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## THE DEARRANGEMENT OF NITROUREA AND ITS APPLICATION IN SYNTHESIS

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Nitrourea might be expected to dearrange<sup>1</sup> in two modes to form on the one hand (1) nitroamide and cyanic acid, and on the other (2) ammonia and nitrocyanic acid. The nitro group would promote the dearrangement and the molecule would fall apart more readily than does the molecule of urea. We have found abundant proof of dearrangement of the first sort, but only meager evidence for that of the second. We have isolated nitroamide and cyanic acid from solutions of nitrourea and have prepared nitrourea by the combination of nitroamide with cyanic acid. Since nitrourea dissolved in water dearranges in part into nitroamide and cyanic acid, and since nitroamide decomposes into nitrous oxide and water, it follows that an aqueous solution of one equivalent of nitrourea may be used, with great advantage, for purposes of synthesis as if it were a solution of one equivalent of cyanic acid itself.

Nitrourea decomposes on melting with the evolution of gas and yields a sublimate and a solid residue. The gases consist of water, nitrous oxide, cyanic acid, carbon dioxide and ammonia, and the solid materials of monoammonium cyanurate along with small quantities of ammelide, urea and biuret. These are the products which would be expected from the predicted dearrangements. The nitroamide breaks down into water and nitrous oxide. The cyanic acid in part escapes as such, in part combines with ammonia to form urea and in part polymerizes to form cyanuric acid, which combines with a portion of the ammonia to form ammonium cyanurate—and the latter substance by loss of water yields ammelide. Although nitrocyanic acid,  $O_2N-NCO$ , is not a known substance, it would, from analogy with known nitramines, be expected to decompose into nitrous oxide and carbon dioxide. The presence of ammonia and of carbon dioxide in the products of the decomposition of nitrourea by heat suggests strongly that this substance does dearrange into nitrocyanic acid and ammonia, but constitutes the only real evidence which we have found on that point. The presence of biuret might perhaps be explained by supposing that it is formed, as Werner<sup>2</sup> supposes it to be formed in aqueous solution, by the combination of cyanic acid with urea. We have found that

<sup>1</sup> Cf. (a) Davis and Underwood, *THIS JOURNAL*, **44**, 2595 (1922); (b) Davis and Blanchard, *ibid.*, **45**, 1816 (1923); (c) Davis, *Proc. Nat. Acad. Sci.*, **11**, 68 (1925); (d) Davis and Abrams, *Proc. Am. Acad. Arts Sci.*, **61**, 437 (1926); (e) Davis and Luce, *THIS JOURNAL*, **49**, 2303 (1927).

<sup>2</sup> Werner, "The Chemistry of Urea," Longmans, Green and Co., London, 1923, p. 25.

urea and cyanic acid do not combine in aqueous solution to form biuret, and prefer the more likely explanation that the cyanic acid combines with itself to form a dimer, dicyanic acid,  $\text{NH}_2\text{-CO-NCO}$ , which then combines with ammonia to form biuret—but wish to reserve a fuller discussion of the matter for a later paper.

When nitrourea is boiled with water, the nitroamide which results from its dearrangement breaks down completely, and nitrous oxide is given off quantitatively. Experiments in which nitrourea was heated with water in a sealed tube until gas was no longer produced, and in which silver nitrate was then introduced into the solution without opening the tube, showed that the production of cyanic acid is also quantitative.

A freshly prepared aqueous solution of nitrourea does not give the biuret test. After boiling it gives the biuret test, but contains no biuret. On evaporation to dryness, it yields a residue of practically pure urea, evidently formed by the combination of cyanic acid with ammonia produced by the hydrolysis of another portion of the cyanic acid.

The great ease with which nitrourea dearranges in aqueous solution may be shown by several striking experiments. A freshly prepared cold aqueous solution of nitrourea gives with silver nitrate a white crystalline precipitate of silver nitrourea. When the liquid is warmed, the precipitate dissolves; when this clear liquid is boiled for a minute or two, it deposits an insoluble precipitate of silver cyanate. If the freshly prepared solution is boiled, cyanic acid may be detected by its vinegar-like odor in the gases which are evolved. A freshly prepared cold solution gives, with copper sulfate and pyridine, a lilac-colored crystalline precipitate of copper pyridine nitrourea, insoluble in chloroform. The boiled solution with these reagents gives no precipitate, but the liquid yields a blue chloroform extract which contains copper pyridine cyanate. When copper pyridine nitrourea is allowed to stand in contact with water and chloroform at laboratory temperature, the chloroform turns blue after only a few hours, and if the mixture is allowed to stand overnight the copper pyridine nitrourea disappears entirely. Nitrourea recrystallized from warm, not boiling, water, under conditions where no gas is evolved, has an indefinite melting point between  $135$  and  $150^\circ$ . It may be obtained perfectly pure by recrystallization from ether, benzene or chloroform, in which solvents it does not dearrange, and melts sharply at  $158.4\text{--}158.8^\circ$  with decomposition.

