

Mechanistic Studies in the Chemistry of Urea. Part 9.¹ Reactions of 1,2-Diaminoethane and Related Compounds with Urea and *N*-Alkylated Ureas

By Anthony R. Butler* and Ishtiaq Hussain, Department of Chemistry, The University, St. Andrews, Fife KY16 9ST

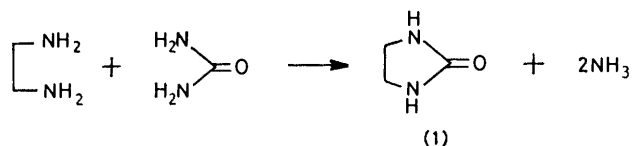
Reaction of urea with 1,2-diaminoethane results in formation of imidazolidin-2-one (1). Isotopic labelling and a study of the reactions of *N*-alkylated 1,2-diaminoethane indicate that the reaction mechanism involves an isocyanate intermediate. 1,3-Diaminopropane gives a similar product.

IMIDAZOLIDIN-2-ONE, or ethyleneurea (1), is a substance of some industrial importance as it is used to render cotton fabrics crease resistant. It can be synthesised by reaction of several substances with 1,2-diaminoethane, e.g. diethyl carbonate,² phosgene,³ and urea. The last reaction is the subject of this study. This preparation was first reported by Hansen⁴ but a yield of 10% was obtained. However, Schweitzer⁵ discovered that, if water is added, the yield increases to 98%.

RESULTS AND DISCUSSION

The ammonia liberated by the reaction in Scheme 1 could come either from the urea or from the diaminoethane. When the urea used was labelled with nitrogen-15 we found none of this isotope in the imidazolidin-2-one formed. However, the ammonia evolved, which was trapped as ammonium chloride, did contain nitrogen-15. Thus, it is the carbon-nitrogen bond of urea which is broken during the course of the reaction.

There are several possible mechanisms for this reaction, the most probable of which are given in Scheme 2. (a) Reaction occurs by simultaneous nucleophilic attack of both ends of the diamine molecule with concerted elimination of two molecules of ammonia in a single step process. (b) Formation of the intermediate (2) is followed by intramolecular nucleophilic attack on



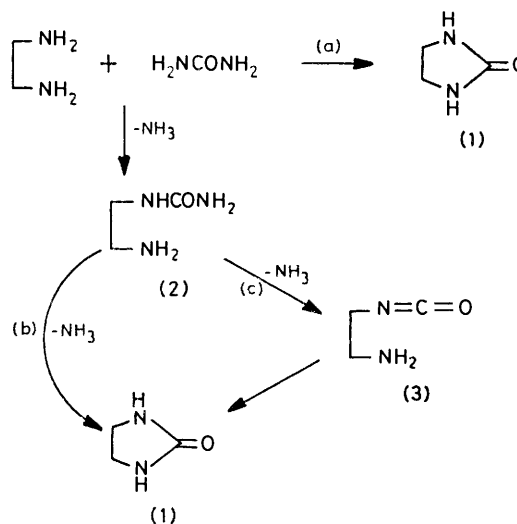
SCHEME 1

the carbonyl group, with elimination of ammonia. (c) Intermediate (2) is converted into an isocyanate (3), with loss of ammonia, and subsequent cyclisation of (3) gives (1).

Similar considerations have been applied by Hegarty and Frost⁶ to the hydrolysis of *p*-nitrophenyl *N*-phenylcarbamate and the conversion of *p*-nitrophenyl *N*-(2-aminophenyl)carbamate into *o*-phenyleneurea. They found evidence for the intermediacy of an isocyanate and so, *a priori*, (c) is the favoured route.

Hegarty and Frost⁶ trapped an isocyanate intermediate in the hydrolysis of *p*-nitrophenyl *N*-phenyl-

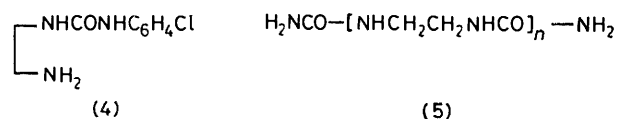
carbamate by reaction in the presence of *p*-chloroaniline and isolated *N*-phenyl-*N'*-(*p*-chlorophenyl)urea. We carried out a similar experiment by heating a mixture of urea, diaminoethane, water, and *p*-chloroaniline but the



SCHEME 2

last of these was recovered unchanged, and we found no trace of (4), which could have been formed by reaction of (3) with *p*-chloroaniline. However, this negative result does not disprove the intermediacy of (3) as intramolecular reaction, to form (1), may well proceed more readily than intermolecular reaction with *p*-chloroaniline.

