tion of carbon monoxide and carbon dioxide), the amount of degradation increasing with lengthening time of exposure. These changes could not be explained simply by the presence of oxygen in the nitrogen or that retained in the cellulose at the start of the exposure.

2. The rate of degradation increased with increasing oxygen content in the atmosphere.

3. The rates of change of chain length and copper number during irradiation in nitrogen did not correspond to the rates calculated on the assumption that the reaction was of the first-order type.

4. Exposure of *β-d*-glucose and cellobiose likewise resulted in the production of carbon monoxide and carbon dioxide, but at a considerably slower rate than in the case of cellulose. No change could be detected in the reducing power of these sugars, but exposed samples showed an increased absorption of ultraviolet light.

5. Cellulose irradiated in the absence of oxygen was left in an unstable state at the conclusion of the exposure—*i. e.*, the changes which the cellulose underwent during irradiation continued to occur during storage when air was present, but ceased when air was absent.

6. The post-irradiation effect was increased by raising the temperature to 70° and by replacing the air in the storage bottles with oxygen. A small portion of the increased post-irradiation effect at 70° was due to the temperature alone.

7. The post-irradiation effect was deferred or produced *ad libitum* by alternating the atmospheres several times between nitrogen and oxygen. If the time of storage in oxygen was sufficiently long, the post-irradiation effect came to an end.

8. Cellulose which had been irradiated in the presence of oxygen still underwent the post-irradiation reaction. However, the effect was smaller and became almost negligible when the time during irradiation in oxygen was extended from four to ten days.

APPLETON, WISCONSIN RECEIVED FEBRUARY 12, 1944

[CONTRIBUTION FROM THE DEPARTMENT OF CHEMISTRY OF THE ILLINOIS INSTITUTE OF TECHNOLOGY]

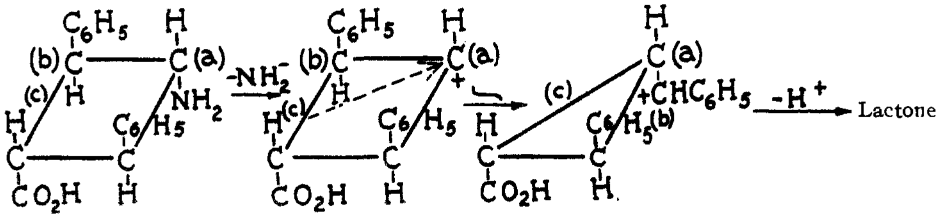
Studies in the Truxillic Acids. I. The Rearrangement of the Zeta-Truxinamic Acids and the General Theory of Molecular Rearrangements[1]

BY IRVING S. GOLDSTEIN[2] AND HERBERT I. BERNSTEIN

A general theory of molecular rearrangements was proposed by Whitmore[3] in 1932. The only essential modification since then has been that of the Walden inversion occurring on the carbon receiving the migrating group.[4]

Virtually all aliphatic rearrangements studied thus far fit into this theory. The evidence has been summarized briefly in a recent paper.[5]

It was further shown in that publication[5] that the amino acids of the truxillic and truxinic acid series lend themselves admirably for testing the stereochemical implications of the theory. Thus ε-truxillamic acid yielded the lactone of 1^c-carboxyl-2^c-benzoxyl-3^t-phenylcyclopropane upon treatment with nitrosyl bromide.[6] The theory would illustrate this as follows



The amino group is removed with its octet of electrons. Carbon a makes up for the resulting deficiency by taking a pair from the adjacent atom b, the pair constituting the bond c. The shifting electrons join carbon a opposite to the position held by the amino group. Thus carbon atom b, with only six electrons, is below the plane of the new cyclopropane ring. The missing electrons are supplied to b by a carboxyl oxygen and result from the loss of the carboxyl H, thus forming a lactone. The various steps need not be consecutive, but may all occur together, somewhat as in S_N2 substitution. Similar degradations of α-truxillaminic,[7] γ-truxillaminic,[8] β-truxinaminic,[9] and δ-truxinaminic acids[9] yielded isomeric cyclo-

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[1] Presented before the Organic Division of the American Chemical Society, Detroit, Mich., April, 1943.

