A General Synthetic Strategy for Functionalized Oligo(bipyridines): New Building Blocks for Supramolecular Chemistry and their First Application in Macromolecules

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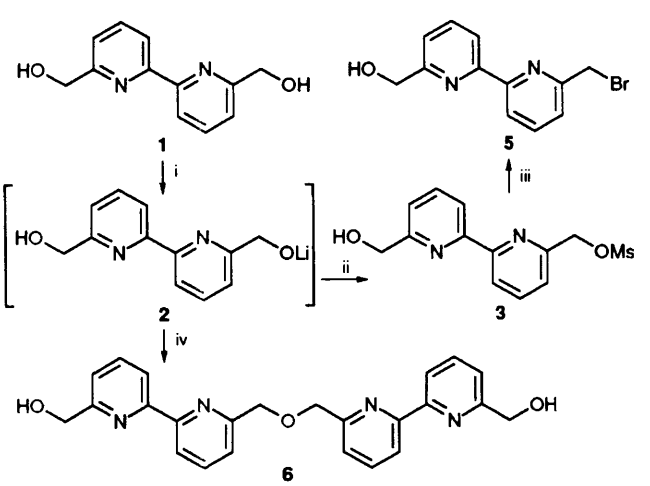
The first directed syntheses of unsymmetrically 6,6′-functionalized 2,2′-bypyridine building blocks and a general synthetic strategy to higher generations of functionalized oligo(bipy) units are described; a block copolymer containing a bis(bipy) unit is prepared and complexed with copper(I) ions to obtain a supramolecular aggregate.

The design of molecular species which can form well-defined macromolecular architectures by spontaneous, recognition-directed self-assembly of their components is a major goal in supramolecular chemistry. Such systems may display cooperative effects and are based *e.g.* on hydrogen bonding or metal complex formation.[1]

It has been known for several years that oligo(bipyridines) spontaneously form helical metal complexes, whereby two oligo(bipyridine) strands wrap around Ag^I or Cu^I cations.[2] This self-organization process shows a highly cooperative effect and is very similar to the formation of the double-helix in nucleic acids. Oligo(bipyridines) containing two to five 2,2′-bipyridine (bipy) units[2] as well as polymers containing bipy subunits[3] have been synthesized *via* chemistry based on well-described 6,6′-substituted-2,2′-(bipy) building blocks [*e.g.* 2,2′-(bipy) compounds: 6,6′ = Me, Me; CH_2Cl, CH_2Cl; CH_2Br, CH_2Br; or CH_2OH, CH_2OH; 6 = CH_2Cl, CH_2Br or CH_2OH and 6′ = Me. Bis(bipy) compounds: 6, 6‴ = Me, Me; 6 = CH_2Br, CH_2OH, 6‴ = Me].[4]

However, there are no examples of 6,6′-bis(functionalized)oligo(bipy) units known (functional groups like CH_2OH or CH_2Br) which facilitate their incorporation into other ligand backbones (*e.g.* a polymer backbone). Such systems should show novel properties in material science, spectroscopy or electronics due to the helicity, self-organization and cooperative features of the bipy units.

We describe here a new synthetic procedure towards such building blocks (Scheme 1) and their first application (Scheme 2). The key intermediate is the formation of an unsymmetrical substituted 6,6′-*bis*functionalized 2,2′-(bipy) building block. Treatment of the 6,6′-bis(hydroxymethyl)-2,2′-bipyridine **1** in THF with 1 equiv. of *n*-butyllithium at −55 °C gave a white precipitate (the monolithium salt).[5] Reaction with 1 equiv. of methanesulfonyl chloride (MsCl) gave 65% of the 6-(methanesulfonylmethyl)-6′-hydroxymethyl-2,2′-bipyridine **3**† [mp 100–101 °C, ^1H NMR Fig. 1(*a*)]. Reaction with LiBr in THF gave the 6-bromomethyl-6′-hydroxymethyl-2,2′-bipyridine **5** (88%, mp 130–131 °C).[6,7]