Water does not appear to play a chemical role in the reaction and acts only as a moderator. We tried toluene in place of water. Reaction does occur, as evidenced by the ammonia evolved, but the solid product appears to be a polymer, probably of the linear type (5). If *n* is

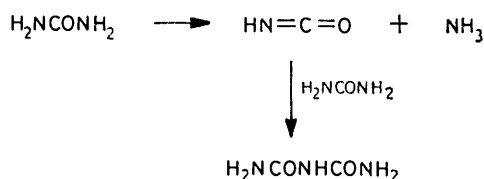


large then the elemental analysis of (5) is almost the same as that of (1). Also, many of the spectral properties will be identical. However, the m.p. of the product (191°) is very different from that of (1) (130°). Although

the main fragment in the mass spectrum is at m/e 86, M^+ for (1), there are many smaller peaks of higher m/e . The appearance of the spectrum is characteristic of a polymer. It would appear, then, that water is a specific moderator for the formation of (1).

As both carbon–nitrogen bonds of the urea are broken during reaction, imidazolidin-2-one (1) should be obtained by reaction of 1-methylurea, 1,1-dimethylurea, and 1,3-dimethylurea with 1,2-diaminoethane. These bonds were broken in the case with the first two but, instead of (1), polymeric material was obtained although the experimental conditions were the same as those which produced the monomer on reaction with urea. There was no evidence, in the ^1H n.m.r. spectra of the polymers, for the presence of *N*-methyl groups. The gas evolved during reaction was a mixture of methylamine, or dimethylamine, and ammonia.

No reaction occurred with 1,3-dimethylurea and this suggests that formation of the intermediate (2) is blocked. With urea formation of (2) must parallel the biuret reaction,⁷ where diaminoethane replaces the second molecule of urea (Scheme 3). 1,3-Dimethylurea does



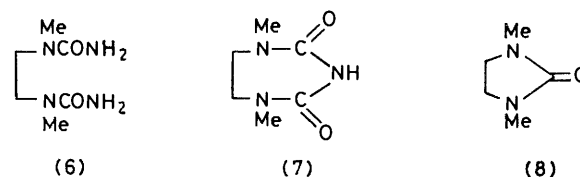
SCHEME 3

not appear to undergo a simple biuret reaction and 1,5-dimethylbiuret is made by the reaction of 1-methylurea with methyl isocyanate.⁸ Therefore, 1,3-dimethylurea does not react with diaminoethane in a manner parallel to that shown in Scheme 3 and is recovered unchanged from the reaction mixture.

We now consider the effect of *N*-methylation of the diamine upon the course of the reaction. The isocyanate intermediate (3) cannot form from 1,2-bis(methylamino)ethane and so reaction with urea should give a different type of product. In fact, (6) was obtained. This compound was identified by elemental analysis, spectral data, reaction with nitrous acid (which gave CO_2), and alkaline hydrolysis (which gave NH_3). This result is inconsistent with routes (a) and (b) (Scheme 2), but supports formation of an isocyanate intermediate.

However, our result appears to be inconsistent with the work of Lien and his co-workers⁹ who obtained 1,3-dialkylimidazolidin-2-ones by reaction of 1,2-dialkylaminoethanes with urea. The experimental conditions they used were very similar to ours, except that they used no moderator and heated for a longer period. We were able to resolve this inconsistency. The action of heat (*ca.* 300°) on (6) resulted in formation of a paste, most of which was soluble in chloroform, and the evolution of ammonia. On cooling the solution crystals were deposited which we identified, by spectral means, as the cyclic biuret (7). Removal of solvent from the filtrate