We have obtained nitroamide from the dearrangement of nitrourea by dissolving the latter substance in water, warming until active gassing had commenced, freezing in liquid air, drying out the ice by triturating it with anhydrous sodium sulfate, extracting with ether, and finally by concentrating the ether extract and precipitating with petroleum ether. The resulting nitroamide, identified by its properties and by analysis, was found on heating to break down quantitatively into water and nitrous oxide,

We have also isolated nitroamide from a solution of urea nitrate in concd. sulfuric acid. We have shown that the dearrangement is reversible by producing nitrourea by the direct combination of nitroamide and cyanic acid, by stirring together silver cyanate and an aqueous solution of nitroamide to which dilute hydrochloric acid had been added.

Nitrourea dissolves in cold concd. sulfuric acid to form a solution which contains cyanic acid and nitroamide. On standing the sulfuric acid dehydrates the nitroamide slowly, nitrous oxide comes off, the mixture warms up, the cyanic acid is hydrated in part to form carbon dioxide and the effervescence becomes vigorous. Such a solution after effervescing actively for about an hour exploded with a distinctly audible puff and visible flash but without any damage to the beaker in which it was contained. The nitroamide which is present in a cold solution of nitrourea in concd. sulfuric acid may also combine with water under the hydrating action of the sulfuric acid to form nitric acid, and does this if the environment is such that the nitric acid may enter into other reactions. Such a solution in the nitrometer gives up quantitatively the nitrogen corresponding to the nitro group of its nitrourea.<sup>3</sup> We have used such a solution for the nitration of aniline, phenol, acet-*p*-toluide and cinnamic acid, in a manner similar to that in which a sulfuric acid solution of nitroguanidine has been used.<sup>1d</sup> No gas is given off if the nitration mixtures are kept below 0°. If they are allowed to warm up, effervescence becomes violent.

The spontaneous decomposition of nitrourea in aqueous solution is influenced by acids and by bases in the same way as the spontaneous decomposition of nitroamide.<sup>4</sup> The substance may be recrystallized without change from boiling water or from boiling alcohol if the solvent contains a small amount of sulfuric acid. Inorganic and organic bases promote the decomposition. We have noted in a number of cases that pure air-dried nitrourea stored in soft glass bottles decomposes after a few months, blowing out the stopper, giving off ammonia and leaving a pasty residue which contains water, urea and ammonium cyanurate, and have been able to show that the effect is due to the alkali of the glass which is dissolved by the water retained in the air-dried nitrourea. The decomposition does not occur in hard glass even if moisture is present, but does occur in hard glass if the sample is moistened with an aqueous extract of soft glass. It does not occur in an atmosphere dried with phosphorus pentoxide, even when sodium bicarbonate is in contact with the nitrourea.

Strong ammonia water dropped upon nitrourea hisses like water on phosphorus pentoxide. When an excess is used and the solution is evaporated to dryness, pure urea is obtained quantitatively. When one molecular equivalent of aniline is dissolved in a saturated aqueous solution of

<sup>3</sup> Cope and Barab, *THIS JOURNAL*, **38**, 2552 (1916).

<sup>4</sup> Brönsted and Pedersen, *Z. physik. Chem.*, **108**, 189 (1924).

nitrourea and the liquid is allowed to stand at laboratory temperature, crystals of phenylurea are found to have separated after twenty-four hours, and after forty-eight hours the yield is nearly quantitative. When nitrourea is added to an aqueous solution of a primary aliphatic amine, such as methylamine, the reaction is very vigorous and requires cooling to moderate it. With less basic amines the reaction is correspondingly slower. Since the mono-substituted aliphatic ureas dearrange but little in boiling water, the reaction mixtures may be evaporated hot and give excellent yields of pure products. With suitable variations of procedure, we have prepared, from the corresponding primary amines, methylurea, ethylurea, *n*-butylurea, benzene-azo-phenylurea, ethylene-diurea, *m*- and *p*-uraminobenzoic acid, sodium *p*-uraminobenzene-sulfonate, hydantoic acid,  $\alpha$ -uramino- $\alpha$ -isobutylic acid and ethyl hydantoate. The advantages of the method are especially apparent in the cases of methyl- and ethylurea. Nitrourea yields nothing but gases and a principal product which is practically pure at once and not deliquescent, while the older method with potassium cyanate and the hydrochloride of the amine yields a product which is contaminated with mineral salts and is deliquescent and difficult to purify.

