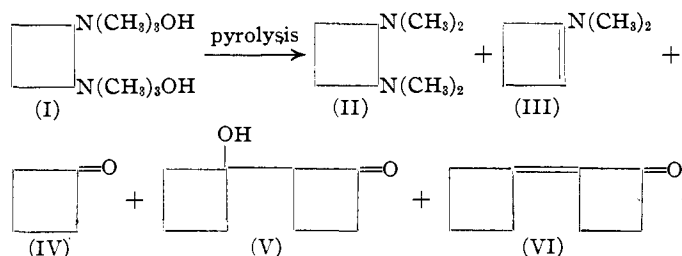


[CONTRIBUTION FROM THE GATES AND CRELLIN LABORATORIES OF CHEMISTRY, CALIFORNIA INSTITUTE OF TECHNOLOGY, No. 895]

Cyclobutane Derivatives. II. The Thermal Decomposition of *trans*-1,2-Cyclobutane-*bis*-(trimethylammonium) Hydroxide

BY EDWIN R. BUCHMAN, MAURICE J. SCHLATTER AND ALF O. REIMS

The investigation of the thermal decomposition of *trans*-1,2-cyclobutane-*bis*-(trimethylammonium) hydroxide (I) was carried out as part of a research program directed toward the synthesis of cyclobutadiene. The diquaternary base was made by stepwise methylation (see Experimental) of *trans*-1,2-diaminocyclobutane.¹ Although its decomposition was studied carefully under a variety of conditions, no indication for the formation of the desired hydrocarbon² was obtained. The nature of the products may be seen from the accompanying chart.



Because of its unstable nature³ (III) was not isolated. It is undoubtedly the parent compound from which (IV), (V) and (VI) are derived and must be considered the principal primary product of the reaction.

Experimental⁴

trans-Tetramethyldiamino-1,2-cyclobutane (II).⁵—Crude *trans*-1,2-diaminocyclobutane hydrochloride obtained¹ either by the action of hydrazoic acid on *trans*-1,2-cyclobutanedicarboxylic acid or from crude *trans*-1,2-cyclobutanediurethan was methylated. The hydrochloride from

(1) Buchman, Reims, Skei and Schlatter, *THIS JOURNAL*, **64**, 2696 (1942).

(2) For examples of hydrocarbon formation from the pyrolysis of 1,2-diquaternary bases see Hurd and Drake, *ibid.*, **61**, 1943 (1939).

(3) Compare other molecules containing the C=C—NR₂ grouping; Merling, *Ber.*, **24**, 3108 (1891); Willstätter, *Ann.*, **317**, 267 (1901); Ciamician and Silber, *Ber.*, **26**, 2738 (1893); Willstätter and Waser, *ibid.*, **44**, 3423 (1911); von Braun and Kirschbaum, *ibid.*, **52**, 2261 (1919); K. H. Meyer and Hopff, *ibid.*, **54**, 2274 (1921); von Braun and Ritter, *ibid.*, **55**, 3798 (1922). (The picrate mentioned here, m. p. 157° is in all probability dimethylamine picrate); Fuson, *THIS JOURNAL*, **50**, 1446 (1928); Ti, *Chem. Abst.*, **30**, 4463 (1936); see also Mannich and co-workers, *Ber.*, **69**, 2106, 2112 (1936).

(4) All melting points are corrected.

(5) When *cis*-1,2-diaminocyclobutane¹ was refluxed with excess of aqueous formaldehyde and formic acid, approximately the theoretical amount of carbon dioxide was evolved. However, after evaporating the resulting solution and making basic, only an insoluble, non-distillable tar was obtained.