[2] Submitted by Irving S. Goldstein in partial fulfillment of the requirements for the degree of M.S. Now serving in the U. S. Navy.

[3] Whitmore, THIS JOURNAL, **54**, 3274 (1932).

[4] Bartlett and Pockel, *ibid.*, **59**, 820 (1937).

[5] Bernstein and Wallis, *J. Org. Chem.*, **7** 261 (1942).

[6] Stoermer, Neumarker and Schmidt, *Ber.*, **58**, 2707 (1925).

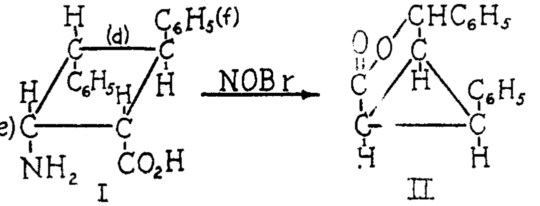
[7] Stoermer and Keller, *ibid.*, **64**, 2783 (1931). See also ref. 8.

[8] Stoermer, Schenck and Pansegrau, *ibid.*, **60**, 2575 (1927).

[9] Stoermer and Ashrand, *ibid.*, **64**, 2793 (1931).

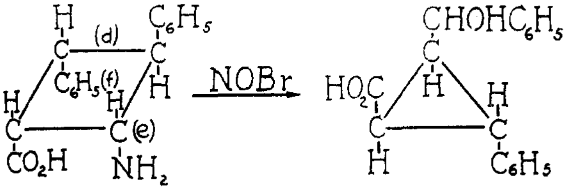
propane compounds whose configurations are explained readily by the general theory.

All of the possible stereoisomeric 1-carboxyl-2-benzoxyl-3-phenylcyclopropanes have been prepared and characterized by Schenck.[10] In this paper he also notes the fact that ζ-truxinic-a-amino acid (I) yielded a cyclopropane in which all three groups were *cis* (II), while the b-amino acid (III) gave an unknown bromo acid and a hydroxyl-acid having the phenyl group *trans* (IV).



I II

ζ-Truxinic-*b*-amino acid



III IV

ζ-Truxinic-*a*-amino acid

No experimental facts were given, and the only reference was to an unpublished Doctoral Dissertation.[11] These results can be explained by the theory illustrated above only by the additional assumption that the rearrangement is accompanied by an inversion of the ring-carbon bearing the phenyl group in the final cyclopropane compound. The pair of electrons making bond d (I) must shift onto carbon atom e. Therefore, regardless of whether retention or inversion of configuration occurred during the rearrangement, the a-amino acid should have yielded a cyclopropane with the phenyl f and carboxyl groups *trans* to each other, since neither of these groups is affected by the various changes. The b-amino acid (III) similarly should have yielded a three-membered ring with the phenyl and carboxyl groups *cis*. In other words, assuming inversion at e, we might have expected the a-amino acid (I) to yield IV, while the b-amino acid (III) should have given II.

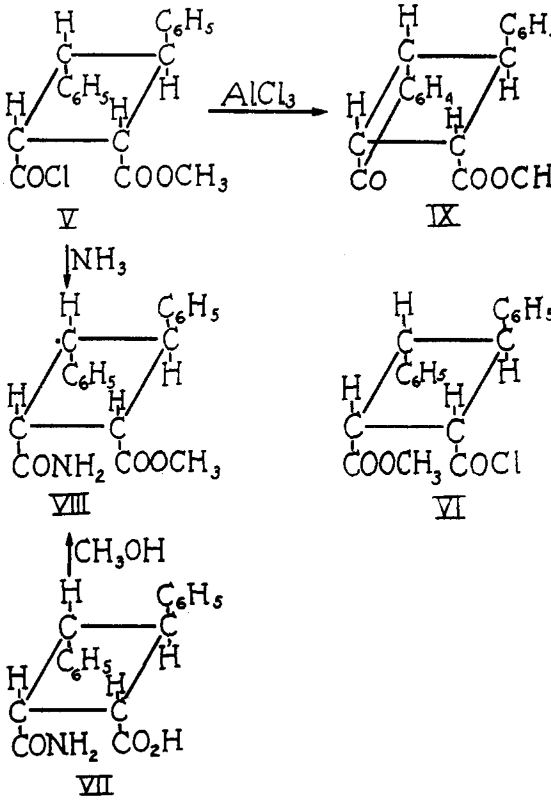
The amino acids (I and III) have been prepared and are newly described in the present paper. They were degraded with both nitrosyl bromide and nitrous acid. ζ-Truxinic-a-amino acid (I) gave principally the lactone (II) upon treatment with both nitrosyl bromide and nitrous acid. From nitrosyl bromide and the b-amino acid (III) a good yield of an unknown bromo-acid was obtained, but no acid IV. Only oils were obtained from nitrous acid and III. The degradation of the a-amino acid (I) to II checks the statement of Schenck,[10] and cannot be explained merely by the general theory of molecular rearrangements.

