

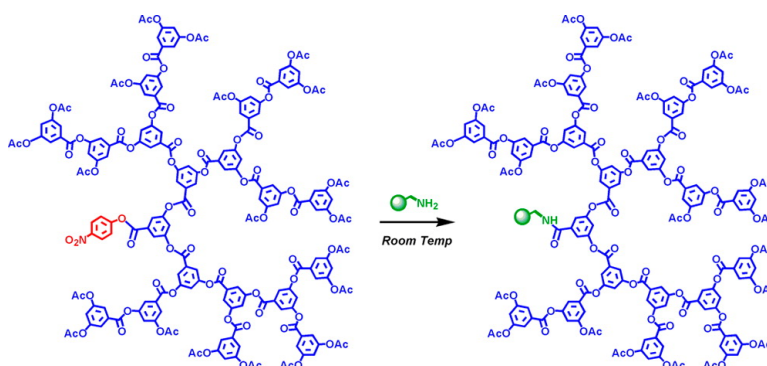
Communication

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## Postsynthetic Modification at the Focal Point of a Hyperbranched Polymer

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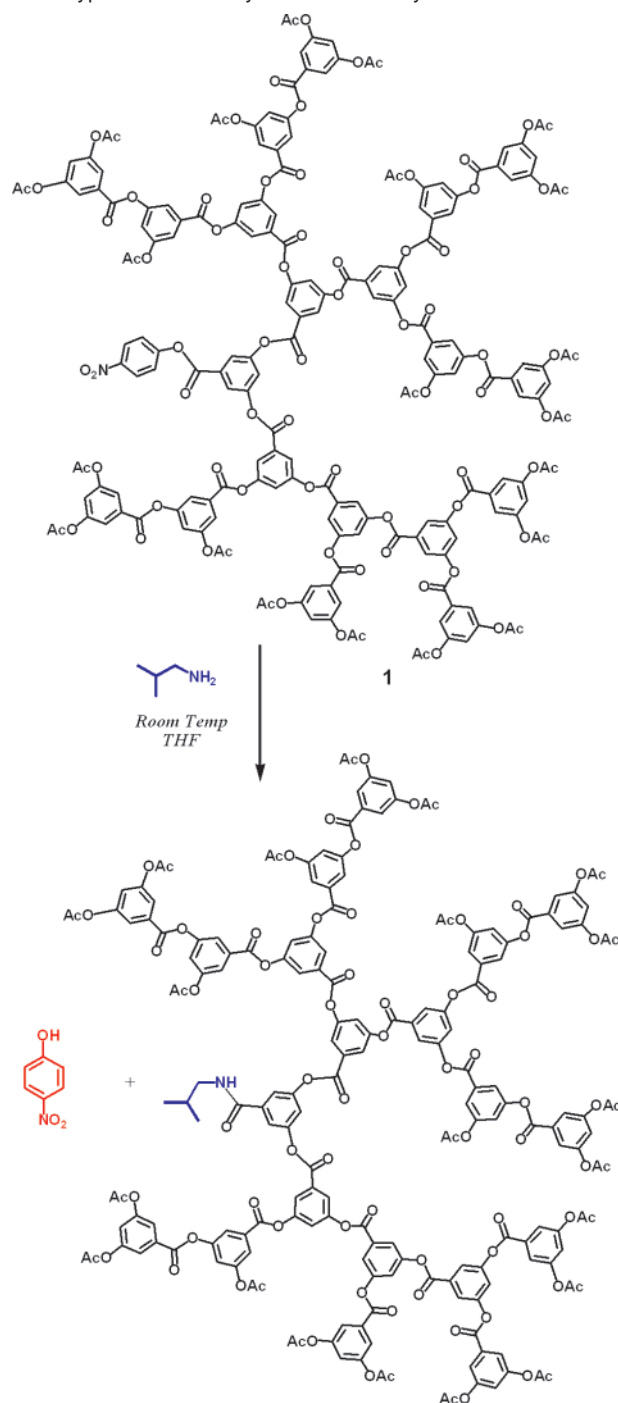
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Hyperbranched polymers (HBPs) can be synthesized using simple one-pot methods<sup>1</sup> making them attractive alternatives to dendrimers for more general applications; however, current methodologies offer limited synthetic control. One particular area that represents a significant challenge is the synthesis of HBPs containing functional core or focal point units. This is of particular interest to dendrimer and HBP chemists alike. Although structural core molecules have been used to initiate polymerizations, which in turn help to limit molecular weight,<sup>2</sup> reduce polydispersity,<sup>3</sup> and increase the degree of branching within HBPs,<sup>4</sup> the incorporation of a functional core/focal point is considerably more challenging and has received little attention. In this communication we present a postsynthetic methodology that enables a series of molecules to be incorporated at the focal point of a hyperbranched polyester under mild conditions.<sup>5</sup>

