($\underline{C}H_3O$), 61.2, 61.7 (2 $\underline{C}H_2O$), 165.2 ($\underline{C}OOCH_3$), 168.1, 169.2 (2 $\underline{C}$=O) [7]. IR spectrum (ν, cm^{-1}): 1750, 1733 (C=O). Mass spectrum (m/z): 199 $[M - C_2H_5O]^+$, 185 $[M - COOCH_3]^+$, 171 $[M - COOC_2H_5]^+$, 39 $[C_3H_3]^+$.

(2-Chloronorbornyl)malonic Ester (XVI), bp 112-114° (0.04 mm). PMR spectrum (δ, ppm): 1.18 t, 1.21 t (2 CH_3CH_2CO), 3.07 d [$CH(CO)_2$], 3.91 m (CHCl), 4.13 q, 4.14 q (2 CH_2O). Mass spectrum (m/z): 289 M^+.

(2-Chlorol-hexenyl)malonic ester (XVII) was separated by adsorption chromatography (eluent: benzene). PMR spectrum (δ, ppm): 0.93 t (CH_3), 1.27 t (2 CH_3CH_2CO), 1.1-1.8 m (2 CH_2), 2.38 m (CH_2C=), 4.05 d [$CH(CO)_2$, J = 9.5 Hz], 4.16 q (2 CH_2O), 5.85 d (CH=, J = 9.5 Hz). IR spectrum (ν, cm^{-1}): 1750, 1736 (C=O), 1751 (C=C), 860 (CCl).

CONCLUSIONS

The oxidative addition of chloromalonic ester to 1-hexene, 1-hexyne, norbornene, acrylonitrile, and methyl acrylate has been carried out under the influence of the $Mn(OAc)_3$—LiCl system. It yields functionally substituted 1,3-dichlorides that are used for the synthesis of substituted 1,1-diethoxycarbonylcyclopropanes.

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REACTION OF N-HYDROXY(ALKOXY)AMIDYL AND AMIDOXY RADICALS IN THE SODIUM PEROXYDISULFATE—COPPER CHLORIDE OXIDIZING SYSTEM

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UDC 541.515:547.298:542.943.7

In contrast to the N-alkylamidyl radicals [1], the N-hydroxy(alkoxy)amidyl radicals have been studied relatively little. The structure of alkoxyamidyl radicals in the ground state was established by theoretical calculations and EPR [2, 3]. Some reactions of these radicals have been investigated, particularly dimerization to the unstable dialkoxydiacyl hydrazines [4, 5], intramolecular cyclization to N-alkoxylactams during homolytic addition at the aromatic ring [5], and the mechanism of oxidation by potassium ferricyanide in alkaline medium [6].

In continuation of our investigation of the reactions of heterocentered acyloxy and amidyl radicals in sodium peroxydisulfate—chloride ion oxidizing systems [7-10], we have studied the one-electron oxidation of alkanehydroxamic acids and their N- and O-methyl-substituted derivatives (Ia-d) to N-hydroxy(alkoxy)amidyl radicals (IIa-c) and isomeric amidoxyl radicals (IIIa, b, d), and the reactions of these radicals in the sodium peroxydisulfate—copper chloride system:

$$\underset{\text{(Ia—d)}}{R(CH_2)_4CONR'OR''} \xrightarrow{Na_2S_2O_8—CuCl_2} \underset{\text{(IIa—c)}}{R(CH_2)_4\dot{C}ONOR''} + \underset{\text{(IIIa, b, c)}}{R(CH_2)_4CONR'\dot{O}}$$

R = R′ = R″ = H (a); R = Me, R′ = R″ = H (b); R = R′ = H, R″ = Me (c); R = R″ = H, R′ = Me (d).

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Translated from Izvestiya Akademii Nauk SSSR, Seriya Khimicheskaya, No. 9, pp. 2068-2073, September, 1984. Original article submitted July 21, 1983.

