crux of the issue, the specific manner in which the trans double bonds are positioned within the taxane framework, was deduced through the combined adaptation of one-bond $^1H/^{13}C$ COSY correlation and NOE experiments.[13] Several of the more diagnostic measurements are given in the illustrations.

Molecular mechanics calculations (MODEL version KS 2.96)[14] provided indication that **9** might be as much as 3 kcal/mol more thermodynamically stable than **10**. Indeed, heating **10** in C_6D_6 at 67 °C resulted in its *unidirectional* conversion to **9**, $k_1 = 2.58 \times 10^{-4}\ s^{-1}$, $t_{1/2} = 45$ min. The relative ease of this diastereomeric interconversion places **10** closer to *trans*-cyclononene ($t_{1/2} \approx 4$ min at 0 °C)[3] than to *trans*-cyclooctene ($t_{1/2} = 122$ h at 132.7 °C)[1c] in the intrinsic ability of these molecules to overcome their internal rotational barriers. The thermal stability of **10** is, however, more than adequate to allow for its individual utilization in synthesis, thus providing a new dimension to this area of chemistry.

Both **9** and **10** undergo osmylation to give diols **11a** (60%) and **12a** (84%), respectively, by electrophilic attack from the only available direction external to the ring. Subsequent acetylation provided **11b** and **12b** efficiently.

In summary, this study has established the feasibility of controlling stereochemistry by means of rotationally restrictive nonbonded interactions and laid the groundwork for possible entry to various taxanes including **1** by this useful tactic. Our current efforts are focused on these applications.

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Dendritic Analogues of Engineering Plastics: A General One-Step Synthesis of Dendritic Polyaryl Ethers

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Dendritic or cascade polymers in which the ratio of branch sites to repeat units approaches unity have emerged recently as an important new concept in macromolecular design. We report here the first general single-step route to dendritic polyaryl ethers which are hyperbranched analogues of linear polyaryl ethers, a common class of engineering plastics. Specifically, we have prepared a family of four polymers based on aryl ethers by polymerization of AB_2 monomers, each of which contains a single phenolic hydroxyl group and two aryl fluorides which are activated toward nucleophilic displacement by carbonyl, sulfone, or tetrafluorophenyl moieties.[1,2] High molecular weights can be achieved with low polydispersities; molecular weights can be controlled by reaction conditions, and some properties of the polymers have been examined.

Although Flory proposed that polymerization of AB_x ($x \geq 2$) monomers should yield highly branched but soluble polymers,[3] most dendritic macromolecules have been prepared by stepwise processes which yield highly monodisperse, structurally precise materials in small quantities.[4] The time and labor involved in stepwise processes make the resulting materials too expensive for virtually any commodity application. Several groups have carried out one-step syntheses of dendritic macromolecules based upon AB_x monomers.[5-10] The first example by Webster and Kim yielded low molecular weight brominated polyphenylenes with a DP (degree of polymerization) of ca. 25 by polymerization of (3,5-dibromophenyl)boronic acid.[5] Later, Kim demonstrated the polymerization of the dihydrochloride salt of diaminobenzoyl chloride, yielding polyamides,[7] and Fréchet demonstrated the polymerization of bis(trimethylsiloxy)benzoyl chloride, yielding polyesters.[8] None of the existing one-step polymerizations of AB_x monomers permits control over the molecular weights of the final polymers.

Treatment of monomers **1a–d** in THF with an excess of NaH yielded solutions of their sodium salts (Scheme I). The solutions were filtered to remove excess NaH; the THF was removed in vacuo, and dimethylacetamide (DMA) or dimethyl sulfoxide (DMSO) was added. Heating the resulting solutions for 0.5–2 h at 100–180 °C effected polymerization. The resulting reaction mixtures were cooled and filtered to remove NaF, precipitated into 1 N HCl or 10% 1 N HCl in methanol, filtered, and dried. Polymerizations of **1a** and **1b** were insensitive to temperature, but polymerizations of **1c** and **1d** at 140 °C yielded insoluble gels, presumably caused by cross-linking due to reaction of the acetylene moieties. Polymerization at 100 °C yielded completely soluble polymers.

