The Effect of the Substituents (Alkyl-groups) on the Thermal Dissociation of Carbaminic Acid Esters

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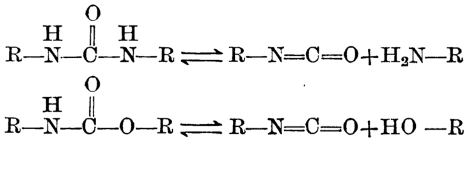
Introduction

The kinetics of the thermal dissociation of urea(1),(2) and carbaminic acid ester(3) in fatty acid have already been reported. On heating, these compounds dissociate, respectively, to isocyanate and amine, and to isocyanate and alcohol.



$$R-\overset{H}{N}-\overset{\overset{O}{\|}}{C}-\overset{H}{N}-R \rightleftharpoons R-N=C=O+H_2N-R$$

$$R-\overset{H}{N}-\overset{\overset{O}{\|}}{C}-O-R \rightleftharpoons R-N=C=O+HO-R$$

When the ester is heated in fatty acid, the dissociated isocyanate reacts with the solvent acid and forms carbaminic acid-fatty acid-anhydride, which easily decomposes to acylated amine and carbon dioxide.

In the previous reports, it has been shown that the dissociation process is the rate-determining step and the rate can be measured by determining the amount of carbon dioxide evolved during the reaction.

In the present work, the effects of substituents (alkyl-groups) on the thermal dissociation of

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(1) T. Hoshino, T. Mukaiyama and H. Hoshino, *J. Am. Chem. Soc.*, **74**, 3097 (1952).

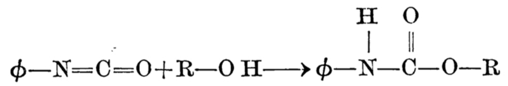
(2) T. Hoshino, T. Mukaiyama and H. Hoshino, This Bulletin, **25**, 392 (1952).

(3) T. Hoshino, T. Mukaiyama and H. Hoshino, ibid. **25**, 396 (1952).

carbaminic acid esters were studied.

The dissociation of the esters may be considered to proceed by a intramolecular proton transfer. On the consideration, when the rates of dissociation of phenyl-carbaminic acid alkylesters ($\phi-\overset{H}{\overset{|}{N}}-\overset{O}{\overset{\|}{C}}-OR$) are measured, the relative rates denote the ability of —OR groups as proton acceptors and when that of alkyl-carbaminic acid phenylester ($R-\overset{H}{\overset{|}{N}}-\overset{O}{\overset{\|}{C}}-O-\phi$) are measured, the relative rates denote the ability of $R-\overset{H}{\overset{|}{N}}-\overset{O}{\overset{\|}{C}}-$ groups as proton donors.

The addition reactions of alcohols to isocyanate, the reversal of the dissociation reaction, have been investigated kinetically.(4),(5),(6),(7)



$$\phi-N=C=O+R-OH\longrightarrow\phi-\overset{H}{\overset{|}{N}}-\overset{O}{\overset{\|}{C}}-O-R$$

The rates of the reaction have the following order.

$$R= Me>Et>isoPr\gg tert\text{-}Bu$$

In the reaction of alkyl-groups, the rate depends on whether the reactant is a primary, secondary, or tertiary alkyl-group. On the experimental facts, the rates of the thermal dissociation of phenylcarbaminic acid-methylester, -isopropylester and -*tert* butylester were determined. The rates showed the following order.

$$tert\ Bu\gg isoPr\geqq Me$$

The rates of the thermal dissociation of acetyl-, methyl- and isopropylcarbaminic acid phenylester were determined and they showed the following order.

$$Acetyl\gg isoPr>Me$$

Several fatty acids were used as the solvent and the effect of the solvent on the dissociation of ester were studied.

