CLVII.—*The Hydrolysis of Guanidine.*

By James Bell.

While it is generally accepted that urea is the product of the direct hydrolysis of guanidine in accordance with the simple equation

$$CN_3H_5 + H_2O = CON_2H_4 + NH_3 \quad . \quad . \quad . \ (1)$$

the mechanism of this reaction has not hitherto been investigated. Ossikovszky (*Bull. Soc. chim.*, 1872, **18**, 161) obtained ammonia and carbon dioxide on boiling a solution of guanidine sulphate with excess of alkali and of acid, respectively: he therefore concluded that urea was formed as an intermediate product in this decomposition. The credit of being the first to obtain urea from guanidine is given to Baumann, whose only reference to this reaction consists of one sentence (*Ber.*, 1873, **6**, 1376), where he states, without giving his experimental evidence, that urea can be obtained by boiling the solution of a guanidine salt with excess of barium hydroxide solution. Almost thirty years later, Fleming (*Chem.-Ztg.*, 1900, **24**, 56) obtained impure urea in this way, but gave no quantitative results. Krall, however, in an attempt to investigate the mechanism of this reaction, was unable to obtain any urea on boiling a solution of the free guanidine base under a reflux condenser (J., 1915, **107**, 1396).

By means of the xanthhydrol test (Fosse, *Compt. rend.*, 1913, **157**, 948) the author has been able to establish definitely the formation of urea, and to determine the extent of the reaction under various conditions. From the results obtained, information has been gained as to the mechanism of the reaction and of the accompanying secondary changes.

When a solution of free guanidine was boiled under a reflux condenser, ammonia gas was evolved and cyanate, carbonate, and urea were detected in the solution. In certain reactions, where urea, ammonium cyanate, and carbonate are produced, it has been shown that cyanic acid is first formed and is then hydrolysed on the one hand to ammonium carbonate, while on the other it combines in its *iso*-form with ammonia to form urea (Werner and Fearon, J., 1920, **117**, 1078). It has now been proved, however, that, in the case of guanidine, urea is the first product formed. When an aqueous solution of guanidine was allowed to remain at the ordinary temperature, the odour of ammonia developed and urea was found present, but no cyanate could be detected by the delicate copper–pyridine test (Werner, J., 1923, **123**, 2577). Barium nitrate also gave a negative test for carbonate, which was confirmed by the fact that the alkalinity of the solution remained constant. The first phase in the hydrolysis of guanidine is, therefore, represented by equation 1, the mechanism of which is discussed later.

It would thus appear that the production of ammonium cyanate and carbonate was due to the decomposition of urea, when boiled in the strongly alkaline solution of free guanidine (Werner, J., 1918, **113**, 84). This decomposition by guanidine was definitely proved by an experiment in which one equivalent of urea was added to a solution of guanidine, when an increase was obtained in the amount of cyanate and carbonate produced on boiling (Expt. 8). The next phases are therefore :

$$CON_2H_4 = NH_4OCN \quad . \quad . \quad . \quad . \quad (2)$$
$$NH_4OCN + 2H_2O = (NH_4)_2CO_3 \quad . \quad . \quad . \quad . \quad (3)$$

When a sufficiently dilute solution of guanidine was boiled under a reflux condenser, there was no escape of carbon dioxide, resulting from the dissociation of ammonium carbonate, whereas the amount of ammonia evolved was greater than that required for equation 1. This could only arise from the further changes :

$$NH_4OCN + CN_3H_5 = CN_3H_5,HOCN + NH_3 \quad . \quad . \quad . \quad (4)$$
$$(NH_4)_2CO_3 + 2CN_3H_5 = (CN_3H_5)_2,H_2CO_3 + 2NH_3 \quad . \quad . \quad (5)$$

The amount of ammonia evolved was equal, within the limits of experimental error, to that required by these equations. It should be clearly understood that the latter changes (equations 4 and 5) took place under the special conditions stated above. With stronger solutions of guanidine, some carbon dioxide escaped through the reflux condenser and was not, therefore, all fixed as guanidine carbonate. Moreover, when a solution of guanidine was boiled without a reflux condenser, all the carbon dioxide escaped, urea and guanidine cyanate being left in the solution.

