Homogeneous Catalyzed Reduction of Nitro Compounds. I. The Synthesis of Oximes

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Received April 24, 1973

Copper salts solubilized in alkylpolyamine solvents have been found to promote the homogeneous reduction of nitroalkanes to oximes by carbon monoxide in good yields and conversions. Catalysis is favored by the use of cuprous salts of weak acids solubilized in alkylpolyamine solvents of $pK_a > 9.2$. The suggested reaction path involves the formation of a copper–nitroalkane complex by combination of the solvated cuprous carbonyl with the nitroalkane anion and is followed by CO insertion into the copper–oxygen bond of the said complex. Silver salts also catalyze the synthesis of oximes under more stringent conditions.

The action of CO upon solutions of copper salts leads to the formation of cuprous CO complexes that have pronounced activity as reducing agents.[1] Brackman has demonstrated that the activity of cuprous CO complexes toward certain oxidizing agents is considerably enhanced through coordination of the metal with appropriate ligands, and that coordination with amines, in particular, will greatly increase the activity of the CO adduct.[2] Copper salts in piperidine and other secondary amines when treated with CO, for example, will reduce such diverse oxidants as copper(II) amines, nitrobenzene, and methylene blue.[2] The nitrobenzene reduction products were not identified in that work, but a similar cuprous CO adduct is probably the active intermediate in the reported[3] reduction of nitrobenzene to aniline by CO and solutions of copper acetate in aqueous amine.

As part of a program to examine the utility of homogeneous catalysis for effecting reactions of $C-NO_2$ compounds, we report here that solutions of cuprous salts in amine solvents are excellent catalysts for the selective CO reduction of nitroalkanes to the corresponding oximes.[4] This represents one of the first examples of the use of homogeneous catalysis for reducing nitroalkanes.[5] Kinetic studies, together with a general examination of the scope of the reaction, have been carried out in order to gain some understanding of the mechanism of this catalysis.

Results and Discussion

Synthesis.—The selective reduction of nonaromatic nitro compounds to oximes by CO and solutions of copper salts is a fairly general synthesis technique that is applicable to both linear and cyclic, primary and secondary nitroalkanes and nitroalkanes in dilute paraffin streams such as may be obtained by paraffin nitration. The method requires mild experimental conditions and allows ease of product separation. While preferred conditions can, to some extent, be determined by the nature of the nitro compound, generally catalysis is favored by the use of copper(I) salts of weak acids, such as cuprous acetate, solubilized in highly basic alkylpolyamine solvents like 1,3-propanediamine and 1,6-hexanediamine. In contrast to most other methods for preparing aliphatic oximes from nitroalkanes,[6] this synthesis is truly catalytic, and reasonable reaction rates have been achieved at substrate–copper mole ratios of 100.

Summarized in Table I are typical syntheses data for the preparation of C_3–C_{12} aliphatic oximes. The oximes were obtained in 52–89% yields; the aldoxime, propanal oxime, was found to undergo rapid secondary reactions, and no effort was made to optimize the yield of this product. Among other nitroalkanes, the general order of reactivity is 1-nitroalkanes > 2-nitroalkanes > 3–6-nitroalkanes, but with mixtures of nitroalkanes, the copper(I) solutions are not sufficiently selective to sequentially reduce the individual homologs.

Kinetic Studies.—The reaction of carbon monoxide with solubilized copper salts has been investigated by several groups of workers.[1,2,7] In aqueous media, reduction of copper(II) to copper(I) may proceed by more than one path,[1] and may lead, *via* the formation of CO insertion complexes, to the stable cuprous carbonyl complex, $Cu(CO)^+$.

$$2Cu(II) + 3CO + H_2O \longrightarrow 2Cu(CO)^+ + CO_2 + 2H^+ \quad (1)$$

In the absence of additional substrate, the solvated cuprous carbonyl will undergo reduction to the metal, disproportionation, or hydrolysis, depending upon the prevailing chemical conditions. In the presence of nitroalkanes, we find the major products to be oximes, with concomitant oxidation of the CO to CO_2. The reduction of nitrocyclohexane to cyclohexanone oxime by cuprous acetate–ethylenediamine solutions has been studied in some detail in this work, and the *initial* rate was found to be first order in copper, at least over the concentration range 5–50 mM Cu (see Figure 1). Deviations from first-order kinetics are evident at higher copper concentrations, where reduction may become diffusion controlled or, more likely, dimerization of the copper complex becomes important. Wright, for example, has reported significant polymerization of cuprous acetate in amine solutions at concentrations above 0.1 M.[8] A typical rate plot, also showing the formation of cyclohexanone oxime, is reproduced in Figure 2.

That cuprous ion is important in the catalyst cycle is demonstrated by the following observations: (a) catalyst solutions containing nitroalkane and CO

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[1] J. J. Byerley and E. Peters, *Can. J. Chem.*, **47**, 314 (1969).

