A New Synthetic Route for Transition Metal Complexes with Schiff Bases

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Abstract

A new preparation method of Schiff base metal complexes is proposed, based on the transimination reaction between ammonium or ammonium-like salts and the imino portion of some N-substituted salicylaldimine–metal chelates. The reaction was carried out through a general acid catalysis induced by the ammonium ions and by the metal centre. It was mainly applied to the preparation of Ni(II), Cu(II) and Co(II) complexes. The reaction took place rapidly on addition of a slight excess of the ammonium salt to a non-aqueous solution of the Schiff base complex, at room temperature. The method can also be applied to the preparation of *N*-salicylidene amino acid complexes.

Introduction

Schiff bases and the relevant metal ion complexes find interest in organic chemistry, biochemistry and inorganic chemistry. Enzymatic aldolization [1], enzymatic decarboxylation [2], and perhaps, even the visual process [3] all appear to involve Schiff base formation and hydrolysis. Pyridoxal phosphate-dependent enzymatic reactions also seem to involve both the hydrolytic and aminolytic cleavage of Schiff bases [4].

Schiff base formation involves a two-step reaction between the carbonyl compound and the amino compound [5]. Metal ions contribute to the formation of Schiff bases by creating stable complexes, thus producing a favourable overall free energy of reaction [6]. Furthermore, the metals were found to catalyze these reactions by serving as a reaction template [7] and acting as rudimentary enzymes. Moreover, numerous studies have established that imines, particularly when present in cationic form $>C=N^{+}<$, readily undergo reaction with a variety of nucleophilic reagents [8]. The reaction with amines (transimination or 'trans-Schiffization') occurs by attack on the protonated or cation imine, as in the case of other additions to this group [9].

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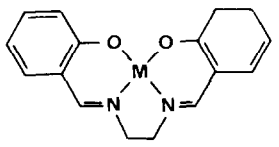
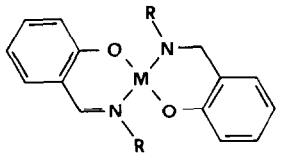
Despite the large number of studies available, the transimination reaction involving an iminic group directly coordinated to a metal centre has never been investigated. For this reason, it was decided to promote a study on the kinetics [10] and equilibria [11] between Schiff bases coordinated to various transition metals and ammonium or ammonium-like ions including the amino acids.

This study also made it possible to realise a new synthetic method of these complexes, which is reported in this paper. The Schiff bases considered here are derived from the salicylaldehyde and are coordinated to transition metals.



≡ M Salen



≡ M (BS-R)$_2$

Experimental

Materials

All the salts and the solvents employed were obtained commercially and used with no further purification.

Preparation of the Schiff Base Complexes

The complexes were prepared according to the methods described in the literature [12] and then employed for the transimination reactions (eqns. (1) and (2)), which were obtained by mixing a four-fold excess of the chloride of an ammonium salt, $R'NH_3Cl$, with complex $M(BS\text{-}R)_2$ methanol. The salts and complexes examined in this paper are reported in Table 1. The typical preparation of a compound is as follows.

Bis(*N*-salicylaldimino)nickel(II): $Ni(BS\text{-}R)_2$ (1 g, about 2.5 mmol), where R = alkyl or aryl, and NH_4Cl (0.5 g, about 10 mmol) were mixed in 50 ml of

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TABLE 1. Transimination reactions between $M(BS\text{-}R)_2$ or MSalen and $R'NH^+_3$ chlorides in methanol[a]