The molecular weights of polymers **2a** and **2b** were significantly affected by monomer concentration in the polymerization reaction. Higher concentrations yielded higher average molecular weights and broader molecular weight distributions (Table I). Adventitious H_2O in the DMA may be responsible. Alternatively, at lower concentrations, unimolecular termination reactions such as cyclization of a phenolate with one of the many activated aryl fluorides surrounding it in the same molecule are favored. At higher concentrations bimolecular reactions are favored, yielding higher molecular weight materials before termination. Two lines of evidence argue for the latter explanation. The molecular weights appear to be independent of the solvent, and we have been unable to find any sign of unreacted terminal hydroxyl groups in the products by ^1H NMR spectroscopy, particularly in the low mo-

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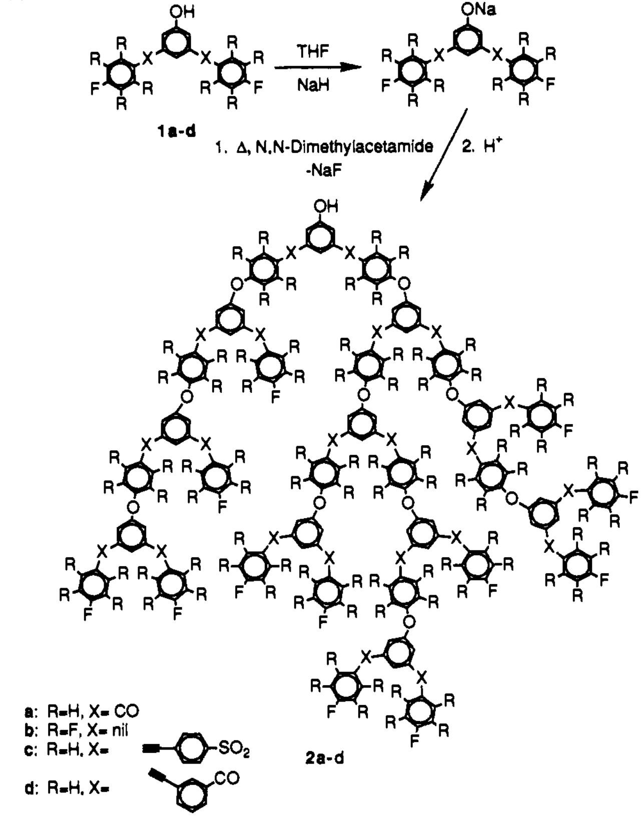
0002-7863/93/1515-356$04.00/0

Scheme I



lecular weight polymers. Ideally every polymer molecule should have a single unreacted hydroxyl group and DP + 1 unreacted fluorophenyl groups. If cyclization is the dominant termination process, then the hydroxyl groups will be largely consumed and a polymer molecule will have DP unreacted fluorophenyl groups.

These dendritic macromolecules have high (0.35 g of **2a**/mL of THF at 25 °C) solubilities in typical organic solvents such as $CHCl_3$, THF, and toluene. In addition to size exclusion chromatography, we have characterized the new dendritic macromolecules by ^{1}H, ^{13}C, and ^{19}F NMR spectroscopies.[11] The spectra of all of the polymers showed resonances corresponding to either C_6H_4F or C_6F_5 terminal groups, which are only slightly perturbed from their positions in the monomers. All other resonances in the NMR spectra were consistent with transformation of phenol and fluorophenyl moieties into diaryl ethers. We have analyzed the ^{1}H and ^{13}C NMR spectra of the polymers in the hope of determining the degree of branching as described by Frechet et al. but have been unable to do so because of the distance separating the aryl fluorides.[8]

Thermal gravimetric analyses under nitrogen at 10 °C/min showed that all retain >95% of their mass up to 500 °C and have high thermal stability as do linear poly(ether ketone)s and poly(ether sulfone)s. We observe glass transition temperatures (Table I) ranging from 135 to 231 °C but no evidence for melting or crystallization. These T_g's are higher than one might expect for materials that have such large fractions of end groups. The T_g's appear to be independent of molecular weight in the case of polymers **2a** and **2b**, and the T_g for polymer **2c** derived from the most rigid monomer, **1c**, is, as might be expected, higher than the rest.

Table I. Polymerizations in Dimethylacetamide

monomer	conc (M)	yield[a] (%)	M_w[b]	M_n[b]	M_w/M_n[b]	T_g (°C)
1a	0.19	79	11 300	7 410	1.53	140
1a	0.75	85	19 100	9 040	2.11	144
1a	2.2	83	66 600	16 200	4.11	143
1b	0.04	73	29 200	17 300	1.69	152
1b	0.27	82	33 700	20 300	1.66	152
1b	1.0	50	134 000	35 500	3.78	151
1c	0.4	55	38 500	18 800	2.04	231
1d	0.5	66	38 700	8 880	4.36	135

[a] Yield of isolated polymer after one precipitation. [b] Size exclusion chromatography values versus polystyrene standards.

