

Transition Metals in Homogeneous Catalysis

Part I: Cupric amino acid complexes

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ABSTRACT. The importance of the transition elements in modern chemistry is emphasized with special mention of their role in catalysis. A new copper coordination complex is described, bis(2-methyl, 5-phenyloxazolidine-4-carboxylato) copper (II) dihydrate. This compound is isolated as an intermediate in the copper-catalysed condensation reaction of aldehydes on amino-acids and is of importance in the synthesis of food products starting from petroleum derivatives.

Metal ions play an important role in the control mechanisms of chemical reactions and in particular, transition metals are crucial components of many catalysts. Two broad classes of chemical compounds may contain transition metals: coordination complexes and organometallic compounds. Complexation of organic or inorganic ligands to transition metal ions yields complex structures where the coordinated molecules have different properties and reactivities than in the free state. The bonding type is mainly ionic or of the Lewis acid-base form. Thus, the strength of the bonds depends on the charge on the metal ion and on the basicity of the ligand donor groups (Hay 1976 and Angelici 1973).

Formation of metal-carbon bonds yields organometallic compounds which are well known intermediates in catalytic reactions. Many such synthetic complexes, usually air-sensitive, have been isolated and characterized. This knowledge contributes greatly to the understanding of reaction mechanisms and to the elaboration of new pathways for the production of useful molecules. The bonding in organometallics is usually

covalent and comprises direct sigma metal-carbon bonds as well as extensive π electrons.

Most industrial chemists use heterogeneous catalysis as a convenient means of preparing organic compounds or purifying petroleum derivatives in an economic way, ideally by recycling the solid catalyst if it is not inactivated by degradation. However, homogeneous catalysis is often necessary when one wants specific compounds in high yields with minimal isomerism. Thus, soluble molecular transition metal complexes or clusters are being synthesized so improvements can be made in the design of new catalysts. The link between heterogeneous and homogeneous catalysis has been pointed out recently (Osborn 1981).

We now wish to report the isolation and characterization of a solid copper coordination complex of a substituted amino acid, bis(2-methyl, 5-phenyloxazolidine, 4-carboxylato) copper (II) dihydrate. This complex is of importance in the synthesis of food products starting from petroleum derivatives, as outlined in Figure 1. Indeed using the well-known Wacker process, ethylene is oxidized to acetaldehyde using palladium and copper chlorides as catalysts (Hartley 1973). Higher aldehydes can also be produced in hydroformylation reactions catalyzed by cobalt carbonyls, starting with simple compounds widely available to the petroleum industries, namely olefins, hydrogen and carbon monoxide gases (Heck 1969). Glycine is made by improved Strecker synthesis (Greenstein and Winitz 1961) where sodium cyanide and formaldehyde are reacted with ammonia, followed by acid or base hydrolysis. The overall reaction scheme would be the following:

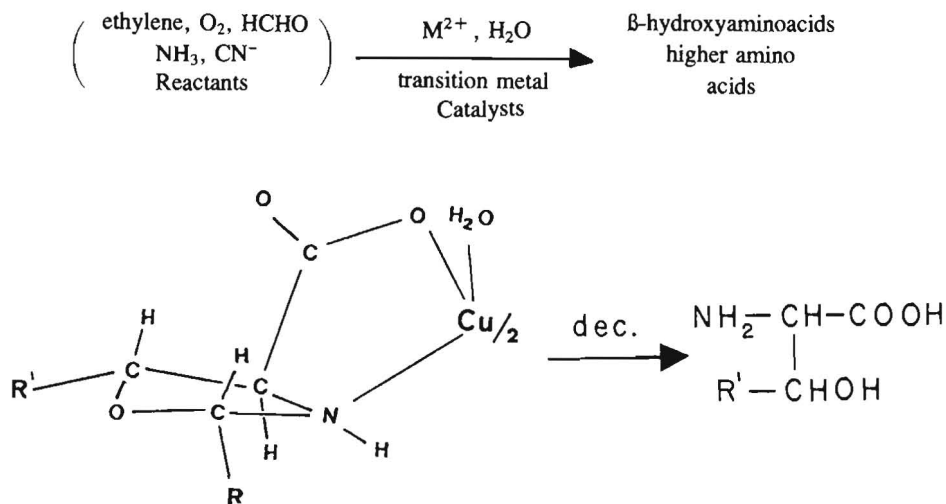


Fig.1. Structure of the copper complex which yields β -hydroxyamino acids. R = CH₃, R' = phenyl or methyl.

Experimental

The reactants were made by mixing equimolar amounts of amino-acids and sodium hydroxide with a half-equivalent quantity of cupric sulfate pentahydrate. Reagent grade products were used throughout. The resulting precipitate of bis(glycinato)aquocopper-(II) was filtered and washed with cold water.