20 g. of *trans*-acid was refluxed for four hours with 200 g. of aqueous 36% formaldehyde⁶ and 100 g. of 90% formic acid. During the first half hour a rapid gas evolution took place; after the reaction subsided small additional amounts of formaldehyde and formic acid were added to insure complete methylation. The resulting solution was concentrated to a small volume on the steam-bath and the base liberated by treating with excess of strong sodium hydroxide solution and taken up in ether. The ether solution was dried and distilled over sodium; yield 10 g. (50% from *trans* acid) of product boiling chiefly at 164°. From 50 g. of crude urethan a 71% yield of methylated base was obtained; the methylation reaction proceeds therefore with at least this efficiency. On refractionation the base distilled with practically no range, b. p. 83° at 50 mm., b. p. 101° at 100 mm., *d*₄²⁰ 0.8455, *n*_D²⁰ 1.4472.

Anal. Calcd. for C₈H₁₈N₂: C, 67.55; H, 12.76; N, 19.70. Found: C, 67.54; H, 13.17; N, 19.63.

The dipicrate C₂₀H₂₄N₆O₁₄ (analysis) precipitated when ethereal solutions of the components were mixed, yellow needles, m. p. 244° dec.,⁷ from aqueous alcohol.

Preparation of *trans*-1,2-Cyclobutane-*bis*-(trimethylammonium) Hydroxide (I).—The diquaternary iodide was conveniently prepared by adding slowly 67 g. of methyl iodide (40% excess) to a solution of 23.8 g. of (II) in 67 cc. of methanol while cooling in an ice-bath. After a few minutes, crystals started to come out. When the precipitation was complete, the product⁸ was filtered off and washed with methanol, yield 65.9 g. (92%); additional amounts could be recovered from the mother liquors. A portion of the salt was recrystallized from aqueous ethanol, colorless plates, m. p. 251° dec.⁷

Anal. Calcd. for C₁₀H₂₄I₂N₂: C, 28.18; H, 5.68; N, 6.57. Found: C, 28.08; H, 5.87; N, 6.80.

The salt is difficultly soluble in solvents except water; it was found possible to recover it by continuous extraction with chloroform. When its aqueous solution was treated with aqueous sodium picrate, a precipitate was obtained, orange-yellow needles from water, m. p. 288° dec.,⁷ analysis indicates the expected formula C₂₂H₂₈N₆O₁₄.

The direct methylation of *trans*-diaminocyclobutane with methyl iodide in the presence of alkali did not yield

(6) Regarding methylation by this method see Clarke, Gillespie and Weisshaus, *THIS JOURNAL*, **55**, 4571 (1933).

(7) Minimum temperature at which a fresh sample will decompose when introduced into a bath at this temperature for twenty seconds.

(8) This product consisted solely of diiodide; cases have been reported [Rupe and Bohny, *Helv. Chim. Acta*, **19**, 1305 (1936)] of tetramethyldiamino ring bases (apparently *trans*-configuration) reacting with only one mole of methyl iodide.

the expected product.⁹ A solution of 12.6 g. of crude diamine hydrochloride (from urethan) in 90 cc. of methanol was mixed with 136 g. of methyl iodide (100% excess), and a solution of 53.6 g. of potassium hydroxide (100% excess) in 170 cc. of methanol was added slowly with stirring while refluxing gently over a period of one and one-half hours. The refluxing was continued for an additional two hours and the mixture evaporated to dryness *in vacuo* at about 40°. Exhaustive extraction of the residue with chloroform gave no hexamethylated salt. The product, after several recrystallizations from absolute alcohol, was homogeneous and consisted of colorless feather-like crystals decomposing sharply at 218.0–218.5°.

Anal. Calcd. for $C_6H_{21}IN_2$: C, 38.04; H, 7.45; N, 9.86. Found: C, 37.94; H, 7.17; N, 9.66.

The formulation of this compound as (1-dimethylamino-cyclobutyl-2)-trimethylammonium iodide was confirmed by its conversion to the diquaternary iodide by heating for fifteen hours at 100° in a sealed tube with excess methyl iodide in ethanol.