The above conclusions are dependent upon the correctness of the structures. All eight 1-carboxyl-2-benzoxyl-3-phenylcyclopropanes have been prepared and their configurations characterized[10]. Furthermore, if they were confused, then the degradation experiments previously run with other truxillic and truxinic acids[5] would no longer substantiate the general theory.

There also seems to be little doubt of the correctness of the configurations assigned to the amino acids. These are based on the reactions of the two isomeric ζ-truxinic-methyl ester-acid chlorides with aluminum chloride.[12] The compound which formed a truxonic (IX) ester was called ζ-truxinic-a-acid chloride-b-methyl ester (V). No ketonic compounds resulted from similar treatment of the isomer (VI). It is possible, but improbable, that the above authors[12] confused the a and b acids.

The configurations of the ζ-truxinamidic acids then were deduced from the conversion of both the a-amido acid (VII) and the ζ-truxinic-a-acid chloride-b-methyl ester (V) to the same a-amido acid-b-methyl ester (VIII).

As was shown in a previous publication,[5] it may be safely assumed that the amino acids have the same configuration as the amido acids from which they were prepared by the Hofmann degradation.



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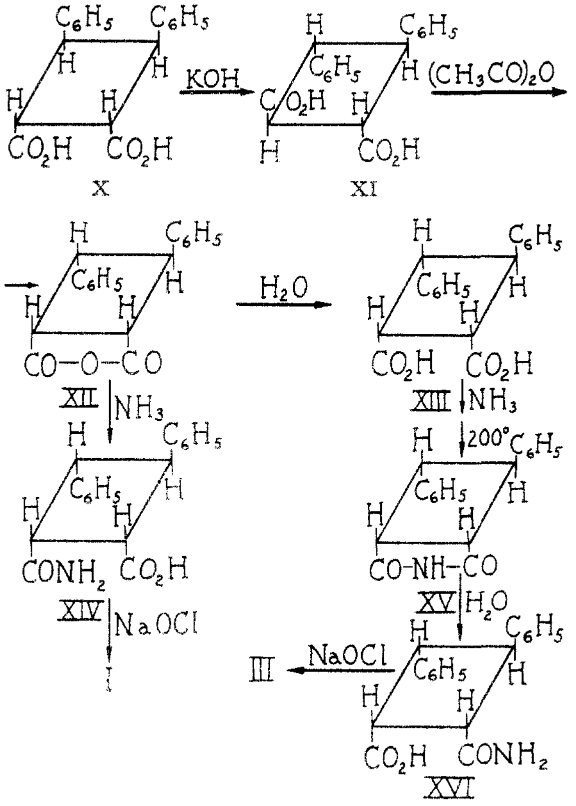
(10) Schenck, *J. Prakt. Chem.*, **134**, 215 (1932).

(11) Rasenack, Dissertation, Rostock, 1928.

(12) Stoermer and Klockmann, *Ber.*, **58**, 1164 (1925).

The flow sheet for the preparation of amino acids I and III from β-truxinic acid (X) is given below.



Experimental[13]

Preparation of δ-Truxinic Acid (XI).[14]—β-Truxinic acid (X)[15] was fused with eight times its weight of powdered potassium hydroxide. The fusion mixture became fluid, then pasty, then fluid again. At this point the flame was removed. The cooled fusion mixture was dissolved in water, and ice and hydrochloric acid were added. The resulting solid was filtered and recrystallized from aqueous methanol to yield crystals of δ-truxinic acid, m. p. 174–175°. From 127 g. was obtained 118 g. of δ-truxinic acid, a 93% yield.

