 81 outer Si−Cl (note the intensity difference). SEC (Figure 1, left) shows the size progression from G_1 to G_3 and the low polydispersity (1.00 to 1.02) of **5**, **7**, and **9**. The dendrimers are moderately air- and moisture-sensitive, yielding phenol dendrons upon reaction with water. Such degradable dendrimers can find use whenever removal of the dendrimer is necessary after formation of capsules at the dendrimer periphery for the design of hollow capsules with preorganized hole size.[12] The construction of such elaborate nanomaterials could become all the more attractive as the dendrimer synthesis would be fast and convenient as shown here.

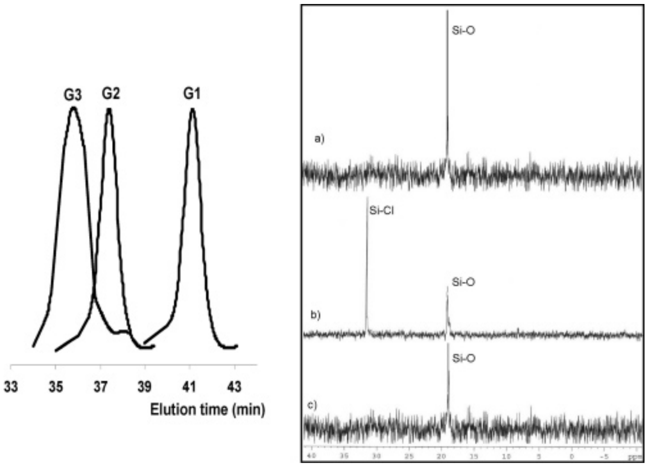


Figure 1. Left: size-exclusion chromatograms of the 27-allyl (**5**, G_1), 81-allyl (**7**, G_2) and 243-allyl (**9**, G_3) dendrimers. Right: ^{29}Si NMR of (a) **7** (81-allyl dendrimer), (b) **8** (81-Cl dendrimer), (c) **9** (243-allyl dendrimer) (see the Supporting Information for details).

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Supporting Information Available: Experimental procedures, ^{1}H, ^{13}C, and ^{29}Si NMR spectra of all of the G_1, G_2, and G_3 dendrimers, and MALDI TOF mass spectrum of G_1. This material is available free of charge via the Internet at http://pubs.acs.org.

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[11] Such a 1 → 3 C-branched connectivity[2] has been reported for the first time by Newkome with the synthesis of the so-called "*arborols*": Newkome, G. R.; Yao, Z.; Baker, G. R.; Gupta, V. K. *J. Org. Chem.* **1985**, *50*, 2003.

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[13] **Synthetic Procedure.** Dimethylchlorosilane (2 equiv per branch) and 5 drops of Karsted catalyst were added to a solution of the 3^{n+2}-arm polyolefin dendrimer (n = generation number) in dry ether (20 mL). After the mixture was stirred at 25 °C for 12 h, the solvent and dimethylchlorosilane in excess were removed under vacuum, yielding the chloro-terminated dendrimer with 3^{n+2}-arms. The sodium salt **4** of the phenoltriallyl dendron was added to a solution of 3^{n+2}-arm choro-terminated dendrimer (1 equiv per branch) in ether (20 mL), and the instantaneous formation of a precipitate (NaCl) was observed together with the formation of the $3^{n'+2}$-arm polyolefin dendrimer ($n' = n + 1$). This sequence of reactions was carried out repeatedly identically in situ for the first, second, and third generations (there is no experimental obstacle for continuation beyond the third generation). The reactions were monitored by ^{1}H and ^{29}Si NMR for each generation (see the full NMR data in the Supporting Information).