

## The Hydrolytic Behaviour of some Pentadentate Schiff-base Type Macrocycles

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(Received December 2, 1985)

### Abstract

The protonation constants of a series of pentadentate  $\alpha,\alpha'$ -diimine macrocycles based on 2,2'-bipyridine have been determined by potentiometric titration in aqueous solution, and are discussed with respect to the hydrolytic behaviour of these systems in alkaline solution.

### Introduction

The synthesis of  $\alpha,\alpha'$ -diimine macrocyclic ligands based on 2,2'-bipyridine and 1,10-phenanthroline, has most often been brought about by a metal-ion assisted condensation of the appropriate bis-(hydrazino)-heterocyclic fragment with the desired dicarbonyl species (Scheme 1) [1]. Commonly used

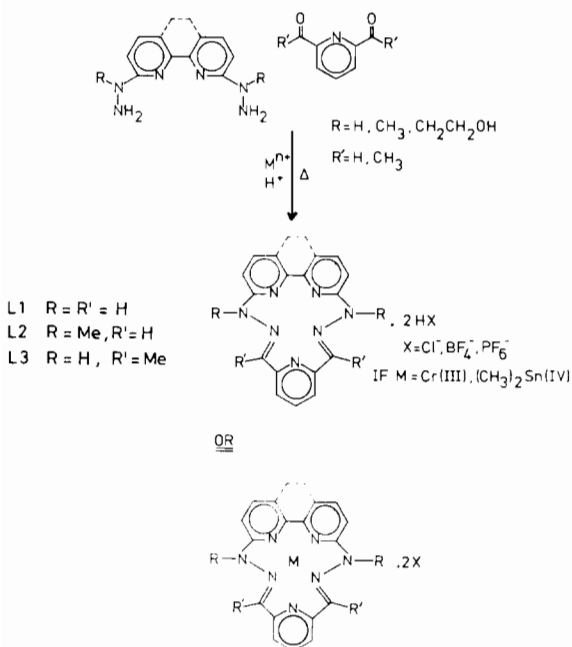
metal ions include zinc(II), nickel(II), cobalt(II), chromium(III) and tin(IV). For the latter two metal ions, the macrocyclic ligand is obtained free of metal, as the salt  $[H_2L]X_2$  [2]. Some controversy has surrounded the role played by many of these metal ions as supposed templates for the condensation reactions since, in certain cases, notably chromium(III), the yield of product macrocycle can be similar in acid solution  $pH \approx 2$  in the absence of any added metal [3]. As part of a general study of the role played by metal ions in the synthesis of macrocyclic diimine ligands, the protonation behaviour of a series of such ligands was examined by potentiometric titration in aqueous solution. The ligands studied were those based on 2,2'-bipyridine, L1, L2 and L3.

### Experimental

The ligands were synthesised by the literature methods [4] using a transient chromium(III) template, and isolated as the salts  $[H_2L]X_2$  (L1, X =  $BF_4^-$ ; L2, X =  $BF_4^-$ , L3, X =  $Cl^-$ ). Recrystallisation from dilute, aqueous HX solution yielded the products with elemental analyses,  $^1H$  NMR, infra-red and mass spectra fully in accord with the proposed formulation. Protonation constants for L1, L2 and L3 were determined by potentiometric titration in 0.05 M  $KNO_3$  solution in a cell of the form:



where  $Q \approx QH|Pt$  represents the quinhydrone electrode [5]. The solution of ligand containing a known excess of hydrochloric acid was titrated against standard 0.1 M NaOH solution using an automatic titration assembly at the University of Stirling [6]. The potentiometric cell was standardised using potassium hydrogen phthalate and tris(hydroxymethyl)aminomethane buffers over the approximate pH range 4.0 to 8.0 [5]. The water used to make up all solutions was prepared by distilling previously de-ionised water, reboiling it under a stream of nitro-

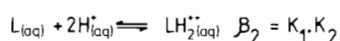
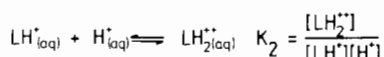
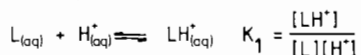


Scheme 1.

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gen and allowing it to cool, protected from CO<sub>2</sub>. The ionic medium for the titration was prepared by weight to a known density, from the Merck Suprapure reagent. An approximately 0.1 M HCl solution was prepared from constant boiling, analytical grade, hydrochloric acid and standardised by potentiometric titration against tris(hydroxymethyl)aminomethane using Gran's method to determine the end point [7]. The sodium hydroxide used as the main titrant, was standardised, again using Gran's method, against potassium hydrogen phthalate. Protonation constants were calculated from the potentiometric data using the programme MINQUAD [8] on the University of Stirling Vax computer. Experimental details of the titrations and the results are presented in Scheme 2.

For the processes;



$$L_1 \quad \log K_1 = 7.6(1) \quad \log K_2 = 3.8(1) \quad \log \beta_2 = 11.4(2)$$

$$R = 0.015 \quad Q = 0.02 \text{ mequiv}$$

$$L_2 \quad \log K_1 = - \quad \log K_2 = - \quad \log \beta_2 = 11.2(2)$$

$$R = 0.031 \quad Q = 0.03 \text{ mequiv}$$

$$L_3 \quad \log K_1 = 8.3(1) \quad \log K_2 = 3.6(1) \quad \log \beta_2 = 11.9(2)$$

$$R = 0.010 \quad Q = 0.1 \text{ mequiv}$$

Titration aliquot volume = 0.01 ml

R = crystallographic R-factor; Q = mmols of L per titration level

Scheme 2.

