[Chem. Pharm. Bull. 27(2) 357—365 (1979)]

UDC 547.298.71.04 : 543.25.06

Oxidation of Hydroxylamine Derivatives. III.[1] Anodic Oxidation of N-Hydoxy and N-Alkoxycarbamates

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(Received July 17, 1978)

Anodic oxidation of several N-hydroxycarbamates is studied by cyclic voltammetry and controlled potential electrolysis in acetonitrile with or without amines at a glassy-carbon electrode. In the presence of excess amine, the corresponding N,O-dialkoxycarbonyl- and O-alkoxycarbonyl-N-hydroxycarbamates, alcohols and N-alkylacetamides, are produced from ethyl and benzyl N-hydroxycarbamates. N-Methylation of the compound markedly decreases the yields of the corresponding alcohol and N-alkylacetamide, whereas it increases O-alkoxycarbonylation of the starting compound and the demethylated product. O-Alkylated N-hydroxycarbamates yield N,N′-dialkoxycarbonyl-N,N′-dialkoxyhydrazines quantitatively. Plausible oxidation processes for these compounds are proposed.

Keywords——anodic oxidation; N-hydroxycarbamates; glassy-carbon electrode; oxidative alkylation and alkoxycarbonylation; oxidative N–N coupling

In anodic oxidation of miscellaneous hydroxylamine derivatives[1,3a,b] including hydroxamic acid[3c] we reported that intermediates generated at electrode undergo various reactions depending on the substitutions on the nitrogen and oxygen atoms.

Several N-hydroxycarbamates, ROCONHOH, similarly to some carbamates, have been received much attention because of their carcinogenic action.[4] It has been reported that the reaction between deoxyribonucleic acid (DNA) and N-hydroxyurethane (ethyl N-hydroxycarbamate) causes degradation of DNA and the degradation is promoted by oxidizing agents.[4d] The oxidation process of N-hydroxycarbamates, therefore, is interesting in relation to the biological activities of N-hydroxycarbamates. In this paper, we investigated the anodic oxidation of N-hydroxycarbamates in acetonitrile at a glassy-carbon electrode, and observed the alkylation and/or alkoxycarbonylation of nucleophiles present in the solution, such as water, added amine or the starting N-hydroxycarbamates. Compounds tested in this study are as follows.

ROCONHOH (I)
a: R=Et
b: $R=C_6H_5CH_2$

$ROCONHOCO_2R$ (II)
a: R=Et
b: $R=C_6H_5CH_2$

$(ROCO)_2NOCO_2R$ (III)
a: R=Et
b: $R=C_6H_5CH_2$

EtOCONMe(OH) (IV)

$EtOCONMe(OCO_2Et)$ (V)

EtOCONHOR (VI)
a: R=Et
b: $R=CH_2=CHCH_2$

$$\begin{matrix}EtOCONOR\\ |\\ RONCO_2Et\end{matrix}$$

(VII)
a: R=Et
b: $R=CH_2=CHCH_2$

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[1] Part II: S. Ozaki and M. Masui, *Chem. Pharm. Bull.* (Tokyo), **26**, 1364 (1978).

[2] Location: *133-1, Yamada-Kami, Suita-shi, Osaka.*

[3] *a*) H. Sayo, S. Ozaki, and M. Masui, *Chem. Pharm. Bull.* (Tokyo), **21**, 1988 (1973); *b*) S. Ozaki and M. Masui, *ibid.*, **23**, 1702 (1975); *c*) *Idem*, *ibid.*, **25**, 1179 (1977).

[4] *a*) E. Boyland and R. Nery, *Biochem. J.*, **94**, 198 (1965); *b*) A.W. Pound, *Pathology*, **1**, 27 (1969); *c*) D.V. Randive, K.N. Arjungi, and S.V. Bhide, *Indian J. Cancer*, **10**, 333 (1973); *d*) K.P. Mullinix, S. Rosenkranz, and H.S. Rosenkranz, *Biochim. Biophys. Acta*, **312**, 1 (1973); *e*) J. Elis, *Proc. Eur. Soc. Toxicol.*, **16**, 133 (1975).

Results and Discussion

Cyclic Voltammetry

Typical cyclic voltammograms of Ethyl N-hydroxycarbamate (Ia; R = Et) at a stationary glassycarbon electrode in acetonitrile are shown in Fig. 1 and the results of voltammetry on a series of N-hydroxycarbamates together with those of the oxidation products are summarized in Table I.

