

Tautomerism of Urea

by

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The problem of the tautomerism of urea has been the subject of some controversy. A number of authors advanced the idea of the existence of a zwitterionic structure [1], [2]. X-ray examination of interatomic distances in urea by Wyckoff and Corey [3] gave support to this concept and to the idea of the resonance structures of the compound [4]. Dipole moment measurements [5] also indicated a resonance hybrid of urea. Resonance in urea was also evidenced by former calculation of the values of force constants [6] and magnetic susceptibility [7].

Further support was given by investigation of the structure of urea salts [8]—[10] and by infrared investigation of urea inclusion compounds in the independent papers of Kutzelnigg and Mecke [11] and Daniewski, Dąbrowska, Piasek and Urbański [12]. Also comparative examination of infrared spectra of crystalline urea freshly crystallized from methanol and dissolved in methanol seems to support the concept of zwitterionic (imidol) structure [13] and explain the experimental observations reported by McAdie and Frost [14] that urea possesses altered properties when in presence of water, methanol and ethanol.

Although the concept of zwitterionic structure of urea seems to be highly reasonable in the light of the foregoing considerations, no final proof could be alleged and some authors did not agree with this concept.

Thus Ebert [15] considered zwitterionic structure rather improbable and Hermans [16] pointed out that tautomerism of urea has never been demonstrated. Thiourea, on the contrary, can furnish *S*-alkyl derivatives of *iso*-thiourea through the action of simple alkylating agents upon thiourea in polar solvents [17].

In the present investigation we examined infrared spectra of urea dissolved in polar solvents, and succeeded in alkylating urea to obtain *O*-alkyl derivatives of *iso*-urea. This experimental fact gives final evidence of the tautomerism of urea.

Infrared spectra

It has now been found that urea dissolved in water, methanol or ethanol gives a medium intensity band with the frequency 1650 cm.^{-1} forming a shoulder

with a higher intensity band $1629\text{--}1620\text{ cm.}^{-1}$ produced by bending NH vibrations [18]—[20], [9].

As described in our previous paper [12], a very strong band 1650 cm.^{-1} is present in *O*-alkyl derivatives of *iso*-urea and is absent in dry, crystalline urea, and should be assigned to the vibrations of C=N present in the imidol form of urea, i.e. in "*iso*-urea".

The same shoulder 1650 cm.^{-1} is present in urea freshly crystallized from any of the polar solvents mentioned above or in urea kept for several hours in an atmosphere saturated with the same solvent.

Judging from the intensity of the shoulder 1650 cm.^{-1} in the solution of urea in methanol or ethanol, the concentration of the imidol form of urea is of the order of a few per cent. This low concentration should account for the absence of the band $c. 3600\text{ cm.}^{-1}$ (characterizing OH group vibrations) in the spectrum of solutions of urea. Moreover, the use of methanol or ethanol as solvent makes the finding of the OH group in the dissolved substance difficult. A special investigation will be devoted to this problem.

O-alkylation of urea

We found that urea dissolved in methanol and ethanol can react with diazomethane and diazoethane to give *O*-methyl and *O*-ethyl-*iso*urea, respectively. The yield was 11—12 per cent.

Both *O*-alkyl derivatives proved to be identical with those prepared from cyanamide according to Stieglitz [21]. The identification was based on the identity of physical properties including infrared absorption spectra and chemical composition.

It was also found that no methylation or ethylation of urea occurred when the reaction was carried out in a less polar solvent such as ethyl ether.

Discussion

These experiments seem to suggest that the tautomerism of urea exists and occurs in polar solvents such as water or alcohols. The tautomerism should be expressed by equation (3) of our former paper [13].

Experimental

Infrared absorption spectra were determined in a double-beam recording Hilger spectrophotometer model H-800 with optics of rock salt.

The substances were examined either as thin films of crystalline solids or in solution. The solutions were nearly saturated and applied as films of capillary thickness.