Preparation of ζ-Truxinic Acid (XIII).[14]—To 169 g. of δ-truxinic acid was added 145 g. of fused sodium acetate and 365 g. of acetic anhydride. The mixture was refluxed for three hours at 200–210°. After cooling, it was poured into 2 liters of water, and the mixture heated to cause hydrolysis of the acetic anhydride. The flask was cooled as soon as a reaction had started. After standing overnight, the resultant solid was filtered off and dried, wt. 95.5 g. This was recrystallized from aqueous methanol to give crystals of m. p. 235–236° (d.). The recorded m. p. of ζ-truxinic acid is 239°.[12]

Preparation of ζ-Truxinic-a-amido Acid (XIV).[12]—A solution of 46.5 g. of crude ζ-truxinic acid and 140 g. of acetic anhydride was heated for two hours at 140–150°. The acetic acid formed and excess anhydride were removed by distillation *in vacuo*, and the residue dissolved in benzene. Ammonia was passed through the solution of the resulting anhydride until no more heat of reaction was evident. The voluminous precipitate was filtered, dried and dissolved in water. The resultant cloudy mixture was filtered until a clear yellow solution resulted. Acidification yielded a precipitate, which when filtered and dried weighed 30.5 g., m. p. 198–200°, yield 66%. Recrystallization from aqueous acetone raised the m. p. to 202–204°; literature,[12] m. p. 204°

Preparation of ζ-Truxinic-a-amino Acid (I).—The method of Stoermer was used.[5] To 5.0 g. of ζ-truxinic-a-amido acid was added 70 cc. of 0.5 *N* sodium hypochlorite solution, and the resulting solution kept at 38–40° for two hours. It was then carefully neutralized, and made just basic with dilute sodium hydroxide. The small amount of insoluble precipitate was filtered off, and carbon dioxide passed into the clear filtrate. After an hour precipitation was complete and the precipitate filtered and dried; wt. 3.3 g., m. p. 178–180° (d.) when placed in the bath at 170°. Assuming this to be the a-amino acid, a yield of 73% resulted. Acidification of mother liquor yielded 1.2 g. of product, m. p. and mixed m. p. with ζ-truxinic acid 228–233° (d.).

The acetyl derivative was prepared from the amino acid and acetic anhydride, and recrystallized from aqueous alcohol, m. p. 224–225°.

Anal.[16] Calcd. for $C_{19}H_{19}NO_3$: N, 4.53. Found: N, 4.50.

Preparation of ζ-Truxinic-b-amido acid (XVI).[14]—Gaseous ammonia was passed through a solution of 49 g. of ζ-truxinic acid in 1 liter of alcohol until no heat of reaction was evident. The resultant precipitate was filtered, washed with alcohol, and dried to give 42.5 g. of **ammonium ζ-truxinate,** yield 78%.

The ammonium truxinate was packed into a test-tube, placed in an oil-bath at 180°, and the bath heated to 200–210° for fifteen minutes, the resulting melt being stirred occasionally. The tube was cooled, benzene and petroleum ether added, and the mixture thoroughly triturated and filtered. The residue was treated with sodium carbonate solution, and the insoluble material filtered off. This precipitate was recrystallized from alcohol to give **ζ-truxinimide** (XV), m. p. 167–168°; literature,[14] 168–168.5°. From 38.5 g. of ammonium ζ-truxinate fused in seven batches was obtained 20.5 g. of the imide, a yield of 63%. The sodium carbonate solution was acidified to give 8.5 g. of a solid, m. p. 165°. Recrystallization from aqueous alcohol did not change the m. p. The m. p. of pure δ-truxinic acid was 174–175°; mixed with the above solid was 165–168°. The acid fraction was possibly the impure δ-acid.