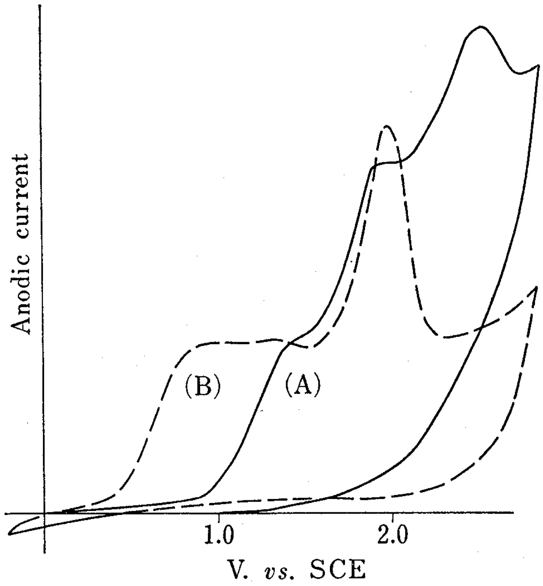


Fig. 1. Cyclic Voltammograms of N-Hydroxyurethane in MeCN–0.1 M $NaClO_4$ at a Glassy-Carbon Electrode

(A): Ethyl N-hydroxycarbamate.
(B): Ethyl N-hydroxycarbamate + excess γ-collidine.

The peak potential of the first wave are close to those for the corresponding hydroxamic acids.[3c)] Substitution of methyl group on the nitrogen atom shifts the first peak potential (E_{P1}) to a less positive, whereas O-alkylation shifts E_{P1} to a more positive just as observed in the oxidation of hydroxamic acids.[3c)] The effect of substitution on the peak potential of the first wave suggests that the first wave is ascribed to electron transfer from the lone pair electrons on the nitrogen atom of N-hydroxycarbamates.

In the presence of excess amine, the N-hydroxycarbamates developed an extra oxidation wave at a lower potential (E_{Pe}) than E_{P1}. The potential of the extra peak is lower, the stronger the basicity of added amine. O-Substituted derivatives did not show an extra peak

TABLE I. Cyclic Voltammetric Data of N-Hydroxycarbamates and Oxidation Products in MeCN–0.1 M $NaClO_4$, 25° at a Glassy-Carbon Electrode

Compound	E_p[a]			
	E_{pe}[b]	E_{P1}	E_{P2}	E_{P3}
EtOCONHOH (Ia)	0.85 (0.71)	1.35	1.77	2.35
$EtOCONHOCO_2Et$ (IIa)	1.50	2.45		
$C_6H_5CH_2OCONHOH$ (Ib)	0.80	1.35	1.80	2.15
$C_6H_5CH_2OCONHOCO_2CH_2C_6H_5$ (IIb)	1.70	2.20		
EtOCONMe(OH) (IV)	0.65 (0.58)	1.20	1.46	2.03
$EtOCONMe(OCO_2Et)$ (V)		2.15		
EtOCONHOEt (VIa)	c) (1.23)	1.65	2.55	
 EtOCONOEt $EtONCO_2Et$ (VIIa)		2.45		
$EtOCONHOCH_2CH=CH_2$ (VIb)	c) (1.00)	1.80	2.48	
 $EtOCONOCH_2CH=CH_2$ $CH_2=CHCH_2ONCO_2Et$ (VIIb)		2.38		

a) Peak potential of wave in volt vs. SCE.
b) Extra anodic wave appearing on addition of γ-collidine or isopropylamine (the value in the parentheses). The molar ratio of (added amine)/(hydroxycarbamate) was about four.
c) No extra peak appeared on addition of γ-collidine.

on addition of γ-collidine, the weaker base. The extra oxidation peak is thought to be derived from the oxidation of partially ionized form of the N-hydroxycarbamates just as observed in the oxidation of hydroxamic acids,3c) because they are both weak acids.5)

TABLE II-1. Products of Anodic Oxidation of N-Hydroxycarbamates (2×10^{-2} M)

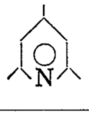
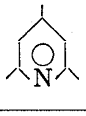
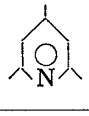
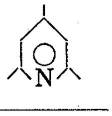
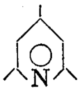
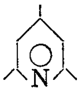
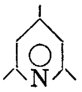
Compound ROCONHOH	R=Et (Ia)				R=$C_6H_5CH_2$ (Ib)		
E_{app}a)	1.25	1.0	0.40c)	0.65	1.35	0.80	0.45c)
nb)	0.59—1.18	1.40	1.06	2.46	0.64—1.14	1.27	1.24
base added	no			Pr^iNH_2	no		
Product	Yieldd)						
$(ROCO)_2NOCO_2R$	0	5*	e)	0	Trace	8*	e)
$ROCONHOCO_2R$	Trace	34*	100.6*	38*	24*	38*	56*
N_2O	e)	57*	e)	e)	e)	60*	e)
$RNHCOCH_3$	33—64	3—5	Trace	0	63	1—2	1—2
ROH	6—16	40	e)	38	1—4	36	31
CO_2	60	48	e)	22	63	+f)	e)
$ROCONHPr^i$				18			
CH_3COCH_3				21			

