

New Cascade Molecules Centered about Phosphorus

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Received 8 September 1992

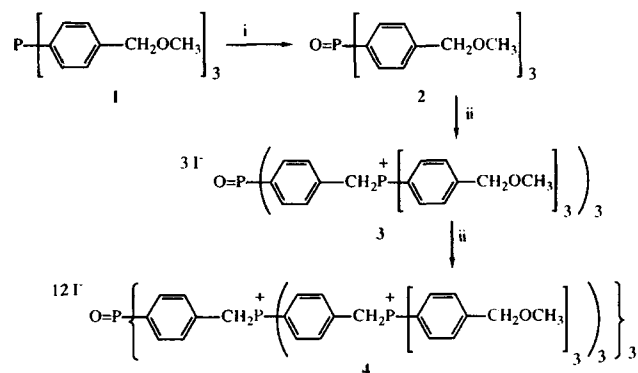
ABSTRACT

Cascade molecules in which the branch points are phosphonium ion sites have been synthesized bearing phosphorus in a variety of oxidation states at the core. In addition to the previously reported phosphonium ion core species, these new cascade molecules include those bearing phosphine, phosphine oxide, and phosphorane cores.

INTRODUCTION

A recent interest of our laboratory has been in the preparation and investigation of an intriguing category of molecules, cascade molecules (dendrimers, chemical fractals) [1] in which phosphorus has been incorporated at the core and branch points of the structure. Our efforts have been particularly concerned with the preparation and study of species in which phosphorus is present as phosphonium ion sites, rendering the covalent structure positively charged, with "free floating" associated anions [2,3]. These species represent the first dendrimers bearing charged sites within the covalent framework.

The current efforts have been concerned with the preparation and investigation of dendrimers which retain the phosphonium ion branch points but are modified at the core to contain phosphorus in other oxidation states. Of specific interest are those with phosphine cores (accessible through the



SCHEME 1

i. H_2O_2 , acetic acid (48% yield); ii. TMSI, acetonitrile; tri(*p*-methoxymethyl)phenylphosphine (first, 63% yield; second, 77% yield).

phosphine oxide or phosphine sulfide species) and those with phosphorane cores. Phosphine cores provide entry into the investigation of a wide range of chemical interactions, including those as nucleophile and metal complexation agent, modified by the presence of a large, highly charged ancillary structure. A phosphorane core provides the first dendrimer involving pentadirectional elaboration from a single atom.

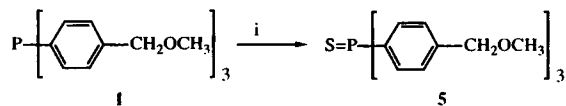
RESULTS AND DISCUSSION

The elaboration of all of the dendrimers considered in the present work begins with the previously reported tri(*p*-methoxymethyl)phenylphosphine. [2,3] The preparation of the phosphine oxide core dendrimer beginning with 1 is accomplished as shown in Scheme 1.

Oxidation of the phosphine 1 to the phosphine

Dedicated to Prof. James Cullen Martin on the occasion of his sixty-fifth birthday.

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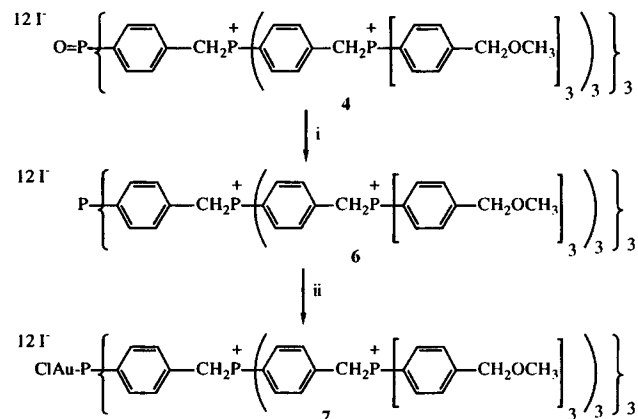
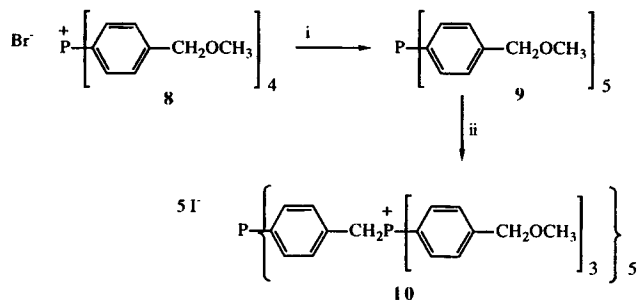
**SCHEME 2**