By the same general method we have prepared, from nitrourea and the corresponding secondary amines,  $\alpha,\alpha$ -dimethylurea,  $\alpha,\alpha$ -diethylurea,  $\alpha,\alpha$ -di-*n*-propylurea and its picrate,  $\alpha,\alpha$ -di-*n*-butylurea (new) and its picrate (new),  $\alpha,\alpha$ -di-*iso*-amylurea and its oxalate and picrate (new), and 2,3,4-trihydroquinolylurea.

Derivatives of urea in which one aromatic and one aliphatic group are attached to the same nitrogen atom dearrange so readily in water solution that any attempt to purify them by recrystallization from that solvent only results in making them less pure. If they are boiled in water solution, they dearrange in part, the cyanic acid is hydrolyzed to ammonium carbonate, the secondary amine escapes with the steam and part of the material is lost. By allowing the amine to stand at laboratory temperature in contact with water and a slight excess of nitrourea until crystals had separated and could be removed, or until the mixture had spontaneously evaporated to dryness, in which case the whole residue was worked up with a non-dearranging solvent like benzene or petroleum ether, we have obtained  $\alpha$ -methyl- $\alpha$ -phenylurea,  $\alpha$ -ethyl- $\alpha$ -phenylurea,  $\alpha$ -*n*-propyl- $\alpha$ -phenylurea (new), its picrate (new) and oxalate (new), and  $\alpha$ -*n*-butyl- $\alpha$ -phenylurea (new) in excellent yields.

In the experiments with di-*n*-propylamine and *n*-propylaniline, in addition to the expected urea derivatives, there were obtained, respectively,  $\omega,\omega$ -di-*n*-propylbiuret (new) and  $\omega$ -*n*-propyl- $\omega$ -phenylbiuret (new). No  $\omega,\omega$ -disubstituted biurets have heretofore been described. We have identified our substances by analysis and by comparison with the materials pro-

duced by a new method which has been found to be a general one for the preparation of  $\omega,\omega$ -disubstituted biurets, namely, the interaction of nitro-biuret with secondary amines, as described in the next paper of this series. In the present cases the cyanic acid from the dearrangement of nitrourea evidently combines with itself to form dicyanic acid, which then combines with the secondary amine to form the  $\omega,\omega$ -disubstituted biuret.

Nitrourea is but little affected by refluxing with dry alcohols and may be recovered unchanged. When refluxed with moist alcohols, it dearranges; the cyanic acid in part combines with the alcohol to form carbamic ester and in part apparently combines with itself to form dicyanic acid, which then combines with the alcohol to form allophanic ester. We reserve a fuller discussion of dicyanic acid for another paper. Allophanic esters are converted to carbamic esters by refluxing with alcohols. Nitrourea dearranges much more rapidly than urea, and in practice yields more allophanic ester because the solution is not subjected to so long a refluxing. Otherwise the reaction of nitrourea with alcohols has no more interest for purposes of synthesis than the reaction of urea itself.

### Experiments

Experiments which are indicated in the foregoing with sufficient clearness are not again discussed in this section.

**Preparation of Nitrourea.**—Nitrourea was prepared by a modification of the original method of Thiele and Lachman.<sup>5</sup> Two hundred grams of carefully dried urea nitrate was added in small portions at a time with stirring to 300 cc. of concd. sulfuric acid<sup>6</sup> (1.84) while the temperature of the mixture was kept below 0°. After the last portion had been added, the cold milky mixture was allowed to stand for one minute and was then poured into a liter of ice and water. The finely-divided white precipitate was collected on the filter, sucked as dry as might be, and, without washing, was immediately dissolved while still wet in boiling alcohol.<sup>7</sup> The liquid deposited pearly leaflets on cooling. It was chilled in ice water before filtering and the crystals were rinsed with cold alcohol. The alcoholic mother liquors were used for the crystallization of several successive batches. The air-dried product was sufficiently pure without another crystallization. Samples of it have remained unchanged in hard glass bottles for several years; yield, 90% or better.

**Decomposition by Heat.**—Nitrourea (0.6148 g.) was decomposed by heating at 170° in the vacuum of a mercury pump. The gases were allowed to stand overnight in order that the cyanic acid might polymerize on the walls of the apparatus. There resulted 0.2520 g. of residue (41%) which gave tests for biuret and cyanuric acid but which gave no color with the diphenylamine reagent, and 55.4 cc. of gas (at 761 mm. and

<sup>5</sup> Thiele and Lachman, *Ann.*, **288**, 281 (1895).

<sup>6</sup> Instead of 700 cc. as recommended by Thiele and Lachmann and by Ingersoll and Armendt, "Organic Syntheses," John Wiley and Sons, Inc., New York, **1925**, Vol. V, p. 85.

<sup>7</sup> The precipitate still contained enough acid to prevent the dearrangement of the nitrourea in boiling alcohol. For a second recrystallization it was found to be unsafe to heat the alcohol above 60°.