The free base (I) was prepared from the diiodide by shaking it in aqueous solution with an excess of freshly prepared silver oxide (washed free of alkali by decanting several times with distilled water) until the colloidal particles in the supernatant liquid had coagulated. The mixture was then filtered rapidly with suction and the filter cake washed with distilled water. The filtrate and washings were concentrated *in vacuo* at 40° to a small volume and the resulting gray to brownish, cloudy solution used for pyrolysis. In order to avoid carbonate formation all operations involving the free base were carried out in an atmosphere of nitrogen.

Thermal Decomposition of (I).¹⁰—The decomposition was carried out by heating at approximately 250° in a glass vessel without a catalyst and was extensively studied in the range 350–420° in the presence of platinized asbestos. No essential differences in the course of the reaction under these varied conditions could be detected. In the following a typical pyrolysis carried out at 350–360° is described.

The apparatus has been previously described.¹¹ The spiral gas wash bottle contained 100 cc. of 3 *N* hydrochloric acid. The air was displaced from the apparatus with carbon dioxide and the concentrated solution of the base (from 42.6 g. = 0.1 mole of diiodide) dropped on platinized asbestos at 350–360° over a period of fifteen minutes. No gas collected in the gasometer¹² and very little went into the hydrochloric acid wash bottle.

The pyrolysis distillate was made acid with a small excess of 6*N* hydrochloric acid and the neutral products removed by several extractions with ether. The basic material was recovered from the aqueous phase by making alkaline with 6*N* sodium hydroxide solution and continu-

ously extracting with ether. The contents of the hydrochloric acid wash bottle were investigated separately.

Investigation of Neutral Products.—The ether solution containing this fraction was dried with anhydrous sodium sulfate and the ether removed by distillation through an efficient total reflux column. The residue was fractionated carefully in specially designed equipment, which treatment gave 1.8 g. of material boiling from 80–100°, smaller amounts of an intermediate fraction and 1.3 g. of material boiling at 5 mm. over a 10° range at approximately 85°.

The lower boiling (80–100°) liquid was shown to contain cyclobutanone (b. p. 98.5–99°¹³) as its chief constituent. Its odor was similar to that of cyclopentanone; it formed a bisulfite addition compound¹³ somewhat less readily¹⁴ than the five ring ketone. The ketone derivatives, with one exception, checked the literature description for the corresponding cyclobutanone derivatives; semicarbazone (analysis) rosetts of white needles from water, m. p. 212.0–212.5° (lit. m. p. 211–212° dec.¹⁵), phenylhydrazone pale yellow needles from aqueous alcohol m. p. 98.0–98.5° (lit. m. p. 95–96°^{16a}) decomposed after a few days' standing, 2,4-dinitrophenylhydrazone, orange-red needles, m. p. 147.0–147.2°¹⁶ from absolute alcohol.

Anal. Calcd. for $C_{10}H_{10}N_4O_4$: C, 48.00; H, 4.03; N, 22.39. Found: C, 48.27; H, 4.07; N, 22.53.

The higher boiling fraction (1.3 g.) consisted of 1-(1'-hydroxycyclobutyl-1'-)-cyclobutanone-2 (V) mixed with smaller amounts of 1-cyclobutylidene-cyclobutanone-2 (VI). From the mixture, with phenylhydrazine, with semicarbazide and with sodium bisulfite, derivatives were obtained which however were not suitable for characterization. The 2,4-dinitrophenylhydrazones were prepared from approximately 0.1 g. of ketone mixture by adding to a hot suspension of 0.2 g. of 2,4-dinitrophenylhydrazine in 3 cc. of glacial acetic acid, heating for twenty minutes at 80°, evaporating to dryness in a stream of nitrogen and removing the last of the volatile material at 1 mm. and 80°. The residue was taken up in benzene and chromatographed¹⁷ on alumina. Three zones appeared on the column, a thin dark brown very strongly adsorbed layer on the top of the column (due to impurities), a moderately strongly adsorbed yellow zone (derivative of (V)) and a very weakly adsorbed orange zone (derivative of (VI)) which was washed completely into the filtrate.

