Pergamon

Tetrahedron Letters 39 (1998) 3689–3692

TETRAHEDRON LETTERS

Facile and Efficient Syntheses of 2,2'-bipyridine-based Bis(phosphonic) Acids

Virginie Penicaud, Fabrice Odobel*, and Bruno Bujoli*

Laboratoire de Synthèse Organique, CNRS et Université de Nantes, BP 92208, Faculté des Sciences et des Techniques, 2, rue de la Houssinière, 44322 Nantes Cedex 03, France

Received 27 February 1998; accepted 19 March 1998

Abstract

The synthesis and characterization of new 2,2'-bipyridine ligands bearing two phosphonic acid groups either on the (4,4'), (5,5') or (6,6') positions are described.

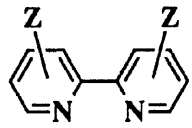
Keywords: phosphonic acids and derivatives; diamines; bicyclic heterocyclic compounds.

There has been a continuing interest in 2,2'-bipyridine compounds mainly due to their rich coordination chemistry. Indeed, complexation of bipyridine derivatives affords compounds suitable for various applications ranging from metallo-supramolecular chemistry [1], to conversion of light into chemical energy [2], catalysis [3], metal sensors [4] and molecular electronics [5]. The covalent attachment of well defined compounds into hybrid organic-inorganic materials, such as zirconium phosphonates, or solid surfaces such as semi-conductor metal oxides, is an important step in the development of molecular-level devices.

Phosphonic acids are well known to react with all transition metal cations and with lots of metal oxides [6]. In some cases, with metals such as Al^{III}, Ga^{III} or Zr^{IV}, Ti^{IV}, the metal-O3PR bonds are very stable even in severe media such as oxidative, reductive, acid or basic conditions.

Recently we embarked on a program aimed at immobilizing 2,2'-bipyridine moieties into metal phosphonate frameworks which may find applications in supported homogeneous catalysis and photo-induced charge separation. The key feature of this approach is to functionalize the desired ligand by phosphonic acid moieties (PO_3H_2). In previous studies we have reported that the organic block can act as an "internal template"; its geometry has indeed a strong influence on the structure, texture and properties of the resulting metal phosphonates [7]. It was thus of interest to synthesize a series of new 2,2'-bipyridines which bear two PO_3H_2 substituents, either directly bonded to the bipyridyl core (**1a**, **1b**) or separated by a $C(O)NHC_3H_6$ spacer (**2b**, **2c**).

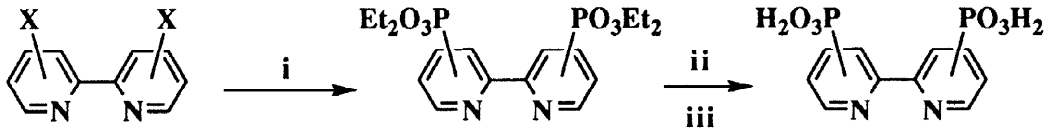
0040-4039/98/$19.00
PII: S0040-4039(98)00647-9



1a: 4,4': Z = PO_3H_2; **2b:** 5,5': Z =$C(O)NHC_3H_6PO_3H_2$
1b: 5,5': Z = PO_3H_2; **2c:** 6,6': Z =$C(O)NHC_3H_6PO_3H_2$

During the course of this work, Grätzel and co-workers [8] reported the preparation of 4-(diethoxyphosphoryl)terpyridine via a cross coupling reaction between 4-bromoterpyridine and diethyl phosphite catalysed by $Pd(PPh_3)_4$, following the methodology developed by Hirao [9].