When investigating the rates of formation of these different products, it was noticed that, after a time, the proportion of guanidine cyanate present decreased as the reaction proceeded, showing that it also was undergoing change. Bamberger (*Ber.*, 1887, **20**, 68) has brought forward evidence for the isomeric change of guanidine cyanate to dicyanodiamidine in accordance with the equation

$$NH_2{\cdot}C(:NH){\cdot}NH_2,HOCN = NH_2{\cdot}C(:NH){\cdot}NH{\cdot}CO{\cdot}NH_2.$$

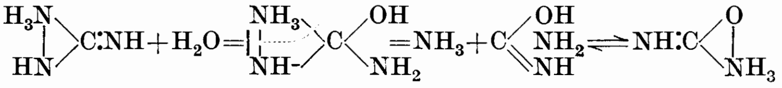
The latter compound, however, could not be detected in the products formed during the hydrolysis of guanidine, and is therefore not formed under the conditions in question. Even after evaporation of some of the neutralised solution to dryness, no change of guanidine cyanate to dicyanodiamidine occurred. There can be no doubt that guanidine cyanate forms only urea or guanidine carbonate, or, in all probability, both these substances, a conclusion which is also the only one consistent with the quantitative data. More definite information as to the hydrolysis of guanidine cyanate would require separate investigation.

On boiling dilute solutions of guanidine (of approximately $N/8$ strength), no evidence could be obtained of its dissociation into ammonia and cyanamide. However, when a normal solution was boiled, dissociation to a small extent was indicated by the formation of melamine, $C_3N_6H_6$, the tripolymeride of cyanamide. This dissociation is obviously a side reaction and not concerned in the formation of urea, since, in the first place, cyanamide does not produce urea under the conditions of these experiments, and in the second, a greater yield of melamine would have been obtained, in view of the ready polymerisation of cyanamide.

Krall (*loc. cit.*) has given reasons for doubting the usually accepted formula for guanidine, *viz.*, $\mathrm{NH{:}C(NH_2)_2}$, and suggests that in solution, the free base exists probably as an equilibrium mixture of the two forms

$$\text{(A.)}\quad \mathrm{NH_2{\cdot}C}\left\langle\begin{matrix}\mathrm{NH_3}\\ |\\ \mathrm{N}\end{matrix}\right. \rightleftharpoons \mathrm{NH{:}C}\left\langle\begin{matrix}\mathrm{NH_3}\\ |\\ \mathrm{NH}\end{matrix}\right.\quad \text{(B.)}$$

Increase of alkali hydroxides would increase the proportion of B, and addition of acids that of A. In the course of the present work, additional evidence has been obtained in favour of this view. When a solution of free guanidine in presence of excess of alkali was kept at the laboratory temperature, the rate of formation of urea was greater than in the case of guanidine alone, whilst the alkali appeared to take no part in the reaction (Expts. 1 and 2). This fact is explained most easily on the above conception of the constitution of guanidine. As a rule, the NH: radical is the more readily hydrolysed, and hydrolysis would therefore take place through the B form. The presence of additional alkali increases the proportion of B and therefore increases also the rate of hydrolysis. The mechanism of the reaction may be best explained thus :



$$\left.\begin{matrix}\mathrm{H_3N}\\ |\\ \mathrm{HN}\end{matrix}\right\rangle\mathrm{C{:}NH}+\mathrm{H_2O}=\left.\begin{matrix}\mathrm{NH_3}\\ |\\ \mathrm{NH-}\end{matrix}\right\rangle\mathrm{C}\left\langle\begin{matrix}\mathrm{OH}\\ \\ \mathrm{NH_2}\end{matrix}\right.=\mathrm{NH_3}+\mathrm{C}\left\langle\begin{matrix}\mathrm{OH}\\ \mathrm{NH_2}\\ \mathrm{NH}\end{matrix}\right.\rightleftharpoons\mathrm{NH{:}C}\left\langle\begin{matrix}\mathrm{O}\\ |\\ \mathrm{NH_3}\end{matrix}\right.$$

