hydrochloric acid or sodium hydroxide, yields ethylenediamine.[10] The mechanism of the rearrangement of I by sodium hydroxide could parallel that induced by lithium aluminum hydride. Attack by hydroxide ion on I could produce the anion VI which would rearrange to VIII. Reaction of VIII with water would then give N,N′-ethyleneurea.

The above sequence of reactions provide a facile three-step degradation of ethyl succinate to either N,N′-dimethylethylenediamine or ethylenediamine.

Experimental

3-Benzenesulfonoxy-5,6-dihydrouracil.—The improved preparation is described by a typical experiment: To a stirred solution of sodium succinohydroxamate (11.3 g.) in pyridine (65 ml.) at 25° was added dropwise benzenesulfonyl chloride (25 g.). The temperature of the mixture was kept between 25 and 30°. After the addition of the chloride, the solution was stirred for 45 minutes. The pyridine solution was poured into 300 ml. of water, then neutralized by 75 ml. of glacial acetic acid. The mixture was refrigerated overnight and the crystals filtered off next day. The yield of dry crude product was 11.3 g. (88% based on the salt), m.p. 170–173°. Further crystallization from 2-propanol afforded a pure sample, m.p. 175–176°. The m.p. reported previously was 158–160°. A new sample prepared by the older method now melted at 175–176°.

Reductive Lossen Rearrangement.—(a) To a suspension of lithium aluminum hydride (2.5 g.) in ice-cold tetrahydrofuran (50 ml.) was added 3-benzenesulfonoxy-5,6-dihydrouracil (2.5 g.) and the mixture refluxed for 5 hours. The mixture was poured onto ice and dilute hydrochloric acid and extracted with ether. The acid solution was warmed to expel dissolved ether, cooled, was made alkaline with solid sodium hydroxide pellets and distilled in part. The distillate (200 ml.) was made alkaline with solid sodium hydroxide pellets and treated with benzenesulfonyl chloride (7 ml.). After this mixture had stood at room temperature for several days, the derivative crystallized. The benzenesulfonyl derivative recrystallized from alcohol in fine needles, m.p. 123–124°. The yield was then 0.95 g. or 29% based on the starting material. Two further crystallizations from alcohol, and one from acetic acid raised the m.p. to 129–131°. Further recrystallization from ethyl acetate did not raise the m.p.

Anal. Calcd. for $C_{16}H_{20}N_2O_4S_2$: C, 52.15; H, 5.47; N, 7.61. Found: C, 51.90; H, 5.21; N, 7.62.

The mixed m.p. with an authentic specimen[11] of similar m.p. was undepressed.

(b) Similarly, 3-benzenesulfonoxy-5,6-dihydrouracil (1.1 g.) was reduced by lithium aluminum hydride (2.7 g.) in tetrahydrofuran (50 ml.), and worked up as above. The alkaline distillate (200 ml.) was again made alkaline and treated with benzoyl chloride to afford the crystalline derivative (0.5 g., 41%), m.p. 175°. Recrystallization from benzene raised the m.p. to 177–178°.

Anal. Calcd. for $C_{18}H_{20}N_2O_2$: C, 72.94; H, 6.80; N, 9.46. Found: C, 72.86; H, 6.85; N, 9.37.

The melting point of this benzoyl derivative was undepressed on admixture with an authentic specimen.[12]

N-Methyl-1,3-propanediamine.—A solution of 3-methylaminopropiononitrile (4.2 g.) in ether (10 ml.) was added dropwise to lithium aluminum hydride (1.9 g.) in ether (100 ml.). The mixture was refluxed 0.5 hour, and decomposed by 20% NaOH (1.5 ml.) and then water (7 ml.). The ether solution was decanted from the granular inorganic precipitate and distilled. The amine distilled at 140–143°, n^{13}_D 1.4453. Tarbell[5] lists the boiling point of this amine as 138–141° and n^{20}_D 1.4479.

