THE ROLE OF COPPER(I) COMPLEXES IN THE SELECTIVE FORMATION OF OXAZOLES FROM UNSATURATED NITRILES AND DIAZOESTERS

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Summary

The 1,3-dipolar addition of ketocarbenes (generated from diazoesters) to nitriles is promoted at room temperature by palladium acetate and even more efficiently by copper trifluoromethanesulphonate. The reduction of copper(II) to copper(I) is a key step in the catalytic process, as shown by kinetic studies, EPR and polarography.

Introduction

As part of a general investigation of transition metal catalyzed reactions of diazo compounds, we recently studied the addition of alkyl diazoacetates (ADA) to nitriles and observed the easy formation of oxazoles (III) in the presence of $Pd(OAc)_2$ as catalyst [1].

$$RC \equiv N \ + \ N_2CHCOOR' \longrightarrow \text{(III)} \ + \ N_2 \tag{1}$$

$$(I) \qquad\qquad (II)$$

In the case of unsaturated nitriles ($R = CH_2=CH$, $CH_2=C(CH_3)$, $C_6H_5CH=CH$) the competition between the triple and the double bond results in a highly selective attack of the nitrile group (80 % yield with maleic anhydride (MAN)), whereas only the olefinic function is involved in the non-catalytic process.

A recent publication by Kochi [2] on the high efficiency of copper(II) trifluoromethanesulphonate, $Cu(OTf)_2$, as catalyst for the cyclopropanation of olefins, prompted us to compare the behaviour of $Pd(OAc)_2$ and $Cu(OTf)_2$ as catalysts with nitriles as substrates. We find that even better yields in oxazoles (III) are obtained when the copper salt is used instead of the palladium salt, except for acrylonitrile (see Table 1). Furthermore the copper catalyst is more convenient for mechanistic studies, since it is more stable and since the oxidation states of copper are more easily detected and the corresponding physico-chemical measurements are more reliable.

Results and discussion

A. General catalytic behaviour

The kinetics of the reaction (followed by measuring the volume of the evolved nitrogen) indicate the formation of new complexes from the initial $Cu(OTf)_2$, with consequent enhanced reactivity (Fig. 1, curves a and b). Thus addition of ADA to a nitrile solution of $Cu(OTf)_2$ leads initially to a very rapid evolution of a definite amount of nitrogen, which is proportional to the concentration of the copper complex; subsequently, a smooth curve is observed during the whole reaction (Fig. 1a). Addition of a further amount of ADA does not again cause an initial rapid nitrogen evolution; a smooth curve is obtained from the beginning (Fig. 1b) and the rate is higher. Further addition of ADA does not cause any further modification to the kinetics, and the reaction is first order in both diazoester and catalyst: $R = k[ADA][Cu]$. Using $Cu^IOTf(C_6H_6)_{0.5}$ as catalyst (prepared by refluxing Cu powder and $Cu(OTf)_2$ in C_6H_6), the same kinetic behaviour is observed as in curve (b),

Fig. 2. (A) $[Cu^{2+}]$ (in arbitrary units) measured by EPR spectroscopy. (B) Volume of N_2 formed during the reaction. $[Cu(OTf)_2]$ 2.7×10^{-4} mol; $[N_2CHCOOBu]$ 1.76×10^{-3} mol; solvent 5 ml methacrylonitrile; T 313 K.
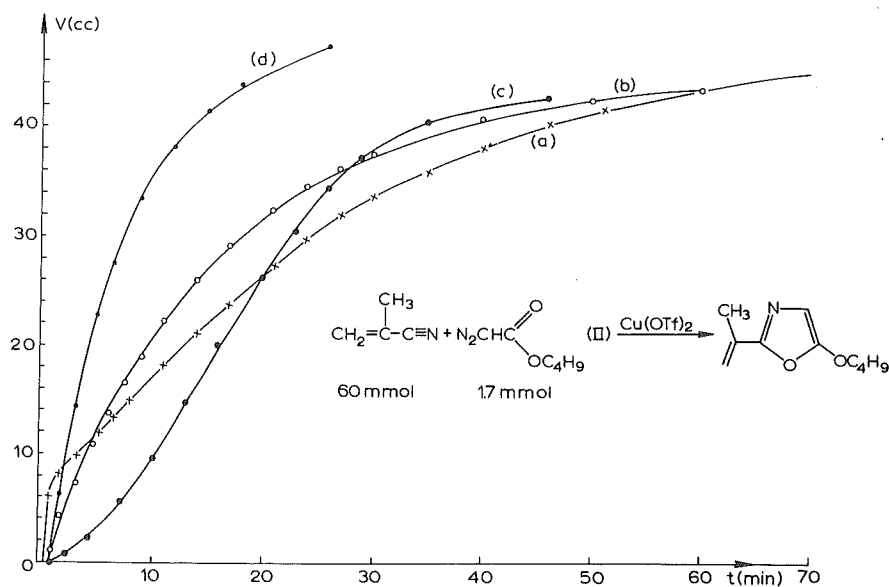
Fig. 1. Selective formation of copper(I) complexes in unsaturated nitriles, with 0.17 mmol $Cu(OTf)_2$ as catalyst at 30°. (a) First addition of $N_2CHCOOC_4H_9$ (II), (b) second and third addition of II, (c) after oxidation by O_2 and (d) second addition of II after oxidation.