TABLE II-2. Products of Anodic Oxidation of N-Hydroxycarbamates (2×10^{-2} M)

Compound EtOCONMe (OH) (IV)			
E_{app}a)	0.7	1.0	0.7
nb)	1.24	2.35	3.31
base added			Pr^iNH_2
Product	Yieldd)		
$EtOCONMe(OCO_2Et)$ (V)	20*	26*	26*
$EtOCONHOCO_2Et$ (IIa)	g)	66*	64*
N_2O	e)	36*	e)
$EtNHCOCH_3$	e)	0	0
EtOH	e)	3	8
CO_2	0	0	f)
HCHO	52	47	h)
EtOCONHOH (Ia)	25	0	0
$EtOCONHPr^i$			8
CH_3COCH_3			11

EtOCONHOR	R=Et (VIa)		R=CH_2=$CHCH_2$ (VIb)
E_{app}a)	1.65	1.40	1.70
nb)	1.12	1.03	0.99
base added	no		
Product	Yieldd)		
EtOCONOR (VII) $RO\overset{\mid}{N}CO_2Et$	5*	95*	94*
$EtNHCOCH_3$	40	0	0
EtOH	33	0	0

a) Applied potential in volt *vs*. SCE.
b) Coulombs passed per mol of the substrate.
c) The concentration of the substrate was about 5×10^{-2}.
d) mol per cent on the basis of the starting material (without asterisk), or theoretical yield (with asterisk).
e) Not estimated in this run.
f) Detected only by GLC, but not determined gravimetrically as barium carbonate.
g) One of the products, N-hydroxyurethane interfered with the estimation on GLC or colorimetric determination of the compound.
h) See experimental section.

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5) *a*) O. Exner and W. Simon, *Collect. Czech. Chem. Commun.*, **30**, 4078 (1965); *b*) J.D. Aubort and R.F. Hudson, *Chem. Commun.*, **1970**, 938.

As shown in Table I, some of the second wave at E_{P2} or the third wave at E_{P3} of the N-hydroxycarbamates are close to E_{P1} of the corresponding oxidation products, but some other waves are thought to be derived from unstable intermediates existing only in time scale of the cyclic voltammetry, because they disappeared after exhaustive electrolysis.

Controlled Potential Electrolysis and Oxidation Process

Ethyl N-Hydroxycarbamate (Ia) and Benzyl N-Hydroxycarbamate (Ib)——The results obtained on controlled potential electrolysis of a series of N-hydroxycarbamates are summarized in Table II.

The initial concentration of the starting material was about 2×10^{-2} M except otherwise stated. When Ethyl N-hydroxycardamate (Ia) was electrolyzed at the potential of the first wave in a divided cell, the electrolytic current near the end of electrolysis increased steeply with evolution of carbon dioxide, and fell to the background current. Number of Faradays passed per mol of substrate (n) is about 0.6 to 1.2 and a considerable amount of N-ethylacetamide were obtained, but no compound containing ethoxycarbonyl group was detected. The result suggests that a fairly large amount of Ethyl N-hydroxycarbamate and/or its oxidation products containing ethoxycarbonyl group seemed to be decomposed with evolution of carbon dioxide. On the electrolysis of benzyl N-hydroxycarbamate (Ib), the similar result, except for the yield of a considerable amount of O-benzyloxycarbonyl group (IIa), was obtained. Hence the rather wide spread of n values observed on the electrolysis may be attributed to decomposition of the substrates. Indeed the N-hydroxycarbamates were found to be unstable in acidic solution such as that in the anodic compartment. The solution in the anodic compartment became more and more acidic with progress of electrolyses, because proton was liberated on the oxidation of the N-hydroxycarbamates. Then the electrolysis was carried out in the presence of excess amine. In the presence of excess γ-collidine or isopropylamine, Ia and Ib yielded about 40% of ethyl N-(ethoxycarbonyloxy)carbamate (IIa; R=Et) and benzyl N-(benzyloxycarbonyloxy)carbamate (IIb; $R=C_6H_5CH_2$), respectively. Smaller amount of ethyl N-(ethoxycarbonyl)-N-(ethoxycarbonyloxy)carbamate (IIIa; R=Et) and benzyl N-(benzyloxycarbonyl)-N-(benzyloxycarbonyloxy)carbamate (IIIb; $R=C_6H_5CH_2$) were also obtained from each compound, respectively. The yields of IIa and IIb increased up to 100% and 56%, respectively, when the concentration of the substrates was increased to about 5×10^{-2} M and lower potential than the above was used. On the oxidation, about 60% of nitrous oxide (theoretical yield) and still fairy large amount of carbon dioxide were also formed, although the evolution of carbon dioxide was not so violent as that observed on the electrolysis in the absence of amine. About 40% of ethyl and benzylalcohols were obtained together with a small amount of N-ethyl and N-benzylacetamides. As shown in Table II, in the presence of amine the yields of ethanol and benzylalcohol were predominant over those of N-ethyl and N-benzylacetamides, respectively, but in the absence of amine the ratio of the yields of both compounds were reversed.

