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Simple Modification in Hexakis-Addition for Efficient Synthesis of C_{60}-Centered Dendritic Molecules Bearing Multiple Aromatic Chromophores

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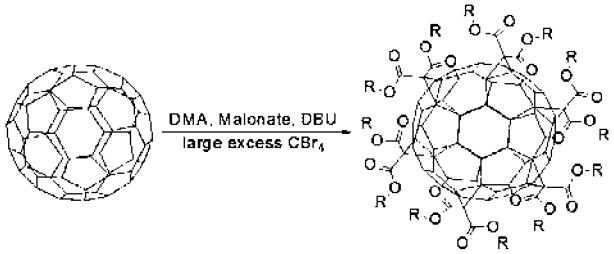
ABSTRACT



In the templated hexakis-addition reaction of malonic esters with C_{60} to prepare dendritic macromolecules that are terminated symmetrically with 12 derivatized pyrenes, a simple modification to use a much larger excess of the bromination agent resulted in dramatic increases in the product yields.

The highly symmetric molecule C_{60} is considered to be an ideal core for dendritic molecular structures.[1−3] In particular, C_{60} can be functionalized in a highly symmetric fashion via templated hexakis-addition reactions.[4−9] Several C_{60}-centered dendritic macromolecules have been synthesized.[3,10−12] However, the hexakis-addition of C_{60} with bulky and/or complex functional groups typically suffers from low reaction yields, often only a few percent on the basis of consumed C_{60}.[3,10−12] Because of the low yields, the separation of the desired hexakis-adducts from reaction mixtures is by no means a straightforward task. In our synthesis of the C_{60}-centered dendritic macromolecules bearing multiple aromatic chromophores (**1**−**3** in Scheme 1),[13] we found a simple modification to the commonly used reaction conditions for the templated hexakis-addition of C_{60} to achieve substantially improved product yields.

The malonic esters in Scheme 1 were prepared by using procedures similar to those already reported in the literature.[14] The experimental details are provided in Supporting Information. The commonly used reaction conditions for the

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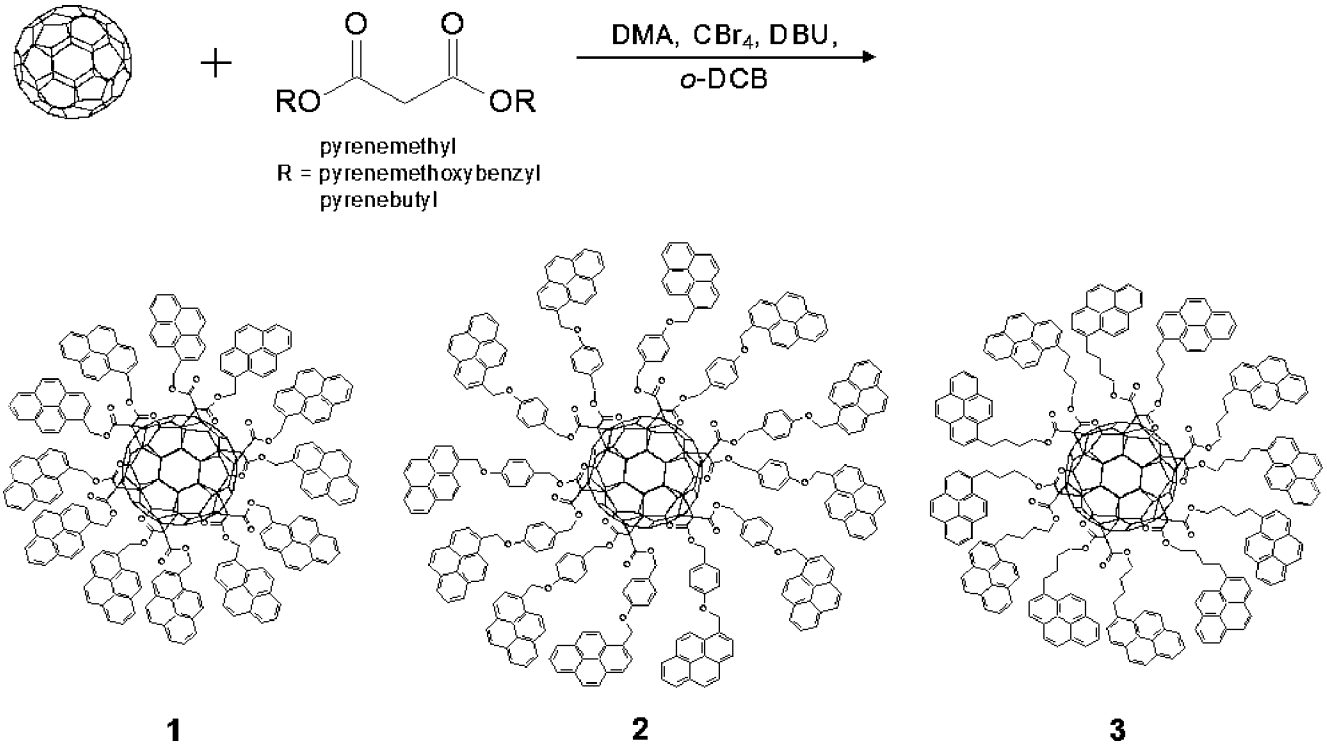
Scheme 1