Benzoylation of the amine in pyridine afforded a gum which could not be induced to crystallize. Treatment of the amine (0.4 g.) with benzenesulfonyl chloride (0.3 ml.) in 10% potassium hydroxide solution caused the separation of an oil. The alkaline solution was decanted from the alkali-insoluble material and acidified. The gum which precipitated crystallized on trituration with alcohol and was recrystallized from the same solvent. It formed colorless needles, m.p. 95°.

Anal. Calcd. for $C_{16}H_{20}N_2O_4S_2$: C, 52.15; H, 5.47; N, 7.61. Found: C, 52.07; H, 5.93; N, 7.34.

Acknowledgment.—Professor A. J. Birch is kindly thanked for providing facilities in his laboratory at the University of Sydney.

---

[10] C. M. Buess and L. Bauer, *J. Org. Chem.*, **20**, 33 (1955).

[11] This sample, kindly donated by Dr. F. Lions, was prepared by the methylation of N,N′-ethylenedibenzenesulfonamide.

[12] This specimen was synthesized from N,N′-dimethyl-N,N′-ethylenedibenzeneamide by hydrolysis with hydrobromic acid in phenol, and benzoylation of the resulting amine (Found: N, 9.42).

CHICAGO 12, ILLINOIS

[CONTRIBUTION FROM THE DEPARTMENT OF PHYSICS AND CHEMISTRY, GAKUSHUIN UNIVERSITY]

On the Thermal Dissociation of Organic Compounds. X. The Effects of the Solvents (Amines and Fatty Acids) on the Thermal Dissociation of Urethans

BY TERUAKI MUKAIYAMA AND YOICHI HOSHINO

RECEIVED SEPTEMBER 7, 1955

The rate constants of the thermal dissociation of urethans in amine and fatty acid solvents have been measured. The dissociation of urethan proceeds through the double transfer of a proton under the influence of both a basic and an acidic medium. The mechanisms of dissociation of urea and urethan are similar to those of carbonyl addition compounds, *i.e.*, the carbonyl-forming elimination reaction. It can be shown that these amphoteric compounds dissociate in the presence of either basic or acidic catalysts.

Introduction

Previous papers in this series[1–9] have shown that, on heating, ureas and urethans dissociate as

$$\mathrm{RHNCONHR} \rightleftarrows \mathrm{RNCO} + \mathrm{H_2NR} \qquad (1)$$

$$\mathrm{RHNCOOR} \rightleftarrows \mathrm{RNCO} + \mathrm{HOR} \qquad (2)$$

In the dissociation of urethan, for example, the nitrogen atom of urethan donates a proton to form an isocyanate and the oxygen atom accepts a proton to form an alcohol. Therefore, it can be assumed

---

[1] T. Hoshino, T. Mukaiyama and H. Hoshino, THIS JOURNAL, **74**, 3097 (1952).

[2] T. Hoshino, T. Mukaiyama and H. Hoshino, *Bull. Chem. Soc. Japan*, **25**, 392 (1952).

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

[4] T. Mukaiyama, S. Motogi and Y. Hamada, *ibid.*, **26**, 49 (1953).

[5] T. Mukaiyama and T. Matsunaga, THIS JOURNAL, **75**, 6209 (1953).

[6] T. Mukaiyama, S. Ozaki and T. Hoshino, *Bull. Chem. Soc. Japan*, **27**, 578 (1954).

[7] T. Mukaiyama, *ibid.*, **28**, 253 (1955).

[8] T. Mukaiyama, S. Ozaki and Y. Kobayashi, *ibid.*, **29**, 57 (1956).

[9] T. Mukaiyama and Y. Fujita, *ibid.*, **29**, 54 (1956).

that the reaction occurring in dissociation requires double transfer of the proton, namely, protonation and deprotonation of urethan, and that it must be catalyzed by an acid and a base.