Added isopropylamine was recovered partly as isopropylurethane and as isopropylammonium perchlorate, while γ-collidine was recovered only as γ-collidinium perchlorate. Ethylisopropylamine, an expected product, was not detected. The generation of acetone in a yield of about 20% based on the amount of starting hydroxycarbamate implies that a part of isopropylamine was oxidized together with the starting hydroxycarbamate, even though a much lower potential than the oxidation potential of the amine (*ca.* 1.5 V *vs.* SCE) was applied, and this result explains the larger n values observed in the presence of isopropylamine (*ca.* $n=2.46$) over those observed in the case of γ-collidine (*ca.* $n=1.40$).

For the anodic oxidation of the N-hydroxycarbamates, reaction Chart 1 is proposed on the basis of the n values, products and their relative yields described above. The cyclic voltammetric behaviors of Ia and Ib on addition of excess amines suggest that the hydroxy group of these compounds are partially ionized. The negative charge produced on the oxygen makes the oxidation potential less positive depending on the degree of separation of the proton from the oxygen, that is, the electron density of the oxygen atom depends on the strength of the base present.

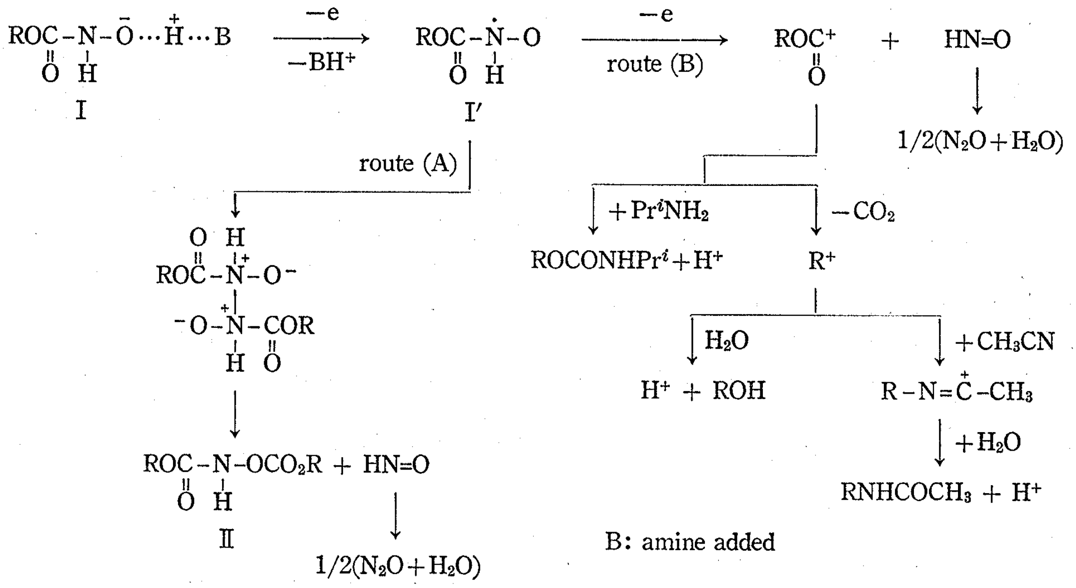
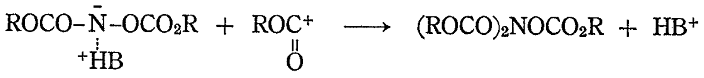