templated hexakis-addition of C_{60} are generally the same as those originally reported by Hirsch and co-workers.[7,8] These conditions were applied to the synthesis of compounds **1**−**3**. For compound **2**,[13] as an example, the reaction conditions were to use *o*-dichlorobenzene as the solvent and to match the amount of C_{60} (0.05 mmol) with the templating agent 9,10-dimethylanthracene at 10 equiv, the malonic ester at 10 equiv, carbon tetrabromide at 10 equiv, and the base 1,8-diazabicyclo[5.4.0]undec-7-ene (DBU) at 20 equiv. A product yield of 17% could be achieved.[13] However, the same set of reaction conditions for the synthesis of **1** resulted in only a negligible amount of product, insufficient for any meaningful separation and isolation of the compound. On the other hand, while the synthesis of compound **3** under similar conditions was possible, with a comparable product yield of 16%, the compound was in a complex reaction mixture and thus very difficult to separate and especially challenging to obtain in a purified form.

In a search for better yields in the synthesis of **1**−**3**, we found that a simple modification to the commonly used conditions could substantially improve the hexakis-addition reactions. With such a modification of using a much larger excess of the bromination agent carbon tetrabromide, 5−10 times the usual amount, compound **1** could be synthesized and isolated in 10% yield, and the yields for compounds **2** and **3** were more than doubled.

For the synthesis of **1** under the modified reaction conditions, a solution of purified C_{60} (35 mg, 0.05 mmol) and 9,10-dimethylanthracene (100 mg, 0.5 mmol) in *o*-dichlorobenzene (50 mL) was prepared and stirred for 5 h. To the solution was added bis(pyrenemethyl) malonate (266 mg, 0.5 mmol) and an excess amount of carbon tetrabromide (1.62 g, 5 mmol, 10 times that commonly used in the literature[8,13]). The resulting solution was stirred for 30 min, followed by the addition of DBU (150 mg, 1 mmol). After constant stirring at room temperature for 8 days, the reaction mixture was filtered, concentrated, and separated on a silica gel column by using first hexane and then chloroform as eluents. The desired fraction in chloroform was concentrated and precipitated into hexane, and the precipitate was filtered and washed with acetone to obtain **1** as a yellow-colored solid (20 mg, 10% yield). The molecular structure of **1** was confirmed by results from both NMR and the matrix-assisted laser desorption ionization−time-of-flight (MALDI-TOF) MS characterizations.[15] Apparently, the simple modification of using a much larger excess of the bromination agent while keeping other reaction parameters constant changed the preparation of **1** from being impossible to producing a decent yield.