The kinetics of the thermal dissociation of ureas and urethans in fatty acid and alcohol solvents[7,9] have been studied and the results show that, in general, the rate of dissociation increases as the acidity of the solvent increases. It can be concluded that, an acidic medium, the protonation of urea or urethan by solvent acid is an important factor in the dissociation.

In the present study, the kinetics of the thermal dissociation of urethan in basic media, such as amines, and those in acidic media, such as fatty acids, were investigated in order to gain a better understanding of the dissociation.

1-Phenyl-3,3-dibenzylurea, m.p. 125°, identified by mixed m.p. with an authentic sample, was obtained in good yields on heating benzyl N-phenylcarbamate (1 mole) and dibenzylamine (10 moles) in tetralin (100 moles) at 165° for 3 hr. The mechanism shown by equation 3 and 4 is proposed. For this reaction

$$C_6H_5NHCOOCH_2C_6H_5 \rightleftarrows C_6H_5NCO + HOCH_2C_6H_5 \tag{3}$$

$$C_6H_5NCO + HN(H_2CC_6H_5)_2 \rightleftarrows C_6H_5NHCON(H_2CC_6H_5)_2 \tag{4}$$

As isocyanates add to amines instantaneously forming ureas quantitatively, reaction 3 is the rate-determining step of the process comprising reactions 3 and 4. Therefore, when urethan reacts in a large excess of amine, the rate of dissociation of urethan becomes measurable if one determines the amount of unreacted amine remaining.

As described in the previous reports, the steps in the dissociation of urtehan in fatty acid solvent are considered to proceed *via* eq. 5 to 7. Reaction 5

$$RHNCOOR \rightleftarrows RNCO + HOR \tag{5}$$

$$RNCO + HOOCR \rightleftarrows RHNCOOCOR \tag{6}$$

$$RHNCOOCOR \longrightarrow RHNCOR + CO_2 \tag{7}$$

is the rate-determining step in the above sequence; the reaction can be followed by measuring the rate of evolution of carbon dioxide (eq. 7).

The mechanisms of dissociation of carbamic acid derivatives, such as urea and urethan, are similar to those of carbonyl addition compounds. It can be shown that these amphoteric compounds dissociate in the presence of either a basic or an acidic catalyst.

Experimental

Procedure and Analysis. In Amines.—In carrying out the dissociation of urethan in amines, a definite quantity of amine and tetralin was measured into a 20-ml. reaction tube having a ground glass stopper. The reaction tubes were placed in a thermostat for 20 min. to attain the constant temperature, and then a small glass tube containing a weighed amount of urethan was put into the solution. 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 ±0.05° at a temperature near 165° using a tetralin–mercury regulator. The amount of amine remaining was determined by titration with 0.1 *N* hydrochloric acid, back-titration being carried out with 0.1 *N* sodium hydroxide, using methyl red as indicator. (In the case of benzylamine, *p*-nitrophenol was used as the indicator.)

In Fatty Acids.—The apparatus was the same as that described in the previous reports.[1,6]

Materials.—Benzyl N-phenylcarbamate was prepared from phenyl isocyanate and benzyl alcohol, m.p. 76°, recrystallized from aqueous ethanol. Cinnamyl N-phenylcarbamate was prepared from phenyl isocyanate and cinnamyl alcohol, m.p. 88–89°, recrystallized from aqueous ethanol.

The following amines were used: laurylamine, b.p. 134–135° at 15 mm.; benzylamine, b.p. 83° at 30 mm.; di-*n*-butylamine, b.p. 68–99° at 21 mm.; hexamethylenediamine, b.p. 104° at 23 mm.; ethanolamine, b.p. 74° at 12 mm.

The following fatty acids were used: *n*-caproic acid, b.p. 104–105° at 17 mm.; *n*-capric acid, b.p. 122–123° at 3.5 mm.; monochloroacetic acid, b.p. 184°; phenylacetic acid, b.p. 117° at 4.5 mm.

Tetralin was distilled twice and used within a week.