i. Sulfur, toluene (91% yield).

oxide **2** is accomplished readily using hydrogen peroxide, the product being easily purified using flash chromatography. The selective and facile cleavage of the benzylic ether linkages of **2** and **3** is accomplished by treatment with iodotrimethylsilane to form the corresponding benzylic iodide, **[4]** a species particularly suited for direct elaboration of a further generation of the cascade structure. Although further elaboration of the simpler systems previously reported has been accomplished [2,3], the phosphine oxide system noted here was carried only to a second generation of cascade. In addition, the simple phosphine sulfide species **5** was prepared, as shown in Scheme 2, although it was not utilized in cascade elaboration.

Once the phosphonium cascade structure had been elaborated about the phosphine oxide core, the core site was reduced to the free phosphine using trichlorosilane according to a standard procedure. **[5]** This was followed by coordination of the free phosphine core with gold (I) using the procedure described by McAuliffe *et al.* [6] starting with sodium tetrachloroaurate. The material generated in this manner is a Au(I) complex bearing a single phosphorus ligand and exhibiting a UV maximal absorption (in addition to other absorptions due to the aromatic rings present) at 275 nm, shifted to lower energy from that observed for the corresponding complex of triphenylphosphine (249 nm). **[6]** The reactions involved are illustrated in Scheme 3.

Both the reduction and gold complexation re-

**SCHEME 3**i. Cl_3SiH , acetonitrile, methylene chloride (99% yield); ii. NaAuCl_4 , acetone, ethanol (97% yield).**SCHEME 4**

(i) 4-(methoxymethyl)phenyllithium, diethyl ether (83% yield);

(ii) TMSI, acetonitrile; tri(*p*-methoxymethyl)phenylphosphine (95% yield).

actions occur in high yield. Thus, in spite of the sterically large and charged groups attached to the phosphorus, the core site remains accessible to incoming reagents for continued reaction.

In addition to the preparation of cascade molecules with a three coordinate phosphorus core, expansion of the core coordination state has been accomplished. A neutral quinquedirectional phosphorus core site (phosphorane) was generated using the previously reported [2,3] tetra(*p*-methoxymethyl)phenylphosphonium bromide (**8**). Expansion of the phosphonium ion site to a phosphorane species was accomplished using a modification of a standard procedure [6]. The resultant phosphorane **9** was then elaborated to a first generation cascade species **10** bearing phosphonium ion sites surrounding the phosphorane core using the reaction sequence noted previously. These reactions are illustrated in Scheme 4.

The material **10** constitutes the first cascade molecule bearing an atomic quinquedirectional core site.

All new materials exhibit elemental analyses in accord with their proposed structures. For new materials (**2**)–(**6**) and (**9**)–(**10**), IR and NMR (^1H and ^{31}P) spectra have been measured, which exhibit signals in accord with the proposed structures. Analytical and spectral data are given in Table 1.