Complexes	R'							
	H 9.2[b]	Me 10.6[b]	Et 10.6[b]	Bu 10.6[b]	Ph 4.6[b]	HO 5.8[b]	H_3N 7.9[b]	$H_3NC_2H_4$ 6.9[b]
$Ni(BS\text{-}H)_2$		1, −1	1, −1	1, −1	2	1	2	1
$Cu(BS\text{-}H)_2$		1, −1		1, −1	U	1	2	1
$Ni(BS\text{-}Et)_2$	1, −1	U		1, −1	2	1	2	1
$Ni(BS\text{-}Bu)_2$	1, −1	U	1, −1		2	1	2	1
$Ni(BS\text{-}Ph)_2$	1, 2	N	N	N	2	1	2	1
$Cu(BS\text{-}Ph)_2$	N	N	N	N		U	2	1
$Ni(BS\text{-}OH)_2$	N	N	N	N	N		N	1, −1
NiSalen	N	N	N	N		1, −1	N	
Other reactions:								
M = Ni	R = H, Ph, OH		R' = DNH[e]			reaction (2)		
M = Co	R = H		R' = $H_3N\text{-}C_2H_4$			reaction (1)		
M = Ni, Cu	R = H		R' = HOC_2H_4, Gly[c], GlyEt[d]			reaction (1)		

1, −1, 2 indicate that the reaction products are those predicted by the direct eqn. (1), by that inverse (−1) and by eqn. (2), respectively; N = reaction has not been observed; U = the reaction gives unidentified products. [a]Likewise in ethanol and acetonitrile; in tetrahydrofuran and chloroform, the reactions are slower and gave smaller yields. [b]pK_a in water [14]. [c]Glycine hydrochloride. [d]Glycine ethyl ester hydrochloride. [e]2,4-Dinitrophenyl-hydrazine hydrochloride.

methanol. The solution was stirred for 30 min at room temperature, or at 50–60 °C if the reagents were not very soluble. During this time, the colour changed from green to red and a precipitate began to form. The solid obtained (yield 90%) was separated by filtration, washed with water and recrystallized from acetone.

In some cases, the reaction product was obtained by concentrating and cooling the solution; in other cases, the solvent was completely evaporated and the residue was washed with water, in order to eliminate the excess of ammonium salt, which enhances significantly the solubility of complexes in organic solvents.

The reaction between NiSalen and NH_3OHCl was exceptionally slow, and the mixture was allowed to reflux for 20 h.

All reaction products were recrystallized, dried under vacuum and identified by elemental analysis and infrared spectra.

Results and Discussion

The transimination reaction of free Schiff base and amine is known to occur both when the imine group is in the cationic form (>C=N$^+$<) and when the reaction is subject to general base catalysis by a second amine molecule [9].

In Schiff base metal complexes, iminic nitrogen has a partially cationic nature. This proves that the transimination reaction with these compounds is possible. However, this reaction seems to be very slow. As a matter of fact, only two significant examples [13] of this reaction, often performed in very drastic experimental conditions are reported in the literature: the chelate refluxed with excess amine or in amine used as solvent. Under these conditions, several complexes examined underwent decomposition and the reaction yield was always small. The reduced reactivity must be related to the smaller cationic nature of the iminic nitrogen bonded to the metal instead of the proton. In our opinion, this restriction can be overcome by using an ammonium salt instead of amine, thus producing a general acid catalysis directly induced by the reagent. A detailed mechanistic pathway of this reaction will be published elsewhere [10].

Bidentate Schiff base metal complexes, $M(BS\text{-}R)_2$, react with ammonium (or ammonium-like) salts rapidly giving almost quantitative yields according to eqn. (1)

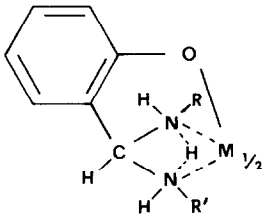
$$M(BS\text{-}R)_2 + 2R'NH_3^+ = M(BS\text{-}R')_2 + 2RNH_3^+ \quad (1)$$

In some cases the transimination reaction gives the free Schiff base (eqn. (2))

$$M(BS\text{-}R)_2 + 2R'NH_3^+ = 2HBS\text{-}R' + 2RNH_2 + Me^{2+} \quad (2)$$

The results are reported in Table 1.