Experimental Part

A 35 ml. long-necked, round-bottomed flask was connected to a gas buret by means of a capillary tube. Halfway along the capillary tube, a 10 ml. bulb was inserted and this was maintained at 0° to condense the reaction product less volatile than carbon dioxide. Prior to the experiment, carbon dioxide gas was passed through the acid contained in the flask for thirty minutes. By the treatment, carbon dioxide evolved during the reaction can be measured thoroughly. However, there was found a minor difference depending upon whether carbon dioxide was previously absorbed in the solvent acid or not. Then a sealed ampoule containing a sample was inserted and the ampoule was broken for the reaction. The reaction vessel was maintained at a desired, constant temperature by immersion into the vapors above a suitable boiling liquid contained in a three-necked flask equipped with condenser and thermometer; the reaction vessel was inserted in the centre neck of the flask. Vapors of the following liquids were used as heating agent: water, xylene, anisole, cyclohexanole and aniline. During the course of an experiment the temperature remained satisfactorily constant.

Phenylcarbaminic acid methylester,(8) m. p. 47°, recrystallized from petroleum ether.

Phenylcarbaminic acid isopropylester,(9) m. p. 86°, recrystallized from 50% ethanol-water solution.

Phenylcarbaminic acid *tert* butylester,(10) m. p. 136°, recrystallized from 50% ethanol-water solution.

Methylcarbaminic acid phenylester was prepared from methylisocyanate and phenol according to the procedure similar ot that described by R. Leuckart.(11) Recrystallized from petroleum ether, m. p. 83°.

Anal. Calcd for $C_8H_9N_1O_2$: N, 9.27
Found N, 8.91%

Isopropylcarbaminic acid phenylester was prepared from isopropylisocyanate and phenol by the same method as described in methylcarbaminic acid phenylester, recrystallized from petroleum ether, m. p. 85°.

Anal. Calcd for $C_{10}H_{13}N_1O_2$: N, 7.82
Found N, 7.77%

Acetylcarbaminic acid phenylester,(12) m. p. 117°, recrystallized from 50% ethanol-water solution.

Monochloroacetic acid, isovaleric acid and propionic acid were distilled twice. Caproic acid and α-chloro isocaproic acid were purified by vacuum distillation.

The ratio of ester to fatty acid was 1 mole: 100 moles.

The rate constants were computed by the same

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(4) Tenney L. Davis and James McC. Farnum, *J. Am. Chem. Soc.*, **56**, 883 (1934).

(5) Baker and Holdsworth, *J. Chem. Soc.*, **1947**, 713.

(6) John W. Baker and J. Gaunt, *J. Chem. Soc.*, **1949** 9, 19, 24, 27.

(7) Elizabeth Dyer, Hugh A. Taylor, Shirley J. Mason and Jan Samson, *J. Am. Chem. Soc.*, **71**. 4106 (1949).

(8) A. W. Hofmann, *A.*, **74**, 17; *Ber.*, **3**, 654.

(9) Franz Gumpert, *J. Pr.*, **32**, 279. (1885).

(10) E. Knoevenagel, A., 297, 148. (1897).

(11) R. Leuckart, *J. Pr.*, **41**, 318 (1889).

(12) Otto C. Billeter, *Ber.*, **36**, 3216 (1903).

method as described in the previous report.(2) For example, the experiment gave the following result, calculated with the value of $t=7$ min.

Table 1

Thermal Dissociation of Phenylcarbaminic Acid *t*-Butylester in Caproic Acid at 180.5°

Time (min.)	CO_2 evolved (cc.)	Time (min.)	CO_2 evolved (cc.)	ΔY
2.5	13.3	9.5	53.9	40.6
3.0	17.9	10.0	55.4	37.5
3.5	22.5	10.5	57.2	34.7
4.0	26.7	11.0	59.0	32.3
4.5	29.3	11.5	60.6	31.3
5.0	32.5	12.0	62.0	29.5
5.5	36.0	12.5	63.2	27.2
6.0	38.4	13.0	64.4	26.0
6.5	41.0	13.5	65.3	24.3
7.0	43.3	14.0	66.2	22.9
7.5	45.9	14.5	66.9	21.0
8.0	48.2	15.0	67.6	19.4
8.5	50.4	15.5	68.5	18.1
9.0	52.2	16.0	69.0	16.8

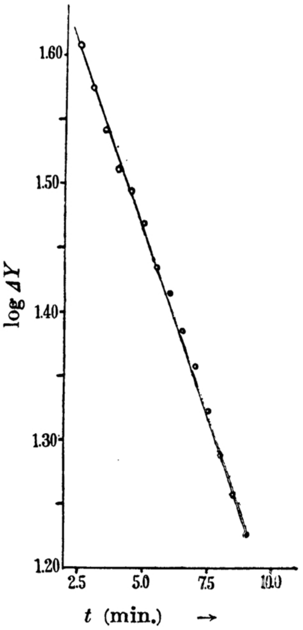


Fig. 1.—Thermal dissociation of phenylcarbaminic acid *t*-butylester in caproic acid at 180.5°. The plot of log Y against t.