The yellow zone was eluted with 2% acetic acid in benzene, the eluate filtered and evaporated to dryness in an inert atmosphere. The residue (230 mg.) was crystallized from benzene yielding clusters of orange needles, m. p. 186–187°.¹⁷

Anal. Calcd. for $C_{14}H_{16}N_4O_5$: C, 52.49; H, 5.04; N, 17.49. Found: C, 52.96; H, 5.30; N, 17.20.

(13) Kishner, *J. Russ. Phys.-Chem. Soc.*, **39**, 923 (1907) [*Chem. Zentr.*, **79**, I, 123 (1908)].

(14) Compare Petrenko-Kritschenko and Kantscheff, *Ber.*, **39**, 1456 (1906).

(15) (a) Curtius, *J. prakt. Chem.*, [2] **94**, 362 (1916); (b) Demjanow and Dojarenko, *Ber.*, **55**, 2740 (1922); (c) Lipp and Köster, *ibid.*, **64**, 2824 (1931).

(16) Lipp, Buchkremer and Seeles, *Ann.*, **499**, 20 (1932), report the m. p. of this compound as 132–133°.

(17) See Zechmeister and Cholnoky, "Principles and Practice of Chromatography" (translation by Bacharach and Robinson), John Wiley and Sons, Inc., New York, N. Y., 1941. The chromatographic separation of 2,4-dinitrophenylhydrazones has been described by Strain, *THIS JOURNAL*, **57**, 758 (1935).

(9) Compare von Braun, Kruber and Danziger, *Ber.*, **49**, 2642 (1916); von Braun and Neumann, *ibid.*, **53**, 109 (1920).

(10) See Schlatter, Thesis, California Institute of Technology, 1941.

(11) Schlatter, *THIS JOURNAL*, **63**, 1733 (1941).

(12) In an exactly similar pyrolysis but carried out at 410–420°, about 300 cc. of gas was collected. A sample of this condensed at –70° giving a mobile liquid with a pleasant unsaturated odor. The analysis carried out in a semimicro combustion apparatus indicated an H/C ratio of 1.94; calcd. for cyclobutadiene, C_4H_4 , 1.0.

The column filtrate containing the material which had given rise to the orange zone was also evaporated to dryness in an inert atmosphere and the residue (40 mg.) crystallized from benzene and isopropyl ether. Clusters of scarlet blades were obtained sintering at 184°; the color¹⁸ agrees well with the formulation of this substance as a derivative of an α,β unsaturated ketone (VI).

Anal. Calcd. for $C_{14}H_{14}N_4O_4$: C, 55.62; H, 4.67; N, 18.54. Found: C, 55.67; H, 4.97; N, 18.93.

Investigation of Basic Products.¹⁹—The ether solution obtained by continuous extraction of the liberated bases from the pyrolysis distillate was carefully distilled to remove solvent and the residue fractionated in special equipment. Because of the small amounts of material available (0.4 cc.) accurate separations were not achieved. The unsaturated base, 1-dimethylaminocyclobutene-1 (III) was not isolated nor could any characteristic derivative be obtained. However, cyclobutanone (identified as semi-

(18) According to a generalization formulated by Dr. C. E. Redemann (based on unpublished observations made in this Laboratory), when the parent carbonyl compound has a double bond conjugated with the carbonyl group, the 2,4-dinitrophenylhydrazone is colored red; a few exceptions are known. The method used above to prepare the dinitrophenylhydrazones of (V) and (VI) is based on a procedure recommended by Redemann.