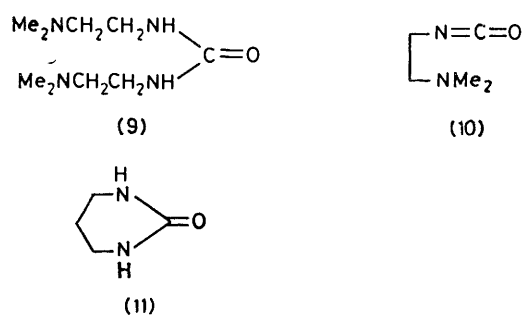
left an oil, 1,3-dimethylimidazolidin-2-one (8),¹⁰ which is the product expected from Lien's work. The material insoluble in chloroform was cyanuric acid. It was identified by comparison with an authentic sample. Thus it would appear that bisureas like (6) are intermediate in Lien's synthesis of dialkylimidazolidin-2-ones. What is not clear is whether (6) decomposes into (7) and (8) concurrently, or to (7) first, which reacts further to give (8). We favour the latter as conversion of (6) into (8) involves the simultaneous elimination of ammonia and cyanic acid while, if reaction proceeds with the



intermediacy of (7), these processes occur in a stepwise manner. The fact that (7) can be isolated supports this view.

The same product (6) was obtained by reaction of 1,2-bis(methylamino)ethane with 1-methylurea and with 1,1-dimethylurea. With 1,3-dimethylurea there was no reaction.

Reaction of 1-dimethylamino-2-aminoethane with urea gave yet another type of product, an *N*-substituted urea (9). We can readily rationalise this as cyclisation of the isocyanate intermediate (10) is not possible, and so it reacts with a second molecule of the diamine to give



(9). This is further evidence to support the isocyanate intermediate.

We found that a parallel reaction occurs when 1,2-diaminoethane was replaced by 1,3-diaminopropane. The solid products obtained on reaction with urea and with 1-methylurea was a mixture of (11) and polymeric material.

EXPERIMENTAL

Reaction of Urea and 1,2-Diaminoethane.—A mixture of urea (6 g, 0.1 mol), diaminoethane (6 g, 0.1 mol), and water (3.6 ml) was refluxed for 3 h and the gas evolved passed into aqueous HCl. After 3 h the mixture became a paste but, during the next hour, turned into a pale liquid and, on cooling, solidified. The material was recrystallised from chloroform to give imidazolidin-2-one (1) (6.5 g, 75%),

m.p. 130° (lit.,¹¹ 131°), m/e 86 (M^+), δ_H (CF_3CO_2H) 3.64, δ_C (H_2O) 43.4 and 169.4 p.p.m. Ammonium chloride was isolated from the solution through which the evolved gas had passed.

The above experiment was repeated using urea containing 3% nitrogen-15. The mass spectrum of the imidazolidin-2-one obtained was identical with that obtained above but in the mass spectrum of the ammonium chloride isolated there was a peak at m/e 29 (^{14}N - ^{15}N) which is not found in isotopically normal ammonium chloride.

When toluene was used as the moderator a material was obtained, m.p. 192°, in 60% yield, the spectral properties of which were identical with those of (1), except that the mass spectrum had only a small peak at m/e 86 and many small peaks at higher values.

The first experiment described above was repeated using 1-methylurea instead of urea. The product, obtained in 70% yield, had the following properties: m.p. (decomp.) 280°, m/e 86 (large) and small peaks at higher values, δ_H (CF_3CO_2H) 3.58, δ_C (CF_3CO_2H) 42.5, 42.8, and 163.6 p.p.m. (Found: C, 41.0; H, 7.1; N, 32.3. Calc. for $C_3H_6N_2O$: C, 41.9; H, 7.0; N, 32.5%). The material appears to a polymer of (1).

With 1,1-dimethylurea another product (60%; also a polymer) was obtained, m.p. 184°, m/e 86 (M^+) (large) and small peaks at higher values, δ_H (CF_3CO_2H) 3.63 p.p.m.

Reaction of Urea with 1,2-Bis(methylamino)ethane.—The same procedure was used to give 1,1'-dimethyl-1,1'-dimethylenebisurea (6) (95%), m.p. 262°, m/e 174 (M^+), ν_{max} (mull) 3 400, 3 190 (NH), and 1 655 cm^{-1} (C=O), δ_H (CF_3CO_2H) 3.20 (6 H, s), and 3.80 (4 H, s), δ_C (CF_3CO_2H) 36.6 (q), 48.8 (t), and 162.4 (s) p.p.m. (Found: C, 41.3; H, 8.65; N, 33.0. $C_6H_{14}N_4O_2$ requires C, 41.35; H, 8.1; N, 32.15%). The same product was obtained when urea was replaced by 1-methylurea or 1,1'-dimethylurea.