First-order kinetics with respect to ester were observed. The results of the rate studied are summarized in Table 2 and 3.

Table 2

The Rate Constants of the Thermal Dissociation of Phenylcarbaminic Acid Alkylesters in Fatty Acids

Ester	Rate const. (min.$^{-1}$)	Temp. (C°)	Solvent
-*tert*-butyl	1.35×10^{-1}	180.5	caproic acid
	2.60×10^{-1}	138.7	α-chloroisocaproic acid
	1.93×10^{-1}	99.9	monochloroacetic acid
-isopropyl	2.48×10^{-2}	181.0	caproic acid
	4.88×10^{-3}	159.1	α-chloroisocaproic acid
	5.87×10^{-2}	181.0	monochloroacetic acid
-methyl	1.84×10^{-2}	181.0	caproic acid
	6.90×10^{-3}	159.0	α-chloroisocaproic acid
	3.22×10^{-2}	181.4	monochloroacetic acid

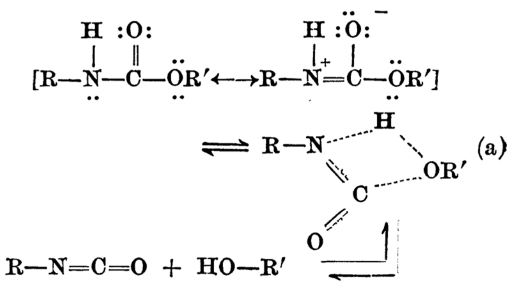
Table 3

The Rate Constants of the Thermal Dissociation of Alkylcarbaminic Acid Phenylester in Fatty Acids

Ester	Rate const. (min.$^{-1}$)	Temp. (C°)	Solvent
acetyl-	1.25×10^{-1}	137.6	caproic acid
	1.51×10^{-1}	138.9	propionic acid
	1.46×10^{-1}	139.1	isovaleric acid
isopropyl-	2.58×10^{-2}	153.7	caproic acid
	2.18×10^{-2}	153.7	α-chloroisocaproic acid
	9.20×10^{-3}	138.7	propionic acid
	3.05×10^{-2}	153.7	isovaleric acid
methyl-	4.74×10^{-3}	153.7	α-chloroisocaproic acid
	6.17×10^{-3}	153.7	caproic acid
	2.86×10^{-3}	138.3	propionic acid
	6.96×10^{-3}	153.4	isovaleric acid

Discussion

On the experimental results, it can be concluded that carbaminic acid esters dissociate to isocyanate and alcohol by the proton transfer. Whether it proceeds by a tautomerization as described in the previous report or by a catalytic action of the solvent acid, the transition state can be considered as the state (a). The (a) shows a loose state of bond between oxygen and carbon according to the transferring proton from nitrogen, forming a new bond with oxygen.



In case of phenylcarbaminic acid alkylesters, the relative rates are shown in the table 4.

Table 4

Relative Rates of the Thermal Dissociation of Phenylcarbaminic Acid Alkylester in Fatty Acids

Solvent	Ester		
	-methyl	-isopropyl	*tert*-butyl
Caproic acid (at 181°)	1	1.3	7.3
α-Chloroisocaproic acid (at 159°)	1	0.7	very large
Monochloroacetic acid (at 181°)	1	1.8	very large

These results will be explained by using the terms chemical driving force and chemical inertia introduced by Evans and Polanyi.(13) The energy of formation of the new molecule is to a certain extent utilized in disrupting the old one. In the case of phenylcarbaminic acid alkylesters, the chemical driving force necessary for the rupture of the ester linkage may be attributed to the formation of the alcohol. The chemical driving force of esters may be orderized as follows.

tert-Bu>isoPr>Me

By chemical inertia is meant the work that must be done to produce reaction. In this case, it is contributed to the work in breaking the C—O linkage and to that in overcoming the interference action against the transferring proton from nitrogen to oxygen. In these esters, there are few differences in the former effect and the chemical inertia will be controlled by the latter effect. By the inductive effect of the alkyl- groups, it will be orderized as follows:

Me>isoPr>*tert*-Bu

The difference between the chemical inertia and the chemical driving force is the necessary patentialenergy of activation. By the consideration, it will be concluded that the activation energy of esters will be in the following order.

