

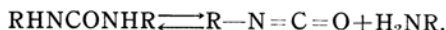
On the Thermal Dissociation of Organic Compounds. VII. The Urea Linkage (1,3-Dibenzylurea and 1-isopropyl-3,3-diethylurea in Alcohols)

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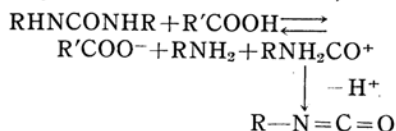
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Introduction

As described in the previous reports¹⁻³⁾, ureas thermally dissociate into isocyanates and amines:

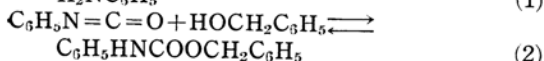
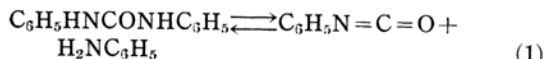


The kinetics of the thermal dissociation of ureas in various fatty acids have been studied and the results show that the rate of dissociation increases as the acidity of the solvent acid increases. A general acid catalysis for the thermal dissociation of urea in fatty acids can be shown as,



In this experiment, the kinetic data on the thermal dissociation of ureas in alcohols have been determined in order to gain an understanding of the dissociation of ureas in a very weak acid, as in alcohols.

By the present experiment, benzyl N-phenylcarbamate, m.p. 78°, was obtained on heating 1,3-diphenylurea in a large excess of benzyl alcohol at 170° for 3 hrs. In this case, the mechanism shown by equation (1) and (2) can be considered.



The dissociation reaction of urea is a reversal of the formation reaction and the

addition of isocyanate and amine to form urea proceeds very rapidly, when accompanied by a liberation of heat. In eq. (1), the equilibrium between urea and isocyanate—amine is in favor of the left side of the reaction. When urea is heated in alcohol, isocyanate dissociated forms urethane according to eq. (2) which removes a considerable part of isocyanate, the equilibrium will be disturbed and a readjustment must take place. Thereupon an additional amount of urea will dissociate, forming isocyanate and amine until the equilibrium is again established.

Thus, when urea is reacted in a large excess of alcohol, if the reaction (1) is the rate-determining step, the rate of dissociation of urea becomes measurable if one determines the amount of amine formed according to eq. (1).

As has been previously mentioned, 1,3-diphenylurea dissociates more readily than 1,3-dibenzylurea used in the present experiment and the use of the former urea seemed to be convenient for the kinetic study because it dissociates at a lower temperature than the latter. In the titration of aniline formed from the former urea, however, the change in pH at the equivalence point is small, which makes the experiment difficult. Therefore 1,3-dibenzylurea and 1-isopropyl-3,3-diethylurea which form strong bases were used.

Experimental

Materials.—1,3-Dibenzylurea was prepared from benzyl isocyanate⁵⁾ and water, m.p. 167°C, recrystallized from ethanol.

1-Isopropyl-3,3-diethylurea was prepared from isopropyl isocyanate⁵⁾ and diethylamine, m.p. 66°C,

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. Mukaiyama and T. Matsunaga, *J. Am. Chem. Soc.*, **75**, 6209 (1953).

4) T. Mukaiyama, S. Ozaki and T. Hoshino, *This Bulletin*, **27**, 578 (1954).

5) T. Curtius and E. Boetzel, *J. prakt. Chem.*, **64**, 316 (1901).

6) O. Hamsch, *J. prakt. Chem.*, **125**, 182 (1930).

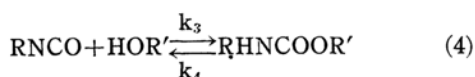
recrystallized from petroleum ether.

The following alcohols were used: benzyl alcohol, b.p. 112°C at 20 mm.; anisyl alcohol, b.p. 147°C at 20 mm.; 1,2-propanediol b.p. 91°C at 16 mm.; ethylene glycol, b.p. 120°C at 20 mm.; diethylene glycol, b.p. 137°C at 15 mm.; triethylene glycol, b.p. 166°C at 15 mm.; 1,4-butanediol, b.p. 136°C at 24 mm.; glycerol, b.p. 185°C at 23 mm.:

Procedure and Analysis.—In carrying out the dissociation reaction, a definite quantity of alcohol was measured into a 20 ml. reaction tube having a ground stopper. The reaction tubes were then placed in a thermostat for 20 min. in order to allow them to attain the constant temperature. Thereupon a small glass tube containing a weighed amount of urea was put into the alcohol and shaken hard to dissolve out the urea. At appropriate intervals of time the tubes were removed from the thermostat and the reaction was stopped by rapid cooling with cold water. The temperature control of the reaction thermostat was accurate to $\pm 0.05^\circ\text{C}$ within the temperature range 165–190°C using a tetraline-mercury regulator. The amounts of amine produced were determined by titration with 0.1 normal hydrochloric acid, back-titration being carried out with 0.1 normal sodium hydroxide, using methyl red as indicator.