Reaction of urea with diazomethane. Diazomethane prepared from nitrosomethylurea (25 g.) in ether (150 ml.) dried over potassium hydroxide was added to pure urea (m.p. 133° , 15 g.) in freshly distilled methanol (200 ml.) and all was kept for several hours at room temperature. Steady evolution of nitrogen ceased after 24—48 hours. Then ether and alcohol were distilled off under reduced pressure and the residue was extracted with dry ether. The crude product (3.5 g.) was distilled at $78\text{--}82^\circ$ (6—9 mm.) to obtain pure *O*-methylisourea, m.p. $44\text{--}45^\circ$ (2.1 g., 11.3%).

There was no change in m.p., when the reaction product was mixed with a standard sample according to Stieglitz and McKee [21].

The infrared spectrum was taken and proved to be identical with that of the standard sample.

The product was dissolved in dry ether, saturated with dry hydrochloride to obtain *O*-methyloisourea hydrochloride, m.p. 128–130° which remained unchanged when mixed with a standard sample [21] (Found N 25.2%, calc. for $C_2H_7ON_2Cl$: N 24.8%).

Reaction of urea with diazoethane was carried out as with diazomethane. Diazomethane was prepared from nitrosoethylurea (30 g.) in ether and added to urea (15 g.) in ethanol. The crude product (3.8 g.) was purified by distillation (b.p. 90–92°, 9 mm.) to yield pure *O*-ethylisourea, m.p. 42° (2.6 g., 11.8%). There was no change of m.p. when the product was mixed with the standard sample prepared according to Stieglitz and McKee [21].

The infrared spectrum proved to be identical with that of the standard sample.

The product was transformed into its hydrochloride as above. When mixed with a standard sample the m.p. 122° was unchanged [21] (found N, 23.1%, calc. for $C_3H_9ON_2Cl$: N 22.65%).

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REFERENCES

- [1] I. Langmuir, *J. Am. Chem. Soc.*, **42** (1920), 42.
- [2] G. Devoto, *Gazz.*, **60** (1930), 52.
- [3] R. W. G. Wyckoff and R. B. Corey, *Z. Kristallogr.*, **89** (1934), 462.
- [4] Ph. Vaughan and J. Donohue, *Acta Cryst.*, **5** (1952), 530.
- [5] W. D. Kumler and G. M. Fohlen, *J. Am. Chem. Soc.*, **64** (1942), 1944.
- [6] J. Kellner, *Proc. Roy. Soc.*, **A. 177** (1941), 456.
- [7] G. W. Bhagavantam, *Indian J. Phys.*, **4** (1929), 1.
- [8] R. Wizinger, *J. prakt. Chem.*, (2), **154** (1939), 33.
- [9] R. B. Penland, S. Mizushima, C. Curran and J. K. Quagliano, *J. Am. Chem. Soc.*, **79** (1957), 1575.
- [10] W. Kutzelnigg and R. Mecke, *Chem. Ber.*, **94** (1961), 1706.
- [11] W. Kutzelnigg and R. Mecke, B. Schrader, F. Nerdel and G. Kresse, *Z.f. Elektrochemie*, **63** (1961), 109.
- [12] W. Daniewski, U. Dąbrowska, Z. Piasek and T. Urbański, *J. Chem. Soc.*, (1962), 2340.
- [13] Z. Piasek and T. Urbański, *Bull. Acad. Polon. Sci., Sér. sci. chim.*, **10** (1962), 113.
- [14] H. G. McAdie and G. B. Frost, *Canad. J. Chem.*, **33** (1955), 1257.
- [15] L. Ebert, *Ber.*, **64** (1931), 679.
- [16] P. H. Hermans, *Introduction to theoretical organic chemistry*, Elsevier, Amsterdam, 1954, pp. 87–89.
- [17] F. Arndt, *Ber.*, **54** (1921), 2236.
- [18] H. J. Becher, *Chem. Ber.*, **89** (1956), 1953.
- [19] J. F. Stewart, *J. Chem. Phys.*, **26** (1957), 248.
- [20] A. Yamaguchi, T. Miyazawa, T. Shimanouchi and S. Mizushima, *Spectrochim. Acta*, **10** (1957), 170.
- [21] J. Stieglitz and R. A. McKee, *Ber.*, **33** (1900), 1517.

