SYNTHESIS AND INFRARED SPECTRA OF GUANYLUREAS[1]

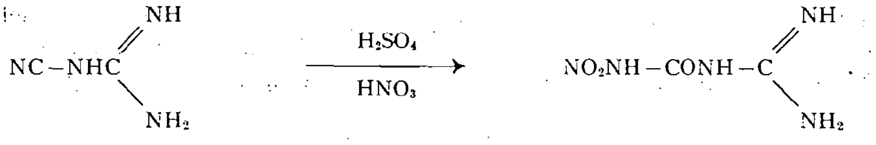
By Paul A. Boivin, W. Bridgeo,[2] and Jean L. Boivin

ABSTRACT

When 1-amidino-3-nitrourea is reacted in aqueous solutions of amines, nitrous oxide and carbon dioxide are eliminated and guanylureas are formed, together with disubstituted ureas as by-products. The infrared absorption spectra of some disubstituted ureas and nitrates of guanylureas are discussed with tentative assignment of bands to some groups.

INTRODUCTION

1-Amidino-3-nitrourea (II) is prepared in good yield by nitration of dicyandiamide (I) in mixed nitric–sulphuric acid:



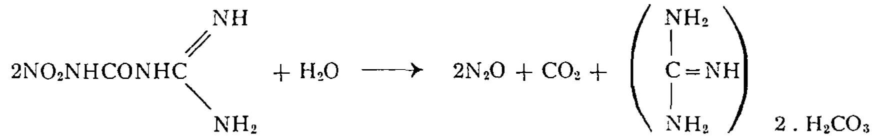
$$NC{-}NHC\begin{array}{l}/\!\!/ NH\\ \backslash NH_2\end{array} \xrightarrow[HNO_3]{H_2SO_4} NO_2NH{-}CONH{-}C\begin{array}{l}/\!\!/ NH\\ \backslash NH_2\end{array}$$

(I) (II)

According to its configuration, it is a mixed derivative of nitrourea and guanidine. As a nitrourea derivative, it is not expected to be a stable compound in aqueous solution. Davis and Blanchard (5) have shown that nitrourea decomposed into nitrous oxide, carbon dioxide, and water.

The rate of decomposition is increased by alkaline catalysts such as amines. The isocyanic acid formed in the decomposition of nitrourea reacts with amines to yield substituted ureas. Moreover the substituted ureas (6) are transformed in aqueous solution into either a primary amine and isocyanic acid or an isocyanate and ammonia.

The decomposition of 1-amidino-3-nitrourea in aqueous solution is known to yield guanidine carbonate, nitrous oxide, and carbon dioxide according to the following equation:



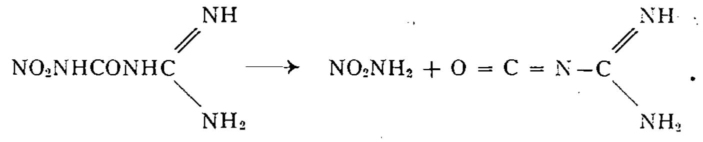
$$2NO_2NHCONHC\begin{array}{l}/\!\!/ NH\\ \backslash NH_2\end{array} + H_2O \longrightarrow 2N_2O + CO_2 + \left(\begin{array}{c}NH_2\\ |\\ C{=}NH\\ |\\ NH_2\end{array}\right) 2\,.\,H_2CO_3 \quad .$$

Since nitrous oxide is formed, this gas might come from the decomposition of nitramide which should be present at some stage of the decomposition. 1-Amidino-3-nitrourea could therefore decompose as suggested by T. L. Davis for nitrourea according to the following equation:

---

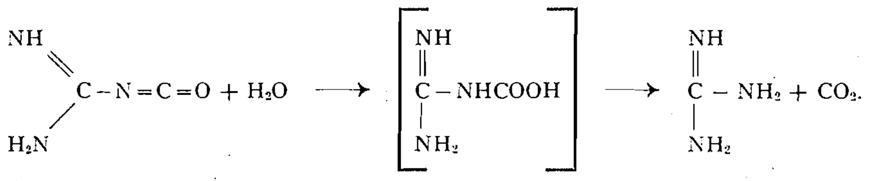
[1] *Manuscript received October 9, 1953.*
Contribution from the Department of Chemistry of the University of Ottawa, and the Organic Section of Canadian Armament Research and Development Establishment, Valcartier, Que.