Chart 1

The observed *n* values, products and their yields suggest that about a half of the intermediate (I′) will undergo N–N coupling to give II *via* route (A) and another half of I′ will be further oxidized to alkoxycarbonyl cation and nitroxyl *via* route (B). The higher yield of II in the oxidation with higher concentration of I and lower applied potential also supports the Chart 1, that is, the coupling of I′, is predominant under the above condition over route (B) which is more predominant as higher the potential and lower the concentration of I′. The nitroxyl will dimerize and dehydrates to nitrous oxide. The larger part of alkoxycarbonyl cation undergoes decarboxylation to the corresponding alkyl cation, while the smaller portion reacts with added isopropylamine to give N-isopropylurethane. The alkyl cation reacts with water or the solvent, acetonitrile, to give the corresponding alcohol or N-alkylacetamide, respectively. The oxidation products show that γ-collidine added on the electrolysis would not react with the alkoxycarbonyl cation, contrary to isopropylamine, and acts only as a proton acceptor probably because of a larger steric hindrance around the nitrogen atom. The molar ratio of the generated alcohol to the N-alkylacetamide seems to show that in the absence of excess amine, *i.e.*, at the acidic condition, the alkyl cation reacts predominatly with acetonitrile, while in the electrolysis with excess amine, the alkyl cation reacts predominantly with water present as a contaminant in acetonitrile. The results suggest that in the absence of excess amine the proton generated in the reaction protonates water molecule and thus the free molecule of acetonitrile reacts as a nucleophile more than water does.

A smaller amount of IIIa ($R=Et$) and IIIb ($R=C_6H_5CH_2$) is likely formed by the reaction of partially ionized oxidation products, IIa and IIb[6] with the corresponding alkoxycarbonyl cation, respectively, as below.



$$\mathrm{ROCO\text{-}}\underset{\vdots\atop {}^{+}\mathrm{HB}}{\overset{-}{\mathrm{N}}}\mathrm{\text{-}OCO_2R} + \mathrm{RO}\underset{\overset{\|}{\mathrm{O}}}{\mathrm{C}}^{+} \longrightarrow \mathrm{(ROCO)_2NOCO_2R} + \mathrm{HB^+}$$

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6) As shown in the results on cyclic voltammetry, IIa and IIb also show an extra anodic wave in the presence of excess amine.

Ethyl N-Hydroxy-N-methylcarbamate——As shown in Table II, in the presence of γ-collidine, oxidation of ethyl N-hydroxy-N-methylcarbamate (IV) at 0.70 V showed *n* value of about 1.24 and yielded 20% of ethyl N-(ethoxycarbonyloxy)-N-methylcarbamate (V), 52% of formaldehyde and fairly large amount of Ia. When the oxidation potential was intended to raise up to 1.0 V, and also in the case of excess isopropylamine was present, the electrolytic current at the beginning of the run exceeded easily over the maximum out put of the potentiostat used, and thus the applied potential was necessarily set at lower potential until the current decreased down to the maximum out put of the instrument, and then it was raised up to 1.0 V or 0.7 V with the progress of electrolysis. The results, therefore, reflect the unusual experimental procedure. In the electrolysis, *n* value increased up to 2.35 in the former case and about 26%, 65%, and 50% of V, IIa and formaldehyde, respectively, were obtained. Considerable amount of nitrous oxide was detected, but carbon dioxide and an expected product nitrosomethane[3c] was not detected.

When excess isopropylamine was present, *n* values increased about by one (*ca.* 3.31) and a small amount of N-isopropylurethane and acetone was obtained similarly to that observed on the electrolysis of Ia.

From the above results, the following reaction Chart is proposed for the anodic oxidation of IV.