[2] W. Brackman, *Discuss. Faraday Soc.*, **46**, 122 (1968).

[3] H. R. Appell, *J. Org. Chem.*, **32**, 2021 (1967).

[4] J. F. Knifton, British Patent 1,269,483 (1972).

[5] For the reduction of nitro compounds *via* homogeneous catalysis see also (a) F. L'Eplatterier, P. Matthys, and F. Calderazzo, *Inorg. Chem.*, **9**, 342 (1970); (b) J. E. Kmiecik, *J. Org. Chem.*, **30**, 2014 (1965); (c) J. Kwiatek, *Catalysis Rev.*, **1**, 37 (1967); (d) S. Murahashi and S. Horiie, *Bull. Chem. Soc. Jap.*, **33**, 78 (1960).

[6] See P. A. S. Smith, "Open Chain Nitrogen Compounds," Vol. II, W. A. Benjamin, New York, N. Y., 1966, Chapters 8 and 14.

[7] J. J. Byerley and J. Y. H. Lee, *Can. J. Chem.*, **45**, 3025 (1967).

[8] L. W. Wright, S. Weller, and G. A. Mills, *J. Phys. Chem.*, **59**, 1060 (1955).

TABLE I

SYNTHESES OF ALIPHATIC OXIMES FROM NITROALKANES CATALYZED BY CUPROUS SALTS IN ALKYLPOLYAMINES[a]

Nitroalkane	Solvent	Conversion, mol %	Major product[b]	Yield, mol %[c]
1-Nitropropane	1,6-Hexanediamine	100	Propanal oxime	52[d]
2-Nitropropane	1,6-Hexanediamine	>95	Acetone oxime	58[d]
1-Nitroheptane	1,3-Propanediamine	100	Heptanal oxime	76
Nitrocyclohexane	1,3-Propanediamine	100	Cyclohexanone oxime	89
Nitrododecanes[e]	1,3-Propanediamine	100	Dodecanone oximes	85
Nitrated *n*-dodecane[f]	1,3-Propanediamine	100	Dodecanone oximes	84

[a] Experimental conditions: 2.5–5.0 mmol Cu; 25–50 mmol RNO_2; 85°, 1 atm CO. [b] Oximes were identified by comparison of melting points or boiling points (see Experimental Section) and spectral properties (infrared, nmr) with those reported in the literature. [c] Based upon moles of nitroalkane charged. [d] Estimated by gas chromatography by comparison with authentic samples. [e] An isomeric mixture of 2- through 6-nitrododecanes. [f] A mixture of 25.9% (v/v) nitrododecanes, 64.1% (v/v) *n*-dodecane, and 10% other materials including dodecanones, prepared by liquid–vapor phase nitration of *n*-dodecane.

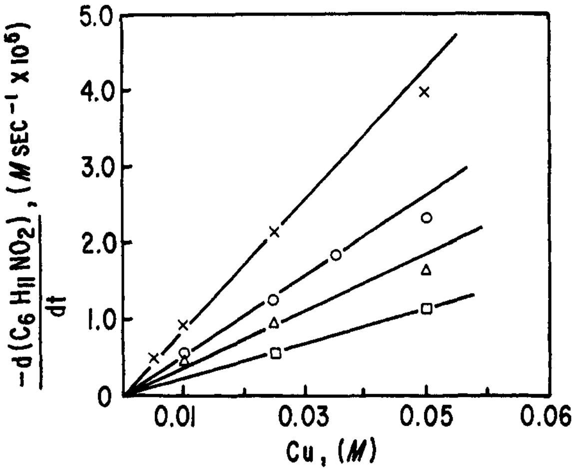

Figure 1.

remain pale yellow [indicative of copper(I) in amines[9]] throughout the reduction to oxime; (b) initially blue-colored solutions of the corresponding copper(II) salts reduce the nitroalkane at a markedly slower rate; and (c) solutions of cuprous acetate, and those of cupric acetate that have been pretreated with CO until pale yellow, show very similar rates of reduction (Table II). No nitroalkane reduction was detected in the absence of metal complex. The reaction mixture remains homogeneous throughout the formation of oxime, and there is no evidence, at least in dilute solution, for further reduction of the copper(I) to the metal or hydrolysis to the oxide. Identical results were obtained with or without the addition of glass beads.