The rate constants of the thermal dissociation of urethan in amines and fatty acids were determined under the following conditions: (a) urethan (1 mole) and amine (10 moles) in a solvent (100 moles): The urethans were benzyl N-phenylcarbamate and cinnamyl N-phenylcarbamate. The amines were lauryl-, benzyl-, hexamethylene-di-, di-*n*-butyl- and ethanolamines. The solvents were tetralin and benzyl alcohol. On plotting the amount of amine, ΔY, remaining in the reaction at regular intervals of time a straight line is obtained. This indicates a first-order reaction rate. The rate constant is given by the gradient of such a plot.[10] The results are shown in Table I; the rates were first order with respect to urethan.

(b) Urethan (1 mole) and fatty acid (10 moles) in tetralin (100 moles): The urethans were benzyl N-phenylcarbamate and cinnamyl N-phenylcarbamate. The fatty acids were *n*-caproic, *n*-capric, monochloroacetic and phenylacetic acids. The rate constants were obtained by the same method as in the case of dissociation in amines. The results are shown in Table II. The rates were first order with respect to urethans.

Discussion

The effects of the solvents on the thermal dissociation of urethans are noted as follows: (1) In amines, the rate of dissociation increases as the basicity of the solvent amine increases. As shown in Table I, the rates of dissociation of urethans in five amines increase in the following order: benzylamine < hexamethylenediamine ≃ lauryl amine ≃ ethanolamine < di-*n*-butylamine.

TABLE I

THE RATE CONSTANT OF THE THERMAL DISSOCIATION OF URETHAN IN AMINES

Amines	Solvent	Benzyl N-phenylcarbamate $k \times 10^3$, min.$^{-1}$	Cinnamyl N-phenylcarbamate $k \times 10^3$, min.$^{-1}$	t, °C.
Benzyl-	Tetralin	5.83	5.44	165.0
Di-*n*-butyl-	Tetralin	33.6	20.4	165.8
Lauryl-	Tetralin	15.2	14.5	165.0
Hexamethylenedi-	Tetralin	12.6	10.4	165.0
Lauryl-	Benzyl alcohol	12.0	9.33	165.0
Ethanol-	Benzyl alcohol	13.2	12.4	164.9

(2) In fatty acids, the rate of dissociation increases as the acidity of the solvent acid increases. As shown in Table II, the rates of dissociation of urethans in four fatty acid solvents increase in the following order: *n*-capric acid ≃ *n*-caproic acid < phenylacetic acid < monochloroacetic acid.

(3) The relative rates of dissociation of two urethans in these two kinds of solvents show a reversed relation. In amine solvents, benzyl N-

---

[10] E. A. Guggenheim, *Phil. Mag.*, **2**, 538 (1926).

TABLE II

THE RATE CONSTANT OF THE THERMAL DISSOCIATION OF URETHAN IN FATTY ACIDS

Fatty acids	Solvent	Benzyl N-phenyl-carbamate $k \times 10^3$, min.$^{-1}$	Cinnamyl N-phenyl-carbamate $k \times 10^3$, min.$^{-1}$	t, °C.
Monochloroacetic	Tetralin	10.9	270	165.0
Phenylacetic	Tetralin	6.13	12.0	165.0
n-Caproic	Tetralin	2.52	4.3	165.0
n-Capric	Tetralin	1.86	2.56	165.0

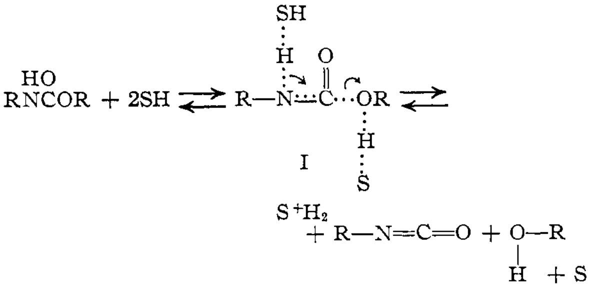
phenylcarbamate dissociates faster than cinnamyl N-phenylcarbamate; however, in fatty acid solvents, the latter dissociates faster than the former urethan.