HBPs are typically prepared using elevated temperatures and reduced pressures.<sup>6</sup> Functional molecules incorporated using this methodology must therefore be of low volatility and robust enough to survive these aggressive polymerization conditions. To allow more delicate cores to be incorporated, we proposed a postsynthetic approach. The initial polymer **1** was prepared using 3,5-diacetoxy benzoic acid with 0.4 equiv of *p*-nitrophenyl acetate as the core/focal point unit, using a polymerization first reported by Turner et al.<sup>6</sup> The *p*-nitrophenyl ester functionality is activated toward reaction with amines at room temperature.<sup>7</sup> It was postulated that this would result in preferential aminolysis at the core. In addition to this, *p*-nitrophenyl esters are not sensitive to alcohols, which allows for simple purification of the resulting polymer by means of precipitation. As an initial proof of principle, a HBP containing a *p*-nitrophenyl ester at its focal point (with a 100% level of incorporation,<sup>8</sup> 50% degree of branching and an  $M_n$  of 3050) was reacted with isobutylamine for 3 h (this was found to be the optimum reaction time after monitoring the yield and conversion every hour for 5 h). Isobutylamine was specifically selected because the methyl groups give rise to an intense doublet at 0.85 ppm in its <sup>1</sup>H NMR spectrum. This occurs in a region of the <sup>1</sup>H NMR spectrum not occupied by polymer peaks and is observable even at low levels of incorporation. The reaction was monitored using <sup>1</sup>H NMR, which showed a reduction in the doublet at 8.32 ppm from the *p*-nitrophenyl ester  $\beta$  hydrogens. Conversely, a doublet at 0.86 ppm from the isobutylamide appeared. Doping experiments confirmed this peak was indeed from incorporated isobutyl amide. Both free and incorporated signals were observed together, the doublet from the incorporated isobutylamide (0.86 ppm) being slightly shifted from the free isobutylamine (0.84 ppm). Percentage conversion was calculated from <sup>1</sup>H NMR using the peak intensities of the incorporated amine units (the methyl doublet at 0.86 ppm), or the intensity of the remaining *p*-nitrophenyl ester peak (doublet at 8.32 ppm), employing the signal from the polymer acetoxy groups as internal standard. The percentage reduction in the *p*-nitrophenyl ester doublet corresponded directly to the “increase” in the isobutyl amide doublet. By using these methods, a respectable 51% level

**Scheme 1.** Postsynthetic Reaction of a *p*-Nitrophenyl Ester Cored Hyperbranched Polyester with Isobutylamine



of conversion was recorded (Table 1). Although this evidence confirmed that the isobutylamine had reacted with the polymer at