0568-5230/84/3309-1887$08.50

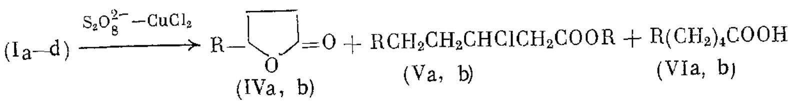
TABLE 1. Oxidation of Alkanehydroxamic Acids (Ia-d) by the $Na_2S_2O_8$—$CuCl_2$ System*

Hydroxamic acid	Time, h	Conversion, %	Reaction products and yield, % on converted substrate			
			γ-lactone	3-chloro-acid	alkanoic acid	other products
(Ia)	2	–	(IVa), 7	(Va), 2	(VIa), 59	–
	5	–	(IVa), 17	(Va), 6	(VIa), 66	–
	8	100	(IVa), 18	(Va), 6	(VIa), 76	–
(Ib)	2	–	(IVb), 8	(Vb), 5	(VIb), 63	–
	8	100	(IVb), 8	(Vb), 5	(VIb), 79	–
(Ic)	8	100	(IVa), 12	–	(VIa), 70	δ-Valerolactone (VII), 3; $C_4H_9COOCH_3$ (VIII), 12
(Id)	2	94	(IVa), 13	–	(VIa), 85	–

*85-90°, 50 mmole of I, 50 mmole of $Na_2S_2O_8$, 50 mmole of $CuCl_2 \cdot 2H_2O$, 150 ml of water.

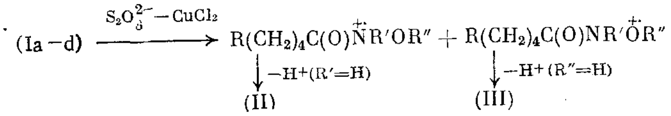
Starting compounds Ia-c were obtained as individual compounds, while N-methylpentanehydroxamic acid (Id) was obtained by the spontaneous N → O migration of the acyl fragment, as we have already shown [11]; it exists as a 3:1 mixture with the isomeric N-methyl-O-pentanoylhydroxylamine.

When the hydroxamic acids Ia-d are oxidized by an equimolar amount of $Na_2S_2O_8$ in the presence of 1 equiv. of $CuCl_2$ in aqueous solution at 85-90°, there are formed γ-lactones (IVa, b), 3-chloroalkanoic acids (Va, b), and alkanoic acids (VIa, b) (Table 1):



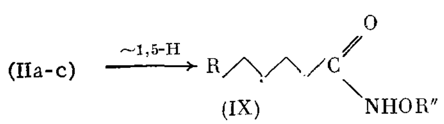
Thus for alkanehydroxamic acids (Ia) and (Ib) that do not have substituents at the hydroxylamine N and O atoms, three main reaction courses are typical: oxidative lactonization to γ-lactone (IVa, b), oxidative chlorination to form 3-chloroalkanoic acids (Va, b), and hydrolysis to alkanoic acid (VIa, b). A 3-chloropentanoic acid does not form from O-methylpentanehydroxamic acid (Ic), while besides γ-lactone IVa and acid VIa, δ-valerolactone (VII) and methyl pentanoate (VIII) were also identified in the reaction products. N-methylpentanehydroxamic acid (Id) mainly hydrolyzes, but does not lactonize to IVa to a significant extent.

The mechanism of the formation of γ-lactones (IV) and 3-chloroalkanoic acids (V) comprises, in our opinion, the competitive formation of two kinds of radicals in the one-electron oxidation of (Ia-d): the nitrogen-centered N-hydroxy(methoxy)amidyl (II), and the oxygen-centered amidoxyl (III):

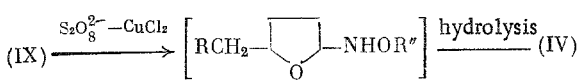


The generation of N-alkoxyamidyl radicals in the oxidation of O-substituted hydroxamic acids was described in [5].