To 20.5 g. of the ζ-truxinimide was added 150 cc. of 10% alcoholic potassium hydroxide. After five hours of standing, the initially clear solution became a crystalline mass. This was dissolved in 2 liters of water, and the aqueous solution filtered clear. Acidification of the filtrate yielded a precipitate which was filtered and dried, wt. 21.0 g., m. p. 215–216° (d.) when placed in bath at 200°. This represented an over-all yield of 43% based on the crude ζ-truxinic acid. Recrystallization from aqueous acetic acid gave crystals of m. p. 229–230° (d.) when placed in bath at 220°; literature[14] m. p. 225–226° (d.) when placed in bath at 200°.

Preparation of ζ-Truxinic-b-amino Acid (III).—The reaction was run at 38–40° for two hours, after which most of the insoluble sodium salt of the b-amido acid had disappeared. The remaining solid was filtered, and the preparation continued as above. From 16.7 g. of the ζ-truxinic-b-amido acid was obtained 12.0 g. of the amino acid, m. p. 171–173°, and 3.5 g. of starting material. The mixed m. p. of the a- and b-amino acids was 162–168° (d.). The net yield was practically quantitative. The acetyl derivative of ζ-truxinic-b-amino acid from aqueous alcohol had m. p. 124–125°.

Anal. Calcd. for $C_{19}H_{19}NO_3$: N, 4.53. Found: N, 4.48.

Reaction of ζ-Truxinic-a-amino Acid with Nitrosyl Bromide.—A nitrosyl bromide solution was made by pass-

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(13) Melting points uncorrected.

(14) Stoermer and Scholtz, *Ber.*, **54**, 85 (1921).

(15) Bernstein and Quimby, THIS JOURNAL, **65**, 1845 (1943).

(16) Analyses through the courtesy of Dr. T. S. Ma, University of Chicago.

ing nitric oxide into a mixture of 5.6 g. of bromine in 200 cc. of dry ether in an ice-salt bath. The solution was then slowly added to 7.0 g. of ζ-truxinic-a-amino acid just covered with dry ether. The temperature was kept below −5°. After addition was completed, the reaction mixture stood until the evolution of nitrogen ceased. It was then shaken with a sodium bisulfite solution until the ether was colorless, followed by a similar shaking with a potassium carbonate solution. Acidification of this latter solution yielded only a small amount of an oil from which no crystals could be obtained.

The ether solution was dried over anhydrous potassium carbonate, then concentrated to give a total of 3.5 g. of white needles, m. p. 130–133°. Upon decolorizing with charcoal from a benzene solution, crystals were formed by the addition of petroleum ether (b. p. 60–70°), m. p. 133°. The known m. p. of lactone II was 133°.[8]

The lactone was boiled with 10% alcoholic potassium hydroxide for one minute, diluted with water, and hydrochloric acid added. The resulting precipitate was filtered, dried and recrystallized from benzene to give crystals of m. p. 148–149° (d.). The m. p. of 1^c-carboxyl-2^c-benzoxyl-3^c-phenylcyclopropane was reported[8] as 145–146°. Treatment of the above acid in methyl alcohol with diazomethane in ether yielded lactone II, m. p. and mixed m. p. 132–133°. This dehydrating action of diazomethane had been observed previously with the optically active acid.[5]

Reaction of ζ-Truxinic-b-amino Acid with Nitrosyl Bromide.—The nitrosyl bromide solution was added to 7.0 g. of the b-amino acid as described in the previous experiment. The reaction seemed slower. There was a small amount of ether insoluble material, m. p. 230–233°, possibly α,γ-diphenylbutadiene tetrabromide.[8] The ether was shaken with sodium bisulfite solution, then a potassium carbonate solution as above. Acidification of the latter solution yielded an oil which gradually solidified to yield 3.5 g. of crystals, m. p. 125–137°. Recrystallization from aqueous alcohol gave needles of m. p. 137–139°. Elementary analysis showed bromine to be present. This product will be thoroughly studied at a later date.

The ether solution was dried over potassium carbonate, and the ether evaporated off leaving an oil from which no crystals could be obtained. Treatment of the oil with boiling 10% alcoholic potassium hydroxide for one minute, dilution with water, and acidification also yielded an oil. From this oil, by means of decolorization with charcoal and two recrystallizations was obtained a small quantity of crystals, m. p. 168–169°.