Similarly, the large excess in carbon tetrabromide under otherwise the same reaction conditions increased the yield of compound **2** from 17 to 35%.[16] For compound **3**,[17] there was not only a more than doubling of the product yield to 40% but also a much improved separation and purification of the sample via conventional silica gel column chromatography. For the latter, we speculate that the modified

(15) ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.95 (d, J = 7.5 Hz, 12H), 7.86 (d, J = 7.5 Hz, 12H), 7.80 (s, 12H), 7.76~7.65 (m, 48H), 7.57 (d, J = 7.5 Hz, 12H), 7.42 (d, J = 7.5 Hz, 12H), 5.57 (s, 24H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ 163.18, 146.62 (cage sp^2), 141.96 (cage sp^2), 134.76, 134.27, 130.59, 129.39, 128.20, 127.93, 127.84, 127.53, 127.27, 126.01, 125.49, 125.42, 124.75, 124.24, 122.37, 120.09, 70.04 (cage sp^3), 67.04, 46.48 ppm; MALDI-TOF MS (M^+) 3904.

reaction conditions might be against the formation of byproducts with similar molecular structures to that of the hexakis-adduct (such as pentaadducts), which thus made it easier to isolate the compound from the reaction mixture.

There are generally speaking a limited number of C_{60} hexakis-adducts available in the literature, with hardly any C_{60}-centered dendritic macromolecules symmetrically functionalized with multiple chromophores for comparison. This is probably a result of the difficulty associated with hexakis-addition under the commonly used reaction conditions (which do not allow the preparation of **1**, for example). A summary of other C_{60} hexakis-adducts with various functionalities, based on an exhaustive literature search, is provided in Supporting Information. Except for those of simple dialkyl malonic esters,[8,18−23] the hexakis-adducts are always produced in low yields and are typically separated from their respective reaction mixtures by using specialized HPLC techniques, reflecting the level of technical challenge and complexity. Thus, the simple modification reported here for substantially higher yields in the templated hexakis-addition of bulky and/or complex malonic esters may have broad implications in the synthesis of C_{60}-centered dendritic macromolecules with currently unaccessible functionalities.

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Supporting Information Available: Experimental details on the synthesis and characterization of the malonic esters and a summary of other C_{60} hexakis-adducts with various functionalities. This material is available free of charge via the Internet at http://pubs.acs.org.

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(16) **Compound 2:**[13] ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.03∼8.02 (m, 2H), 7.97 (d, J = 7.5 Hz, 12H), 7.89∼7.81 (m, 72H), 7.09 (d, J = 8.5 Hz, 24H), 6.84 (d, J = 8.5 Hz, 24H), 5.41 (s, 24H), 5.15 (s, 24H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ 163.70, 159.10, 145.87 (cage sp^2), 141.10 (cage sp^2), 131.33, 131.05, 130.57, 130.50, 129.47, 129.04, 127.86, 127.39, 127.19, 127.13, 126.69, 125.79, 125.20, 124.68, 124.45, 122.82, 114.79, 69.15 (cage sp^3), 68.53, 68.36, 45.59 ppm; MALDI-TOF MS (M^+) 5177.

(17) Purified C_{60} (35 mg, 0.05 mmol) and DMA (100 mg, 0.5 mmol) were dissolved in *o*-DCB (50 mL). After the solution was stirred at room temperature for 5 h, carbon tetrabromide (1.62 g, 5 mmol) and bis-(pyrenebutyl) malonate (308 mg, 0.5 mmol) were added. The solution was stirred for another 30 min, followed by the addition of DBU (150 mg, 1 mmol). After reaction for 8 days, the solvent *o*-DCB was removed. The solid sample was separated on a silica gel column by using first hexane to remove DMA and then chloroform to isolate the hexakis-adduct. The chloroform fraction thus collected was concentrated and then precipitated into hexane. The precipitate was filtered and washed with acetone to obtain **3** as a yellow-colored solid (88 mg, 40% yield): ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.98∼7.82 (m, 96H), 7.50 (d, J = 7.5 Hz, 12H), 4.01 (t, J = 6.5 Hz, 24H), 2.95 (t, J = 7.5 Hz, 24H), 1.60∼1.50 (m, 48H) ppm; ^{13}C NMR (125 MHz, $CDCl_3$) δ 166.37, 145.90 (cage sp^2), 141.10 (cage sp^2), 135.90, 131.43, 130.89, 129.88, 128.59, 127.46, 127.28, 127.12, 126.63, 125.80, 125.10, 124.88, 124.77, 124.70, 123.20, 69.40 (cage sp^3), 66.70, 45.65, 32.86, 28.44, 27.87 ppm; MALDI-TOF MS (M^+) 4409.

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