Stereoselectivity and mechanism of Cu^{2+} transfer between chiral, multidentate ligands

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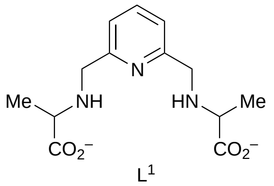
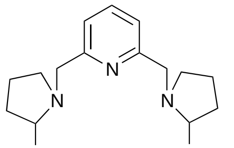
The ligand-exchange kinetics between the enantiomers of [Cu(alamp)] or [Cu(promp)] and (*S*)-pdta are measured by CD spectroscopy; three different reaction intermediates are proposed, involving the three different states of N-protonation of pdta; at pH < 7 an associative mechanism involving a cage-like, hydrogen-bonded intermediate is suggested for [Cu(alamp)] in which the metal ion is transferred in a single rate limiting step from one ligand to the other.

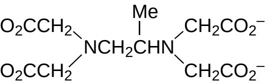
Stereoselectivity has not been used to investigate metal-ion-transfer reactions in aqueous solutions. Only two communications concerning stereoselective metal-ion transfer in organic solvents are reported in the literature. Kurganov *et al.*[1] observed rate differences in the dismutation of copper(II) complexes with N-substituted optically active diamines in acetonitrile and in nitrobenzene and Warmuth and Elias[2] reported stereoselective ligand exchange of nickel(II) Schiff-base complexes in acetone. In the following, we present some preliminary results of the stereoselective ligand exchange between the chiral copper(II) complexes of deprotonated *N,N′*-[(pyridine-2,6-diyl)bis(methylene)]bis(alanine) [alamp (L^1)] or *N,N′*-[(pyridine-2,6-diyl)bis(methylene)]bis(proline) [promp, (L^2)] and (*S*)-1,2-diaminopropanetetraacetic acid [(*S*)-H_4pdta (H_4L^3)] according to eqn. (1). From the known protonation constants of the ligands[3] and



L^1



L^2



$$\begin{array}{c} {}^-O_2CCH_2 \diagdown \quad \overset{Me}{|} \quad \diagup CH_2CO_2^- \\ NCH_2CHN \\ {}^-O_2CCH_2 \diagup \qquad \qquad \diagdown CH_2CO_2^- \end{array}$$

L^3

$$[CuL] + (S)\text{-}H_n\text{pdta}^{(4-n)-} \rightleftharpoons [Cu\{(S)\text{-pdta}\}]^{2-} + H_mL^{(2-m)-}$$

$$L = (R,R)\text{- or } (S,S)\text{-}L^1,\ (R,R)\text{- or } (S,S)\text{-}L^2 \qquad (1)$$

the formation constants of [CuL^1], [CuL^2][4] and [CuL^3]$^{2-}$,[5] it can be calculated that the equilibrium (1) lies to more than 96% to the right, and that the concentration of free Cu^{2+} is < 1% over the whole pH range from 4 to 11 under the measurement conditions. Reaction rates are determined under pseudo-first-order conditions, the exchange ligand $H_n$pdta$^{(4-n)-}$ being initially present in a tenfold excess. The rate of the reaction is best measured by the change of the intensity of the circular dichroism (CD) at λ = 607 nm, at which the product complex has no CD signal.

From the observed rate constants, represented as a function of pH in Fig. 1,† the following conclusions can be drawn: (*i*) for both [CuL^1] and [CuL^2] the reaction takes place by at least three different pathways corresponding to the two protonated and the entirely deprotonated form of pdta as indicated in Scheme 1; (*ii*) with L^1 as the ligand the reaction is fastest with H_2pdta^{2-}, whereas the relative rates with [CuL^2] are Hpdta^{3-} > H_2pdta^{2-} > pdta^{4-}; (*iii*) all the reactions show small but significant stereoselectivity, which is highest for the exchange reaction between [CuL^1] and H_2pdta^{2-} in the pH range 4–7. The ratio of the observed rate constants for the two diastereoisomeric couples is k_Δ/k_Λ = 1.3 ± 0.1 {k_Δ stands for the reaction between [Cu{(*R,R*)-L^1}] and (*S*)-pdta}.