This view of the constitution of guanidine has received support from Plimmer in his recent investigation of its behaviour towards nitrous acid (J., 1925, **127**, 2658).

EXPERIMENTAL.

A solution of free guanidine was prepared by the precipitation of guanidine carbonate solution with one equivalent of barium hydroxide solution and filtering off the barium carbonate. The filtrate, which was an approximately $N/8$-solution, always contained some guanidine carbonate, owing to the absorption of carbon dioxide from the air by the strongly alkaline liquid during filtration. This carbonate was estimated at the outset and the necessary corrections were applied throughout.

In the experiments described, the urea formed was estimated by neutralising an aliquot part of the liquid, evaporating the solution to dryness, extracting the residue with glacial acetic acid, and adding excess of xanthhydrol, dissolved in methyl alcohol. After 12 hours, the precipitate of dixanthylurea was collected on a weighed filter-paper, washed with alcohol, dried, and weighed. A small correction was applied for the slight solubility of dixanthylurea in the mixture of acetic acid and methyl alcohol, the value of this correction being determined in preliminary control experiments. The carbon dioxide in solution was estimated volumetrically, after precipitation as barium carbonate. Cyanates were estimated by precipitation and weighing as silver cyanate.

Dicyanodiamidine was tested for by adding copper sulphate and sodium hydroxide solutions, when the characteristic pink copper derivative of this substance was precipitated. Melamine was identified by its picrate.

In all the experiments, where a solution of guanidine was boiled, the burner was adjusted to secure quiet ebullition only.

Expt. 1. Changes produced in *N*/8-solution of guanidine at the ordinary temperature. *a* is the percentage of guanidine hydrolysed to urea.

Time (days) ...	5	10	20	31	60	70	156	189
a..................	3·25	6·1	11·3	19·2	31·4	35·1	62·4	70·5

No cyanate or carbonate was formed.

Expt. 2. Changes produced at the ordinary temperature in *N*/8-solution of guanidine containing sodium hydroxide (1 mol.).

Time (days)	8	41	102	128
a	9·5	34·5	64·9	70·4

Here the velocity of hydrolysis was greater than in the solution of guanidine alone. No cyanate or carbonate could be detected.

Expt. 3. Changes produced in *N*/8-solution of guanidine after 1½ hours' boiling under reflux.

100 C.c. of solution were used containing 0·702 g. of the free base. Urea, cyanate, and carbonate in the resulting liquid were estimated. Increase in alkalinity of liquid on boiling = 9·8 c.c. of *N*/10-acid (this included the ammonia evolved). This increase could only be due to the formation of ammonium carbonate as in equation 3. Increase in alkalinity, calculated from the carbonate found in solution, = 9·9 c.c. of *N*/10-acid. Hence no carbon dioxide escaped through the condenser. The ammonia evolved, calculated from equations 1, 4, and 5, = 8·05 c.c. of *N*-acid (Found : NH_3 = 8·0 c.c. of *N*-acid). The following results represent the percentages of the different products, calculated in terms of the guanidine, from which each was originally derived, in accordance with equations 1—5 : Urea, 36·5; ammonium cyanate, 9·05; ammonium carbonate, 4·15; guanidine cyanate, 9·07; guanidine carbonate, 8·30. Total, 67·05%.

Expt. 4. Changes produced in *N*/8-solution of guanidine after boiling under reflux for 3 hours.