## Discussion

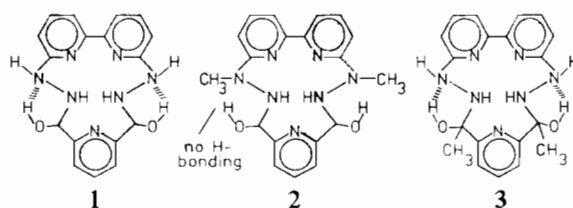
The choice of the quinhydrone electrode was a result of the observation that several different glass electrodes were found to be unreliable, giving an erratic response, possibly due to fouling of the electrode surface either by ligand absorption or by the presence of fluoride from the hydrolysis of fluoroborate in aqueous solution. Despite the useful range of the quinhydrone electrode being below pH 8 in most circumstances and the slightly longer equilibration times required in comparison to the glass electrode, no problems with regard to its use with the systems under consideration were encountered. It was found that if an acidified, standard solution of ligand was prepared in advance, a certain degree of slow ligand decomposition occurred; there-

fore the ligand salt was weighed directly into the titration vessel and the titration completed as rapidly as possible, in order to minimise decomposition.

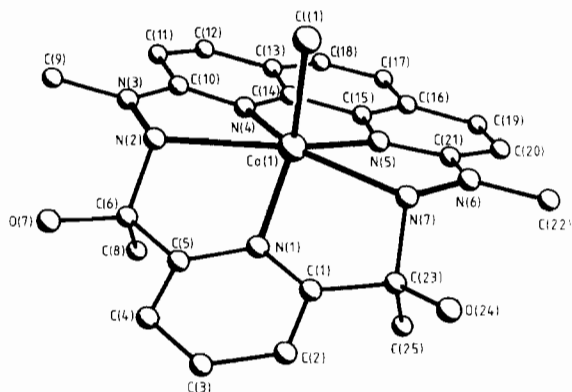
It was noted that as the pH of the titration solutions of L1 and L3 was increased above approximately pH 4, the initially orange-red solutions developed a strong green colour. The original orange colour could be regenerated upon acidification. No such colour change was observed with L2; instead, as the solution pH approached pH 7, the solution became turbid and a precipitate of 6,6'-bis( $\alpha$ -methylhydrazino)-2,2'-bipyridine was formed, presumably as a result of ligand hydrolysis. Such hydrolysis was only observed above pH 8 for L1 and L3, the solutions remaining green until complete hydrolysis had occurred.

The UV-Vis spectra of aqueous solutions of L1 and L3 were recorded as a function of pH for comparison with the known protonation behaviour. It was found that in both cases, formation of the green species was coincident with the formation of the monoprotonated ligand, an associated absorption at 600 nm reaching its maximum intensity at approximately pH 4.5, and remaining there until reduced by hydrolysis in alkaline solution. The rate of formation of the green species from the orange, was too rapid to be followed by stopped-flow techniques. A preliminary kinetic study of the loss of the green species in alkaline solution, the process being followed spectrophotometrically at 600 nm, indicated that above pH 7.5, the reaction rate was independent of [OH<sup>-</sup>], the reaction at each pH value chosen being initially first order in [L] although the behaviour became increasingly more complex as the reaction proceeded.

Although the exact nature of the green species remains uncertain, it does not seem unreasonable to assign them the structures (1-3). Such carbinol-



amine species have been isolated as their metal complexes from template synthesis and characterised by X-ray crystallography [9]. A recently completed X-ray structure of the Co(III) complex of the carbinolamine derived from a related phenanthroline based ligand is depicted in 4 [10]. Such carbinolamine species have been suggested as reaction intermediates in the formation of imine systems in general and in many enzyme-catalysed processes [11]. Carbinolamines tend, in general, to be transient species,



4

being rapidly converted either to starting materials or products, depending on prevailing conditions, unless stabilised in some way. In the structurally-characterised carbinolamines related to this work, the stabilisation is provided by coordination to a metal ion. One possible explanation of the observed difference in the behaviour of the ligands examined here is that in the case of L1 and L3, the green, carbinolamine species are stabilised by intramolecular hydrogen bonding. From molecular models of these systems, the N-methyl groups in L2 may tend to disfavour such bonding for steric reasons. The hydrogen bonded species would tend to be more resistant towards further hydrolysis. For L2, where no discrete protonation steps were observed, this could indicate that the monoprotonated species was unstable with respect to disproportionation of  $\text{LH}_2^{2+}$  and L. Without any stabilisation of the resulting carbinolamine, rapid, irreversible hydrolysis would occur, resulting in the precipitation of the acyclic precursors. This precipitation could well be the driving force for the disproportionation process.

It has been found that in the absence of added metal ion template, the macrocyclic products were not isolable unless the pH of the reaction mixture was below approximately pH 4. This is not surpris-

ing since above this pH, any macrocycle produced would exist in the carbinolamine form, with the possibility of facile hydrolysis to yield starting materials and increase the likelihood of forming unwanted, polymeric products.

A knowledge of the protonation behaviour of these pentadentate macrocyclic ligands has helped to rationalise several aspects of their behaviour in aqueous solution and can therefore be of assistance when considering the synthesis of these and related systems and the formation and behaviour of their metal complexes.

#### Acknowledgements

The authors would like to thank the S.E.R.C. for financial support. We would also like to thank Dr. Robert M. Clay and Dr. Brian G. Cox of the University of Stirling for the potentiometric and kinetic facilities and for helpful discussions.

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