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Cinnamil - An Oligopyridine Precursor

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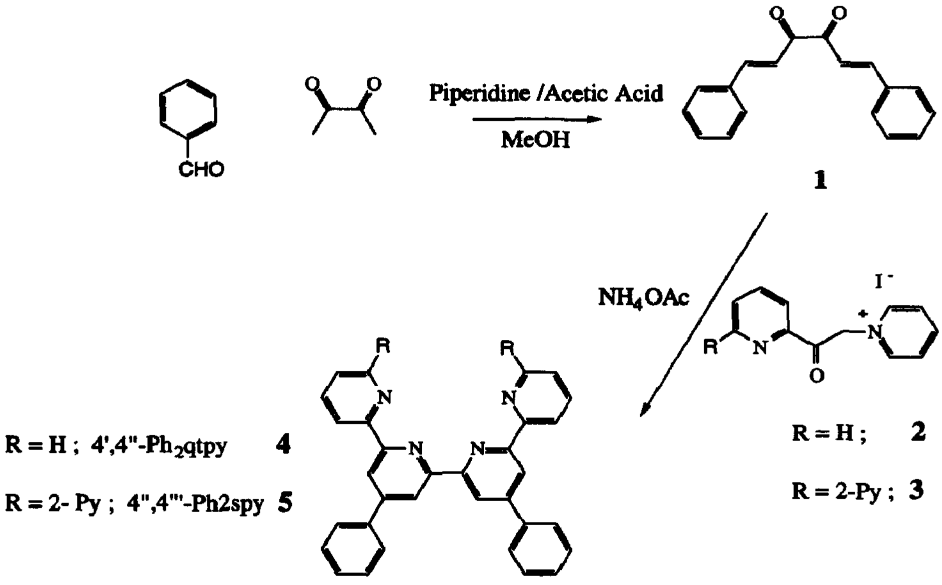
Abstract. A new methodology has been employed to synthesize a quaterpyridine, a sexipyridine and a quaterpyridine analogue in which the central 2,2'-bipyridine unit is derived from cinnamil.

The coordination chemistry of oligopyridines with transition metal ions has been the subject of much interest in recent years. Oligopyridines containing even numbers of pyridine rings can be synthesized by either the symmetrical coupling of smaller units or by the formation of pyridine rings from acyclic precursors. In general, 2,2':6',2":6",2"'-quaterpyridine (qtpy) and its derivatives are prepared using coupling methods [1] whilst the larger even-numbered oligopyridines can be prepared by either coupling [2] or Potts or Kröhnke methodologies. [3] We have now extended the methodology of Kröhnke [3] to synthesize 2,2':6',2":6",2"'-quaterpyridines and a 2,2':6',2":6",2"':6"',2"":6"",2""'-sexipyridine by the generation of a central 2,2'-bipyridine unit from the acyclic moiety 1,6-diphenylhexa-1,5-diene-3,4-dione, cinnamil.

Using the methodology described by Sorenson and co-workers, [4] cinnamil (**1**) was prepared as orange crystals in a yield of 11% from the reaction of diacetyl with an excess of benzaldehyde in methanol using piperidinium acetate as a catalyst. A variety of alcoholic solvents were investigated, but methanol reliably gave the best yields. The poor yield of the reaction product is, however, compensated for by the inexpensive nature of the starting materials.

Reaction of cinnamil with two molar equivalents of the Kröhnke reagent *N*-[1-oxo-2-(2-pyridyl)ethyl]-pyridinium iodide (**2**) [3] in the presence of ammonium acetate (scheme 1) resulted in a bis-cyclization reaction occurring to afford 4',4"-diphenyl-2,2':6',2":6",2"'-quaterpyridine (4',4"-Ph_2qtpy, **4**) as a colourless solid in a yield of 50% after recrystallization. [5] Optimum yields in this cyclization reaction were obtained using ethanol as the solvent - the use of either methanol or acetic acid resulted in lower yields.

The introduction of the phenyl substituents into the 4' and 4" positions of the quaterpyridine was found to have little effect on the formation, and the behaviour, of complexes with metal ions compared to those formed with the unsubstituted quaterpyridine. This is demonstrated by the formation of dinuclear helical structures on reaction of the bis-substituted ligand with either copper(I) [6] or silver(I) [7] salts. The electrochemical behaviour of solutions of the dicopper(I) complex of 4',4"-Ph_2qtpy and of qtpy are very similar; the diphenyl substituted complex shows an irreversible oxidation process at –0.03 V (*vs* Fc/Fc^+) and an irreversible reduction process at –0.36V. These compare with the values of +0.05V and –0.42V, respectively, found for the corresponding qtpy complex.