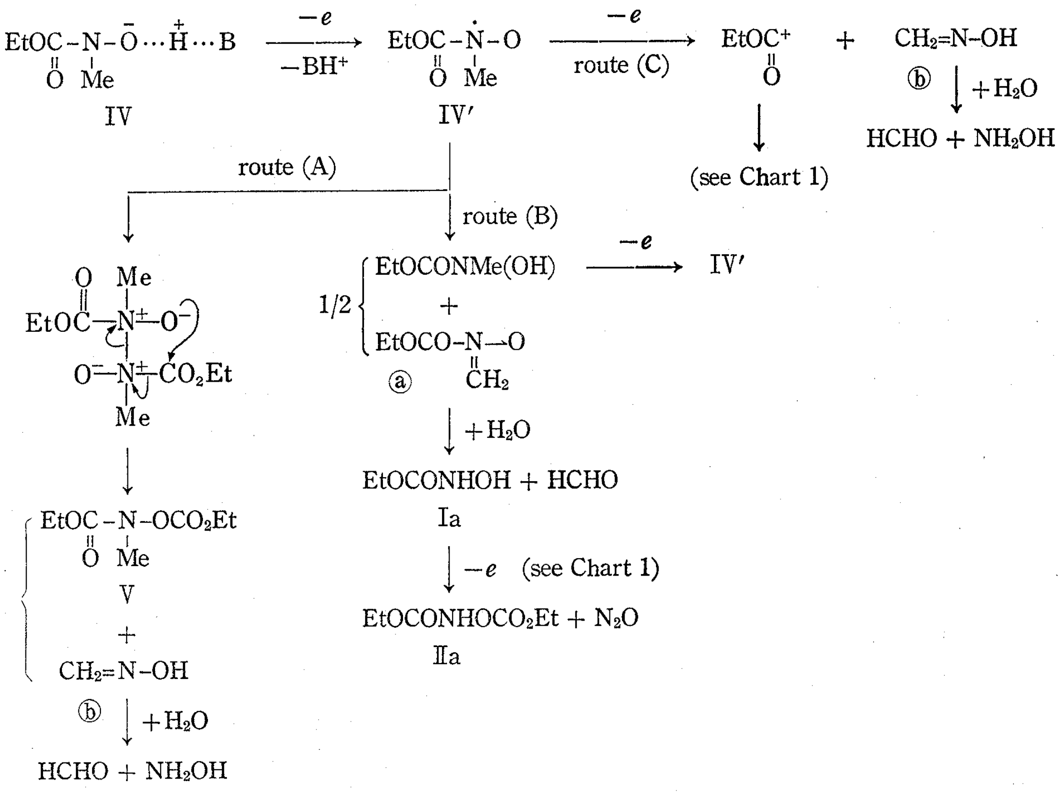


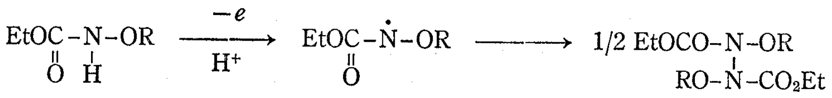
Chart 2

Route (A), route (B) and route (C) correspond to one-, more than two- and two-electron processes, respectively. The observed *n* values of 2.3—2.4 and the distribution of products suggests that about a quarter of the intermediate (IV′) undergoes N–N coupling to give ethyl N-(ethoxycarbonyloxy)-N-methylcarbamate (V) *via* route (A), and larger part of IV′ undergoes disproportionation *via* route (B) to give IIa or is oxidized further *via* route (C). Much larger yield of IIa than that expected on the basis of the oxidation of Ia may be attributed partly to the lower applied potential at the early stage of the electrolysis, but this result is not completely understood.

The yield of IIa shows that N-ethoxycarbonyl-N-methylene-N-oxide (a) is completely hydrolyzed to produce ethyl N-hydroxycarbamate (Ia) during the electrolysis, whereas formaldoxime (b) is not completely hydrolyzed under the condition. Compound (b) is, however, thoroughly hydrolyzed under the condition used in colorimetric determination of formaldehyde[7] carried out on the electrolyzed solution, but the hydroxylamine produced by the hydrolysis, of course, does not contribute to n value in the experiment, though its oxidation potential is less than 1.0 V. The amount of formaldehyde determined, however is less than that of IIa. This is probably due to loss of formaldehyde in the course of the electrolysis, which tends to increase with increasing the duration of electrolysis.

Ethyl N-Alkoxycarbamates——In the presence of γ-collidine, electrolysis of ethyl N-ethoxycarbamate (VIa; R=Et) was carried out at about 0.25 V lower potential (1.40 V) than that of the first wave to avoid the electrolysis of γ-collidine (E_P of γ-collidine is about 1.90 V). Observed n value was nearly one and nearly quantitative amount of N,N′-diethoxy-N,N′-diethoxycarbonylhydrazine (VIIa; R=Et) was produced. Without γ-collidine, anodic oxidation of VIa gave a considerable amount of N-ethylacetamide and ethanol together with a small amount of VIIa. This suggests that decarboxylation of the ethoxycarbonyl intermediate will take place in a similar manner as those observed in the oxidation of Ia and Ib.