Subsequently the radicals (IIa-c) rearrange with 1,5-migration of a H atom to 3-[hydroxy(alkoxy)aminocarbonyl]alkyl radicals (IX):

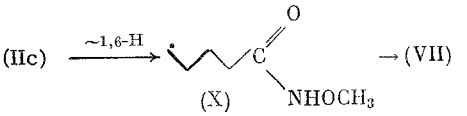


From the homolytic cyclization of (IX) at the C═O group, followed by oxidation there form 2-[hydroxy(alkoxy)amino]substituted 2-tetrahydrofuryl cations, the hydrolysis of which under these reaction conditions yields γ-lactones (IVa, b):

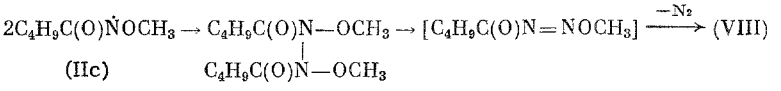


These lactones can also form when the (IX) radicals are oxidized to the respective carbonium ions which then undergo heterolytic cyclization. This lactonization mechanism is analogous to that which we proposed for amidyl radicals [8].

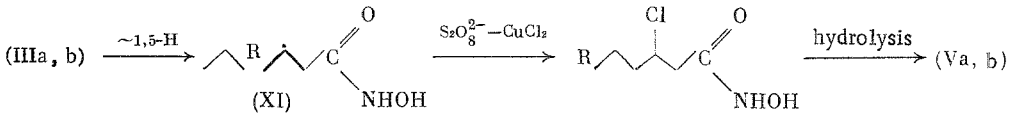
In the N-methoxyamidyl radical (IIc) generated from Ic, along with 1,5-migration there also occurs 1,6-migration of an H atom, which yields radical X; oxidative lactonization of the latter according to the scheme described above yields δ-valerolactone (VII):



Radical (IIc) is also a precursor of methyl pentanoate (VIII), which probably forms by the following route (cf. [5, 12]):



Rearrangement of radicals (IIIa, b) with 1,5-migration of an H atom yields 2-(hydroxyaminocarbonyl)alkyl radicals (XI), which are oxidized by a ligand transfer mechanism to 3-chloroalkanehydroxamic acids; under the reaction conditions these hydrolyze to the 3-chloroalkanoic acids (Va, b):

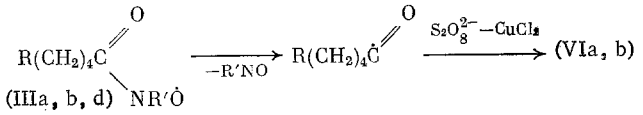


In agreement with the proposed mechanism of formation of the 3-chloroalkanoic acids (Va, b) is the absence of (Va) in the oxidation products of O-methylpentanehydroxamic acid (Ic), from which the generation of an O-centered radical of the (III) type is unlikely.

It must be noted that 1,5-migration of an H atom is to be preferred in radical IIa rather than in the homologous radical (IIb), because in (IIa) the conjugation of the $CH_3\dot{C}H(CH_2)_2$-C(O)NHOH with the CH_3 group is stabilized, and at the same time the extent of rearrangement of radicals (IIIa, b) with 1,5-migration of an H atom need not depend significantly on the substituent R. Accordingly, the ratio of γ-lactone to 3-chloroalkanoic acid (IV)/(V) decreases from 3 to 1.5 when we go from pentanehydroxamic acid (Ia) to hexanehydroxamic acid (Ib). Formation of γ-lactone (IVa, b) by 1,6-migration of H in the (III) radicals and the subsequent oxidative cyclization can be considered as only a side route, since γ-valerolactone (IVa) also forms in the oxidation of hydroxamic acid (Ic), from which the generation of a III type radical is unlikely.

Under the reaction conditions the hydroxamic acids (Ia-d) hydrolyze to the respective alkanoic acids (VIa, b); as shown in model tests (see Experimental), the hydrolysis can occur in the presence of sodium bisulfate, the decomposition product of $Na_2S_2O_8$. As has been established [7, 9], acids (VIa, b) are oxidized to lactones by the $Na_2S_2O_8$—$CuCl_2$ system. But in contrast to the regioselective γ-lactonization in the oxidation of hydroxamic acids (Ia, b, d), the alkanoic acids yield a mixture of γ- and δ-lactones. This fact, along with the absence of 3-chloroalkanoic acids (Va, b) in the oxidation of (VIa, b) [7, 9], and the independence of the (IV)/(V) ratio on reaction time or substrate conversion in the oxidation of (Ia, b), makes it possible to reject possible γ-lactone formation (IVa, b) from alkanoic acids (VIa, b).