Reactions (1) and (2) are possible only with salts derived from ammonia or primary amines $R'NH_3^+$, i.e. when at least three hydrogen atoms are bonded to the same nitrogen atom. This can be justified by assuming the geminal diamine intermediate formation.



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The intramolecular migration of the protons allows the coordination exchange of the two nitrogens and the formation of a new complex (eqn. (1)) or of a new Schiff base (eqn. (2)).

Vice versa, secondary and tertiary amine salts readily give addition to the iminic double bond but not transimination. In this case, deamination of intermediate **1** can only give the unreacted starting compound. The formation of intermediate **1** also justifies a second general observation which can be drawn from Table 1: reactions (1) and (2) always take place when the $R'NH_3^+$ acidity is greater than RNH_3^+. This condition favours both the intermediate formation and the following intramolecular protonic exchange towards the final product. However, as reactions (1) and (2) are equilibrium reactions, the equilibrium position will be influenced by the mass effect and by the relative stability and solubility of the reagents and products. Thus, it was possible to conduct the reactions in both directions by changing these factors (see Table 1, reactions (1) and (−1)).

Reaction (2) occurs essentially with the anilinium salt. The marked acidity of this furthers its addition to the iminic double bond and the following protonic exchange, but the mesomeric effects of the phenylic group reduce the electronic density on the nitrogen and the bonding M–N strength. The Schiff base is released through the phenolic oxygen protonation from the 'strong' acid $PhNH_3^+$.

By using the diamine salts the transimination reaction yields a quadridentate Schiff base. Reaction (1) with ethylenediamine dihychloride, gives the MSalen complex through an intramolecular process which follows the addition to the first double iminic bond. With a similar mechanism, the hydrazinium ion releases the (2-hydroxyphenyl)methylenehydrazone (HBS–N–N–BSH) which is unable to supply a stable coordination owing to the strong tension on the N–M–N bond angle.

Finally it should be noted that even the NiSalen complex, which is described in the literature [11, 15] as a complex able to give stable adducts with the ammonium salts, can give transimination if the reaction times are protracted conveniently and a large salt excess is used.

The possibility of applying reaction (1) to the amino acid salts as well, appears very important. The introduction of these groups is as fast as that of other ammonium salts and, from a synthetic-mechanistic point of view, it opens interesting prospects for this class of reactions which are involved in several processes of biological interest. The $Cu(BS\text{-}H)_2$ complex reacts in ethanol with glycine ethyl ester hydrochloride or with glycine hydrochloride in order to produce the complexes bis(ethyl *N*-salicylideneglycinato)Cu(II), $Cu(BS\text{-}GlyEt)_2$, or bis[(*N*-salicylideneglycinato)Cu(II)], $[Cu(BS\text{-}Gly)]_2$, respectively. The first reaction also occurs with $N(BS\text{-}H)_2$ and if carried out in methanol it gives the corresponding methyl derivative complexes (ester-exchange reaction) [13, 16].

The Zn(II) and Pd(II) complexes also underwent transimination exchange (reaction (1)), but in low yields (about 30–40%). In these cases, by-products of hydrolysis or reduction are obtained too, similarly to the traditional synthesis reactions [12].

With regard to the solvent function, it was observed that those having a small dielectric constant, and thus low dissociating properties, such as chloroform and tetrahydrofuran, drastically decrease the transimination rate due to the lowered ionic concentration of $R'NH_3^+$.

In conclusion, we think that, despite the limited number of cases examined, the proposed transimination reaction has a general validity which can be extended to other metal centers and can represent a positive alternative to traditional methods. This reaction is characterized by high yields, by a high rate at room temperature, and by its simplicity: it is possible to obtain complexes with various substituents on the iminic nitrogen using other complexes easy to prepare and amine chloridrates, which are easier to find and to be purified than the amines used in traditional methods.

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