Electrolysis of ethyl N-allyloxycarbamate (VIb; $R=CH_2=CHCH_2$) was affected so much by the surface condition of electrode that the electrolysis was often interrupted even at early stage of the run, in which a heavy filming on the carbon electrode was observed. For the oxidation, the carbon electrode must have especially a very smooth and clear surface, then the electrolysis at E_{P1} gave n value of about one and yielded nearly quantitatively N,N′-diallyloxy-N,N′-diethoxycarbonylhydrazine (VIIb). Both of VIa and VIb did not show the extra anodic wave on addition of γ-collidine as described in the results of cyclic voltammetry above. This means that the hydrogen on the nitrogen atom of the N-alkoxycarbamates behaves as a weaker acid than the hydrogen on the oxygen atom. An electron transfer from the lone pair electron on the nitrogen atom of unionized molecule is, therefore, the first stage of the oxidation. From these results we propose the following reaction chart for the anodic oxidation of VI.



$$\mathrm{Et}\underset{\overset{\|}{\mathrm{O}}}{\mathrm{OC}}\text{-}\underset{\overset{|}{\mathrm{H}}}{\mathrm{N}}\text{-OR} \xrightarrow[\mathrm{H^+}]{-e} \mathrm{Et}\underset{\overset{\|}{\mathrm{O}}}{\mathrm{OC}}\text{-}\dot{\mathrm{N}}\text{-OR} \longrightarrow 1/2\ \begin{matrix}\mathrm{EtOCO\text{-}N\text{-}OR}\\ |\\ \mathrm{RO\text{-}N\text{-}CO_2Et}\end{matrix}$$

Chart 3

Conclusion

On anodic oxidation, the hydroxycarbamates other than O-alkylated hydroxycarbamates (N-alkoxycarbamates) alkoxycarbonylate the starting materials and the added amines, and alkylate nucleophile such as water and acetonitrile with alkyl cation produced. Substitution of methyl group on the nitrogen atom markedly decreased the amount of alkylation of acetonitrile and ethoxycarbonylation of the added amines, whereas it increased the proportion of ethoxycarbonylation of the starting carbamate and its demethylation product.

These results are interesting in connection with the studies reporting that: (i) ethyl N-hydroxycarbamate is an effective tumor initiating agent, though ethyl N-hydroxy-N-methylcarbamate (IV) is not[4b]; and (ii) S-ethyl and S-carbethoxy derivatives of cystein was found in urine of animals dosed with ethyl N-hydroxycarbamate.[4a] The results of the present study seem likely to give a further support for the suggestion that N- and S-alkylation and/or

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[7] C.E. Bricker and H.R. Johnson, *Ind. Eng. Chem. Anal. Ed.*, **17**, 400 (1945).

ethoxycarbonylation may be an essential step of carcinogenic activity of some N-hydroxycarbamates.

Experimental

Materials——Ia, VIa and VIb were prepared by the method of Jones[8] Ia was purified by the method of Boyland.[9] (77°/0.25 mm, lit.[9] 86—88°/0.6 mm). IIa was prepared according to the literature.[10] (74°/3—4 mm). IIIa was obtained from the reaction of Ia (0.37 mol) with ethyl chloroformate (0.75 mol) in ether containing potassium carbonate (0.75 mol) and a little water at room temperature for 48 hr (118°/0.08 mm, *Anal.* Calcd. for $C_9H_{15}NO_7$: C, 43.37; H, 6.07; N, 5.62. Found: C, 43.11; H, 6.03; N, 5.90). Ib and IIb were prepared according to the literature.[10] IIIb was obtained from the reaction of Ib (0.01 mol) with benzyl chloroformate (0.02 mol) in benzene containing potassium carbonate (5 g) at 40° for 45 hr, and recrystallized from chloroform–petroleum ether, (mp 82—83°, *Anal.* Calcd. for $C_{24}H_{21}NO_7$: C, 66.20; H, 4.86; N, 3.22. Found: C, 66.10; H, 4.85; N, 3.38).

IV was prepared according to the method of Pound.[4b] V was prepared by the reaction of N-methylhydroxylamine (0.15 mol) with ethyl chloroformate (0.30 mol) in ether containing potassium carbonate (0.45 mol), bp. 84°/0.15 mm, *Anal.* Calcd. for $C_7H_{13}NO_5$: C, 43.97; H, 6.85; N, 7.33. Found: C, 43.88; H, 6.85; N, 7.30).

VIIa and VIIb were prepared according to the literature.[11]

N-Isopropylurethane was prepared by the reaction of isopropylamine (0.5 mol) with ethyl chloroformate (0.5 mol) in ether containing sodium carbonate (0.25 mol) at 0—10°, (bp. 69°/10 mm).

Commercial N-ethylacetamide was purified by distillation. Reagent grade N-benzylacetamide was used without further purification.

Nitrous oxide was purchased from Nishio Kogyo Co.