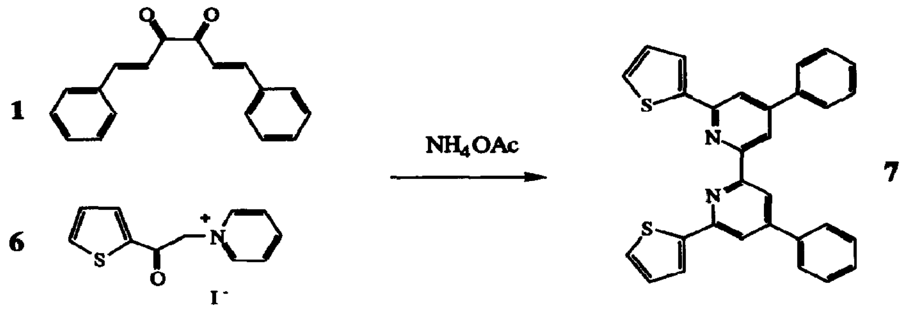


Scheme 1. Synthetic route to 4',4"-diphenyl-2,2':6'2":6",2'"-quaterpyridine (4',4"-Ph$_2$qtpy, 4) and 4",4'"-diphenyl-2,2':6',2":6",2'":6'",2''"':6''",2'''''-sexipyridine (4",4'"-Ph$_2$spy, 5)

The presence of the phenyl substituents on the quaterpyridine does have the effect of lowering the π^* orbital of the ligand as seen by a small bathochromic shift (~10nm) of the metal-to-ligand charge transfer bands from 543nm (ε, 2,800) and 432nm (ε, 4,500) in $[Cu_2(qtpy)_2][PF_6]_2$ to 553nm (ε, 6,100) and 443nm (ε, 10,700) in $[Cu_2(4',4''\text{-}Ph_2qtpy)_2][PF_6]_2$.

In an analogous manner to the preparation of 4',4"-Ph$_2$qtpy, the higher oligopyridine 4",4'"-diphenyl-2,2':6'2":6",2'":6'",2''"':6''",2'''''-sexipyridine (4",4'"-Ph$_2$spy, 5) was prepared from the reaction of cinnamil (1) with an extended Kröhnke reagent 3 [8] formed from the reaction of 6-acetyl-2,2'-bipyridine [9] with pyridine and iodine in an analogous manner to the synthesis of 2. This afforded 4",4'"-Ph$_2$spy [10] as a colourless solid in a yield of 50 %. Although this ligand had limited solubility in organic solvents, it was sufficiently soluble to allow its characterization by the usual spectroscopic techniques. Reaction [11] of this ligand with $[Cu(MeCN)_4][PF_6]$ afforded a deep red diamagnetic solution, from which a red solid was isolated. The observation of a cluster of ions centred at *m/z* 1712 in the positive FAB mass spectrum showing the expected isotope distribution pattern for a tricopper species ($[Cu_3(4'',4'''\text{-}Ph_2spy)_2][(PF_6)_2]$) provides evidence for the formation of the expected trinuclear species $[Cu_3(4'',4'''\text{-}Ph_2spy)_2][(PF_6)_2]_3$. This is consistent with the complex adopting a double helical structure in solution with the copper(I) ions adopting the preferred tetrahedral geometry for a d^{10} configuration.

The ability of 1 to function as a 2,2'-bipyridine precursor has been utilized in the preparation of an analogue of 4',4"-Ph$_2$qtpy in which the two terminal pyridine rings have been replaced by 2-thienyl groups. By using a thiophene derivative as the Kröhnke reagent the reaction with 1 in the presence of ammonium acetate (Scheme 2) afforded colourless 4,4'-diphenyl-6,6'-bisthienyl-2,2'-bipyridine (7).[12] This analogue contains a mixed donor set for coordination to a transition metal ion and these studies are in progress.



Scheme 2. Synthetic route to the 4',4"-bisphenyl-2,2':6',2":6",2'"-quaterpyridine analogue.

The above initial studies demonstrate that cinnamil can act as a precursor to the central bipyridine unit of symmetrically-phenyl substituted oligopyridines containing even numbers of pyridine rings. This provides an alternative method to the coupling method currently in general use. Further studies regarding the applicability of 3,4-dioxo-1,6-diene systems in the synthesis of substituted quaterpyridines are in progress.