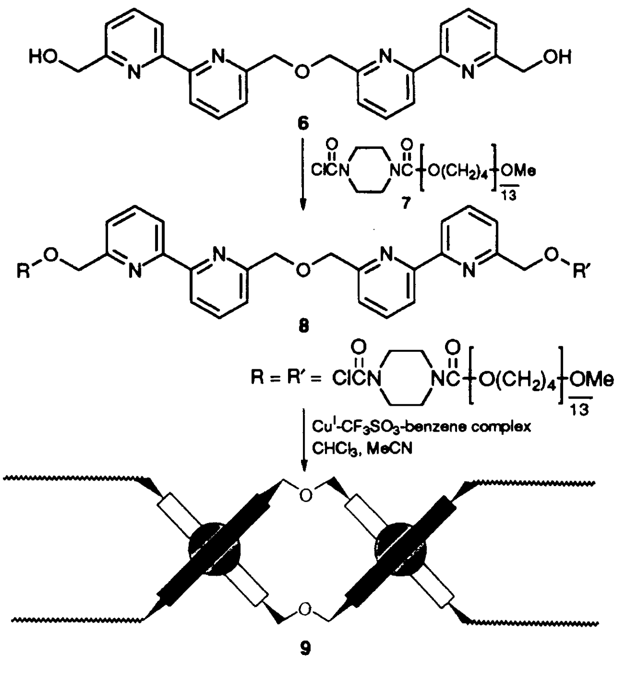


Scheme 1 Syntheses of new unsymmetrical functionalized 2,2′-bipyridine building blocks and the first bisfunctionalized oligo(bipy) molecule—*Reagents and conditions*: i, Bu^nLi, THF, −55 °C; ii, −50 °C, 90 min then MsCl, 10 h, −45 °C then H_2O, −30 °C; iii, LiBr, THF, 1 h, 40 °C; iv **3**, THF, −40 °C 20 h then H_2O, 25 °C.

A solution of **2** was treated with 1 equiv. of **3**. After stirring for 20 h and quenching with water the 6′,6‴-bis(hydroxymethyl)-6,6″-[oxybis(methylene)]bis[2,2′-bipyridine] **6** was isolated as white crystals [52%, mp 187–189 °C, ^1H NMR Fig. 1(*b*)].

To use a bis(bipy) as a building block in a polymer backbone, we treated **6** with a carbamoyl terminated polyether **7** {poly-[oxytetramethylene] with 1-carbonyl-4-piperazinecarboxylic acid chloride end groups}‡ at 0 °C in $CHCl_3$. After stirring for 48 h at 25 °C the polymer **8** was isolated as a white solid in 70% yield.§ The polymer was then treated with copper(I) trifluoromethanesulfonate (1 equiv.) in $CHCl_3$–MeCN (1 : 1, v/v) to give the red polymer ion complex **9**.¶

The synthesis of higher generations of functionalized oligo(bipy) units *via* sequential Williamson condensation was facilitated by groups which would increase the poor solubility of oligo(bipy) ligands and could also be used for subsequent reactions. The first examples for such specially designed building blocks are the 6-(2″-methoxyethoxymethyleneoxymethyl)-6′-(hydroxymethyl)-2,2′-bipyridine **10** [reaction of **2** with 2-methoxyethoxymethyl chloride (MEMCl) at −45 °C, 60% yield] and the 6-(*tert*-butoxytetramethyleneoxymethyl)-6′-(hydroxymethyl)-2,2′-bipyridine **11** (reaction of **3** with the



Scheme 2 Polymer bis(bipy) species and schematic of the dinuclear helical complex

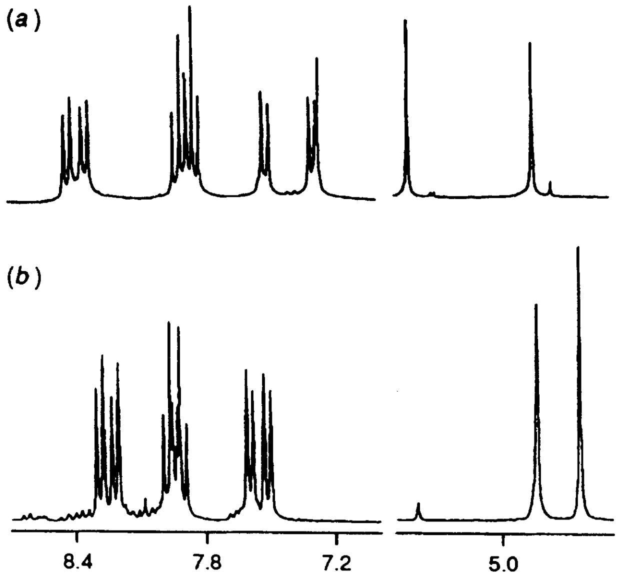
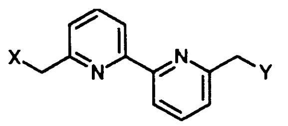
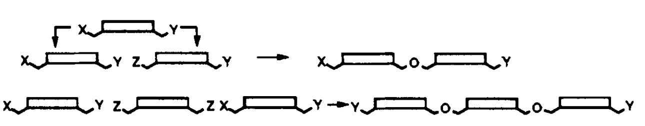


Fig. 1 250 MHz ^1H NMR spectra of (*a*), **3** in $CHCl_3$ and (*b*) **6** in $(CD_3)_2SO$; the SO_2CH_3 signal of **3** and the OH protons are not shown