Cyclic Voltammetry——Cyclic voltammetry was performed with the same apparatus described previously.[1] The electrode system consisted of a glassy-carbon indicator electrode, a glassy-carbon counter electrode and a saturated calomel reference electrode. Measurements were made at 25° with substrate concentration of *ca.* 5 mM and with a scanning rate of 0.05 V sec.$^{-1}$ Concentration of supporting electrolyte, sodium perchlorate, was 0.1 M.

Controlled Potential Electrolysis——The electrolysis was performed with the same apparatus and procedure described previously[1] with 40 ml of anodic solution in an H-type cell. Since the relative amount of the products in such complicated reactions usually depends on the concentration of the substrate and sometimes on the applied potentials, a fixed concentretion must be used to compare the reaction process of various groups of compounds. The concentration of the substrate was ordinary 2×10^{-2} M, which was required for the quantitative determination of the products. In some runs which showed larger *n* values, the applied potential at the early stage of the electrolysis was set at somewhat less positive potential than that of the peak of the wave to decrease the current down to the maximum output of the potentiostat used. The estimation values are the mean of at least ten runs. The quantity of electricity consumed in the electrolysis was calculated by integration of the current-time curve.

Product Analysis——a) Products from Oxidation of Ia: After completion of the electrolysis, solvent was evaporated under reduced pressure and the residue was separated from sodium perchlorate by extraction with chloroform, and the extract was evaporated to dryness and the residue was chromatographed on a silica gel thin-layer (TLC) with chloroform–methanol (10: 1, v/v) as eluent. IIIa, IIa and N-methylacetamide had *Rf* value of 0.95, 0.7 and 0.5, respectively. These compounds were isolated by silica gel column chromatography and were identified by comparing their IR and NMR spectra with those of authentic samples.

Quantitative analysis of the products was performed by GLC using 0.5 μl of electrolyzed solution with an internal standard. A stainless steel column (2 m×3 mm) packed with PEG 20M (Nishio Kogyo *Co.,*) was used at 170° for IIa and N-ethylacetamide, and 210° for IIIa in a JEOL JGC 20K gas chromatograph.

Ethanol and N-isopropylurethane were estimated by GLC (PEG 20M, at 80° and 170°, respectively).

Nitrous oxide was estimated by GLC (molecular sieve 5A, at 150°) using the method of Sutton[12] using 20 μl of electrolyzed solution with external standard.

Carbon dioxide was detected by gas chromatography (molecular sieve 5A, at 150°). During the electrolysis nitrogen gas was passed through the anolyte to aqueous barium hydroxide (5%, w/v). The amount of carbon dioxide evolved was determined gravimetrically as barium carbonate.

b) Products from Oxidation of Ib: IIIb, IIb and N-benzylacetamide were isolated from the electrolyzed solution and determined in a similar manner as described for N-hydroxyurethane (Ia). N-Benzylacet-

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amide, benzylalcohol and IIb were estimated by GLC (PEG 20M, at 210°) and IIIb was estimated on a TLC analyzer (Iatron Laboratories, Inc. Model TH-10). 1 μl of condensed electrolyzed solution was spotted on a silica gel chromarod (CHROMAROD S) and was chromatographed with chloroform as eluent.

c) Products from Oxidation of IV: V and IIa were isolated from the electrolyzed solution and determined in a similar way as in the case of Ia and Ib. Ia produced on the oxidation at 0.70 V was estimated by the colorimetric determination,[9] since Ia was hardly separable from IIa on GLC.

Formaldehyde was estimated by the method of Bricker[7] and Tannenbaum.[13] Isopropylamine was found to interfere with the development of the characteristic colour for chromotropic acid (Bricker's method) and phenylhydrazine-potassium ferricyanate,[13] on the other hand γ-collidine did not interfere with the analysis.

Acetone was identified as 2,4-dinitrophenylhydrazone and estimated with GLC (PEG 20M, at 80°).

d) Products from Oxidation of VI: VIIa was isolated from the electrolyzed solution by column chromatography and was purified by distillation under reduced pressure: colourless oil (*Anal.* Calcd. for $C_{10}H_{20}N_2O_6$: C, 45.44; H, 7.63; N, 10.63. Found: C, 45.45; H, 7.63; N, 10.51). IR and NMR spectra of VIIa were coincided with those of an authentic sample.

Because VIIb was not so stable on distillation as VIIa, it was purified by column chromatography eluted with chloroform–methanol (19: 1, v/v). A pale yellow product was identified by comparing its IR and NMR spectra with those of an authentic sample. VIIa and VIIb were estimated with GLC (PEG 20M, at 170°).

Acknowledgement The authors wish to thank Miss H. Hisamoto for her help in some experiments. This work was supported in part by a Grant from Ministry of Education, Science and Culture, which is gratefully acknowledged.

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