(19) In one pyrolysis carried out at 350–400°, the contents of the hydrochloric acid wash bottle were combined with the pyrolysis distillate and the neutral material removed with ether. The acid solution was then evaporated to dryness *in vacuo*, taken up in a small amount of water and slowly added to potassium hydroxide pellets in an apparatus arranged for distillation. Volatile amines were removed at a bath temperature of 60° and the oily top layer remaining allowed to stand for 24 hours in contact with the concentrated base. During this time the oily layer had been transformed to an amorphous non-volatile solid, difficultly soluble in water and ether, soluble in alcohol and pyridine; it was easily soluble in dilute hydrochloric acid and from the resulting solution was reprecipitated by addition of alkali. Evidently dimethylamine had added to condensation products of cyclobutanone to give high molecular weight bases.

carbazone) was recovered from the fraction boiling at 90–110°. 1,2-bis-(Dimethylamino)-cyclobutane (II) was shown to be present in the appropriate fraction (ca. 0.25 cc.) by conversion to its characteristic dipicrate, dimethiodide and (from this latter) dimethopicrate. The properties of these derivatives agreed with those found above.

The contents of the hydrochloric acid wash bottle were evaporated to dryness *in vacuo* at 100°, giving 12.4 g. of a mixture of the hydrochlorides of dimethylamine and of trimethylamine. The former was identified by its benzenesulfonyl derivative, m. p. 47°²⁰ from isopropyl ether, and the latter by its picrate, yellow needles from aqueous alcohol, m. p. 224–225°.²¹ A comparison of the amount of benzenesulfonyl derivative obtained, with that formed under identical conditions in control experiments from mixtures of dimethylamine and trimethylamine of known composition indicated that these had been formed during the pyrolysis in the ratio of approximately 1 to 5.

Summary

Cyclobutadiene was not detected among the products of thermal decomposition of *trans*-1,2-cyclobutane-*bis*-(trimethylammonium) hydroxide. Dimethylamine, trimethylamine, *trans*-1,2-*bis*-(dimethylamino)-cyclobutane, cyclobutanone and condensation products of the latter were identified as products of the pyrolysis. 1-Dimethylaminocyclobutene-1 is postulated as an unstable intermediate in the reaction.

(20) Beilstein, "Handbuch der organischen Chemie," 4th ed., 1928, Vol. XI, p. 40.

(21) Beilstein, "Handbuch der organischen Chemie," 4th ed., 1923, Vol. VI, p. 280.

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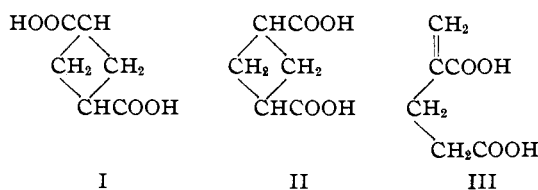
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[CONTRIBUTION FROM THE GATES AND CRELLIN LABORATORIES OF CHEMISTRY, CALIFORNIA INSTITUTE OF TECHNOLOGY, No. 896]

Cyclobutane Derivatives. III. *cis*-1,3-Cyclobutanedicarboxylic Acid

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In 1890 Markownikoff¹ converted *trans*-1,3-cyclobutanedicarboxylic acid (I) into an isomeric acid to which the *cis*-structure (II) was later assigned by E. Haworth and Perkin, Jr.² These



(1) Markownikoff, *J. Russ. Phys.-Chem. Soc.*, **22**, 279 (1890) [*Ber.*, **23**, 432 (1890)].

(2) Haworth and Perkin, *J. Chem. Soc.*, **73**, 330 (1898).

latter authors also reported² that they were able to isolate (II) from the mother liquors resulting from the preparation³ of (I) and from the product of the action of alkali on polymeric methylenemalonic ester. The preparation of (II) by related reactions (from formaldehyde and malonic ester or their equivalents) was claimed in further studies⁴ by Perkin, Jr., and co-workers. Although the acid obtained in this way yielded,^{4c} under relatively mild conditions, products having an open

(3) From the action of sodium ethylate on ethyl α -chloropropionate, Markownikoff and Krestownikoff, *Ann.*, **208**, 333 (1881).

(4) (a) Bottomley and Perkin, *J. Chem. Soc.*, **77**, 294 (1900); (b) Simonsen, *ibid.*, **93**, 1777 (1908); (c) Perkin and Simonsen, *ibid.*, **95**, 1166 (1909).