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Tetrahedron Letters 45 (2004) 7805–7807
Tetrahedron Letters

Synthesis of monophosphonic acid ligands with a phenanthroline core

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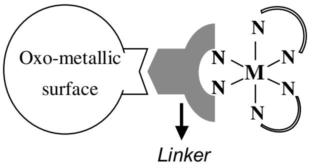
Received 8 June 2004; accepted 15 July 2004

Abstract—The efficient synthesis of two diimine ligands incorporating one benzyl phosphonate group and a phenanthroline core is described. These functionalized ligands constitute a new type of linkers in hybrid organic–inorganic materials based on inorganic oxides and metallic complexes.

The synthesis of hybrid organic–inorganic materials based on inorganic oxides and metallic complexes is an expanding field of investigation. Indeed, the ability to attach metallic polypyridyl complexes to oxide surfaces in controlled architectures (distance, orientation, compacity and rigidity) is essential for the design of new composite systems. Hybrid organic–inorganic materials are known to favour the combination of both the properties of the inorganic and organic moieties;[1] the linker used between these two systems however, plays a major role. Presently, one of the most studied hybrid systems results from the entrapment of polypyridyl complexes, either by attachment on oxide solid surface such as semi-conductor (for the development of molecular level devices)[2] or by incorporation in a phosphonate framework (for supported homogenous catalysis)[3] or in nanocrystalline films of TiO_2 for their utility in dye sensitized solar cells.[4] It appears however that the synergy between the complex and the host is stronger with a covalent grafting.

We are currently investigating the synthesis of hybrid materials based on polyoxometalate (POMs) clusters.[5] The synthesis of such hybrid systems, necessitates the pre-functionalization of the POM cluster the main method consisting in grafting electrophilic groups on a heterovacant POM.[6] Eventually, the covalent incorporation of a POM in a material should result in the formation of a new hybrid material that would most likely benefit the large panel of applications of POMs, in particular their numerous electronic properties.[7] This challenge however requires the control of the linking between the metallic complex and POM moieties (Scheme 1).

Indeed, this link must incorporate three important features: (i) an electrophilic group such as a phosphonate group to ensure the bonding with the POM, (ii) a small aliphatic group between the electrophilic part and the chelating part and (iii) a strong rigid chelating group such as polypyridyls. Among the polypyridyl library, the phenanthroline seems the more adapted, and more especially the 9,10-phenanthroline-5,6-dione. It behaves as a good organic block likely to easily condense with another organic block possessing either a benzaldehyde group[8] or an *ortho*-diaminoaromatic group. The structural modification of 9,10-phenanthroline compounds



Scheme 1. Schematic representation of an example of hybrid system.

Keywords: Phosphonic acids; Polyridyls; Pyrazine; Imidazole; Heterocyclic compounds.

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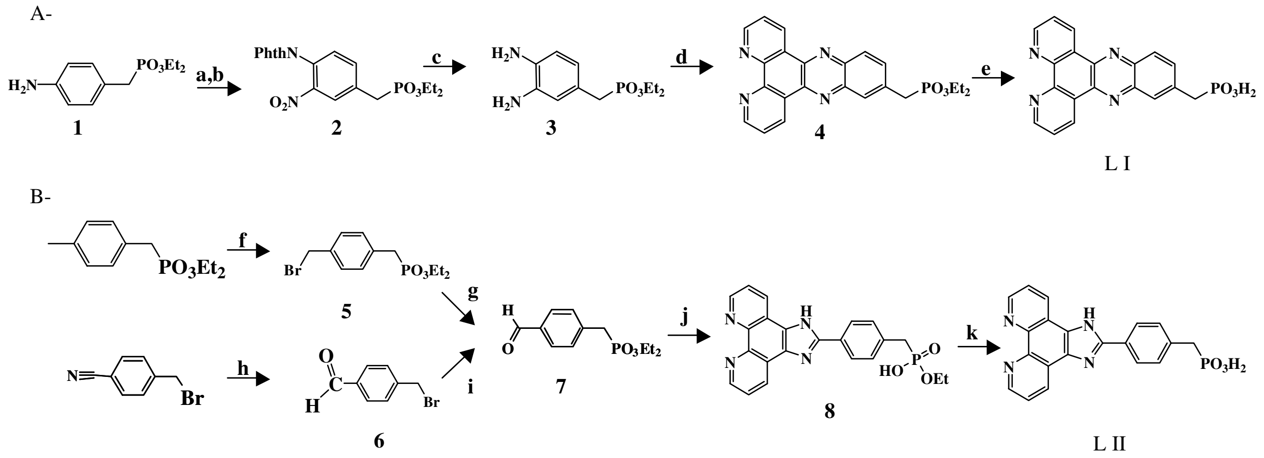
doi:10.1016/j.tetlet.2004.07.067