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References and Footnotes

1. J.-M. Lehn, J.-P. Sauvage, J. Simon, R. Ziessel, C. Piccinni-Leopardi, G. Germain, J.-P. Declerq, and M. Van Meerssche, *Nouv. J. Chim.*, 1983, 7, 413. E.C. Constable, M.J. Hannon, A. Martin, P.R. Raithby, and D.A. Tocher, *Polyhedron*, 1992, **11**, 2971. E.C. Constable, S.M. Elder, J. Healy, and D.A. Tocher, *J. Chem. Soc., Dalton Trans.*, 1990, 1669.
2. E.C. Constable and R. Chotalia, *J. Chem. Soc., Chem. Commun.*, 1992, 64.
3. Kröhnke, F. *Synthesis*, 1976, 1. E.C. Constable, M.D. Ward, and D.A. Tocher, *J. Chem. Soc., Dalton Trans.*, 1991, 1675. K.T. Potts, *Bull. Soc. Chim. Belg.*, 1990, **99**, 741. K.T. Potts, K.A. Gheysen Raiford, and M. Keshavarz-K, *J. Am. Chem. Soc.*, 1993, **115**, 2793.
4. N.A. Sorenson, E. Samuelsen and F.R. Oxaal, *Acta Chem. Scand.*, 1947, **1**, 458.
5. 4',4"-Ph$_2$qtpy (**4**): **1** (0.400 g, 1.53 mmol) was added to a solution of *N*-[1-oxo-2-(2-pyridyl)ethyl]-pyridinium iodide (**2**) (1.0 g, 3.1 mmol) and NH$_4$OAc (8 g, excess) in ethanol (10 ml) and the mixture heated at reflux for 4 h. After cooling, the precipitate that had formed was collected by filtration as a pale brown

solid and recrystallized from *N,N*-dimethylformamide to give 4',4''-Ph$_2$qtpy as a colourless solid (0.35 g, 50%); m.p. >250°C; δ_H (250 MHz, CDCl$_3$) 7.37 (1H, ddd, J = 7.5, 4.8. 1.1 Hz, H$_5$), 7.55 (3H, m, H$_m$,H$_p$), 7.90 (3H, m, H$_o$,H$_4$), 8.72 (1H, d, J = 7.9 Hz,, H$_3$), 8.74 (1H, d, J = 4.8 Hz, H$_6$), 8.77 (1H, d, J = 1.6 Hz, H$_{3'/5'}$), 8.94 (1H, d, H$_{3'/5'}$); *m/z* (EI) 462 (M)$^+$, 385 (M-Ph)$^+$. Found: C, 80.6; H, 4.6; N, 11.7 %. Calc. for C$_{32}$H$_{22}$N$_4$.0.75H$_2$O: C, 80.7; H, 5.0; N, 11.8 %.