Me>isoPr>*tert*-Bu

The tendency agrees with the relative rates of the dissociation of esters determined experimentally.

As the rate of reaction is dependent on the entropy of activation and the activation energy, the entropy term must be involved. The potential energy term, however, will be dominative in the thermal dissociation of phenylcarbaminic acid alkylesters.

In case of alkylcarbaminic acid phenylesters, the relative rates are shown in Table 5.

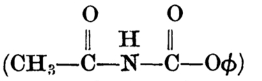
Table 5

Relative Rates of the Thermal Dissociation of Alkylcarbaminic Acid Phenylester in Fatty Acids

Solvent	Ester		
	methyl-	isopropyl-	acetyl-
Caproic acid (at 153°)	1	4.1	very large
Propionic acid (at 138°)	1	3.2	52.8
α-Chloroisocaproic acid (at 153°)	1	4.8	
Isovaleric acid (at 153°)	1	4.3	very large

By the same consideration as in the case of phenylcarbaminic acid alkylesters, the inductive effect of alkyl-group leads to the conclusion that transferring the proton from the nitrogen will be made more easily in methylcarbaminic acid phenylester than in isopropylcarbaminic acid phenylester, which shows that the former ester dissociates more easily than the latter one. The experimental results show, however, that isopropylcarbaminic acid phenylester dissociates faster than methylcarbaminic acid phenylester does. In the isopropylcarbaminic acid phenylester the consideration of the molecular models suggests that the isopropyl-group attached to nitrogen becomes closer to the hydrogen attached to the same nitrogen than the methyl-group in the methylcarbaminic acid phenylester. And according to the steric hindrance, the two hydrogen atoms repel each other. Therefore, the hydrogen attached to nitrogen becomes more active. In this case, the rate seems to be attributed to the steric effect of the substituent group and this will mean that the entropy term may be dominative in the rate factors.

Acetylcarbaminic acid phenylester



$\mathrm{(CH_3{-}\overset{\overset{O}{\|}}{C}{-}\overset{H}{N}{-}\overset{\overset{O}{\|}}{C}{-}O}\phi)$ dissociates faster than isopropylcarbaminic acid phenylester does. In the former ester, by the resonance effect of the carbonylgroups of the R—C=O and COOϕ, the intervening nitrogen aquires a positive potential. Therefore, the proton attached to nitrogen has more tendency to transfer. The phenomenon will make the reaction proceed quickly.

The thermal dissociation of carbaminic acid

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(13) Reviewed by Evans and Polanyi, *Trans. Farad. Soc.*, **34**, 11 (1938).

esters depends on the nature of the solvent acid. In the esters, as shown in the urea linkage, a qualitative relationship was found between the rate constant and the dielectric constant of the solvent acid.

Summary

The rate constants of the thermal dissociation of carbaminic acid esters in fatty acids were determined. In the case of phenylcarbaminic acid alkylestees, the rates showed the following order. *tert*-Bu$\gg$isoPr$\gtrsim$Me
The relative rates may be considered to denote the ability of —OR groups as proton acceptors and the results of the experiment can be explained by the inductive effect of the substituted alkyl-groups.

In the case of alkylcarbaminic acid phenylesters, the rates showed the following order. Acetyl$\gg$isoPr$>$Me
The relative rates may be considered to denote the ability of $R-\overset{H}{N}-\overset{O}{C}-$ groups as proton donors. In acetylcarbaminic acid phenylester, because of the resonance effect of the $R-\overset{\overset{O}{\|}}{C}-$ and COOR groups, the intervening nitrogen aquires a positive potential. The phenomenon will make the hydrogen attached to nitrogen have more tendency to transfer, hence the reaction. That isopropylcarbaminic acid phenylester dissociates faster than methylcarbaminic acid phenylester will be explained by the steric effect of alkyl-groups.

The rates of the thermal dissociation of esters depend on the nature of the solvent acids.

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