The importance of carbon monoxide beyond that of reducing cupric ions is seen by the fact that, under almost stoichiometric conditions, no cyclohexanone oxime was detected with mixtures of nitrocyclohexane and cuprous acetate–ethylenediamine solutions in the absence of CO, *i.e.*, under a nitrogen blanket (see Table II). This points to the importance of a cuprous carbonyl moiety in the catalytic cycle, rather than nitro reduction *via* a redox mechanism[10] involving cuprous ion. As to the nature of the cuprous carbonyl complex responsible for nitroalkane reduction, it has been claimed[11] that each cuprous ion can bind only one CO molecule, and this is consistent with the $Cu(CO)^+$ ion being a critical intermediate in the copper-catalyzed reduction of other substrates by carbon monoxide.[7]

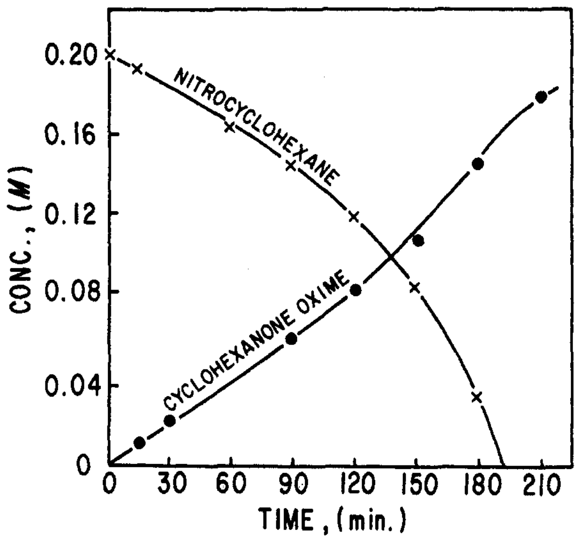

Figure 2.

TABLE II

CYCLOHEXANONE OXIME SYNTHESIS CATALYZED BY COPPER SALTS. CATION–ANION EFFECTS[a]

Solubilized copper salt	Reducing atmosphere	Initial rate of nitrocyclohexane reduction, *M* sec^{-1} × 10^6
Copper(II) acetate monohydrate[b]	CO	4.64
Copper(II) acetylacetonate monohydrate[b]	CO	12.7
Copper(II) carbonate[b]	CO	4.17
Copper(II) chloride dihydrate[b]	CO	1.32
Copper(II) sulfate pentahydrate[b]	CO	<0.1
Copper(I) acetate	CO	5.26
Copper(I) cyanide	CO	<0.1
Copper(I) acetate[c]	N_2	No reaction

[a] Run conditions: 10 m*M* Cu; 0.25 *M* RNO_2; solvent, ethylenediamine; 95°; 1 atm CO. [b] All solutions of copper(II) salts were pretreated with CO until decolorized. [c] 50 m*M* Cu; 100 m*M* RNO_2.

Recently, Rucci, *et al.*,[12] reported an analogous copper(I) ethylenediamine carbonyl complex, [Cu(en)(CO)]-

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(9) S. Weller and G. A. Mills, *J. Amer. Chem. Soc.*, **75**, 769 (1953).

(10) G. Battistuzzi Gavioli, G. Grandi, and R. Andreoli, *Collect. Czech. Chem. Commun.*, **36**, 730 (1971), and references cited therein.

(11) R. Stewart and D. G. Evans, *Anal. Chem.*, **35**, 1315 (1963).

(12) G. Rucci, C. Zanzottera, M. P. Lachi, and M. Carnia, *Chem. Commun.*, 652 (1971).

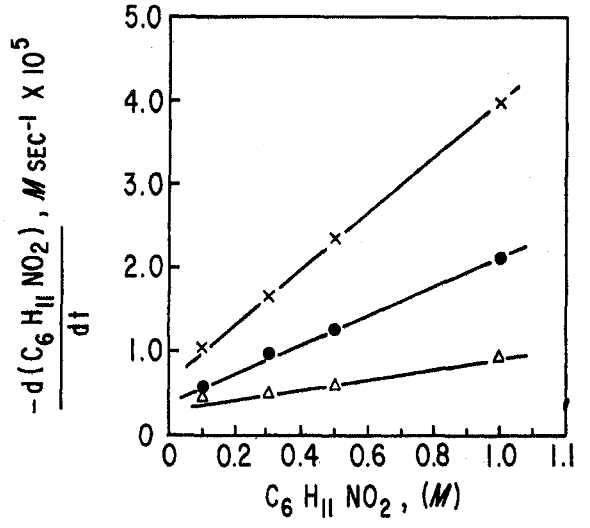

Figure 3.

Cl, and its dimer, which are sufficiently stable to be isolated from copper(I)–amine solutions. A somewhat similar copper(I) carbonyl complex would be expected to be formed in this work with CO-treated solutions of cuprous salts in ethylenediamine (eq 2).