Acetaldehyde was reacted with copper glycinate as described previously (Sharrock and Eon 1979) and the solid intermediate complex was isolated and recrystallized once from methanol. The same reaction, as described elsewhere using mixed aldehydes, yielded the analogous intermediate complex, with a phenyl group replacing a methyl group when 2 moles of acetaldehyde were replaced by 2 moles of benzaldehyde. This light-blue complex was less soluble in water than its methyl analogue, but could be recrystallized from pyridine without formation of a new adduct. We reported previously that decomposition of these solid intermediate complexes yielded pure *threo* forms of β -hydroxyamino acids. The elemental analyses are consistent with the formulation as $\text{CuC}_{22}\text{H}_{28}\text{O}_8\text{N}_2$. Infrared spectra were recorded on a Perkin Elmer model 621 grating spectrometer and electron paramagnetic resonance spectra obtained with a Varian E-9 X-band spectrometer using quartz sample cells. Thermogravimetric analysis was carried out with a Setaram electrobalance and a fully programable oven, under air and nitrogen atmosphere (150 ml/minute) and a heating rate of $5^\circ\text{C}/\text{min}$.

Results and Discussion

When acetaldehyde and benzaldehyde are added to copper glycinate in aqueous base an exothermic reaction takes place with formation of a dark blue solution. So it may be presumed that acetaldehyde reacts more rapidly than the benzaldehyde (Shaw and Fox 1953) on the coordinated glycine. After a few hours at room temperature a precipitate forms which is more abundant than in the pure acetaldehyde case, reflecting the lower solubility of the new complex. In previous work it was shown that mixtures of β -hydroxyamino acids result from the decomposition of the reaction mixtures, with a larger proportion of substituted serines in mixed aldehyde reactions (Sharrock, submitted). An equilibrium probably exists in basic solutions between the various possible products. This also explains the epimerization noted on optically active copper serine systems (Bush *et al.* 1973). However, the solid intermediate complex yields a much improved yield of *threo* β -phenylserine and can be explained by assuming the equilibrium is displaced in favour of the substituted serine because of the lower solubility of the intermediate oxazolidine complex.

Similar solids were also obtained with *iso* and *n*-butylaldehyde, but tended to separate out as large lumps which were not further purified. The infrared spectrum is shown in Fig. 2 and shows absorption typical of OH vibration at 3400 cm^{-1} and CH vibration near 3000 cm^{-1} . A strong antisymmetric and a medium symmetric carboxy-

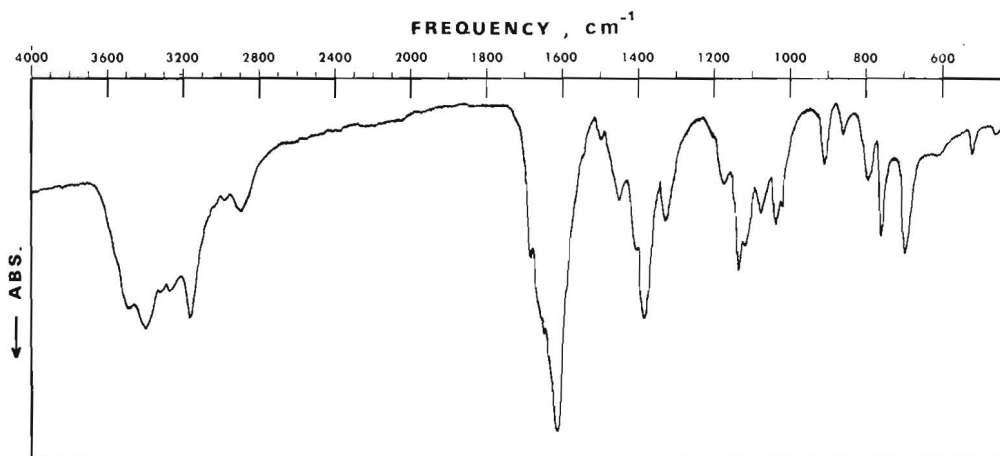


Fig.2. Solid state (KBr pellet) infrared spectrum of the phenyl-substituted complex.

late stretching mode appears at 1610 and 1380 cm^{-1} respectively, as well as other numerous bands in the "fingerprint" region.

The epr spectra of the phenyl-substituted complex is shown in Figure 3 and compared to that of the known intermediate. In methanolic solutions, a copper hyperfine coupling constant of 72 gauss is observed, with a g value of 2.13, compared to 74 gauss and $g = 2.13$ for the dimethyl compound. The more pronounced asymmetry in the copper hyperfine linewidths for the phenyl compound can be related to its larger hydrodynamic radius and slower tumbling rate (Wertz and Bolton 1972). The solid powder spectra are typical of non-magnetically dilute samples with dipolar broadening. Nevertheless, the absorptions are similar to those observed for bis(amino-acid) copper complexes (Yokoi *et al.* 1972) of tetragonal symmetry.