In our laboratory, several attempts to prepare bipyridines **6** and **7**, from the corresponding dibromo- [10] or diiodobipyridines [11], have been examined. First, we have tried the dilithiation of the 2,2'-bipyridyl moiety from **3-5** and subsequent treatment with diethylchlorophosphate, but this procedure was unsuccessful. Then, we have applied to dihalo-bipyridines **3-5** Hirao's conditions [9] and those modified by Grätzel for the phosphonation of terpyridine [8], but both failed to provide the desired phosphonates **6-7**. The strong coordination ability of bipyridine is probably responsible of that failure. Indeed, bipyridine might compete with the triphenylphosphine ligand of the $Pd(PPh_3)_4$ catalyst, thus leading to its deactivation. In order to prevent this ligand exchange on the palladium center, a large excess of triphenylphosphine (10 folds with respect to bipyridine) was added to the reaction medium. This simple modification resulted in the formation of **6** and **7** in 82 % and 87 % yield respectively [12]. Although a large amount of triphenylphosphine is required, this latter is easily separated by chromatography and almost completly recycled.



3 : X = 4,4'-Br
4 : X = 5,5'-Br
5 : X = 5,5'-I

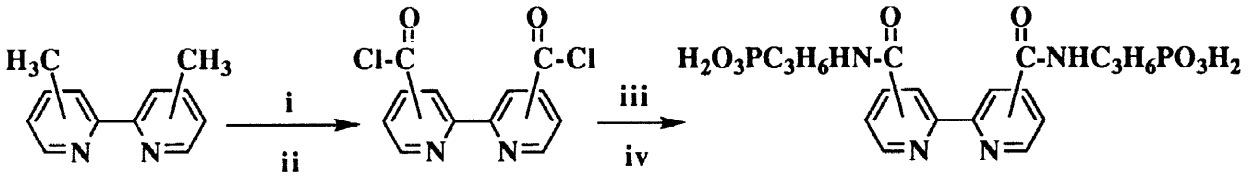
6 : 4,4'-PO_3Et_2
7 : 5,5'-PO_3Et_2

1a : 4,4'-PO_3H_2
1b : 5,5'-PO_3H_2

Conditions : i) HPO_3Et_2, $Pd(PPh_3)_4$, PPh_3, toluene, 110 °C (85%);
ii) Me_3SiBr, CH_2Cl_2, RT ; iii) MeOH, RT (quant.)

The phosphonate groups were then converted into their acidic form under mild conditions using the Mc Kenna's method [13]. Thus, reacting **6** and **7** in dry dichloromethane with 10 equivalents of bromotrimethylsilane for one day at room temperature resulted in their complete transesterification into the corresponding silyl esters, that were hydrolysed in methanol at room temperature to give compounds **1a** and **1b** in quantitative yield.

Compounds **2b** and **2c** were prepared from the corresponding 2,2'-bipyridine-5,5'-bismethyl derivatives **8-9** [14]. The methyl substituents were oxidized to carboxylic acid groups, then converted to acylchlorides and subsequently coupled to diethyl 3-aminopropylphosphonate [15]. After hydrolysis following the Mc Kenna's procedure [13], **2b** and **2c** were isolated in quantitative yield.



8 : 5,5'-CH_3
9 : 6,6'-CH_3

10 : 5,5'-C(O)Cl
11 : 6,6'-C(O)Cl

2b : 5,5'-$C(O)NHC_3H_6PO_3H_2$
2c : 6,6'-$C(O)NHC_3H_6PO_3H_2$

Conditions : i) CrO_3-H_2SO_4 (70%); (ii) $SOCl_2$ (quant.);
(iii) $H_2NC_3H_6PO_3Et_2$, NEt_3, CH_2Cl_2 (90%);
iv) Me_3SiBr, CH_2Cl_2, RT ; then MeOH, RT (quant.)

In conclusion, we have presented an efficient and good yield method to prepare multi-gram quantities of four new 2,2'-bipyridine-based bis(phosphonic) acids.