$$L_xCu(I) + CO \longrightarrow [L_xCu(CO)]^+ \qquad (2)$$

The dependence of the initial rate upon nitrocyclohexane concentration is shown in Figure 3 for three copper concentrations. The linear dependence over the RNO_2 range 0.1–1.0 M is indicative of pseudo-first-order kinetics. Generally, the selective reduction of nitroalkanes to alkyl oximes proceeds *via* the prior formation of the more reactive nitroalkane anion.[6,13] While the equilibrium constants for the ionization of short-chain primary and secondary nitroalkanes in aqueous media are of the order 10^{-8}–10^{-10} (see ref 14), in highly basic alkylamine solvents the nitroalkane molecule will be extensively deprotonated to the anionic form[6] (eq 3). Thus it is this anionic species which is

$$RR'CHNO_2 + B: \rightleftharpoons [RR'CNO_2]^- + BH^+ \qquad (3)$$

likely to be involved in the reduction sequence (see below) leading to the formation of the oxime. In this work, the prior formation of the nitro anion in alkylamine solutions has been confirmed by an intense band in the near-ultraviolet at about 232 mμ.[15]

Although the linear dependence is evident in Figure 3, the plots do not pass through the origin. This suggests faster rates at low nitrocyclohexane concentrations (below *ca.* 0.1 M). The divergence may be due to a second reaction path which is effectively zero order in nitroalkane. Alternatively, dimerization of the nitroalkane anion[6] at higher concentrations could be effectively decreasing the rate values and consequently shifting the plots away from the origin but still maintaining the approximately linear relationship. An extensive study of this low nitrocyclohexane concentration region (<0.1 M) would have been desirable, but difficulties were encountered in obtaining reproducible values.

The important role played by the amine solvent in determining the course of the nitroalkane reduction can be readily seen from the data summarized in Table III. Here nitrododecane reduction by CO and cuprous acetate was examined in a number of structurally different solvents. Only strongly basic alkylpolyamines were found satisfactory for the synthesis of the oximes. Both in the case of nitrododecane and nitrocyclohexane, no oxime was detected with solvents of base strength less than about 9.2 pK_a units; these include typical chelating and nonchelating alkylamines as well as hetrocyclic bases. On the other hand, some reduction of the nitrododecane was detected with all solvents of pK_a greater than about 9.2 units. Good yields of dodecanone oxime were achieved with alkylpolyamines such as 1,6-hexanediamine, 1,3-propanediamine, ethylenediamine, and 3,3′-iminobispropylamine.

TABLE III

CO REDUCTION OF NITRODODECANE CATALYZED BY CUPROUS ACETATE IN VARIOUS AMINE SOLVENTS[a,b]

Solvent			Rate of nitrododecane reduction, M sec^{-1} × 10^6
Composition	pK_a[c]	Major products	
Pyridine	5.45	No reaction	
Morpholine	8.70	No reaction	
Diethanolamine	9.00	No reaction	
N,N,N′,N′-Tetramethylethylenediamine[d]	9.14	No reaction	
Benzylamine	9.34	Dodecanone + dodecylamine	*e*
Tetraethylenepentamine	9.9	Dodecanone oxime	2.5
Diethylenetriamine	9.94	Dodecanone oxime	5.6
Ethylenediamine	10.18	Dodecanone oxime	8.1
n-Hexylamine	10.4	Dodecanone + dodecylamine	*e*
1,3-Propanediamine	10.62	Dodecanone oxime	27.6
3,3′-Iminobispropylamine	10.65	Dodecanone oxime	26.4
1,6-Hexanediamine	11.1	Dodecanone oxime	24.0
Piperidine	11.28	Dodecanone + dodecylamine	*e*

[a] A mixture of isomers 2- through 6-nitrododecanes. [b] Run conditions: 0.1 M Cu, 0.5 M RNO_2, 85°, 1 atm CO. [c] Data taken from "Stability Constants of Metal-Ion Complexes," Section II: Organic Ligands, Chemical Society Special Publication No. 17, 1964, and Supplement No. 1, Special Publication No. 25, 1971; H. K. Hall, *J. Amer. Chem. Soc.*, **79**, 5441 (1957). [d] Some catalyst precipitation with this solvent. [e] Not determined.

Other strongly basic monoamines like *n*-hexylamine and piperidine gave a mixture of products, including some dodecanone oxime, dodecylamine (by further reduction that may involve an internal redox reaction of the copper–alkylamine complex[16]), and carbonyl derivatives[2] including ketones *via* a Nef-type reaction.

While the conditions under which these amine pK_a's were measured (25°, 0.5–1.0 μ) are far removed from the experimental conditions employed here for nitroalkane reduction, nevertheless it is reasonable to assume

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[13] J. Von Braun and O. Kniber, *Chem. Ber.*, **45**, 384 (1912).

[14] D. Turnbull and S. H. Maron, *J. Amer. Chem. Soc.*, **65**, 212 (1943).

[15] F. T. Williams, R. P. K. Flanagan, W. J. Taylor, and H. Shechter, *J. Org. Chem.*, **30**, 2674 (1965).