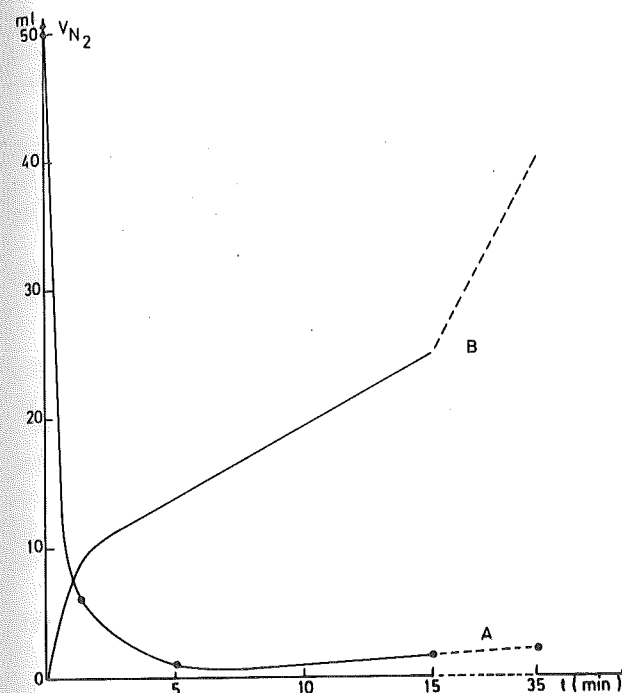without any induction period. These results may be interpreted in terms of a preliminary reduction of copper(II) to copper(I) species, which would correspond to the stoichiometric fast initial reaction in curve (a).

Such reduction has been suggested by Kochi [2] in the case of the cyclopropanation of olefins; with nitriles, we have obtained additional direct evidence for the quantitative reduction of Cu^{II} to Cu^I: indeed, in the EPR spectra of copper(II) trifluoromethanesulphonate solution, the signal ($A_{\|} = 145$ Oe, $g_{\|} = 2.333$, $g_{\perp} = 2.051$) due to Cu^{II} disappears completely upon addition of ADA. Furthermore the comparison of these EPR measurements with kinetic data (Fig. 2) shows that the reduction of copper(II) to copper(I) is parallel to the first part of curve (a). The initial break in curve (a) is therefore associated with the reduction of the copper(II) ion by the diazo ester.

Similarly, in polarographic measurements in acetonitriles, the wave ($E_{1/2} = + 1.03$ V) due to Cu^{II} disappears when a slight excess of ADA is added to a $Cu(OTf)_2$ solution with simultaneous appearance of a new wave ($E_{1/2} = + 0.62$ V) corresponding to reduction to Cu^I. (The system $Co^{3+}Cp_2ClO_4/Co^{2+}$ was used as reference potential).

B. Structural modifications of the catalyst

Several results indicate the very important role played by the coordination of ligands. First, the selectivity versus the site of attack (C=C or C≡N)

in the case of unsaturated nitriles suggests a reaction wherein the substrate is coordinated by the C≡N function.