6. 4',4''-Ph$_2$qtpy (0.020 g, 0.043 mmol) and [Cu(MeCN)$_4$][PF$_6$] (16 mg, 0.043 mmol) were added to degassed methanol (10 ml) under dinitrogen. The mixture was heated at reflux for 3h and after cooling, the deep red precipitate of [Cu$_2$(4',4''Ph$_2$qtpy)$_2$][PF$_6$]$_2$ (0.020 g, 69%) was collected by filtration and washed with diethyl ether; δ_H (250 MHz, CD$_3$CN) 7.21 (1H, dd, J = 6.8, 5.9 Hz, H$_5$), 7.60 (3H, m, H$_{o/m}$, H$_p$), 7.80 (3H, m, H$_4$, H$_{o/m}$), 8.14 (1H, d, J = 4.4 Hz, H$_6$), 8.19 (3H, m, H$_3$, H$_{3'}$, H$_{5'}$); *m/z* (+ve FAB) 1197 (M-PF$_6$)$^+$, 1052 (M-2PF$_6$)$^+$.
7. 4',4''-Ph$_2$qtpy (0.020 g, 0.043 mmol) and AgOAc (0.007 g, 0.043 mmol) were heated at reflux in methanol (10 ml) for 3h. The straw-coloured solution was filtered and then treated with an excess of methanolic [NH$_4$][PF$_6$] to afford an immediate colourless precipitate of [Ag$_2$(4',4''Ph$_2$qtpy)$_2$][PF$_6$]$_2$ (0.018 g, 58%) which was isolated by filtration; δ_H (250 MHz, CD$_3$CN) 7.15 (1H, dd, J = 6.5, 5.1 Hz, H$_5$), 7.65 (3H, m, H$_{o/m}$, H$_p$), 7.95 (4H, m, H$_4$,H$_6$,H$_{o/m}$), 8.13 (1H, d, J = 8.1 Hz, H$_3$), 8.22 (1H, s, H$_{3'/5'}$), 8.43 (1H, s, H$_{3'/5'}$); *m/z* (+ve FAB) 1285 (M-PF$_6$)$^+$, 1139 (M-2PF$_6$)$^+$.
8. E.C. Constable and D.R. Smith, Manuscript in preparation
9. J.E. Parks, B.E. Wagner and R.H. Holm, *J. Organomet. Chem.*, 1973, **56**, 53.
10. 4'',4'''-Ph$_2$spy (**5**): **1** (0.032 g, 0.12 mmol) was added to a solution of (**3**) (0.100 g, 0.25 mmol) and NH$_4$OAc (1 g, excess) in ethanol (10 ml) and the mixture heated at reflux for 4 h. After cooling, the precipitate that had formed was collected by filtration as a pale brown solid and recrystallized from *N,N*-dimethylformamide to give **4** as a colourless solid (0.037 g, 50%); m.p. >250°C; δ_H (300 MHz, CDCl$_3$) 7.36 (2H, m, H$_5$, H$_{3'/5'}$), 7.63 (3H, m, H$_m$,H$_p$), 7.90 (1H, d, J = 7.6 Hz, H$_4$), 7.97 (2H, m, H$_o$), 8.06 (1H, t, J = 7.6 Hz, H$_{4'}$), 8.53 (1H, d, J = 7.6 Hz, H$_{3'/5'}$), 8.70 (1H, d, J = 7.6 Hz, H$_3$), 8.77 (1H, d, J = 7.6 Hz, H$_6$), 8.95 (1H, d, J = 1.1 Hz, H$_{3''/5''}$), 9.00 (1H, d, J = 1.1 Hz, H$_{3''/5''}$); *m/z* (EI) 616 (M)$^+$. Found: C, 79.17; H, 4.31; N, 13.07 %. Calc. for C$_{42}$H$_{28}$N$_6$.1H$_2$O, C, 79.47; H, 4.77; N, 13.24 %.
11. 4'',4'''-Ph$_2$spy (0.020 g, 0.038 mmol) and Cu(MeCN)$_4$ PF$_6$ (0.0021 g, 0.057 mmol) were heated at reflux in MeOH (10 ml) for 3 h in a nitrogen atmosphere. The dark red precipitate formed was isolated by filtration and characterized as [Cu$_3$(4'',4'''Ph$_2$spy)$_2$][PF$_6$]$_2$ (0.016 g, 80 %); δ_H (300 MHz, CD$_3$CN) 7.05 (1H, m, H$_5$), 7.66 (3H, m, H$_o$,H$_p$), 7.71 (3H, m, H$_m$,H$_4$), 7.85 (2H, m, H$_o$), 7.90 (1H, s, H$_{3''/5''}$), 8.02 (2H, d, J = 5.1 Hz, H$_3$,H$_{3'/5'}$). *m/z* (+ve FAB) 1712 (M-PF$_6$)$^+$ 1568 (M-2PF$_6$)$^+$.
12. *N*-[1-Oxo-2-(2-thienyl)ethyl]-pyridinium iodide [3] (**6**) (0.530 g, 1.6 mmol), ammonium acetate (4 g, excess) and cinnamil (**1**) (0.200 g, 0.8 mmol) were heated at reflux in methanol (10 ml) for 12 h. After cooling, the precipitate was isolated by filtration (0.160 g, 42 %); δ_H (250 MHz, CDCl$_3$) 7.16 (1H, m, H$_{4'}$), 7.43 (1H, dd J = 5.0, 1.1 Hz, H$_{5'}$), 7.55 (3H, m, H$_m$, H$_p$), 7.74 (1H, dd J = 3.7, 1.1 Hz, H$_{3'}$), 7.82 (1H, m, H$_o$), 7.90 (1H, d J = 1.1 Hz, H$_5$), 8.75 (1H, d J = 1.1 Hz, H$_3$); *m/z* (+ve FAB) 473 (M+H)$^+$. Found: C, 75.59; H, 4.40; N, 6.11 %. Calc. for C$_{30}$H$_{20}$N$_2$S$_2$.0.25H$_2$O: C, 75.51; H, 4.30; N, 5.87 %

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