[16] W. Gerrard, M. Goldstein, and L. F. Mooney, *J. Inorg. Nucl. Chem.*, **31**, 107 (1969).

that the pK_a data give a fair indication of the *relative* base strengths of the different solvents under the conditions specified in Table III. The function of the amine solvent in the nitroalkane reduction sequence may be at least threefold. Firstly, the more basic solvents will favor the formation of the nitroalkane anion by shifting the equilibrium 3 further to the right. Secondly, the amine solvents will stabilize the cuprous ions against disproportionation to the metal and copper(II).[17] Certainly in this work it was noticeable that solutions of copper(II) acetate in solvents like piperidine were much more rapidly decolorized by CO treatment than with solvents such as pyridine. Thirdly, the more basic amines, as better σ donors to the copper, may promote the electron-transfer steps involved in the reduction to oxime.

The effect of base upon the activity of cuprous salts has been noted previously. Weller and Mills report that the catalytic activity of cuprous salts in organic bases varies significantly with the base strength of the solvent.[9] In a related case, Nakamura and Halpern found that, while the reduction of Ag^+ by CO in aqueous perchloric acid solution is slow even at elevated temperatures (>100°), the addition of ammonia or amine enhances the reactivity of the silver to the degree that reduction proceeds at room temperature.[18] This marked enhancement in reactivity toward CO was attributed to the increase in pH rather than effects associated specifically with complexing of the Ag^+ ion.

Further evidence for the importance of solvent composition in the oxime synthesis can be seen from the data summarized in Table IV. Here the relative rates of reduction of nitrododecane were measured in mixed aqueous–ethylenediamine solutions. As with the CO reduction of nitrobenzene,[3] a marked dropoff in rate was observed with solutions containing more than 10% water.

TABLE IV

DODECANONE OXIME SYNTHESIS CATALYZED BY COPPER ACETATE IN AQUEOUS ETHYLENEDIAMINE[a]

Solvent composition: concentration (v/v) of aqueous component	Relative rate of nitrododecane reduction
<2	1.0
5	0.9
10	0.55
30	0.04
50	<0.01

[a] Run conditions: 0.5 *M* Cu, 0.5 *M* RNO_2, 85°, 1 atm CO.

Among the alkylpolyamine solvents described in Table III, the relative rates of nitrododecane reduction are also in line with the solvent base strengths. The effectiveness of the polyamines as chelating agents is apparently unimportant and may actually retard the rate. For example, diethylenetriamine and tetraethylenepentamine, which both have the capacity to form multiring complexes are considerably less effective than the more basic 1,6-hexanediamine, which is not a chelating agent. The results can be rationalized on the basis of copper(I) chemistry, where chelation in copper(I) multidentate amine complexes is generally either unimportant or leads to ring strain. Witness the cumulative equilibrium constants (log β_2) for cuprous ammine and ethylenediamine complexes, which are both reported[19] as about 10.8. This does not preclude the possibility, however, of bridged ligand complexes, where the polyamine is bonded to two or more copper atoms.

Anion effects also play a role in determining the activity of the copper catalyst. Generally, reduction is favored by the presence of copper salts of weak acids, such as copper acetate (see Table II); sulfate and chloride salts are less active; and cyanide deactivates the catalyst, probably by displacing the carbon monoxide.[2]

It is unlikely, under the conditions of these experiments, that these anions will displace the alkylpolyamine coordinated to the copper. Since the rate generally increases with increasing basicity of the anionic species (Table II), a more plausible explanation is deprotonation of the coordinated amine (RNH_2) by the anion to give a more basic coordinated amido ligand (NHR^-).[20] However, a limited extent of deprotonation is evident from the fact that we find the rate of nitrocyclohexane reduction by cuprous acetate to be independent of excess acetate ion, at least up to a 2-mol excess. Deprotonation of coordinated amine has also been proposed previously in the copper(I)-catalyzed coupling of carbon monoxide and amines.[2]

Pressure–Temperature Effects.—While accurate rate measurements were not made at superatmospheric pressures of CO, generally it was found that the rate of nitroalkane reduction was insensitive to CO pressure, at least up to about 15 atm pressure. This is consistent with a high equilibrium concentration of copper(I) carbonyl. In eq 4, *K* is large,[1] and the equilibrium lies

$$Cu^+ + CO \overset{K}{\rightleftharpoons} Cu(CO)^+ \qquad (4)$$

well to the right under normal conditions. Furthermore, the rate of formation of $Cu(CO)^+$ is fast.[2] Increases in CO pressure should not have any significant effect upon the equilibrium concentration of $Cu(CO)^+$ species, and the rate of nitroalkane reduction should be independent of the carbon monoxide pressure. Some loss in rate has been noted at high pressures of CO (above 15 atm) where the formation of coordinatively saturated copper multicarbonyl species could become important.

An Arrhenius plot, showing the effect of temperature upon the nitrocyclohexane reduction rate, is reproduced in Figure 4. The straight-line plot is indicative of simple kinetics for this reaction over the temperature range studied (80–100°). From the gradient of the plot an experimental activation energy of 16.6 kcal mol^{-1} has been calculated.