Results and Discussion

The steps in the thermal dissociation of urea in alcohol are believed to proceed *via* equations (3) and (4)



The first step is a reversible reaction for which the differential equation is

$$-\frac{d(A)}{dt} = \frac{d(C)}{dt} = k_1(A) - k_2(B)(C) \quad (5)$$

The symbols *A*, *B* and *C* are used for urea, isocyanate and amine, respectively. The rate of change of the concentration of the isocyanate is the difference between the rates of its formation from urea (3) and urethane (4) and the rates of its reaction to form both urethane (4) and urea (3).

$$\frac{d(B)}{dt} = k_1(A) - k_2(B)(C) - k_3(B)(D) + k_4(E) \quad (6)$$

The symbols *D* and *E* are used for alcohol and urethane.

The rate of reaction of alcohol and isocyanate and that of amine and isocyanate are very fast in comparison with that of dissociation of urea and of urethane. Thus, the concentration of isocyanate remains small

and the rate of change of its concentration

$\frac{d(B)}{dt}$ is small, compared with the rate $k_1(A)$

at which it is formed from urea. This means

in view of eq. (6) that $\frac{d(B)}{dt}$ is a small dif-

ference between relatively large quantities so that it may be neglected in comparison with them. Consequently, eq. (6) approximates closely to

$$0 = k_1(A) - k_2(B)(C) - k_3(B)(D) + k_4(E)$$

$$\text{and } (B) = \frac{k_1(A) + k_4(E)}{k_2(C) + k_3(D)}$$

Introduction of the values of (B) into eq. (5) leads to

$$-\frac{d(A)}{dt} = \frac{d(C)}{dt} = k_1(A) - k_2 \left\{ \frac{k_1(A) + k_4(E)}{k_2(C) + k_3(D)} \right\} \cdot (C) \quad (7)$$

If *D* is in great excess compared with *A*, the second term in eq. (7) becomes negligible and the amount of amine formed in the reaction directly gives the amount of urea dissociated.

The amount of amine formed according to eq. (3) was determined by the titration. On plotting the logarithm of the amount of amine formed at regular intervals of time a linear relationship was obtained. This indicates that the reaction was of a first order. The rate constant is given by the gradient of such a plot⁷⁾, as show in Fig. 1.

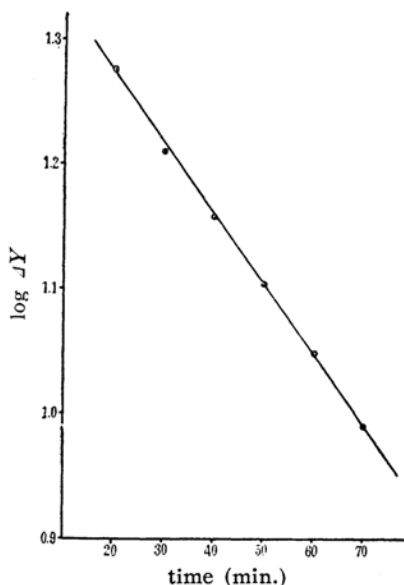


Fig. 1.—The thermal dissociation of 1,3-dibenzylurea in benzyl alcohol at 179.8°C: the plot of $\log \Delta Y$ against time.

7) E. A. Guggenheim, *Phil. Mag.*, 2, 538 (1926).

(a) **1,3-Dibenzylurea (1 mole) in Alcohol (100 moles*)**.—The alcohols were benzyl alcohol, anisyl alcohol, 1,2-propanediol, ethylene glycol, diethylene glycol, triethylene glycol, 1,4-butanediol and glycerol. The results are shown in Table I. The rates were of the first

order with respect to 1,3-dibenzylurea. As an example of a typical run, the thermal dissociation of 1,3-dibenzylurea in benzyl alcohol at 179.8°C is shown in Fig. 1.