26°) which consisted of 9.8 cc. (17.8%) of CO<sub>2</sub> and HNCO (absorbed by caustic), 20.96 cc. (37.8%) of NH<sub>3</sub> and 24.29 cc. (43.9%) of N<sub>2</sub>O.

Twenty-one grams of nitrourea was heated at atmospheric pressure at 158–160° until decomposition commenced. After two or three minutes, when the reaction had subsided, the pasty sublimate was scraped from the condenser and added to the residue from the decomposition, total weight, 12.5 g. (59.9%). The material was entirely soluble in boiling water except for a few milligrams of amorphous matter which was identified as ammeliide. The solution on evaporation gave off ammonia and yielded 4.95 g. of mono-ammonium cyanurate, identified by the fact that it gave off ammonia on warming with sodium hydroxide solution, by the properties of the cyanuric acid obtained from it and by analysis.

*Anal.* Calcd. for C<sub>2</sub>H<sub>5</sub>O<sub>3</sub>N<sub>4</sub>: C, 24.66; H, 4.11; N, 38.36. Found: C, 25.4, 25.5; H, 3.6, 3.5; N, 38.3, 38.6.

When dissolved in boiling water, acidified, chilled and filtered, 1.135 g. yielded 0.9943 g. of cyanuric acid (99.2% of the calcd. amount). The mother liquors yielded more cyanuric acid on acidification, and, after chilling, filtration and evaporation to dryness, a residue from which butyl alcohol extracted the urea, 0.07 g., identified by mixed melting point and by its xanthidrol derivative. The final residue yielded a small quantity of biuret, identified by mixed melting point and by the biuret test.

**Decomposition in Hot Water.**—Samples of nitrourea were dissolved in 10 cc. of water and decomposed by warming until active gas evolution had commenced. The gases were allowed to mix at atmospheric pressure with a confined quantity of air whose temperature, volume and pressure could be measured. Analysis showed that the mixture after the experiment contained only nitrous oxide and the gases normally present in atmospheric air. The results, corrected for the vapor pressure of water and calculated to 0° and 760 mm. (but not corrected for the solubility of N<sub>2</sub>O in water), were as follows: nitrourea, 0.1177, 0.1860; N<sub>2</sub>O found, 24.85, 39.10 cc.; calcd., 25.09, 39.64 cc.

For the determination of the cyanic acid produced by the decomposition of nitrourea, experiments were first tried in which solutions were decomposed in stoppered flasks and then precipitated with silver nitrate, but the results were low, evidently because of the loss of cyanic acid with the gases which escaped when the stopper was removed. Precipitation was therefore accomplished before the gases were allowed to escape. Samples of nitrourea were weighed into Carius tubes, 10 cc. of water was added, then a thin glass ampoule containing 15 cc. of *N*/10 silver nitrate solution and the tubes were sealed. They were then wrapped in wire gauze and warmed in the water-bath until gas production had ceased. After cooling, they were shaken to break the ampoule and the contents were mixed. If the tubes were then opened, the outrushing gas was found to carry away a portion of the liquid. The contents were therefore frozen and loss of solution was avoided when the tubes were opened. The solids were filtered off and washed thoroughly, and unconsumed silver in the filtrate was determined by titration with ammonium thiocyanate: nitrourea, 0.1455, 0.1004; *N*/10 AgNO<sub>3</sub> consumed, 13.7, 9.5 cc.; HNCO found, 0.05892, 0.04086; calcd., 0.05954, 0.04108.

Ten grams of nitrourea was dissolved in 100 cc. of water, warmed until gas evolution had ceased and evaporated to dryness. Ammonia was given off. The residue weighed 1.9 g. and consisted of practically pure urea. In another experiment with the same quantities the cyanic acid was removed, after gassing had ceased, by the addition of an excess of silver nitrate solution. The liquid on evaporation to dryness yielded a residue (containing silver nitrate) from which hot butyl alcohol extracted only 0.08 g. of urea.

**Effect of Certain Other Solvents.**—Half-gram samples of nitrourea were boiled with 50 cc. of benzene, ether and chloroform, respectively, under a condenser the upper

end of which was sealed to a gas buret containing mercury. No gas was produced in either experiment. Nitrourea recrystallized once from alcohol melted with decomposition at temperatures between 146 and 153°. Recrystallization from glacial acetic acid raised the melting point to 158.3–158.6°, while one crystallization from benzene, ether or chloroform, in which solvents it is sparingly soluble, yielded material melting at 158.4–158.8°. Several recrystallizations from water at 50° yielded material of great purity, melting at 158.1–158.3°, only slightly lower than crystals from ether.