Increase in alkalinity, calculated from the carbonate present, = 13·0 c.c. of *N*/10-acid. Increase found = 13·0 c.c. of *N*/10-acid.

Ammonia evolved = 4·45 c.c. of *N*-acid. Calc. : NH_3 = 11·25 c.c. of *N*-acid. This was the only experiment in which the ammonia was not all driven out of solution. Found : Urea, 66·0 ; ammonium cyanate, 6·25 ; ammonium carbonate, 7·05 ; guanidine cyanate, 6·25 ; guanidine carbonate, 14·10. Total, 99·65%.

Expt. 5. Changes produced in *N*-solution of guanidine after 1½ hours' boiling under reflux.

A normal solution of guanidine was prepared by dissolving 4·13 g. of guanidine nitrate in 33·8 c.c. of *N*-sodium hydroxide solution. After boiling, urea, carbonate and cyanate were estimated as before. Increase in alkalinity = 6·4 c.c. of *N*-acid. Increase due to the carbonate found in solution = 3·0 c.c. of *N*-acid. Hence, ammonium carbonate formed = 6·4 c.c. of *N*-acid, and of this, a portion = 3·4 c.c. of *N*-acid, passed through the condenser, whilst the remainder = 3·0 c.c. of *N*-acid, reacted with free guanidine to form guanidine carbonate. Found: Urea, 59·5; ammonium cyanate, 6·45; ammonium carbonate, 9·4; guanidine cyanate, 6·45; guanidine carbonate, 8·9. Total, 90·7%.

Found for the ammonia evolved, 35·2 c.c. of *N*-acid. Calc., 34·2 c.c. The difference is due to ammonia involved in the formation of melamine, a small quantity of which was present. This difference would correspond to a 3% conversion into melamine.

Expt. 6. Changes produced in *N*/15-solution of guanidine containing one equivalent of barium hydroxide, after 1½ hours' boiling under reflux.

The results, in this case, were similar to those of the previous experiments, except that barium cyanate and carbonate were produced instead of the corresponding guanidine salts. The ammonia evolved was not estimated. Found : Urea, 80·0 ; barium cyanate, 13·4 ; barium carbonate, 2·9. Total, 96·3%.

Expt. 7. Changes produced in *N*/7-solution of guanidine, after 1 hour's boiling without reflux.

The solution was boiled in a distillation flask, connected with a condenser and flask for ammonia absorption. Water was added from a tap funnel at intervals to maintain the volume of the solution constant. No carbonate was found in the solution on boiling. Hence all the carbon dioxide escaped. The amount of ammonium carbonate formed was calculated from the increase in alkalinity.

Found for ammonia evolved, 14·3 c.c. of *N*-acid. Calc., 14·4 c.c. Found : Urea, 73·4 ; ammonium carbonate, 1·4 ; ammonium cyanate, 9·6 ; guanidine cyanate, 9·6%. Total, 94·0%.

Expt. 8. Action of guanidine on urea in solution on boiling.

A solution similar to that used in the previous experiment, containing one equivalent of urea (0·9 g.), was boiled for 1 hour under the same conditions. It was assumed that the changes produced in the guanidine were the same as before. The increase in carbonate and cyanate was therefore due to the decomposition of the added urea. Found: Added urea converted into ammonium cyanate and carbonate = 13·3 and 3·7%, respectively. Therefore total urea decomposed = 17·0%.

From the determination of urea in the two experiments, the decomposition of added urea was calculated to be 21·9%. The difference in these results is due to the fact that, in this experiment, more guanidine was fixed as cyanate than in the previous one, and hence the amount of guanidine hydrolysed would be slightly less.

The author gratefully acknowledges his indebtedness to Professor E. A. Werner, Sc.D., for advice received in the course of this work and to Dr. W. R. Fearon, F.T.C.D., at whose suggestion this investigation was undertaken.

TRINITY COLLEGE, DUBLIN. [*Received, February* 16*th*, 1926.]