has been the object of numerous studies due to their rich coordination chemistry. In fact, the large variety of complexes based on phenanthroline or polypyridyl derivatives allows the formation of many different molecular systems with various applications ranging from metallo-supramolecular chemistry,[9] metal sensors,[10] molecular electronics[11] and photosensitizers.[12] Another interest of this work was to test different organic blocks that would include one monophosphonate group and thus to devise an efficient route to diversify the nature of the link. Although, different bipyridils ligands with two phosphonate groups are described in the literature, only few results are related to the monofunctionalization of polypyridyls ligands. Grätzel and co-workers reported monophosphonate terpyridines[13] and recently Schmehl and co-workers reported a bipyridyl monofunctionalization with phenylphosphonate.[14] The key feature of our approach was to functionalize the phenanthroline by only one monophosphonic acid. The functionalization by a bisphosphonic acid would most probably lead to the formation of oligomeric species, as it is the case for the reaction of an aromatic bisphosphonic acid with a divacant POM.[15] This work presents the synthesis of two modified benzylphosphonates and their condensation with 9,10-phenanthroline-5,6-dione. We thus describe here the synthesis of two diimine ligands functionalized with one phosphonic acid substituent. The first organic-phosphonate block (OPB) we used is 4-(diethoxyphosphorylmethyl)-1,2-diamino-phényl (**3**) and the second OPB corresponds to 4-(diethoxyphosphorylmethyl)-1-benzaldehyde (**7**). The synthesis of the latter product was recently described,[16] herein, two alternative syntheses are proposed.

The preparation of compound **3** from 4-(diethoxyphosphorylmethyl)-1-amino-phenyl (**1**) proceeded in four steps. The first reaction achieved the protection of the amino group using phthalic anhydride in acetic acid solution. After evaporation, precipitation and drying, this compound was added to a mixture of HNO_3/H_2SO_4 at −5 °C. The pure product compound **2** was recovered by precipitation in cooled water. The last reaction was performed in ethanol with Pd on activated carbon and with excess of hydrazine monohydrate, at reflux overnight, resulting in the deprotection of the amino group and accompanied with the reduction of the nitro group into a second amino group. The condensation with 9,10-phenanthroline-5,6-dione was then carried out in refluxed ethanol. The hydrolysis was achieved by the McKenna method[17] or in a 12 M HCl aqueous solution to give the pure product 2-(dihydroxyphosphorylmethyl)-pyrido[3,2-*a*:2′,3′-*c*]phenazine (**LI**) in good yield (Scheme 2A).[18]

Two precursors were considered for the synthesis of compound **7**, *para*-4-bromomethyl-xylene or α-bromo-*p*-tolunitrile. Starting from *para*-4-bromomethyl-xylene, the first step consisted in the preparation of 4-(diethoxyphosphorylmethyl)-1-methyl-phenyl **7** using the Arbuzov method.[19] The second step consisted in the bromination of *para*-methyl group by N-bromosuccinimide (NBS) in CCl_4 and dibenzoylperoxide (DBPO) as radical initiator. The formation of the aldehydic groups was obtained by the protocol of Nace and Monagle in DMSO in the presence of $NaHCO_3$.[20] The second method proceeded in two steps from commercial α-bromo-*p*-tolunitrile. First the a-bromo-*p*-tolualdehyde was formed as described by Wen et al.[21] and the expected compound **7** was then obtained by reaction with triethylphosphite. Compound **7** was recovered in acetic acid with NH_4OAc through the protocol of Steck and Day.[8] However, in these conditions solely one of the ester functions of the phosphonate groups was hydrolyzed as observed by ^1H NMR or ESI-MS. An additional reaction was therefore carried out in 12 M HCl aqueous solution to form the final product (4-(dihydroxyphosphorylmethyl)-phenyl)-phenanthrimidazole (**LII**) in good yield (Scheme 2B).[18]

In conclusion, we described an efficient method for the preparation of two new phosphonic acid chelating ligands: 2-(dihydroxyphosphorylmethyl)-pyrido[3,2-*a*:2′,3′-*c*]phenazine (**LI**) and (4-(dihydroxyphosphorylmethyl)-phenyl)-phenanthrimidazole (**LII**). We recently



Scheme 2. Reagents and conditions : (a) phthalic anhydride; (b) HNO_3/H_2SO_4, −5 °C; (c) N_2H_4, Pd/C; (d) 1,10-phenanthrolinedione; (e) HCl 12 M reflux; (f) NBS, DBPO, *hν*; (g) $NaHCO_3$, DMSO; (h) DIBALH; (i) $P(OC_2H_5)_3$; (j) 1,10-phenanthrolinedione, NH_4OAc, CH_3COOH; (k) HCl 12 M reflux.

described the functionalization of POM by compound **5**.[22] The grafting of these ligands on other POM frameworks and their interaction with TiO_2 surface are currently under investigation.

Acknowledgements

We gratefully acknowledge Ally Aukoulo (Laboratoire de Chimie Inorganique, UMR CNRS 8613, ICMMO, Orsay) for fruitful discussion. We thank Vincent Steinmetz for mass spectrometry measurements.

Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.tetlet.2004.07.067. The general procedure and mass spectrum are detailed in Supplementary data.

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