The action of heat of (6) resulted in the evolution of ammonia and production of a white solid 1,5-dimethyl-1,5-dimethylenebisuret (7) (50%), m.p. 190°, m/e 157 (M^+), δ_H ($[^2H_6]$ DMSO) 2.87 (6 H, s), 3.45 (4 H, s), and 8.25 (1 H, s) (Found: C, 45.85; H, 6.9; N, 26.5. $C_6H_{11}N_3O_2$ requires C, 45.85; H, 7.05; N, 26.75%). The other product of reaction isolated was a liquid 1,3-dimethylimidazolidin-2-one

(8) ¹⁰ (35%), m/e 114 (M^+), δ_H ($CDCl_3$) 2.75 (6 H, s) and 3.27 (4 H, s), δ_C ($CHCl_3$) 29.5, 43.3, and 160.1 p.p.m.

Reaction of Urea with 1-Dimethylamino-2-aminoethane.—A mixture of the diamine (8.8 g, 0.1 mol), urea (6 g, 0.1 mol), and water (3.6 ml) was refluxed for 4 h. The ammonia evolved was passed into aqueous HCl and recovered as NH_4Cl . The contents of the flask were cooled, diluted with chloroform, and filtered. The solvents were removed and the residue dried (molecular sieve) to give a viscous oil, 1,3-bis(dimethylaminoethyl)urea (9) (8.8 g, 85%), m/e 87 ($Me_2NCH_2CH_2NH$) and 115 ($Me_2NCH_2CH_2NHCO$), ν_{max} (mull) 3 330 (NH) and 1 660 cm^{-1} (C=O), δ_H ($CDCl_3$) 2.18 (12 H, s), 2.40 (4 H, t), 3.23 (4 H, q), and 6.52 (2 H, t) (addition of D_2O resulted in disappearance of triplet at 6.52 and the quartet at 3.23 changed into a triplet), δ_C ($CHCl_3$) 37.7, 45.0, 59.0, and 160.5 p.p.m. (Found: C, 53.35; H, 11.15; N, 27.7. $C_9H_{22}N_4O$ requires C, 53.45; H, 10.95; N, 27.7%).

Reaction of 1,3-Diaminopropane with Urea.—The normal procedure was repeated using 1,3-diaminopropane. Acetone was added to the product and the insoluble material filtered off. This material was extracted with chloroform and, on removal of solvent, gave trimethyleneurea (11) (40%), m.p. 262° (lit.,¹¹ 260°), m/e 100 (M^+), ν_{max} (mull) 3 240 (NH) and 1 680 cm^{-1} (C=O), δ_H (D_2O) 1.83 (2 H, m) and 3.23 (4 H, t), δ_C (H_2O) 21.1, 40.3, and 159.6 p.p.m. The material insoluble in chloroform was polymeric.

[0/960 Received, 23rd June, 1980]

REFERENCES

- Part 8, A. R. Butler and I. Hussain, preceding paper.
- J. Tafel and L. Reindl, *Ber.*, 1901, **34**, 3286.
- N. A. Puschin and R. V. Mitić, *Annalen*, 1937, **532**, 300.
- R. Hansen, Master's Thesis, Massachusetts Institute of Technology, 1939.
- C. E. Schweitzer, *J. Org. Chem.*, 1950, **15**, 471.
- A. F. Hegarty and L. N. Frost, *J.C.S. Perkin II*, 1973, 1719.
- C. Wiedemann, *Annalen*, 1848, **68**, 3242.
- H. Biltz and A. Jeltsch, *Ber.*, 1923, **56**, 1914.
- M. H. Jussain and E. J. Lien, *J. Heterocyclic Chem.*, 1971, **8**, 507.
- W. R. Boon, *J. Chem. Soc.*, 1947, 307.
- E. Fischer and H. Koch, *Annalen*, 1885, **232**, 222.