**Table 1.** Yields and Conversion for Postsynthetic Modification

focal point unit	yield (%)	conversion (%)	$M_n$	PD
<i>p</i> -nitrophenyl Ester	—	—	3050	1.73
isobutylamine	81	51	3200	1.64
octylamine	74	95	3150	1.66
benzylamine	62	85	3000	1.61
allylamine	72	98	3200	1.46
diallylamine	87	43	3500	1.63
hexylamine	85	77	3250	1.58
dipropylamine	73	48	3150	1.67
diisopropylamine	82	20	3085	1.55
4-aminomethyl pyridine	85	50	3500	1.63
<i>N</i> -methyl-4-nitroaniline	78	25	3125	1.67

the focal point/core, the excess of amine used may have resulted in an aminolysis reaction with the nonactivated esters in the polymer backbone. If this had occurred, the bulk polymer would be cleaved into smaller polymer fragments (some of which would contain isobutylamine). To eliminate this possibility GPC analysis was conducted before and after the reaction. A comparison of the chromatograms confirmed the polymer structure remained intact, with  $M_n$ ,  $M_w$ , and polydispersity unchanged. To further support this, a control reaction was performed using polymer containing no core. After stirring with isobutylamine for 3 h,  $^1\text{H}$  NMR showed no evidence of reaction with isobutylamine, and the GPC traces were once again unchanged. This confirms that incorporation of the isobutylamine is indeed at the core. Having demonstrated the methodology and optimized the reaction, a series of primary, secondary, and aromatic amines were investigated. Reactions generally proceeded with good yield and high conversions (Table 1). A slight reduction in polydispersity (PD) and an increase in  $M_n$  was observed for most products (Table 1). The reduction in PD is due to the purification procedure which removes the smaller molecular weight fractions (precipitation from methanol). This also explains the general increase in  $M_n$  values. Further analysis of the results shown in Table 1 suggests that a certain element of focal point isolation/dense packing was beginning to take place. For example, the linear and flat amines tended to react better (as evident from their higher conversions). This reactivity/size trend was further probed using a series of hexylamines. Conversions of 77, 48, and 20% were recorded after the HBP was reacted with hexylamine, dipropylamine, and diisopropylamine, respectively. It is interesting to note that hexylamine reacted with the polymer, giving a high level of incorporation (77%), while reaction with dipropylamine and diisopropylamine only proceeded to 48% and 20% respectively. This is despite the fact that the dipropylamines are both secondary amines and therefore more reactive/basic than the primary hexylamine. The increased steric bulk of the dipropylamines therefore counteract their increased reactivity. Overall, these results suggest that effective site isolation is being maintained around the 4-nitrophenyl ester at the focal point of the polymer and that the size of the amine unit, rather than its reactivity, governs the level of incorporation.<sup>9</sup> To investigate the possibility of incorporating more “exciting” functional units at the focal point of these hyperbranched polymers, two further amines were studied. In the first example, a pyridine ligand (capable of interacting with various metal centers) was incorporated with a 50% level of conversion, after reaction with 4-aminomethylpyridine under standard conditions.<sup>10</sup> In the second example, *N*-methyl-4-nitroaniline, a widely studied solvchromatic dye,<sup>11</sup> was incorporated with a 25% level of conversion. On this occasion, the low level of incorporation is due to the low nucleophilicity and poor reactivity of the aromatic nitrogen, rather

than any shape/size constraints (i.e. the similarly sized benzylamine and 4-aminomethylpyridine were incorporated with much higher levels of conversion—85 and 50%, respectively). Work is currently underway in our laboratory to study the properties of these new hyperbranched polymers.

In conclusion, we have successfully demonstrated a new methodology for the postsynthetic functionalization of the focal point (core) of a hyperbranched polymer. An element of dense packing was observed for the relatively small polymer under test, as evident from the differences in percent incorporation between linear and bulky reagents. Functional/exotic groups could also be incorporated (albeit with slightly lower yields than those obtained using the simple alkylamines used to demonstrate the methodology). Overall, this postsynthetic approach opens the door for a wide range of sensitive compounds to be incorporated at the focal point of hyperbranched polymers and represents a significant step forward in the synthesis of dendritic polymers.

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**Supporting Information Available:** Detailed synthesis and characterization of **1** and its subsequent postsynthetic reactions. This material is available free of charge via the Internet at <http://pubs.acs.org>.

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