Under the oxidizing conditions N-methylpentanehydroxamic acid (Id) is converted practically completely to the pentanoic acid (VIa). Besides acid hydrolysis, the scheme of (VIa, b) formation from (Ia, b, d) possibly includes β-fragmentation of amidoxyl radicals (IIIa, b, d) to acyl radicals which are then oxidized:



No definite conclusion can be drawn concerning the mechanism of γ-lactone (IVa) formation from N-methylpentanehydroxamic acid (Id), because as noted above (Id) is converted by spontaneous N,O-acylotropy to a mixture with N-methyl-O-pentanoylhydroxylamine containing 25% of the latter [11].

These results on the oxidative lactonization of N-hydroxyamidyl radicals (IIa, b) in the $Na_2S_2O_8$—$CuCl_2$ system and comparison with data on the analogous conversions of the related amidyl radicals [8, 9] show that the change in electron properties of the nitrogen-centered amidyl radical due to the introduction of the hydroxy substituent at the radical center manifests itself in increased regioselectivity of oxidative lactonization, and the radicals IIa, b form exclusively γ-lactones.

EXPERIMENTAL

GLC analysis was carried out on a LKhM-8MD chromatograph with flame ionization detector in N_2 stream, stainless steel column 3000 × 3 mm, with 10% H_3PO_4-treated Carbowax 20M [13] on Celite 545 (52-60 mesh): 3000 × 3 mm with 5% PEGS on Chromosorb P (120-140 mesh) treated with Me_2SiCl_2. PMR spectra of CCl_4 and $CDCl_3$ solutions were recorded on a Tesla BS-497 spectrometer (100 MHz) with HMDS. Mass spectra were obtained on a Varian MAT CH-6 apparatus with direct sample introduction into the ion source; energy of ionizing electrons, 70 eV. IR spectra were obtained on a Perkin Elmer 577 apparatus in thin layer and in CCl_4 solution.

The oxidant $Na_2S_2O_8$, sodium peroxydisulfate, analytical grade, and $CuCl_2$, c.p. grade, were used without further purification. Water was once-distilled.

Pentanehydroxamic acid (Ia) and hexanehydroxamic acid (Ib) were synthesized by acylation of hydroxyalamine with an equimolar amount of methyl pentanoate or methyl hexanoate according to [14], and were repeated by repeated washing with CCl_4; (Ia), 50% yield, mp 77-78°; (Ib), 65% yield, mp 62° (cf. [15]). O-methylpentanehydroxamic acid (Ic) was synthesized by reaction of methyl pentanoate with hydroxylamine and CH_3I in the presence of MeONa, analogous to [16], 80% yield, bp 79-81° (0.15 mm). The spectral properties of the hydroxamic acids (Ia-c) are shown in Table 2. Detailed synthesis and spectral properties of N-methylpentanehydroxamic acid (Id) are given in [11].

Oxidation of Hydroxamic Acids (Ia-d) in the $Na_2S_2O_8$—$CuCl_2$ System. To a mixture of 50 mmole of (Ia-d) and 50 mmole of $CuCl_2 \cdot 2H_2O$ in 100 ml of water were added 50 mmole of $Na_2S_2O_8$ in 50 ml of water dropwise over 1 h at 85-90° with efficient stirring. The solution was stirred at 85-90° for another 1-7 h (see Table 1), cooled, and extracted with three 100-ml portions of ether. The extract was dried with $MgSO_4$ and evaporated, and the residue was analyzed by quantitative GLC. To separate the products, the residue from the oxidation of (Ia-d) was treated with 50 ml of saturated $NaHCO_3$ solution and 20 ml of concentrated NH_3, and extracted with three 50-ml portions of ether. The ether extract was dried with $MgSO_4$ and evaporated; distillation yielded lactones (IVa, b) and (VII). The aqueous phase was acidified with conc. HCl to pH 1-2 and extracted with three 50-ml portions of ether. The extract was dried with $MgSO_4$ and evaporated. Fractional distillation separated the alkanoic acids (VIa, b) and the 3-chloroalkanoic acids (Va, b) 3-chloropentanoic acid (Va), bp 143-145° (15 mm); 3-chlorohexanoic acid, bp 153-156° (14 mm). The spectral properties of the γ-lactones (IVa, b), the alkanoic acids (VIa, b), and δ-valerolactone (VII) were identical with those described previously [7].