A second indication comes from the modification of the kinetics in the presence of solvents as different as hexane, benzene, and ethyl acetate: all of them dramatically depress the yield in oxazole (III), and promote the dimerization of the ketocarbene. The rate of nitrogen evolution, on the other hand, is considerably enhanced. It seems that the occupation of some coordination positions on the copper(I) complex by the substrate (nitrile ligands) is a determining factor in functional selectivity. This implies that the nitrile ligand can compete successfully in the coordination with a second molecule of diazo ester and so promote oligomerization reactions of the ketocarbene. Such complexes of Cu^I and Cu^{II} with nitriles are well known; both $Cu^{II}(ClO_4)_2·N_4$ [3] and $Cu^{II}(SO_3F)_2·N_4$ [4] have a square planar configuration with four nitriles (N) coordinated through the lone pair of the nitrogen atoms. The related Cu^I complexes [3,4] probably involve the same type of bonding, in a tetrahedral geometry. Such a coordination is clearly demonstrated for $Cu(OTf)_2$ by the IR spectra of their solutions in MAN: $\Delta\nu(C≡N)$ in $[Cu^{II}N_4]^{2+}$ = 40 cm^{-1}, $\Delta\nu(C≡N)$ in $[Cu^I N_4]^+$ = 10 cm^{-1}.

Thirdly, the oxidation of the active complex by molecular oxygen, followed by a further addition of the diazo ester leads to curve (c) (Fig. 1). In contrast to the previous experiments, the rapid stoichiometric evolution of nitrogen due to the reduction of Cu^{II} to Cu^I is not observed; on the contrary, a small induction time is necessary prior to the development of a catalytic activity even higher than that before. A further addition of the diazo ester (curve d) confirms that the oxidation has not reformed the initial Cu^{II} salt, since a novel species, which has an extremely high catalytic activity in terms of overall rate, is formed by the reduction in curve (c) (Fig. 1). The yield of oxazole, however, is decreased significantly under these conditions (from 80 down to 30 %) and alkyl maleate and fumarate are formed.

Finally, with $Cu(OTf)_2·Pyr_4$, a substantial induction period is observed which may be ascribed to the necessity of displacing the pyridine ligands prior to the reduction of copper.

In conclusion. These results support a reaction scheme which implies not only a reduction of Cu^{II} to Cu^I species, but also a determinant role of the ligands (and in particular the reactants) in forming the most efficient catalytic species.

TABLE 1

REACTION 1 FOR DIFFERENT NITRILES IN THE PRESENCE OF COPPER TRIFLATE

Conditions: Butyl diazoacetate: $1.75 \times 10^{-3}M$; $Cu(OTf)_2$, anhydrous: $2.7 \times 10^{-5}M$; in 3 ml RCN under N_2 at 293 K. The yields were determined by GLC with an ester standard.

R	Oxazole yield (%)
$H_2C=C(CH_3)$	80
$H_2C=CH$	15
$C_6H_5CH=CH$	50 (313 K)
CH_3	60
C_6H_5	50

These reactions are obviously of definite mechanistic interest in the coordination chemistry of diazo compounds and carbenes. Moreover, they have considerable preparative value, since they represent a unique direct route to unsaturated oxazoles involving use of only catalytic amounts of metal complexes (contrast to ref. 5, where large amounts of metal salts are used in obtaining rather low yields). Some of these oxazoles are new monomers, the addition polymerization of which is being investigated.

Experimental

Preparation of copper(II) trifluoromethanesulphonate. $Cu(OTf)_2$ was prepared by dissolving copper oxide in aqueous trifluoromethane sulphonic acid and evaporating the solution to dryness.

Preparation of copper(I) trifluoromethanesulphonate. $CuOTf(C_6H_6)_{0.5}$ was prepared by boiling $Cu(OTf)_2$ with an excess of copper powder in benzene under nitrogen, for 24 hours. The solution was filtered under nitrogen and the solvent evaporated; the residue was recrystallized from benzene under nitrogen.

Preparation of copper(II) trifluoromethanesulphonate tetrapyridine. This compound was prepared by adding pyridine to an aqueous solution of $Cu(OTf)_2$. The complex crystallized immediately, and filtered off and dried in vacuo.

Preparation of copper(II) trifluoromethanesulphonate tetrakis(methacrylonitrile). A saturated solution of $Cu(OTf)_2$ in methacrylonitrile was heated under nitrogen at 40°C. Cooling to 0°C, gave white hygroscopic crystals in 60 % yield.