Reaction of ζ-Truxinic-a-amino Acid with Nitrous Acid.—A solution of 1.5 g. of ζ-truxinic-a-amino acid in 150 cc. of dilute hydrochloric acid was warmed to 40°, and 1.5 g. of sodium nitrite in 10 cc. of water was slowly added. A solid gradually formed, and a gas was evolved containing oxides of nitrogen. One hour after addition had been completed, the flask was cooled, and the contents filtered. There was obtained 0.5 g. of crystals, which when decolorized and recrystallized from a benzene–petroleum ether solution had a m. p. of 131–133°. The mixed m. p. with the lactone II prepared above was 131–132°, demonstrating their identity.

Reaction of ζ-Truxinic-b-amino Acid with Nitrous Acid.—The reaction with nitrous acid was performed as above. The initial product was an oil, which was extracted from the solution using ether. The ether extract was washed with potassium carbonate solution. Only an oil resulted from acidification of the latter. Evaporation of the ether resulted in an oil, from which by recrystallization from a benzene–petroleum ether solution was obtained a few mg. of solid of m. p. 188–189°.

We wish to thank Dean Frank C. Whitmore of the Pennsylvania State College for his many helpful suggestions.

Summary

Deamination of ζ-truxinic-a-amino acid (1^c-carboxyl-2^c-amino-3^c,4^t-diphenylcyclobutane) with both nitrosyl bromide and nitrous acid gave the lactone of 1^c-carboxyl-2^c-benzoxyl-3^c-phenylcyclopropane. This change cannot be explained by any existing theory of molecular rearrangements without the assumption of an inversion of a carbon atom not directly involved in the reaction. Only a bromo-acid of unknown structure could be isolated from the reaction of nitrosyl bromide and ζ-truxinic-b-amino acid.

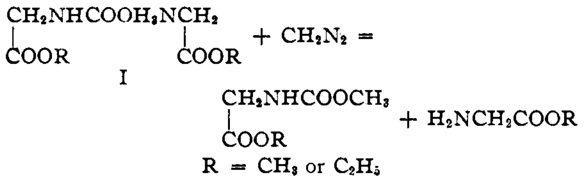
CHICAGO, ILLINOIS RECEIVED JULY 19, 1943

[CONTRIBUTION FROM THE LABORATORY OF HIGH MOLECULAR CHEMISTRY, THE HEBREW UNIVERSITY]

Reaction of Diazomethane with Ammonium Salts of Organic Acids

BY MAX FRANKEL AND EPHRAIM KATCHALSKI

In a previous paper[1] dealing with derivatives of N-carboxy α-amino acid esters, it has been shown that diazomethane reacts with the salt formed between N-carboxyglycine ester and glycine ester (I), yielding N-carbomethoxyglycine ester and glycine ester in about equimolecular amounts. The reaction proceeds according the scheme



$$\underset{\text{COOR}}{\overset{|}{\text{CH}_2}}\text{NHCOOH}_3\text{N}\underset{\text{COOR}}{\overset{|}{\text{CH}_2}} + CH_2N_2 = \underset{\text{COOR}}{\overset{|}{\text{CH}_2}}\text{NHCOOCH}_3 + H_2NCH_2COOR$$

I

$R = CH_3$ or C_2H_5

(I) is a substituted ammonium salt of an organic acid; thus the above scheme represents a reaction between diazomethane and an ammonium salt of an organic acid. As far as we are aware the literature does not contain any references to reactions between diazomethane and ammonium or N-substituted ammonium salts of organic or inorganic acids (*cf.* ref. 2); we therefore included in the paper mentioned[1] experimental results concerning the action of diazomethane on ammonium propionate and on ammonium benzoate. In both cases the methyl esters of the corresponding acids, and ammonia, were obtained.

The object of the present paper is to extend the investigation of this reaction to ammonium salts of dibasic acids and to N-substituted ammonium salts.

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[1] Frankel and Katchalski, THIS JOURNAL, **65**, 1670 (1943).

[2] Sidgwick, "Organic Chemistry of Nitrogen," 351–361 (1937); Smith, *Chem. Rev.*, **23**, 193 (1938).