The thermogravimetric analysis confirms the complex is a dihydrate, losing water near 100°C and accounting for a 7% weight loss. Decomposition follows near 180°C with an initial weight loss near 40%. The final weight of sample is 15.5% of the starting weight and corresponds to the theoretical 15.6% expected for CuO. These results are similar to those published for the dimethyl complex (Maldonado *et al.* 1971), except that a smaller weight loss was obtained under nitrogen atmosphere, with 35% remaining at 500°C. The black tar obtained confirms incomplete combustion of the organics under nitrogen. The results show that discrete molecular copper complexes can be isolated as solid intermediates in aldol-type condensations on copper glycinate. These are useful in understanding the mechanism of the reaction and in isolating stereospecific amino-acid end products.

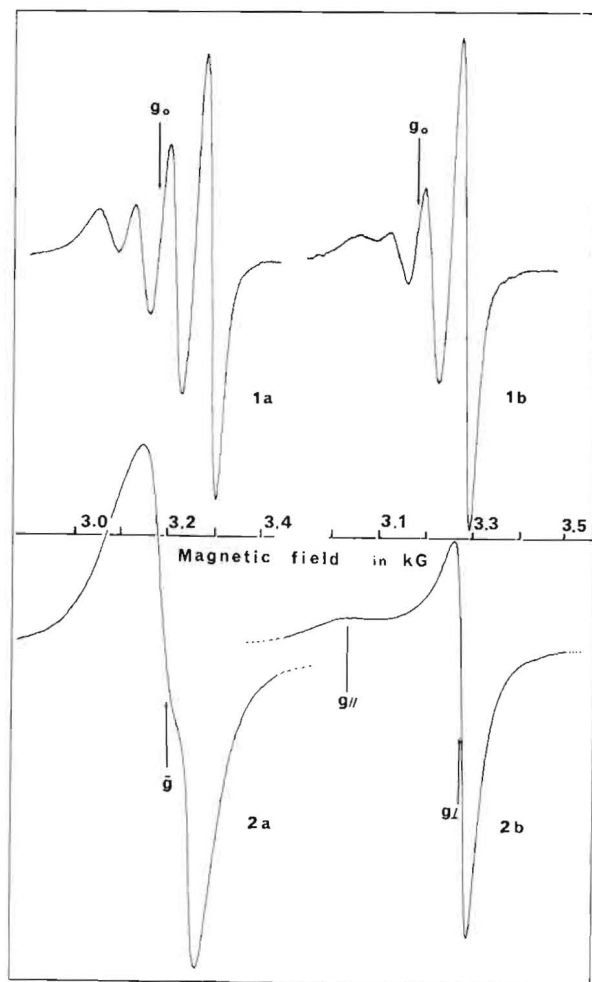


Fig.3. First derivative EPR spectra of the copper amino-acid complexes.

1a: Acetaldehyde intermediate, CH_3OH solution,
 $g_0 = 2.13$, $\nu = 9.454 \text{ GH}_z$

1b: Benzaldehyde intermediate, CH_3OH solution,
 $g_0 = 2.13$, $\nu = 9.454 \text{ GH}_z$

2a: Acetaldehyde intermediate, solid state,
 $g = 2.1333$, $\nu = 9.538 \text{ GH}_z$

2b: Benzaldehyde intermediate, solid state, recrystallized from DMSO,
 $g_{//} = 2.246$, $g_l = 2.075$, $\dot{g} = 2.132$, $\nu = 9.530 \text{ GH}_z$.

Conclusion

Transition metal chelates, of the type studied here, are well known for changing the reactivity of amino-acids and peptides. Through coordination, functional groups may be activated by various metal ions (Pasini and Casella 1974). Formation of peptide bonds has been demonstrated (Brack *et al.* 1975) as well as hydrolysis of coordinated amino-acid esters (Buckingham *et al.* 1967). It has been shown previously that using copper as a catalyst, and simple 2-carbon molecules available from petro-chemicals such as ethanolamine and acetaldehyde that the essential amino-acid threonine may be obtained in good yields and used, for example, in protein synthesis and enrichment (Maldonado 1970). Akabori first suggested that these reactions were of primordial importance in pre-biotic media, were the primitive "amino-acid soup" may have been formed by reactions catalysed by minerals such as clays (Akabori *et al.* 1956). It must be recognized that condensation reactions are complex and may be extended to a large variety of substituted amino-acids. This illustrates well how a metal ion can be a unique catalyst by assembling reactants, activating a reaction and giving a stereoselective product. These transformations all take place inside the "coordination sphere" and are typical of ionic transition metal complexes.

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العناصر الانتقالية في الحفز المتجانس الجزء الأول: معقدات الأحماض الأمينية النحاسية

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يؤكد المقال على أهمية العناصر الانتقالية في الكيمياء الحديثة وبشكل خاص دورها في المحفزات ويصف أيضاً تحضير وعزل معقد جديد لعنصر النحاس، وأهمية هذا النوع من المركبات في اصطناع مواد غذائية بدءاً من مشتقات البترول.