**Nitroamide from Nitrourea.**—Ten grams of nitrourea was dissolved in 100 cc. of water in a large test-tube and warmed in a water-bath at 75° until gas evolution was active. Five cc. of 6 *N* sulfuric acid was added and the liquid was frozen suddenly by immersion in liquid air. The solid mass was broken up in a mortar and extracted with ether previously cooled to –10°. The ice was then allowed to melt and was triturated with anhydrous sodium sulfate until a dry mass was obtained. This was extracted with ten 50-cc. portions of ether. The ether extracts were evaporated separately in a stream of dry air. The first yielded only a very small amount of nitrourea. The second gave crystals of nitrourea which were removed, and the liquid portion when poured into petroleum ether produced a precipitate of shiny flakes of nitroamide. This was purified by dissolving in ether and precipitating with petroleum ether and finally yielded 0.43 g. of nitroamide, pearly white glistening flakes, melting at 72–73° with decomposition into volatile products. Nitrogen by combustion: found, 45.30; calcd. for  $\text{NH}_2\text{NO}_2$ , 45.16.

**Nitroamide from Urea Nitrate.**—Two hundred and fifty grams of urea nitrate was added in small portions at a time to 800 cc. of concd. sulfuric acid, as if for the preparation of nitrourea. The solution was removed from the freezing mixture and allowed to stand at room temperature until vigorous gassing had commenced, when it was poured onto 1 kilo of cracked ice and filtered through an asbestos filter (50 g. of nitrourea was obtained). Anhydrous sodium sulfate (about 1500 g.) was added to the filtrate until a thick mush was obtained and this was extracted repeatedly by triturating it with 100-cc. portions of ether. The combined ether extracts, dried with anhydrous sodium sulfate and worked up as described above, yielded 0.21 g. of nitroamide. Two repetitions of the experiment gave, respectively, 0.7 and 0.05 g. of nitroamide. The three yields were combined and, after four treatments with ether and petroleum ether, gave 0.51 g. of nitroamide, m. p. 71.5–75°; nitrogen by combustion: found, 46.49, 46.21; calcd., 45.16.

**Nitrourea from Nitroamide.**—Three grams of silver cyanate was suspended in 20 cc. of ice water, and 1.24 g. of nitroamide (from potassium nitrocarbamate) was added. Five cc. of 6 *N* hydrochloric acid was added drop by drop while the mixture was stirred with a mechanical stirrer. The stirring was continued for half an hour after the acid had been added. The precipitated silver chloride was removed and the clear liquid was evaporated to dryness at room temperature in a stream of dry air. The residue was extracted with ether and the ether on evaporation yielded 0.13 g. of material melting with decomposition at 146–147° and identified as nitrourea by the facts that it gave a blue color with the diphenylamine reagent and yielded phenylurea when warmed with aniline water. Several experiments in which smaller relative amounts of nitroamide were used were unsuccessful. A similar experiment with nitroamide and silver cyanamide failed to yield any nitroguanidine.

**Effect of Impurities on the Stability of Nitrourea.**—Samples of nitrourea were recrystallized from water (at 50°) which contained in solution ferrous sulfate, ferric nitrate, sulfuric acid, urea, urea nitrate and copper nitrate. The several samples, after drying in the air, were placed in corked test-tubes each in the dark and each in an eastern window. None showed any decomposition after six months.

A sample of nitrourea was recrystallized from water which had been previously refluxed for some time with finely-powdered soft glass. Another sample was washed with sodium bicarbonate solution. One half of each was dried quickly in vacuum over phosphorus pentoxide and put away in sealed glass tubes. The other half of each was dried in the air and placed in corked vials. Of the air-dried samples, that which had been washed with sodium bicarbonate decomposed in two days and that which had been recrystallized from the glass extract in nine days. The pentoxide-dried samples in the sealed tubes showed no signs of decomposition after four months. The tubes were then opened and the contents were emptied onto watch glasses which were allowed to stand in the laboratory under inverted beakers. The sample containing sodium bicarbonate decomposed after three weeks, and that containing glass extract after nine weeks.

**Preparation of Mono-substituted Ureas.**—The primary amine and slightly more than one molecular equivalent of nitrourea were brought together in water, the mixture was warmed to start the reaction or cooled to moderate it and the product was isolated either by filtration or by evaporating the reaction mixture to dryness. Yields are indicated below.