10 X = OH, Y = $OCH_2OCH_2CH_2OMe$
11 X = OH, Y = $O(CH_2)_4OBu^t$



Scheme 3 Schematic representation of the Williamson condensation leading to functionalized oligo(bipy) strands

alcoholate of *tert*-butoxybutan-1-ol in THF, yield 85%).|| These unsymmetrically functionalized molecules open new avenues for the use of oligobipyridines (Scheme 3).[8]

The oligo(bipy) molecules reported here are prime examples of unsymmetrical substituted 6,6′-difunctionalized-2,2-bipyridine building blocks (functional groups like CH_2OH or CH_2Br), which give facile access to the synthesis of functionalized oligobipyridines and open new applications in many fields of organic, supramolecular and polymer chemistry.

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Footnotes

† The mixture was chromatographed on silica eluting with 2% MeOH in CH_2Cl. The unreacted educt **1** was recovered and the 6,6′-bis(methanesulfonyloxymethyl)-2,2′-bipyridine **4** (yield 15%, mp 129–130 °C, ^1H NMR ($CDCl_3$): δ 3.10 (s, SO_2CH_3), 5.42 (s, $CH_2SO_2CH_3$), 7.51 (dd, *J* = 7.7, 0.5 Hz, H-5, 5′), 7.90 (t, *J* = 7.7 Hz, H-4, 4′), 8.43 (dd, *J* = 7.7, 0.5 Hz, H-3, 3′) was transformed to **1** *via* refluxing for 4 h in 10% aq. Na_2CO_3 solution.

‡ **7** was prepared in a reaction of α-[(piperazinylcarbonyl)oxy]-ω-methyl polyoxytetramethylene with an average of 13 oxytetramethylene repeat units with phosgene in $CHCl_3$ at −60 °C. Characteristic ^{13}C NMR signal ($CDCl_3$) of **7** at: δ 45.7 (NCH_2CH_2N of piperazine). The piperazinyl terminated poly(oxytetramethylene) (M_n = 1120 corresponding to an average of 13.2 oxytetramethylene repeating units as determinated by ^1H NMR spectroscopy; H. Hayen, C. D. Eisenbach, unpublished work) was obtained by reaction of α-hydro-ω-oxymethylpoly(oxytetramethylene) (number average molecular mass M_n = 1000) with phosgene to obtain the chloroformiate, which was subsequently reacted with monoprotected piperazine followed by removal of the protecting group (*cf.* C. D. Eisenbach and E. Stadler, *Macromol. Chem. Phys.*, in the press).

§ Purified by dissolution in a minimum amount of $CHCl_3$ and precipitated by addition of MeOH (−78 °C), filtered and freeze dried in benzene; bipy blocks with shorter poly[oxytetramethylene] blocks are partially soluble in the precipitant which accounts for the loss in the yield. Characteristic ^1H NMR signals ($CDCl_3$), δ 4.82 (s, bipyCH_2O-CON), 4.90 (bipyCH_2OCH_2bipy), 7.24 (d, *J* = 7.7 Hz, 2H), 7.58 (d, *J* = 7.7 Hz, 2H), 7.78 (t, *J* = 7.7 Hz, 2H), 7.85 (t, *J* = 7.7 Hz, 2H), 8.32 (d, *J* = 7.7 Hz, 2H), 8.33 (d, *J* = 7.7 Hz, 2H); ^{13}C NMR, δ 67.4 (bipyCH_2OCON), DSC: mp 19.28 °C, ΔH = 161.2 kJ mol^{-1}, M_n = 2710 as determinated by ^1H NMR spectroscopy.

¶ UV spectra: significant and characteristic shift of λ_{max} from 290 nm **8** to 304.5 nm (ε = 23 000) without appearance of any shoulder (*cf.* ref. 2) which proves complete complexation; compare also with earlier results.[3] Transmission electron microscopy studies shows the existence of copper in the polymer by using electron energy loss spectroscopy (EELS) Nitrogen as well as the copper element distribution was obtained by element spectroscopic imaging (ESI) techniques which revealed ordered clusters of $(Cu^I)_2$[bis(bipy)] complexes. These results will be published elsewhere.

|| Characteristic ^1H NMR signals for **10**, δ 3.41 (OCH_3), 3.60 (CH_2CH_2), 3.80 (CH_2CH_2), 4.05 (OH), 4.84 (bipyCH_2OH), 4.93 (bipyCH_2OCH_2); characteristic ^1H-NMR signals for **11**, δ 4.15 (OH), 4.71 (bipyCH_2OCH_2), 4.82 (bipyCH_2OH).

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