Hydrolysis of Pentanehydroxamic Acid (Ia) and O-Methylpentanehydroxamic Acid (Ic), in the Presence of $NaHSO_4$ and $CuCl_2$. (Ia) or (Ic), 50 mmole, was stirred with 50 mmoles of $CuCl_2 \cdot 2H_2O$ and 50 mmoles of $NaHSO_4$ in 100 ml of water at 85-90° for 5 h. The mixture was cooled and extracted with three 100-ml portions of ether, and the extract was dried with $MgSO_4$ and evaporated. GLC of the hydrolysis product of (Ia) gave 47.5 mmole of pentanoic acid (VIa) (95% yield). The reaction product of (Ic) gave 40 mmoles of pentanoic acid (VIa) (80% yield) and 10 mmoles of starting (Ic) (80% conversion).

TABLE 2. Spectral Characteristics of Hydroxamic Acids (Ia-c) and 3-Chloroalkanoic Acids (Va, b)

Compound	IR spectra,* (ν, cm^{-1})	PMR spectrum (δ, ppm)	Mass spectrum, m/z (rel. intensity, %)
(Ia)	960, 1540, 1630, 3100–3300	0,90 t (3H, CH_3), 1,15–1,70 m (4H, $CH_2CH_2CH_3$), 2,20 t (2H, CH_2CO), 10,0 br.s (2H, NH, OH)	117(5, M^+), 85(50), 73(60), 60(80), 57(65), 55(30), 45(30), 43(100), 42(25), 41(70)
(Ib)	970, 1550, 1630, 2800–3300	0,90 t (3H, CH_3), 1,10–1,80 t (4H, $CH_2CH_2CH_3$), 2,25 t (2H, CH_2CO), 9,85 br.s (2H, NH, OH)	130(5), 99(100), 74(25), 71(70), 59(25), 55(40), 44(50), 43(80), 42(25), 41(70)
(Ic)	600, 675, 1520, 1660, 3200, 3450	0,90 t (CH_3CH_2), 1,10–1,80 t (4H, $CH_2CH_2CH_3$), 2,25 t (2H, CH_2CO), 3,70 s (3H, CH_3O), 11,0 s (1H, NH)	131(5, M^+), 89(80), 85(80), 59(70), 57(100), 56(20), 55(50), 54(25), 44(90), 43(100), 42(70), 41(90)
(Va)	790, 1710, 3100–3200	1,05 t (3H, CH_3), 1,80 m (2H, CH_3CH_2CHCl), 2,70 d (2H, CH_2CO), 4,10 m (1H, CHCl), 11,0 s (1H, OH)	100(20), 73(35), 60(100), 56(60), 55(65), 42(75), 41(70)
(Vb)	790, 1710, 3100–3200	0,90 t (3H, CH_3), 1,20 m (2H, CH_2CH_3), 1,50 m (2H, CH_2CH_2CHCl), 2,68 d (2H, CH_2CO), 4,06 m (1H, CHCl), 11,5 s (1H, OH)	–

*IR spectra of (Ia, b) are slightly shifted since these substances were measured in CCl_4.

CONCLUSIONS

1. N,O-unsubstituted alkanehydroxamic acids $R(CH_2)_4CONHOH$ (where R=H or Me) are converted in the $Na_2S_2O_8$–$CuCl_2$ oxidizing system to γ-lactones and 3-chloroalkanoic acids, respectively, by way of N-hydroxyamidyl radicals $R(CH_2)_4CONHO$ and amidoxyl radicals $R(CH_2)_4C(O)NHO$.

2. In the $Na_2S_2O_8$–$CuCl_2$ oxidizing system O-methylpentanehydroxamic acid is converted to a mixture of γ- and δ-valerolactones, with a significant preponderance of γ-lactone.

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