The preparation of metal-phosphonate materials from these phosphonic acids is now under investigation in our laboratory, and preliminary experiments show that these ligands can be efficiently heterogenized. For example, when **2c** was reacted with aluminum nitrate in water (85°C, 4 days), in neutral pH conditions, the corresponding aluminium phosphonate Al4/3(O3PC3H6NHCO-C5H3N-C5H3N-CONHC3H6PO3). 4H2O (**A**) was obtained; the ^{13}C CP-MAS NMR spectrum recorded for this material show that no degradation of the organic moiety occurs during the immobilization step [16]. On the other hand, the ^{31}P and ^{27}Al MAS NMR data give evidence that aluminium selectively reacts with the phosphonic acid groups, with no coordination with the nitrogen atoms of the 2,2'-bipyridine, since the chemical shifts of the ^{31}P and ^{27}Al signals [16] are similar to those classically observed in aluminium alkylphosphonates [17].

Acknowledgements: We gratefully acknowledge Daniel Maume (LDH in Ecole Vétérinaire of Nantes) for mass spectrometry measurements. We thank Regis Garcia (Laboratoire de Catalyse et Synthèse Organique, Lyon) for fruitful discussions.

References and Notes:

[1] Constable EC. In: Karlin KD, editor. Progress in Inorganic Chemistry. New York: John Wiley& Sons Inc., 1994;42:67-92.

[2] Balzani V, Scandola F. Supramolecular Photochemistry. Ellis Horwood, England, 1991 and references therein.

[3] Dutta PK, Das SK. J. Am. Chem. Soc. 1997;119:4311-4312. Töllner K, Biro RP, Lahav M, Milstein D. Science 1997;278:2100-2102.

[4] Wang B, Wasielewski MR, Flamigni L. J. Am. Chem. Soc. 1997;119:12-21. Torrado A, Imperiali B. J. Org. Chem. 1996;61:8940-8948.

[5] Peng Z, Gharavi AR, Yu L. J. Am. Chem. Soc. 1997;119:4622-4632.

[6] Alberti G. In: Sequera CAC, Hudson MJ, editors. Multifunctional Mesoporous Inorganic Solids. Kluwer Academic Publishers, 1993 and references therein. Cao G, Hong H, Mallouk TE. Acc. Chem. Res. 1992;25:420-431.

[7] Fredoueil F, Penicaud V, Bujoli-Doeuff M, Bujoli B. Inorg. Chem. 1997;36:4702-4706. Deniaud D, Spyroulias GA, Bartoli J, Battioni P, Mansuy D, Pinel C, Bujoli B. New J. Chem., in the press.

[8] Zakeeruddin SM, Nazeeruddin MK, Pechy P, Rotzinger FP, Humhry-Baker R, Kalyanasundaram K, Grätzel M. Inorg. Chem. 1997;36:5937-5946.

[9] Hirao T, Masunaga T, Yoshiro O, Agawa T. Synthesis 1981:56-57.

[10] **3** and **4** were respectively prepared according to Maerker G, Case FH, Yu L. J. Am. Chem. Soc. 1997;119:4622-4632 and Francisco FM, Ziessel R. Tetrahedron Lett. 1995;36:6471-6474.

[11] 5,5'-bisiodo-2,2'-bipyridine **5** was prepared by conversion of 5,5'-diamino-2,2'-bipyridine [18] into the bis-diazonium compound followed by reaction with potassium iodide (yield: 70%). ^{1}H-NMR (200MHz, $CDCl_3$): δ 8.15 (2H, dd, H_6), 8.85 (4H, ddd, H_3 and H_4). EI-MS (m/z) : 408 (M+·, 100), 281 (44), 254 (25), 204 (34), 154 (50), 127 (64), 77 (73).