Preparation of oxazoles (III) (general procedure). The diazoacetate (II) (1.75 mmol) was added under nitrogen within 20 hours with an automatic syringe (Sage) to a solution of $Cu(OTf)_2$ (0.027 mmol) in the nitrile I (3 ml) at 293 K.

The corresponding oxazoles were isolated and characterized as described in ref. 1.

Kinetic measurements

The apparatus containing the catalyst was flushed with nitrogen immediately before the introduction of the reactants. Methacrylonitrile (60 mmol) was added to the catalyst (0.17 mmol) and heated to 30° in a thermostatted bath. After dissolution of the complex, the diazo ester (1.7 mmol) was introduced through a septum by means of a syringe.

The progress of the reaction was then followed by measuring the nitrogen evolved by decomposition of the diazo ester.

Oxidation of the catalyst during these experiments (curve c) was carried out simply by flushing the apparatus with oxygen, which was replaced by nitrogen after 5 minutes.

EPR spectra. These were recorded on a Varian E12 spectrometer in acetonitrile solution (90 mg $Cu(OTf)_2$ in 5 ml MAN); samples of the reacting mixture being cooled to 77 K, after various reaction times.

IR spectra. These were recorded, at room temperature, on a Perkin—Elmer 21 spectrometer with saturated solutions of $Cu(OTf)_2$ in MAN. The shifts were measured with respect to $\nu(C\equiv N)$ of free MAN at 2229 cm^{-1}.

Polarographic measurements. These were carried out at room temperature on a Solea PR63 polarograph (three electrodes) fitted with a CMT 5/24 capillary (flow characteristics: 50 cm, 0.485 mg/sec open circuit) using acetonitrile ($0.25 \times 10^{-3} M$/l) solutions of copper triflate. (The dropping time was controlled by a hammer system.) The electrolyte was a 0.2 M/l solution of sodium triflate.

Acknowledgements

References

1 R. Paulissen, Ph. Moniotte, A.J. Hubert and Ph. Teyssié, Tetrahedron Lett., 37 (1974) 3311.
2 R.G. Salomon and J.K. Kochi, J.Amer. Chem. Soc., 95 (1973) 3300.
3 G. Ondrejovic, O. Sandowsky and T. Gazo, Chem. Zvesti, 18 (1964) 281.
4 J.B. Milne, Can. J. Chem., 48 (1970) 75.
5 K. Kitatani, T. Hiyama, H. Nozaki, Tetrahedron Lett., 16 (1974) 1531.

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NOVEL PHOTOREACTION PRODUCTS OF N-SUBSTITUTED FERROCENYLIMINES

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Summary

Ferrocene-aldimines and -ketimines undergo benzophenone sensitized photochemical hydrolysis to give the corresponding ferrocene-carbaldehydes or -ketones.

Although the photochemistry of ferrocene derivatives has attracted increasing attention over the last few years [1] no photochemical reactions of ferrocenylimines have been described. This is surprising since the irradiation of arylimines leads to several products [2]. We now report the sensitized photochemical hydrolysis of ferrocene-aldimines and -ketimines on irradiation for 2 h with a medium-pressure mercury lamp. The results obtained from the photolysis of thirteen compounds are collected in Table 1, in each case the dominant product was ferrocenecarbaldehyde or a ferrocenylketone and in most cases it was the only product.

Under the conditions that we have used, benzaldehyde-N-substituted imines undergo either reductive dimerization [3] or give the corresponding nitriles [4] as the principal products. Benzaldehyde was only obtained by irradiation of benzaldehyde-N-alkylimines when oxygen was bubbled through the reaction mixture [5] and as a minor product from the irradiation of benzylidene-t-butylamine in benzene [4].

Products isolated from the photolysis of phenylhydrazones include hydrocarbons, nitriles, amines and benzaldehyde with the aldehyde usually present as a minor component [6]. The photolysis of ketimines leads to reduction [7,8] or reductive dimerization [8] and the formation of ketones in these reactions does not appear to have been reported.

Several mechanistic pathways have been proposed to account for the formation of aldehydes from imines. Furey and Kan [5] have suggested that the carbon—nitrogen double bond is attacked by photochemically generated

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