(4) The dissociation of urethan is accelerated by both acid and base. The rates of dissociation of urethans in both basic and acidic medium are nearly equal.

These results lead to the conclusion that, in a basic medium, the process of deprotonation by a base to form a conjugated base of urethan is a predominant factor in the dissociation. The dissociation proceeds by eliminating alcohol from the negatively charged conjugated base of the urethan, which accepts a proton from solvent molecule.

On the other hand, in an acidic medium, the process of protonation by solvent acid to form a conjugated acid of urethan is a predominant factor in the dissociation. By a similar mechanism, as in a basic medium, the dissociation proceeds by eliminating isocyanate from the positively charged conjugated acid of urethan, which donates a proton to the solvent molecule.

As mentioned in previous reports,[6,7] the termolecular mechanism for the dissociation of urethan is



$$\overset{\text{HO}}{\text{RNCOR}} + 2\text{SH} \rightleftarrows \text{R—N}\cdots\text{C}\cdots\text{OR} \rightleftarrows \text{S}^+\text{H}_2 + \text{R—N=C=O} + \text{HO—R} + \text{S}^-$$

where SH represents solvent

In the state I, one solvent acts as a base to accept a proton and the other acts as an acid to donate a proton at the same time. By the shift of an electron pair the state I dissociates. As shown in the mechanism, urethan acts as a base and an acid toward the solvent molecule.

Similar mechanisms are considered in the dissociation of carbonyl addition compounds, such as carbonyl hydrates or alcoholates, cyanohydrin and aldol; these also require protonation and deprotonation during the reaction, and are classified as carbonyl-forming elimination reactions.[11] The dissociation of these compounds proceeds to form carbonyl compounds by the shift of an electron pair in the rate-determining step, through the conjugated acid or base in the presence of either a base or an acid catalyst. For example, Bell and Higginson[12] proposed a general acid- and base-catalyzed mechanism for the dehydration (dissociation) of acetaldehyde hydrate and Swain and Brown[13] proposed a termolecular mechanism for the mutarotation of glucose which involves the dissociation of intramolecular hemiacetal.

These carbonyl addition compounds are generally in equilibrium with the component compounds at ordinary temperatures; however, the addition reactions of isocyanate with alcohol or amine to form urethan or urea are highly exothermic and thermodynamically favored by low temperature. Therefore, the dissociation of urethan and urea proceed under the influence of heat.

As shown above amphoteric compounds can dissociate into their components through the double transfer of the proton in the presence of either basic or acidic catalysts.

Another interesting problem is that, in these reversible reactions, the catalysts which are suitable for dissociation also accelerate addition. As shown in the dissociation of urethan, a basic catalyst, such as an amine,[14] and an acidic catalyst, such as aluminium chloride,[15] are also useful in the addition reaction of isocyanate with alcohol to form urethan.

This is reasonably explained by considering the principle of microscopic reversibility[11] in which both addition and dissociation take the same path through a similar intermediate.

Acknowledgment.—The authors wish to express their hearty thanks to Prof. Toshio Hoshino for his helpful advice and encouragement throughout the course of this experiment.

MEJIRO, TOSHIMA-KU, TOKYO, JAPAN

---

(11) C. K. Ingold, "Structure and Mechanism in Organic Chemistry," Cornell University Press, New York, N. Y., 1953, pp. 216, 676.

(12) R. P. Bell and W. C. E. Higginson, *Proc. Roy. Soc.* (*London*), **A197**, 141 (1949).

(13) C. G. Swain and J. F. Brown, THIS JOURNAL, **74**, 2534 (1952).

(14) J. W. Baker and J. Gaunt, *J. Chem. Soc.*, 27 (1949).

(15) R. Leuckart, *J. prakt. Chem.*, **41**, 318 (1890).