The observed stereoselectivity clearly indicates an associative mechanism but the concentration of the intermediate must be low, the rate of the reaction having linear dependence up to a pdta concentration of 0.03 M ($K_i \leqslant 3$ dm^3 mol^{-1}). However, the most interesting observations are: (*i*) the acceleration of the reaction involving [CuL^1] by the presence of the two N–H protons on the exchange ligand, protons which have to be replaced by the metal ion, and (*ii*) the striking difference in the selection of the most favourable reaction pathway for [CuL^1] and [CuL^2]. The only difference between the two complexes able to influence this mechanistic selection is the presence of the two N–H groups in the former, groups which are replaced by alkyl residues in the latter. It becomes therefore evident that in

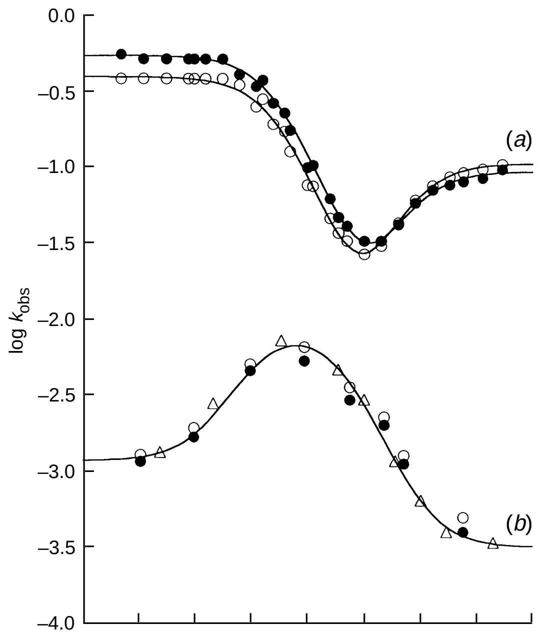
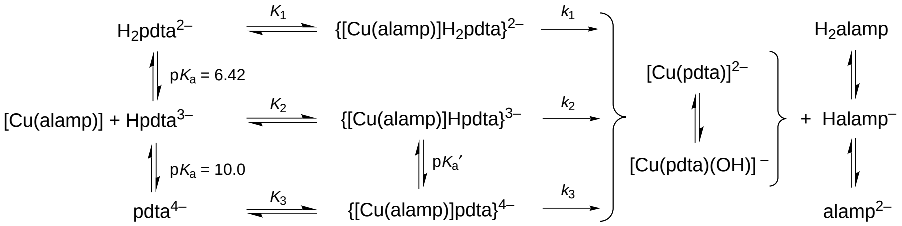


Fig. 1 Observed rate constants for the reaction between [Cu(alamp)] (*a*) or [Cu(promp)] (*b*), with (*S*)-pdta as a function of pH. [Cu^{2+}] = 1 × 10^{-3} M, [alamp] or [promp] = 1 × 10^{-3} M, [(*S*)-pdta] = 1 × 10^{-2} M, [buffer] = 0.2 M {pH = 4.0–5.5 (acetate, values extrapolated to zero buffer concentration), 5.6–6.5 [2-morpholinoethanesulfonic acid monohydrate (MES)], 6.6–7.9 [3-morpholino-2-hydroxypropanesulfonic acid (MOPSO)], 8.1–10.1 (borate)}. Buffer concentration refers to the ionic constituent. *T* = 20 °C; (○) (*R,R*)-ligand, (●) (*S,S*)-ligand, (△) *rac*-pdta.



Scheme 1

the exchange with [CuL^1] the N–H groups of both ligands, H_2pdta^{2-} and alamp are important for stabilising an intermediate containing four hydrogen bridges, a possible structure of which is shown in Fig. 2. Such an intermediate cannot be formed with [CuL^2].

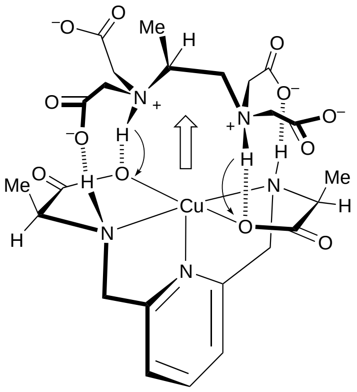


Fig. 2 Possible transition state in metal-ion transfer between [Cu{(*S*,*S*)-alamp}] and (*S*)-H_2pdta^{2-}

Whereas metal-ion transfer between multidentate ligands usually takes place by multistep substitutions, involving intermediates containing dangling groups,[6,7] the proposed hydrogen-bonded intermediate allows a transfer in a concerted single-step reaction avoiding any intermediate solvation and desolvation steps except the elimination of the coordinated water molecule from the starting copper(II) complex. Furthermore, the simultaneous transfer of the two protons ensures the conservation of the local charge distribution during the reaction.

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Footnotes

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† The lines in Fig. 1 represent best fits of the measurements, according to Scheme 1, by using the following values {only mean values were used for the two enantiomers of [Cu(promp)]}

	pK_a'	K_1k_1	K_2k_2	K_3k_3
		$dm^3\ mol^{-1}s^{-1}$		
[Cu{(*R*,*R*)-alamp}]	8.85	39	0.6	10.5
[Cu{(*S*,*S*)-alamp}]	8.85	54	0.95	9.3
[Cu(promp)]	7.6	0.115	0.87	0.031

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