[2] *Graduate Student.*



$$NO_2NHCONHC(=NH)NH_2 \longrightarrow NO_2NH_2 + O=C=N-C(=NH)NH_2$$

This implies the formation of nitramide and guanylisocyanate (7). Nitramide decomposes in the normal way into water and nitrous oxide, and guanylisocyanate like alkyl isocyanate according to the following equation:

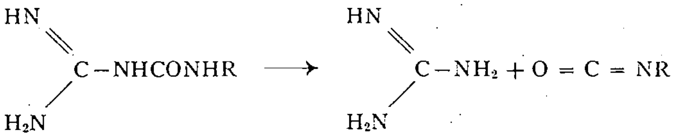


$$(HN=)(H_2N)C-N=C=O + H_2O \longrightarrow \left[HN=C(NH_2)-NHCOOH \right] \longrightarrow HN=C(NH_2)-NH_2 + CO_2.$$

Thus the intermediate formed, guanylcarbamic acid, will decarboxylate rapidly into guanidine and carbon dioxide.

Since guanylisocyanate cannot be isolated, its presence is shown, however, by its reaction with amines. When aniline was boiled with 1-amidino-3-nitrourea in the presence of water, N-phenyl-N′-guanylurea was formed together with diphenylurea as by-product (8).

The formation of diphenylurea indicates a further transformation of N-substituted-N′-guanylurea which can decompose like N-substituted ureas (6). Therefore the guanylurea formed can react with another mole of amine to yield disubstituted ureas according to the following equations:



$$(HN=)(H_2N)C-NHCONHR \longrightarrow (HN=)(H_2N)C-NH_2 + O=C=NR$$

$$O=C=NR + RNH_2 \longrightarrow RNHCONHR.$$

Several N,N′-disubstituted ureas were prepared from 1-amidino-3-nitrourea as a by-product of the synthesis of guanylureas. They are shown in Table I.

TABLE I
N,N′-DISUBSTITUTED UREAS

N,N′-Substituents	M.p., °C.	Ref.
Phenyl	241–242	(4)
Benzyl	170	(10)
o-Tolyl	252	(2)
p-Tolyl	267–268	(1)
p-Bromophenyl	292–293 decomp.	(3)
p-Anisyl	237–239	(9)

In all cases disubstituted ureas were obtained. N-substituted-N′-guanylureas were prepared by refluxing 1-amidino-3-nitrourea with amines in aqueous solution. After removing insoluble disubstituted ureas, nitric acid was added and a solid came out which was the nitrate of N-substituted-N′-guanylureas. They are listed in Table II. All their salts are slightly soluble, the nitrate being most insoluble. Qualitative measurements showed that their sulphate and hydrochloride were also slightly soluble. The nitrate of N-phenyl-N′-guanylurea is as insoluble as nitron nitrate, but is not suitable for the estimation of nitrate.

TABLE II
NITRATES OF N-SUBSTITUTED-N′-GUANYLUREA

N-Substituent	M.p., °C.	Analysis % HNO_3	
		Found	Calc.
Propyl	160–162	30.1	30.4
Amyl	142–143	26.9	26.8
Hexyl	148–150	25.2	25.3
Isobutyl	168–169	28.2	28.5
Hydroxyethyl	153–155	30.3	30.1
Phenyl*	212–213 decomp.	Ref. (8)	
Benzyl	183–184	24.4	24.7
o-Tolyl	180–181 decomp.	25.0	24.7
p-Tolyl	220 decomp.	24.7	24.7
p-Bromophenyl	207–209 decomp.	20.0	19.7
p-Anisyl	213–214 decomp.	23.6	23.3
Morpholinyl	124–125	26.9	26.8

Phenylguanylurea was also isolated as a free base, m.p. 143°–144°C. (8).

If an excess of amine is used, disubstituted ureas are the main products while guanylureas are formed in low yield. 1-Amidino-3-nitrourea is no more stable in water than nitrourea itself. The fact that it gives off one fourth of its nitrogen in the DuPont Nitrometer also explains its similarity to nitrourea (5).

INFRARED SPECTRA

Since guanylureas are mixed compounds of urea and guanidine it was of interest to determine their infrared spectra in order to correlate them with those of guanidine and urea.

The spectra of these compounds are reported in Tables III and IV. Only the more intense bands are reported as wave numbers (cm^{-1}).