TABLE I  
MONO-SUBSTITUTED UREAS

Product	Yield, %	M. p., °C.	Remarks
Methylurea	85	102	Stout needles from dry acetone
Ethylurea	80	92.1–92.4	Crystals from benzene
<i>n</i> -Butylurea <sup>a</sup>	91	96	Fine needles from benzene
Benzene-azophenylurea <sup>b</sup>	3	222–223	Crystals from alcohol
Ethylene-diurea <sup>c</sup>	78	193–194	Crystals from water; decomposes at 200°
<i>m</i> -Uraminobenzoic acid <sup>d</sup>	90	269.5–270.2	Very fine needles from water
<i>p</i> -Uraminobenzoic acid	Not determined		Microscopic needles from water; does not melt at 275°
Sodium <i>p</i> -uraminobenzenesulfonate <sup>e</sup>	Not determined		
Hydantoic acid <sup>f</sup>	60	160–161	Crystals from 50% alcohol
$\alpha$ -Uramino- $\alpha$ -isobutylacetic acid <sup>g</sup>	Not determined	186–187	Crystals from 90% alcohol
Ethyl hydantoate	62	134–135	Crystals from 50% alcohol
Phenylurea	98	147	Thick needles from water

<sup>a</sup> Werner, *J. Chem. Soc.*, **115**, 1101 (1919), has erroneously reported the melting point as 86°. Butylurea is very readily soluble in water, from which it crystallizes on slow evaporation in thin laminated plates. We have obtained plates 11–12 mm. wide and 50–60 mm. in length.

<sup>b</sup> Benzene-azophenylurea has been prepared by Sonn, *Ber.*, **47**, 2443 (1914), by the action of potassium cyanate on amino-azobenzene in acetic acid solution and by boiling an acetic acid solution of amino-azobenzene and urea. The low yield in our experiment is due to the fact that amino-azobenzene is very sparingly soluble in water.

<sup>c</sup> Previously prepared by Volhard, *Ann.*, **119**, 394 (1861), by the interaction of silver cyanate with ethylenediamine hydrochloride. He reported it as colorless needles, m. p. 192°.



<sup>d</sup> Previously prepared by Menshutkin, *Ann.*, **153**, 84 (1870), by fusing together urea and *m*-aminobenzoic acid. He reported, m. p. 269–270°.

<sup>e</sup> Sodium *p*-uraminobenzenesulfonate has been prepared by Pellizzari and Matteucci, *Ann.*, **248**, 156 (1888), by heating together urea and sodium sulfanilate, and the potassium salt by evaporating to dryness a solution of sulfanilic acid and potassium cyanate. We find that nitrourea warmed with an aqueous solution of sulfanilic acid decomposes and gives off gas, but the cyanic acid so produced does not combine with the sulfanilic acid—and we have recovered the unchanged sulfanilic acid quantitatively. By warming nitrourea with an aqueous solution of sodium sulfanilate, concentrating and pouring into alcohol, we have obtained white crystals of sodium *p*-uraminobenzene-sulfonate, identical with those described by Pellizzari and Matteucci.

<sup>f</sup> Lippich, *Ber.*, **41**, 2959 (1908), reports a melting point of 153–156° in an open tube and 163° in a closed tube. We find m. p. 160–161° in an open melting-point tube.

<sup>g</sup> Lippich reports, m. p. 188–189° in a closed tube. We find, m. p. 186–187° in an open tube.

We have not been able to secure any urea derivatives from the interaction of nitrourea with *p*-aminoacetophenone and with acetamide.

**Preparation of  $\alpha,\alpha$ -Dialkylureas.**—The preparation of these substances was carried out in essentially the same way as the preparation of the mono-substituted ureas.

TABLE II

Product	$\alpha,\alpha$ -DIALKYLUREAS		Remarks
	Yield, %	M. p., °C.	
$\alpha,\alpha$ -Dimethylurea	88	182	Crystals from alcohol
$\alpha,\alpha$ -Diethylurea <sup>a</sup>	65	75.0–75.3	Pearly oblong plates from absolute ether
$\alpha,\alpha$ -Di- <i>n</i> -propylurea	57	75.8–76.1	Waxy needles from petroleum ether
Picrate <sup>b</sup>	..	136	Recrystallized from water
$\alpha,\alpha$ -Di- <i>n</i> -butylurea	86	...	Colorless oil at ordinary temp. Nitrogen: Found, 16.13; calcd. for C <sub>9</sub> H <sub>20</sub> ON <sub>2</sub> , 16.27
Picrate <sup>c</sup>	..	82–83	Small plates from water–alc. Nitrogen: Found, 17.29; calcd. for C <sub>15</sub> H <sub>28</sub> O <sub>8</sub> N <sub>5</sub> , 17.45
$\alpha,\alpha$ -Di- <i>iso</i> -amylurea	92	...	Colorless oil at ordinary temp.
Oxalate <sup>d</sup>	..	101.5–102	
Picrate <sup>e</sup>	..	72.8–73.9	Small prisms from water–alc. Nitrogen: found, 16.26; calcd. for C <sub>17</sub> H <sub>27</sub> O <sub>8</sub> N <sub>5</sub> , 16.34
2,3,4-Trihydroquinolylurea <sup>f</sup>	85	146.2–146.6	Colorless needles from water

<sup>a</sup> Franchimont, *Rec. trav. chim.*, **2**, 122 (1883), reported m. p. 70°, and van der Zande, *ibid.*, **8**, 226 (1889), m. p. 74°. Ordinary laboratory ether is not a suitable solvent for the recrystallization of  $\alpha,\alpha$ -diethylurea.