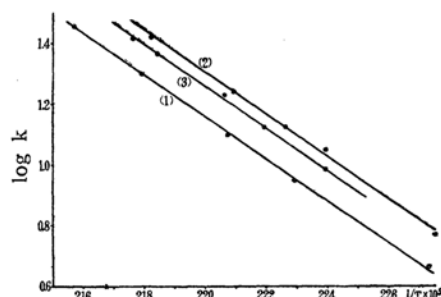


Fig. 2. The thermal dissociation of 1,3-dibenzylurea in benzyl alcohol (1), ethylene glycol (2) and glycerol (3): the plot of $1/T$ against $\log k$.

The kinetic data were further analyzed by means of the Arrhenius equation

$$\ln k = \ln A - (E/RT)$$

and by the absolute rate equation

$$\ln (k/T) = \ln R\kappa/Nh + \Delta S^\ddagger/R - \Delta H^\ddagger/RT$$

The transmission coefficient, κ , was set equal to unity. The calculated kinetic and thermodynamic functions are collected in Table II.

In Table III, the percentage of dissociated urea in the thermal dissociation of 1,3-dibenzylurea (1 mole) in benzyl alcohol, ethylene

TABLE I
THE RATE CONSTANTS OF THE THERMAL DISSOCIATION OF 1,3-DIBENZYLUREA IN ALCOHOLS

Alcohols	$t^\circ(\text{C})$	$k_1 \times 10^2$ (min.^{-1})
Benzyl Alcohol	190.5	2.86
	185.7	2.00
	179.8	1.25
	175.3	0.80
	166.7	0.46
Ethylene Glycol	185.2	2.63
	179.1	1.73
	176.0	1.32
	173.5	1.12
	166.4	0.56
Glycerol	186.3	2.61
	184.5	2.28
	180.2	1.70
	177.5	1.34
	173.3	0.95
Anisyl Alcohol	184.5	2.38
Triethylene Glycol	184.5	1.66
Diethylene Glycol	184.5	1.37
1,2-Propanediol	180.4	1.14
1,4-Butanediol	184.7	0.967

TABLE II
KINETIC AND THERMODYNAMIC FUNCTIONS FOR THE THERMAL DISSOCIATION OF 1,3-DIBENZYLUREA IN ALCOHOLS

Alcohol	T°	$A \times 10^{11}$ (sec.^{-1})	$E(\text{kcal.})$	$\Delta H^\ddagger(\text{kcal.})$	$\Delta S^\ddagger(\text{cal.})$ $\text{mol.}^{-1} \text{ deg.}^{-1}$	$\Delta E^\ddagger(\text{kcal.})$
Benzyl alcohol	458.9	4.62	31.8	32.2	-6.02	34.4
Ethylene glycol	458.4	1.69	30.6	30.6	-8.01	34.3
Glycerol	457.7	2.42	31.0	30.7	-7.30	34.3

TABLE III
THE PERCENTAGE OF DISSOCIATED 1,3-DIBENZYLUREA (1 MOLE) IN ALCOHOLS (100 moles) vs. TIME

Solvent	Temperature ($^\circ\text{C}$)	Time (min.)					Rate constant ($k_1 \times 10^2$) (min.^{-1})
		20	40	60	80	100	
Benzyl alcohol	185.7	10.4	19.2	25.5	30.1	33.0	2.00
Ethylene glycol	185.2	17.1	38.2	49.9	56.7	61.2	2.63
Glycerol	184.5	26.9	48.3	63.0	72.9	80.8	2.28

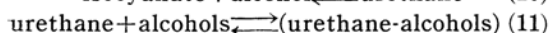
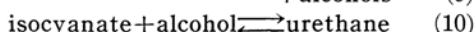
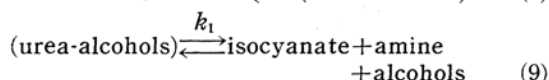
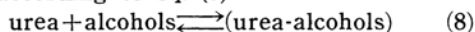
glycol and glycerol (each alcohols 100 moles) are shown against time.

As is seen from Table III, the amount of dissociated urea in ethylene glycol is nearly twice that in benzyl alcohol and that in glycerol is nearly 2.5 times that in benzyl alcohol, while the rate constants, as measured

by the amount of benzylamine produced, of dissociation in these three alcohols are nearly equal. This suggests that the velocities of dissociation of urea in alcohols are dependent on the concentration of the hydroxylic group in the solvent alcohols.