TABLE III
INFRARED SPECTRA OF N,N′-DISUBSTITUTED UREAS

N,N′-Substituents	Band frequencies in cm.$^{-1}$								
Phenyl	695	750	900	1230	1310	1500	1600	1650	3330
Benzyl	695	765	900	1240		1570	1630		3330
o-Tolyl		750	900	1240	1300	1650			3030
p-Tolyl		750	816	1240	1310	1570	1650		3330
p-Bromophenyl		750	820	1240	1560	1630			3310
p-Anisyl		750	825	1240	1570	1630			3330

TABLE IV

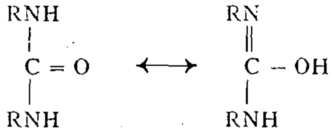
INFRARED SPECTRA OF N-SUBSTITUTED-N′-GUANYLUREAS

N-Substituent	Band frequencies in cm.$^{-1}$														
Propyl	788	820	890	965	1020	1050	1250	1580	1630	1710	1730	3140	3330		
Amyl	728	820	890	950	1010	1060	1240	1270	1350	1570	1630	1710	3140	3330	
Hexyl	722	821	890	960	1050	1230	1270	1570	1620	1630	1710	3140	3330		
Isobutyl		821	885		1020	1260	1340	1580	1630		1710	1730	3140	3330	
Hydroxyethyl	732	821	880	958	1030	1060	1100	1160	1280	1320	1470	1630	1730	3140	3330
Phenyl (base)	695	752	1240	1300	1320	1440	1520	1600	1620	1640	1710	1730	3360	3500	
Phenyl	821		1580	1670	1780	3220	3480								
Benzyl	695	721	821	1230	1570	1650	1720	3140	3330						
o-Tolyl	748	821	1210	1260	1310	1360	1560	1600	1620	1630	1710	1740	3160	3400	
p-Tolyl	724	818	1210	1220	1510	1560	1620	1630	1700	1730	3180	3250	3330		
p-Bromophenyl	724	734	818	858	1210	1510	1560	1600	1620	1710	1730	3130	3250	3330	
p-Anisyl	724	734	818	860	1030	1240	1510	1570	1620	1710	1730	3130	3250	3330	
Morpholinyl	710	734	740	848	1120	1240	1380	1620	1680	1710	3100	3270	3330		
Guanidine nitrate		844	1580	1670	1780	3130	3380								
Urea nitrate		734	815	1580	1680	1710	3270	3380							

N,N′-Disubstituted Ureas

The infrared spectrum of urea itself is not fully explained. Although urea gives a strong absorption band in the keto region, it has not been possible to establish definitely the vibration frequency of the carbamido group. It was thought that the symmetric disubstituted ureas isolated in the course of this work might be of value to elucidate the spectra of urea type compounds.

They all show a sharp and strong absorption band at 3300 cm.$^{-1}$ which is indicative of OH or NH bands. Since $-OH$ groups in these compounds, which are formed by tautomerization, are not likely to occur, the bands are attributed to unassociated NH groups.



$$\mathrm{RNH{-}C({=}O){-}NHR} \longleftrightarrow \mathrm{RN{=}C(OH){-}NHR}$$

In the double bond region, several absorption bands occur. One which is sharp and shows strong absorption is present at 1620–1639 cm.$^{-1}$ and should be due to the amide group. Other bands at 1330–1590 cm.$^{-1}$ indicate the presence of a phenyl ring. It was observed that compounds such as diphenylurea and dibenzylurea show a strong band at 695 cm.$^{-1}$ whereas such a band is absent when the aromatic ring bears a substituent as does N,N′-di-*p*-tolylurea. Also worth mentioning are the bands falling at 750 cm.$^{-1}$ for *o*-phenyl substituted compounds and other bands at 816, 820, and 825 cm.$^{-1}$ which are shown for *p*-phenyl substituted ureas.

Guanylureas

In the case of N-substituted-N′-guanylureas, strong hydrogen stretching vibration bands should be expected in the neighborhood of 3300 cm^{-1}.

Like guanidine and urea nitrates which show NH vibration bands at about 3270 and 3380 cm.$^{-1}$, most guanylureas exhibit two bands at nearly the same frequencies. Absorption bands of higher frequencies are due to NH groups and the band at lower frequencies is probably associated with NH_2 groups which can occur in the guanidine part of the nitrate of guanylurea.

In the double bond absorption region, several bands of different intensities occur which are due either to $C = O$ or $C = NH$. In the case of nitrates of alkylguanylureas, two strong bands occur, one at 1700–1710 cm.$^{-1}$ and the other at 1620–1630 cm^{-1}. In the disubstituted ureas, the band at 1630–1650 cm.$^{-1}$ has been tentatively attributed to the carbonyl group of urea. On the basis of this observation the carbonyl band of the nitrate of alkylguanylureas would fall in this region whereas with arylguanylureas the band would occur at slightly lower frequencies 1600–1630 cm^{-1}.