Mechanism.—The results described above may be rationalized on the basis of Scheme I, where the initial reaction is the combination of the nitroalkane anion with the solvated copper(I) carbonyl, and this is followed by insertion of carbon monoxide into the copper–oxygen bond of the complex, cyclization, and cleavage, to yield the observed products. Consistent with our kinetic measurements, we believe the first step to be

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[17] D. A. Johnson, "Some Thermodynamic Aspects of Inorganic Chemistry," Cambridge University Press, London, 1968, Chapter 4.

[18] S. Nakamura and J. Halpern, *J. Amer. Chem. Soc.*, **83**, 4102 (1961).

[19] "Stability Constants of Metal-Ion Complexes," Chemical Society Special Publication No. 17, 1964.

[20] G. W. Watt and J. F. Knifton, *Inorg. Chem.*, **7**, 1443 (1968).

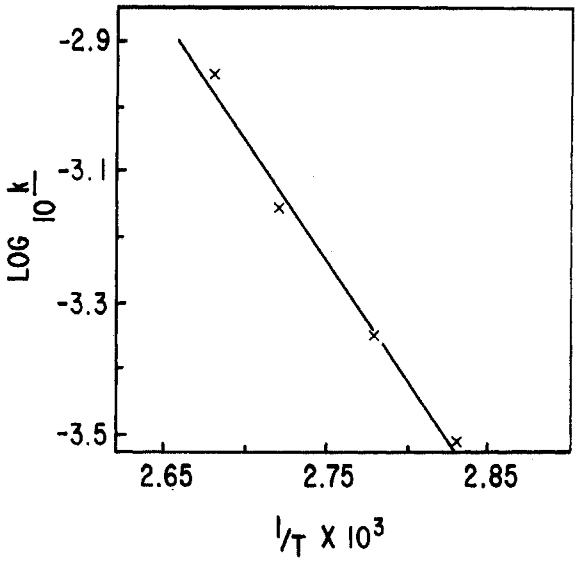
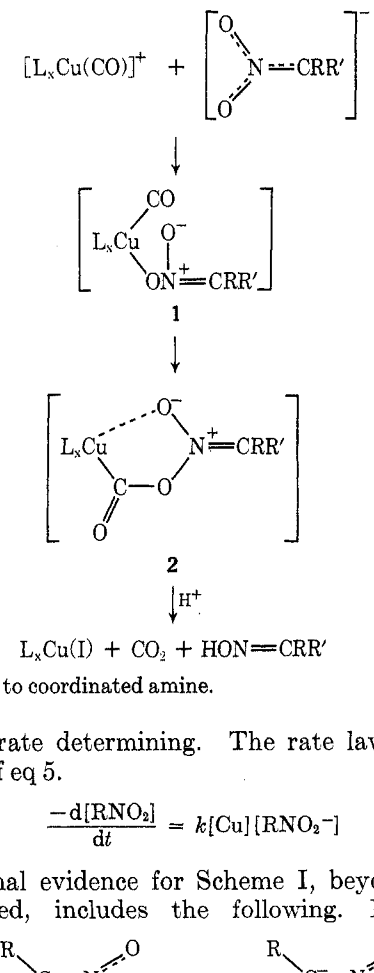


Figure 4.

SCHEME I[a]

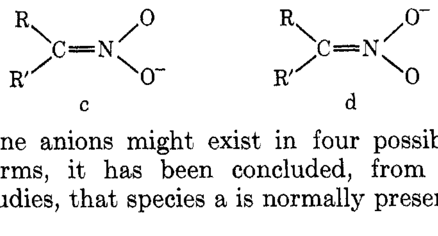


[a] L_x refers to coordinated amine.

slow and rate determining. The rate law is then of the form of eq 5.

$$\frac{-d[RNO_2]}{dt} = k[Cu][RNO_2^-] \qquad (5)$$

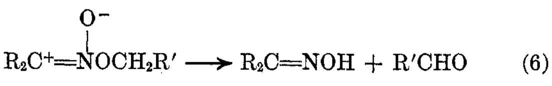
Additional evidence for Scheme I, beyond that already cited, includes the following. First, while



nitroalkane anions might exist in four possible resonance forms, it has been concluded, from spectroscopic studies, that species a is normally present in the largest concentration.[21] Bonding of the nitroalkane anion with the copper(I) carbonyl in intermediate **1** is expected to be through the oxygens, rather than the carbon of the anion, by analogy with known metal nitroalkane compounds.[22]

The carbon monoxide insertion step to give intermediate **2** is an example of a well-documented class of reactions in organometallic chemistry involving insertion of unsaturated compounds, such as carbon monoxide, into metal–oxygen bonds. Pertinent examples include the CO insertion into copper–alkoxide[23] and copper–aquo bonds.[1]