EXPERIMENTAL*General*

All chemicals were of commercial reagent quality and were used without purification with the following exceptions: chloroform and toluene were distilled over phosphorus pentoxide; acetonitrile was distilled over molecular sieves. Tri(*p*-methoxymethyl)phenylphosphine (**1**) and tetra(*p*-methoxymethyl)phenylphosphonium bromide (**8**) were prepared as previously reported [3]. Silica gel for preparative chromatography was from Baker (230–400 mesh). The IR spectra were measured using a Perkin-Elmer 1600 FTIR. The NMR spectra

TABLE 1 NMR (^1H and ^{31}P) Spectral (δ ppm) and Analytical Data for New Compounds

Compound	^1H NMR (δ) ^a	^{31}P NMR (δ) ^b	Formula	C/H Analysis Required (Found)
2	3.4 (9H, singlet)	+30	$\text{C}_{24}\text{H}_{27}\text{O}_4\text{P}$	C: 70.23 (69.85) H: 6.63 (6.66)
	4.5 (6H, singlet)			
	7.6 (12H, AA'BB')			
3	3.4 (27H, broad singlet)	+28, +30	$\text{C}_{93}\text{H}_{99}\text{O}_{10}\text{P}_4\text{I}_3$	C: 59.37 (59.00) H: 5.30 (5.38)
	4.5 (24H, broad singlet)			
	7.6 (48H, multiplet)			
4	3.4 (81H, broad singlet)	+28, ^c +30	$\text{C}_{300}\text{H}_{315}\text{O}_{28}\text{P}_{13}\text{I}_{12}$	C: 57.24 (57.01) H: 5.39 (5.40)
	4.5 (78H, broad singlet)			
	7.6 (156H, multiplet)			
5	3.4 (9H, singlet)	+43	$\text{C}_{24}\text{H}_{27}\text{O}_3\text{PS}$	C: 67.59 (67.25) H: 6.38 (6.38)
	4.5 (6H, singlet)			
	7.6 (12H, AA'BB')			
6	3.4 (81H, broad singlet)	+28, ^c -16	$\text{C}_{300}\text{H}_{315}\text{O}_{27}\text{P}_{13}\text{I}_{12}$	C: 57.39 (57.20) H: 5.06 (5.03) C: 55.34 (54.96) H: 4.88 (4.62)
	4.5 (78H, broad singlet)			
	7.6 (156H, multiplet)			
7	—	—	$\text{C}_{300}\text{H}_{315}\text{O}_{27}\text{P}_{13}\text{I}_{12}\text{AuCl}$	
9	3.4 (15H, singlet)	-94	$\text{C}_{40}\text{H}_{45}\text{O}_5\text{P}$	C: 75.45 (75.43) H: 7.12 (7.12)
	4.5 (10H, singlet)			
	7.6 (20H, multiplet)			
10	3.4 (45H, broad singlet)	-95, +29	$\text{C}_{155}\text{H}_{165}\text{O}_{15}\text{P}_6\text{I}_5$	C: 60.28 (60.32) H: 5.39 (5.40)
	4.5 (40H, broad singlet)			
	7.6 (80H, multiplet)			

^a CDCl_3 solution, relative to internal Me_4Si ; ^b CDCl_3 solution, relative to external 85% H_3PO_4 ; ^c different phosphonium ion resonances cannot be distinguished.

were measured using an IBM-Bruker WP200SY instrument operating at 200 MHz for ^1H and 81 MHz for ^{31}P . Elemental analyses were performed by Desert Analytics, Tucson, AZ, and by Schwarzkopf Microanalytical Laboratory, Woodside, NY.

Preparation of Tri(*p*-methoxymethyl)-phenylphosphine Oxide (2)

To a solution of tri(*p*-methoxymethyl)phenylphosphine (1) (1.00 g, 2.53 mmol) in glacial acetic acid at 0° is added dropwise with stirring 30% aqueous hydrogen peroxide (1 mL). After stirring for 30 minutes, the reaction mixture is poured into water (100 mL) and the resultant precipitate is collected by filtration. The precipitate is purified by flash chromatography (50 g, 2-cm diameter) eluting with acetonitrile. There is thus isolated as a semisolid the pure desired material (0.50 g, 48%) which exhibits IR and NMR spectra and elemental analyses in accord with the proposed structure 2. The IR spectrum (CCl_4) exhibits a strong band ($\text{P}=\text{O}$) at 1210 cm^{-1} (predict 1218 cm^{-1} using the empirical equation of Thomas and Chittenden [7]).