The result can be explained by postulating

the formation of an intermediate complex in equilibrium with urea and alcohol as shown in eq. (8), which dissociates into an isocyanate, an amine and alcohols *via* the rate-determining step according to eq. (9)



The concentration of the complex is given by the following equation,

$$(C_{\text{complex}}) = K \cdot (C_{\text{urea}}) \cdot (C_{\text{alcohol}})$$

and the velocity of dissociation is therefore expressed as,

$$v = k_1 \cdot K \cdot (C_{\text{urea}}) \cdot (C_{\text{alcohol}})$$

(b) **1-Isopropyl-3,3-diethylurea (1 mole) in Alcohols (100 moles).**—The alcohols were benzyl alcohol, anisyl alcohol, diethylene glycol, triethylene glycol and glycerol. The results are shown in Table IV. The rates

TABLE IV
THE RATE CONSTANTS OF THE THERMAL DISSOCIATION OF 1-ISOPROPYL-3,3-DIETHYLUREA IN ALCOHOLS

Alcohols	<i>t</i> (°C)	<i>k</i> × 10 ² (min. ⁻¹)
Benzyl alcohol	169.7	0.99
Anisyl alcohol	169.7	1.20
Ethylene glycol	184.5	fast
Glycerol	169.7	1.53
Triethylene glycol	184.5	1.04
Diethylene glycol	184.5	2.00

were of the first order with respect to 1-isopropyl-3,3-diethylurea.

In the process of dissociation of ureas, the one nitrogen atom of urea accepts a proton to form an amine and the other nitrogen atom donates a proton to form an isocyanate.⁴⁾ The consideration leads to the conclusion that there are two roles of the solvents which control the dissociation.

(a) Ability of solvents to accept a proton from a urea molecule, namely basicity.

(b) Ability of solvents to donate a proton to a urea molecule, namely acidity.

As to the effect of the solvents, it is shown by the present experiment that the rate of dissociation increases in the series,

ethylene glycol > glycerol > anisyl alcohol > benzyl alcohol > 1,2-propanediol > diethylene glycol, triethylene glycol > 1,4-butanediol.

The rates of dissociation in these eight alcohols differ slightly; however, the rates of dissociation in ethylene glycol and in glycerol are faster than in anisyl alcohol and

that in anisyl alcohol is faster than in benzyl alcohol. The basicities of these four alcohols are expected to increase in the following order, which coincides with that of the rates of dissociation.

ethylene glycol > glycerol > anisyl alcohol > benzyl alcohol.

This will lead to the consideration that the stronger the basicities of alcohols the faster the rates of dissociation.

Also, the fact that the rate of dissociation in ethylene glycol is faster than in all other dihydric alcohols (i.e., 1,2-propanediol, diethylene glycol, triethylene glycol and 1,4-butanediol) will show that the larger the molecular size the slower the rates of dissociation.

In order to compare the solvent effects of fatty acids and of alcohols on the thermal dissociation of ureas, the rate constants of the dissociation of 1,3-dibenzylurea and 1-isopropyl-3,3-diethylurea in fatty acids described in the previous report⁴⁾ are listed in Table V.

TABLE V
THE RATE CONSTANTS OF THE THERMAL DISSOCIATION OF 1,3-DIBENZYLUREA AND 1-ISOPROPYL-3,3-DIETHYLUREA IN FATTY ACIDS

Fatty acid	<i>k</i> × 10 ² (min. ⁻¹), <i>t</i> (°C).	
	Urea	1,3-Dibenzyl-urea
		1-Isopropyl-3,3-diethylurea
<i>n</i> -Butyric acid	1.27 (139.6)	3.15 (139.45)
<i>n</i> -Caproic acid	2.68 (155.0)	6.2 (155.0)
<i>n</i> -Capric acid	2.70 (155.0)	3.19 (155.0)
Phenylacetic acid	3.85 (154.9)	very fast (154.9)
Benzoic acid	0.418 (155.0)	1.60 (155.1)

It can be said that these two ureas dissociate more easily in fatty acids than in alcohols. Even in benzoic acid, in which the rates of dissociation of ureas are one-third or one-fourth of those in the other acids, the dissociation proceeds more easily than in alcohols.

This shows that in the process of dissociation of urea the ability of solvents to donate a proton to a urea molecule is an important factor. As the alcohol is a very weak acid, the ability to donate a proton to a urea molecule is so small that the rates in alcohols are slower than in fatty acids.

As the basicities of alcohols are nearly the same as those of ureas, in the case of dissociation in alcohols, alcohols would act as a base to accept a proton. Together with the facts above mentioned that the stronger the