Intermediate **2** is somewhat analogous to the labile nitronate esters (which may be prepared by the alkylation of primary or secondary nitroalkanes in basic media). These esters also undergo N–O bond fission to yield the corresponding aliphatic oximes.[24]



$$R_2C^{+}{=}\overset{O^-}{\overset{|}{N}}OCH_2R' \longrightarrow R_2C{=}NOH + R'CHO \qquad (6)$$

Catalysis by Silver Salts.—Although the CO molecule is relatively inert toward a variety of common oxidizing agents, it can be oxidized under mild conditions by a number of transition and posttransition metal ions.[7,18,25,26] Kinetic studies have shown that oxidation many times proceeds *via* a metal carbonyl intermediate formed by CO insertion into the metal–solvent bond;[7] while this may be followed by decomposition with oxidation of the CO to CO_2 and reduction of the metal, the reaction of these metal carbonyls with certain added oxidizing agents has been demonstrated.[27,28]

For the purpose of broadening the scope of the oxime synthesis, the catalytic activity of other metal carbonyls in amine solvents has been considered. It is reported[29] that silver nitroalkane complexes undergo spontaneous electron transfer to metallic silver and a dimer of the nitro anion. Here we find that CO-saturated solutions of silver salts in polyamines, such as ethylenediamine, will catalyze the reduction of nitroalkanes to oximes in moderate yields (see Table V). A comparison of the silver(I) catalyst with the analogous copper(I) system described above shows the following.

(a) A significant rate of oxime formation is achieved only at superatmospheric pressures of CO with the silver catalyst. Apparently the intermediate silver carbonyl is dissociatively less stable than the analogous copper(I) complex; *i.e.*, the equilibrium constant K in eq 4 is smaller for the Ag complex.

(b) The silver carbonyl is thermally less stable; consequently CO reduction experiments carried out at temperatures of 80° or above lead to the precipitation of silver metal, and a loss of catalyst activity.

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[21] M. J. Brookes and N. Jonathan, *Spectrochim. Acta, Part A*, **25**, 187 (1969); A. H. Norbury, D. Sant, and P. E. Shaw, *J. Inorg. Nucl. Chem.*, **32**, 3401 (1970).

[22] A. C. Lee, *Spectrochim. Acta, Part A*, **28**, 133 (1972), and references cited therein.

[23] T. Saegusa, T. Tsuda, and K. Isayama, *J. Org. Chem.*, **35**, 2976 (1970)

[24] Reference 6, p 413.

[25] N. K. Eremenko and K. I. Matveev, *Kinet. Katal.*, **7**, 707 (1966); J. A. Stanko, G. Petrov, and C. K. Thomas, *Chem. Commun.*, 1100 (1969).

[26] B. R. James and G. L. Rempel, *Chem. Commun.*, 158 (1967).

[27] A. C. Harkness and J. Halpern, *J. Amer. Chem. Soc.*, **83**, 1258 (1961).

[28] A. B. Fasman and V. A. Goldor, *Dokl. Akad. Nauk SSSR*, **155**, 298 (1964).

[29] G. B. Brown and R. L. Shriner, *J. Org. Chem.*, **2**, 376 (1937).

TABLE V

ALIPHATIC OXIMES FROM NITROALKANES CATALYZED BY SILVER SALTS[a]

Silver salt	Nitroalkane	$[RNO_2]/[Ag]$	CO pressure, atm	Nitroalkane conversion, mol %	Oxime yield, mol %[b]
Silver acetate	Nitrododecane[c]	1	1	<2	None
Silver acetate	Nitrododecane	1	8	58	43
Silver acetate	Nitrododecane	1	36	73	56
Silver nitrate	Nitrododecane	1.5	72	64	*d*
Silver acetate	Nitrododecane	10	8	44	36
Silver acetate	Nitrocyclohexane	1.5	72	100	63

[a] Experimental conditions: solvent, 90% (v/v) ethylenediamine, 10% (v/v) water, 85°, 360 min. [b] Based on nitroalkane charged. [c] A mixture of 2- through 6-nitrododecanes. [d] Not determined.

(c) Highly basic alkylpolyamine solvents, such as ethylenediamine, are suitable for the CO reduction of nitroalkanes to oximes by silver salts. Carbonylation in the presence of primary and secondary monoamines is reported to yield *N,N'*-dialkylureas and *N,N,N',N'*-tetraalkyloxamides, respectively.[30]

Other metal ions known to activate molecular CO, including those of mercury(II), cobalt(II), manganese, and nickel, were also considered, but were found inactive for nitroalkane reduction over the range of conditions surveyed. This pattern of activity most likely reflects the relative lability and coordinative unsaturation of the intermediate metal carbonyls. The relatively stable carbonyls of copper(I) and silver(I) contrast with the analogous mercury complex,[27,31] which we find to rapidly dissociate to the metal in the presence of amine. The carbonyls formed from nickel(II) and cobalt salts in strongly basic media may be coordinately saturated, for example, nickel tetracarbonyl, prepared by the CO reduction of nickel salts in aqueous ammonia and 1,2-propanediamine.[32] They do not lend themselves, therefore, to attack by the nitroalkane anion under mild conditions.