Reaction of AB_2 phenolate monomers containing two aryl fluorides activated by carbonyl, sulfonyl, or tetrafluorophenyl moieties permits the controlled syntheses of high molecular weight dendritic polymers. We are currently studying the physical properties and chemistries of these and related polymers.

Registry No. **1a** (homopolymer), 144812-31-7; **1b** (homopolymer), 144812-33-9; **1c** (homopolymer), 144812-35-1; **1d** (homopolymer), 144812-37-3.

Supplementary Material Available: Listings of analytical data for monomers **1a–d** and details of the general polymerization procedure, size exclusion chromatograms of various molecular weights of polymers **2a** and **2b**, and schemes outlining the syntheses of monomers **1a–d** (7 pages). Ordering information is given on any current masthead page.

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[11] Polymer **2a**: ^{1}H NMR ($CDCl_3$) δ 7.85 (bs, 5 H), 7.68 (bs, 2 H), 7.12 (bs, 4 H); ^{13}C NMR δ 193.1, 165.8 (d, J = 256 Hz), 160.7, 155.9, 140.0, 139.8, 132.7, 131.9, 126.5, 118.0, 115.9 (d, J = 22 Hz); ^{19}F NMR δ −105.2. Anal. Calcd for $C_{20}H_{11}FO_3$: C, 75.47; H, 3.48; F, 5.97. Found: C, 75.41; H, 3.17; F, 5.83. Polymer **2b**: ^{1}H NMR (THF-d_8) δ 7.30–7.65 (m); ^{13}C NMR δ 159.5, 146.8 (d, J = 246 Hz), 146.6 (d, J = 230 Hz), 143.9 (d, J = 230 Hz), 143.0 (d, J = 264 Hz), 140.0 (d, J = 251 Hz), 134.8, 131.4, 131.0, 129.9, 120.5, 117.9 (t, J = 17 Hz), 116.5 (t, J = 17 Hz); ^{19}F NMR δ −141.6 (m, 4 F), −153.1 (bs, 2 F), −154.2 (bs, 1 F), −161.6 (bs, 2 F). Anal. Calcd for $C_{18}H_3F_{11}O$: C, 53.22; H, 0.74; F, 42.10. Found: C, 52.85; H, 0.79; F, 41.39. Polymer **2c**: ^{1}H NMR (THF-d_8) δ 7.96 (bs, 8 H), 7.65 (bs, 4 H), 7.57 (bs, 1 H), 7.28 (bs, 4 H), 7.15 (bs, 2 H); ^{13}C NMR δ 166.5 (d, J = 253 Hz), 162.0, 156.7, 143.5, 143.1, 139.0, 137.6, 133.2, 132.2, 131.7, 131.3, 128.7, 128.3, 128.2, 125.8, 124.5, 119.4, 117.5, 117.3, 91.3, 90.2; ^{19}F NMR δ −105.5. Anal. Calcd for $C_{34}H_{19}FO_5S_2$: C, 69.15; H, 3.22; F, 3.22; S, 10.84. Found: C, 68.82; H, 3.17; F, 3.27; S, 10.86. Polymer **2d**: ^{1}H NMR (THF-d_8) δ 7.95 (bs, 2 H), 7.83 (bs, 4 H), 7.65 (bs, 4 H), 7.58 (bs, 1 H), 7.50 (bs, 2 H), 7.25 (2 H), 7.22 (bs, 2 H), 7.16 (bs, 2 H); ^{13}C NMR δ 193.7, 159.2 (d, J = 254 Hz), 139.33, 133.46 (d, J = 26 Hz), 133.2, 131.5, 130.7, 129.6, 126.1, 123.7, 118.4, 116.2 (d, J = 21.6 Hz), 90.7, 90.6, 89.2; ^{19}F NMR δ −105.0. Anal. Calcd for $C_{36}H_{19}FO_3$: C, 83.39; H, 3.66; F, 3.66. Found: C, 82.27; H, 3.54; F, 3.58.

Catalytic Antibodies from Combinatorial Libraries

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It has been demonstrated that antibodies can be endowed with the catalytic abilities intrinsic to enzymes by hyperimmunization of mice with haptens that mimic stable representations of the transition states of selected reactions.[1] The successful generation of the catalytic antibodies depends on insight into the mechanism of the reaction to be catalyzed, synthesis of a hapten, and induction of a panel of hapten-binding antibodies. While the first two maneuvers are well within the purview of most chemists, the method by which monoclonal antibodies are currently produced is not a procedure which is easily adapted to most chemical laboratories. To overcome this problem, we have developed procedures for cloning the immunological repertoire into *Escherichia coli*.[2] In principle these methods can vastly increase

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