General Procedure for the Elaboration of Phosphonium Cascade Structures (3,4,10)

To a solution of precursor methyl benzylic ether (2,3, or 9) (1.20 mmol) in acetonitrile (20 mL) un-

der a nitrogen atmosphere is added dropwise with continuous stirring a solution of iodotrimethylsilane (1.43 g, 7.20 mmol) in acetonitrile (35 mL). After completion of addition the reaction mixture is heated at reflux for 16 hours. Volatile materials are then evaporated under reduced pressure, and the residue is dissolved in acetonitrile (45 mL). To this solution is added dropwise with continual stirring a solution of tri(*p*-methoxymethyl)phenylphosphine (1) (1.41 g, 3.60 mmol) in acetonitrile (35 mL), and the resulting mixture is heated at reflux for 24 hours. Volatile materials are then evaporated under reduced pressure. The residue is passed through a DOWEX 2-X8 column in the iodide ion form, eluting with 30% aqueous ethanol, and the eluents are evaporated under reduced pressure. In this manner, the pure target materials are isolated as semisolids which exhibit IR and NMR spectra and elemental analyses in accord with the proposed structures.

Preparation of Tri(*p*-Methoxymethyl)-phenylphosphine Sulfide (5)

To a solution of tri(*p*-methoxymethyl)phenylphosphine (1) (1.00 g, 2.53 mmol) in toluene (30 mL) under a nitrogen atmosphere is added a dispersion of sulfur (0.16 g, 5.06 mmol) in toluene (10 mL). The reaction mixture is heated at reflux for 48 hours, after which it is filtered to remove un-

reacted and insoluble sulfur, and volatile materials are evaporated under reduced pressure to give the pure target material (0.98 g, 91% yield) as a semisolid which exhibits IR and NMR spectra and elemental analyses in accord with the proposed structure (5).

Reduction of Phosphine Oxide (4) to Phosphine (6)

To a solution of the phosphine oxide (4) (2.58 g, 0.41 mmol) in a 1:1 mixture of methylene chloride:acetonitrile (40 mL) is added trichlorosilane (0.61 g, 4.51 mmol), and the resulting solution is stirred for 4 hours. After this time, volatile materials are evaporated under reduced pressure, the residue is dissolved in methylene chloride (90 mL), and 30% aqueous KOH solution (1 mL) is added. The layers are separated and the organic portion is dried over molecular sieves, and filtered, and volatile materials are evaporated under reduced pressure to give the pure target material (2.56 g, 99% yield) as a semisolid which exhibits IR and NMR spectra and elemental analyses in accord with the proposed structure (6). The disappearance of the P=O band, present in the IR spectra of the precursors, is noted in the IR spectrum (CCl₄) of (6).

Preparation of the Gold(I) Complex (7) of the Phosphine Core Cascade (6)

To a solution of sodium tetrachloroaurate (0.043 g, 0.12 mmol) in a 1:1 acetone:ethanol mixture (10 mL) is added a solution of the phosphine (6) (1.51 g, 0.24 mmol) in chloroform (15 mL). After the mild exotherm subsides, the white precipitate which forms is removed by filtration and volatile mate-

rials are evaporated from the filtrate under reduced pressure to give the target material (0.76 g, 97% yield) which exhibits elemental analyses in accord with the proposed structure (7).

Preparation of Penta(p-Methoxymethyl)-phenylphosphorane (9)

Lithium (0.050 g, 7.2 mmol) is added to diethyl ether (10 mL) under an argon atmosphere, followed by a solution of *p*-(methoxymethyl)bromobenzene (0.031 g, 0.16 mmol) in diethyl ether (10 mL). The reaction mixture is stirred at room temperature for 20 hours, followed by the addition of tetra(*p*-methoxymethyl)phenylphosphonium bromide (0.090 g, 0.15 mmol). The reaction mixture is stirred at room temperature for 3 days, after which the precipitate of lithium bromide is removed by filtration. Volatile materials are evaporated from the filtrate under reduced pressure to yield the pure target material (0.080 g, 83% yield) as a semisolid which exhibits IR and NMR spectra and elemental analyses in accord with the proposed structure (9).

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