[12] General procedure : 0.3g of dibromo bipyridine **4** (0.95 mmol), 0.28 ml of diethyl phosphite (2.17 mmol), 110mg of $Pd(PPh_3)_4$ (0.095 mmol), 2.5g of triphenylphosphine (9.5 mmol), 0.3 ml of triethylamine and 10ml of toluene were heated at 110°C under argon for 6 hours. The reaction mixture was washed with an ammonium hydroxide solution, then with water and dried over $MgSO_4$. Flash column chromatography (SiO_2) eluted with CH_2Cl_2 gave 2.3g of pure PPh_3; pursuing the elution with CH_2Cl_2/CH_3OH : 99/1 gave 357mg of **7** (87% yield). **6** :^{1}H-NMR (200MHz, $CDCl_3$): δ 1.32 (12H, t, CH_3), 4.14 (8H, dq, CH_2), 7.68 (2H, ddd, H_5), 8.77 (4H, m, H_3 and H_6). EI-MS (m/z) : 428 (M+·, 7), 384 (26), 320 (26), 292 (100), 280 (20), 264 (14), 218 (31), 69 (28). **7** :^{1}H-NMR (200MHz, $CDCl_3$): δ 1.33 (12H, t, CH_3), 4.16 (8H, dq, CH_2), 8.22 (2H, ddd, H_4), 8.55 (2H, ddd, H_3), 9.01 (2H, ddd, H_6). EI-MS (m/z) : 428 (M+·, 84), 384 (58), 355 (51), 320 (100), 292 (91), 264 (55), 217 (59).

[13] McKenna CE, Higa MT, Cheung NH, McKenna, MC. Tetrahedron Lett. 1977;:155-158.

[14] Newkome GR, Puckett WE, Kiefer GE, Gupta VK, Xia Y, Coreil M, Hackney MA. J. Org. Chem. 1982;47:4116-4120. Whittle CP. J. Heterocyclic Chem. 1977;14:191-194.

[15] Deniaud D, Schöllhorn B, Mansuy D, Rouxel J, Battioni P, Bujoli B. Chem. Mater. 1995;7:995-1000. **2b** (diethyl ester form):^{1}H-NMR (200MHz, $CDCl_3$): δ 1.32 (12H, t, CH_3), 1.98 (8H, m, $(CH_2)_2P$), 3.61 (4H, dt, CH_2N), 4.10 (8H, dq, CH_2), 7.94 (2H, t, NH), 8.30 (2H, dd, H_4), 8.49 (2H, dd, H_3), 9.16 (2H, dd, H_6). EI-MS (m/z) : 598 (M+·, 1), 447 (1), 377 (80), 194 (23), 123 (24), 31 (100). **2c** (diethyl ester form):^{1}H-NMR (200MHz, $CDCl_3$): δ 1.24 (12H, t, CH_3), 1.86 (8H, m, $(CH_2)_2P$), 3.56 (4H, dt, CH_2N), 4.02 (8H, dq, CH_2), 7.95 (2H, dd, H_4), 8.18 (2H, dd, H_5), 8.35 (2H, t, NH), 8.58 (2H, dd, H_3). EI-MS (m/z) : 598 (M+·, 10), 447 (30), 377 (33), 194 (58), 156 (59), 123 (100).

[16] ^{13}C CP-MAS NMR spectrum of **A** (the ^{13}C NMR values of the corresponding precursor **2c** are given in brackets): 24.6 (22.7 and 23.0), 41.1 (39.2), 122.7 (122.5 and 123.4), 138.8 (138.2), 148.1 (149.2), 152.4 (153.5), 164.7 (164.1) ppm. ^{27}Al MAS NMR of **A**: -13 (80%, AlO_6) and 42 (20%, AlO_4) ppm. ^{31}P MAS NMR of **A**: 15.2 ppm.

[17] Maeda K, Kiyozumi Y, Mizukami F. Angew. Chem. Int. Ed. Engl. 1994;33:2235-2237. ^{27}Al MAS NMR spectrum of β-aluminium methylphosphonate: -17.6 (AlO_6) and 41.2 (AlO_4) ppm.

[18] Zhang B, Breslow R. J. Am. Chem. Soc. 1997;119:1676-1681.