Experimental Section

Carbon monoxide was Matheson C. P. grade. Ethylenediamine was distilled (bp 117–118°) and dried over molecular sieve. Other amine solvents were reagent-grade quality and were flushed wih CO prior to use. The copper(I) and copper(II) salts, 1-nitropropane, 2-nitropropane, nitrocyclohexane, and 1-nitroheptane were commercial products. Nitrododecane, a mixture of 2 through 6 isomers, was prepared by nitration of *n*-dodecane with nitrogen dioxide.

Synthesis Procedure.—The synthesis procedure for making aliphatic oximes is exemplified here for cyclohexanone oxime and dodecanone oximes, using solutions of copper(I) acetate in 1,3-propanediamine as catalyst. Oximes were also prepared with solutions of copper(II) salts; the procedure is similar except that a longer pretreatment with CO is required, to reduce the copper(II) to copper(I), prior to introducing the nitroalkane.

A. Synthesis of Cyclohexanone Oxime.—Copper(I) acetate (1.23 g, 10 mmol) was dissolved, with stirring, in a degassed sample of 1,3-propanediamine (200 ml) maintained at 85° under 1 atm pressure of carbon monoxide. The resulting solution was clear and pale yellow. Nitrocyclohexane (6.45 g, 50 mmol) was added slowly, and the mixture was stirred rapidly at 85° under CO for 2–4 hr. On cooling, the liquid product was concentrated *in vacuo*, diluted with water, and extracted with diethyl ether. The ethereal extracts were reconcentrated and the residual crude cyclohexanone oxime was recrystallized from aqueous ethanol. Cyclohexanone oxime yield was 4.55 g (81%), mp 90° (lit.[33] mp 91°). Identification was also by infrared[34] and nmr[35] spectroscopy and elemental analysis. *Anal.* Calcd for $C_6H_{10}NOH$: C, 63.7; H, 9.79; N, 12.4. Found: C, 63.8; H, 9.7; N, 12.3.

B. Preparation of Dodecanone Oximes.—Copper(I) acetate (2.46 g, 20 mmol) was dissolved, with stirring, in a solution of 1,3-propanediamine (180 ml) and water (20 ml) saturated with carbon monoxide at 85°. Nitrododecane, a mixture of 2 through 6 isomers (21.5 g, 100 mmol), was added slowly, and the whole was stirred rapidly at a temperature of 85° under CO for 3–4 hr. On cooling, the liquid product was concentrated and extracted with diethyl ether, and the ethereal extract was vacuum distilled. Dodecanone oximes, a mixture of 2 through 6 isomers, bp 126–128° (4 mm), with some decomposition [lit.[36] 6-dodecanone oxime, bp 147° (10 mm)], were obtained in 16.7-g (84%) yield. The oximes were identified by infrared,[34] nuclear magnetic resonance,[35] and mass spectrometry. *Anal.* Calcd for $C_{12}H_{24}NOH$: C, 72.3; H, 12.7; N, 7.02. Found: C, 72.2; H, 12.6; N, 7.02.

Kinetic Measurements.—Generally, only initial rates of nitroalkane reduction to oxime were determined in this work. Kinetic studies were carried out in glass apparatus set in a constant-temperature bath. Carbon monoxide was introduced *via* a fritted glass disk and stirring was by a Teflon paddle driven by a high-speed electric motor.

Degassed amine solvent (50 ml) and a weighed quantity of copper salt (0.25–2.50 mmol) were introduced into the 100-ml reaction flask and flushed with CO. Starting with copper(II) salts, the catalyst solution was stirred under CO until the color of the homogeneous solution changed from blue to pale yellow [*i.e.*, until all the copper(II) had been reduced to copper(I)]. There was no evidence of insoluble species either at this stage or after the addition of substrate. A known weight of nitroalkane (5.0–50 mmol) was introduced through a rubber septum, and the rate of reduction was monitored by withdrawing liquid samples (0.2 ml) at regular time periods. The samples were rapidly cooled in ice water and analyzed by gas chromatography with the aid of standard calibration curves. Chromatographic analysis was used to follow both the rate of disappearance of nitroalkane and the formation of oxime.

Rate studies with nitrododecane included *n*-dodecane as an internal standard. Experiments at superatmospheric pressures of CO involved a similar procedure but were carried out in a glass-lined pressure reactor of 300 ml rated capacity.

Acknowledgments.—The author wishes to thank Texaco Inc. for permission to publish this paper, Dr. I. Schwager for technical advice, and Messrs. T. S. Strothers and C. A. Dondero for experimental assistance.

Registry No.—Cyclohexanone oxime, 100-64-1; dodecanone oxime, 33940-11-3; nitrocyclohexane, 1122-60-7; nitrododecane, 27195-75-1.

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