<sup>b</sup> Melting point in agreement with McKee, *Am. Chem. J.*, **42**, 16 (1909).

<sup>c</sup> Dibutylurea and picric acid were dissolved together in alcohol, water was added and the oil which separated crystallized quickly on scratching.

<sup>d</sup> The oxalate precipitated when an alcohol solution of di-*iso*-amylurea was mixed with an aqueous solution of oxalic acid.

<sup>e</sup> Prepared by mixing an alcohol solution of di-*iso*-amylurea with an alcohol solution

of picric acid, diluting with water to precipitate the oil, dissolving the oil in alcohol, adding water to turbidity and allowing to stand. Melts at 72.8–73.9° with previous softening at 66.5–68°.

The preparation was carried out in 50% alcohol because of the slight solubility of tetrahydroquinoline in water alone.

**Purification of  $\alpha,\alpha$ -Di-*n*-butylurea.**—The product separated as a yellow oil which floated upon the reaction mixture. The mixture was extracted with ether, and the ether extract was washed with dilute sulfuric acid for the removal of amine, then with water, dried with anhydrous sodium sulfate and concentrated in a vacuum over sulfuric acid. Attempts to distil the substance at ordinary pressure resulted in almost complete decomposition. It was distilled at a pressure of 2–3 mm. at 118–119°, and the distillate, although a water-white viscous oil of good appearance, smelled strongly of dibutylamine and was plainly less pure than before it had been distilled. The material was finally obtained pure by distilling it in the high vacuum (about 0.001 mm.) of a mercury diffusion pump. The tube containing the crude dibutylurea was sealed to two slender U-tubes (in series) each with a small bulb at the bottom of the U. The second U-tube was sealed to the pump. The tube containing the material and the U-tube nearest to it were then both warmed in an oil-bath at 50°, while the U-tube nearest the pump was cooled with liquid air. Dibutylamine distilled out and collected in white crystals in the cold tube. When no more amine could be collected, the tube containing the substance was heated in the oil-bath at 100–105°, and the U-tube directly connected to this was cooled in liquid air. The dibutylurea condensed in white needles which melted below room temperature to a colorless oil.

**$\omega,\omega$ -Di-*n*-propylbiuret.**—In the preparation of dipropylurea, 30 g. of the amine and 40 g. of nitrourea were used. After the reaction was over, the mixture was extracted with ether and the ether extract was dried with solid caustic potash and concentrated. It yielded a residue which failed to crystallize after two weeks. On treating this with chloroform, 1.2 g. of insoluble material remained which was found to consist largely of urea along with a small amount of inorganic material. The chloroform solution desiccated in high vacuum gave 23.2 g. of white waxy needles of crude  $\alpha,\alpha$ -di-*n*-propylurea, and these extracted with petroleum ether yielded 0.5 g. of material insoluble in that solvent. Three recrystallizations from hot water made this material practically pure, m. p. 129°. It gave no biuret test or nitramine reaction and analyzed 22.28% of nitrogen; calcd. for  $C_8H_{17}O_2N_3$ , 22.46%. A mixed melting point showed it to be identical with the (slightly better) material, m. p. 129–129.4°, prepared from di-*n*-propylamine and nitrobiuret, and discussed more fully in the next paper of this series.

**Preparation of  $\alpha$ -Alkyl- $\alpha$ -phenylureas.**—The reactions between nitro-

urea and mono-alkyl-anilines were carried out in the manner described in the first section of this paper.

TABLE III  
 $\alpha$ -ALKYL- $\alpha$ -PHENYLUREAS

Product	Yield, %	M. p., °C.	Remarks
$\alpha$ -Methyl- $\alpha$ -phenylurea	72	81.8–82.0	Thick prisms from benzene–ligroin
$\alpha$ -Ethyl- $\alpha$ -phenylurea	76	62.3–62.5	Thin plates from petroleum ether
$\alpha$ - <i>n</i> -Propyl- $\alpha$ -phenylurea	80	89.4–89.8	Thick plates and pyramids from benzene–ligroin. Nitrogen: found, 15.60; calcd. for $C_{10}H_{14}ON_2$ , 15.73
Picrate	..	118–118.5	Needles from 50% alcohol. Nitrogen: found, 17.32; calcd. for $C_{16}H_{17}O_2N_5$ , 17.19
Oxalate <sup>a</sup>	..	71–72	Recrystallized from 50% alcohol. Nitrogen: found, 12.37; calcd. for $(C_{10}H_{14}ON_2)_2 \cdot C_2H_2O_4$ , 12.56
$\alpha$ - <i>n</i> -Butyl- $\alpha$ -phenylurea <sup>b</sup>	50	50.5–51.1	Waxy needles, very readily soluble in alcohol, ether and benzene. Nitrogen: found, 14.39; calcd. for $C_{11}H_{16}ON_2$ , 14.58

<sup>a</sup> Softens at 65–66° and melts with decomposition at 71–72°.