Between 1670–1710 cm.$^{-1}$ a strong sharp band occurs with all the nitrates of guanylurea examined; this band would be due to the $C=NH$ group which is shown by guanidine compounds at 1670–1690 cm^{-1}.

The second band in the double bond region showed by guanidine nitrate and urea nitrate is due to the vibration of $N=O$, which band is present in most nitrates of guanylurea whereas it is absent in the case of N′-phenyl-N′-guanylurea, which is free base. It falls at 1310–1380 cm^{-1}.

A band of good intensity at 800–825 cm.$^{-1}$ is attributed to nitrate ion; such a band is formed by inorganic nitrates such as ammonium nitrate (3).

At 695 cm.$^{-1}$, the phenyl and benzyl derivatives show the band characteristic for monosubstituted benzene ring. Weak bands are obtained at 890 cm.$^{-1}$ with nitrates of alkylguanylurea which are indicative of a hydrocarbon chain on a nitrogen atom; they are absent, however, with aromatic substituents.

In conclusion, it can be said that the infrared absorption spectra of guanylureas and disubstituted ureas are in conformity with their chemical structure although it is difficult to distinguish $C = O$ and $C = NH$ owing to the many resonating structures of the guanidine molecule as an ion.

EXPERIMENTAL

Decomposition of 1-Amidino-3-nitrourea in Water

1-Amidino-3-nitrourea (7.35 gm., 0.05 mole) and water (200 ml.) were boiled under reflux. Gases were evolved,—mainly carbon dioxide and nitrous oxide. The latter was collected over a solution of sodium hydroxide. The volume of gas collected measured 1200 ml. at 30°C. at 755 mm. The theoretical value under identical conditions is 1210 ml. The alkaline solution was titrated with standard acid using phenolphthalein as indicator and 0.0258 mole carbon dioxide was found. The theoretical value is 0.025 mole.

In the aqueous solution, which was mainly guanidine carbonate, there was found 2.5 gm. of guanidine estimated as its picrate. Guanidine was found in 85% yield from 1-amidino-3-nitrourea.

Preparation of the Nitrate of N-Substituted-N′-Guanylureas

1-Amidino-3-nitrourea (0.034 mole) was reacted with amines (0.034 mole) in aqueous solution (50 ml.). The solution was boiled until the evolution of nitrous oxide ceased. Then it was evaporated at 60°C. and filtered. The residues were identified as N,N′-disubstituted ureas. The remaining solutions were acidified with nitric acid and yielded the nitrates of N-substituted-N′-guanylurea which were recrystallized from water. Results are listed in Tables I and II.

With a large excess of amines, only disubstituted ureas were formed, as was the case with aniline, which failed to yield N-phenyl-N′-guanylurea.

Estimation of 1-Amidino-3-nitrourea by Nitrometer

Using standard procedure to determine nitrate in a DuPont Nitrometer, 1-amidino-3-nitrourea gave 9.50% of nitro-nitrogen. Calc. for $C_2H_5O_3N_5$: N, 47.6%. Found N, 47.5%.

Infrared Spectra Measurements

The infrared spectra were taken on a Perkin Elmer Spectrophotometer Model 21R. The instrument recorded the spectrogram automatically. All the samples were shaken in mineral oil into a uniform emulsion and placed between rock salt plates at a suitable thickness in order to obtain a good spectrogram. The bands are tabulated in Table III and IV in wave numbers (cm^{-1}). Only those of good intensity are reported.

ACKNOWLEDGMENTS

The authors thank Mr. M. Bédard of Canadian Armament Research and Development Establishment for the determination of infrared spectra.

REFERENCES

1. Bamberger, E. and Destraz, H. Ber. 35: 1878. 1902.
2. Bergèr, F. Ber. 12: 1859. 1879.
3. Chattaway, F. D. and Orten, K. J. P. Ber. 34: 1080. 1901.
4. Craebe, C. and Rostovzeff, S. Ber. 35: 2750. 1902.
5. Davis, T. L. and Blanchard, K. C. J. Am. Chem. Soc. 51: 1790. 1929.
6. Davis, T. L. and Blanchard, K. C. J. Am. Chem. Soc. 45: 1816. 1923.
7. Junod, E. Helv. Chim. Acta, 35: 1667. 1952.
8. Pellizzari, G. Gazz. chim. ital. 53: 384. 1923.
9. Pieschel, F. Ann. 175: 312. 1875.
10. Thiele, J. and Pickard, R. H. Ann. 309: 203. 1899.