<sup>b</sup>  $\alpha$ -*n*-Butyl- $\alpha$ -phenylurea separated from the reaction mixture as a dark-colored oil which did not respond to the usual devices for provoking crystallization but which crystallized spontaneously after standing for several months. The material was purified by treatment with decolorizing carbon and by repeatedly dissolving in alcohol and precipitating with water. The resulting pale yellow oil, dried in vacuum over sulfuric acid, was induced to crystallize by scratching. The substance is insoluble in water but very readily soluble in alcohol, benzene and ether, from all of which it is obtained as an oil.

The easy dearrangement of the  $\alpha$ -alkyl- $\alpha$ -phenylureas may be demonstrated by heating a sample in a melting-point tube at 160–180°. The melt gradually deposits needles of cyanuric acid. The liquid portion consists of the free amine and does not solidify on cooling.

**Effect of Heat on  $\alpha$ -*n*-Propyl- $\alpha$ -phenylurea.**—Three grams of the substance, heated in a distilling flask in the oil-bath, melted but showed no other change until a temperature of 210–215° was reached, when a sudden solidification took place. After a few minutes a liquid phase appeared above the solid one. The mixture, distilled in vacuum, yielded 2.15 g. of propylaniline, 94.3% of the theoretical. The residue in the flask weighed 0.78 g. and proved to consist of cyanuric acid.

**$\omega$ -*n*-Propyl- $\omega$ -phenylbiuret.**—The aqueous mother liquors from the preparation of propylphenylurea (from 50 g. of propylaniline) on evaporation to dryness yielded 2.8 g. of residue. All of this dissolved in 5 cc. of water, except 0.12 g. of material which was identified as cyanuric acid. The aqueous solution on dilution with alcohol deposited a small amount of inorganic matter and the liquid, concentrated and chilled, yielded 1.1 g. of small colorless glistening plates, m. p. 150–151°. Two recrystallizations from alcohol raised the melting point to 151°. The material gave no biuret test or nitramine reaction and analyzed 19.14% of nitrogen; calcd. for  $C_{11}H_{16}O_2N_3$ , 19.00. A mixed melting point showed it to be identical with the (slightly better) material, m. p. 151–151.5°, prepared from propylaniline and nitrobiuret.

### Summary

Nitrourea dearranges into cyanic acid and nitroamide. It has been prepared from these two substances, and they have been prepared from it.

The products from the decomposition of nitrourea by heat are those which would be expected from the two possible modes of its dearrangement.

Nitrous oxide and cyanic acid are produced quantitatively when nitrourea is heated with water.

A solution of nitrourea in concd. sulfuric acid contains nitroamide and may be used as a reagent for nitrations.

Alkalies promote the decomposition of nitrourea; acids hinder it. A very slight alkalinity in the presence of a trace of moisture is sufficient to cause its spontaneous decomposition.

An aqueous solution of nitrourea, being a source of cyanic acid, reacts with ammonia and with primary and secondary amines to form urea and substituted ureas. The yields are excellent, the manipulation is simple and the other products of the reaction are gaseous. The method is especially advantageous for the preparation of those substituted ureas which cannot be heated in water without decomposition. A number of urea derivatives, a few of them new, have been prepared by this method.

$\omega,\omega$ -Di-*n*-propylbiuret and  $\omega$ -*n*-propyl- $\omega$ -phenylbiuret have been obtained as by-products in the preparation of urea derivatives from nitrourea and the corresponding amines.

Moist alcohols react with nitrourea to produce carbamic and allophanic esters.

CAMBRIDGE, MASSACHUSETTS

[CONTRIBUTION No. 39 FROM THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY,  
RESEARCH LABORATORY OF ORGANIC CHEMISTRY]

## THE DEARRANGEMENT OF NITROBIURET AND ITS APPLICATION IN SYNTHESIS

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A study of the dearrangement of nitrobiuret is especially interesting for the reason that it might be expected to produce the unknown dimer of cyanic acid, dicyanic acid,  $\text{NH}_2\text{CONCO}$  (or  $\text{HOC}(\text{NH})\text{-NCO}$ ). Nitrobiuret might be expected to dearrange in four modes, as indicated below. The known or expected decompositions of the nitro-amines from the four modes of dearrangement are also shown.

