# THE PREPARATION OF PURE SODIUM CYANATE FROM UREA

by

R. BADER, D. J. DUPRÉ, AND F. SCHÜTZ

*Department of Pharmacology, University of Birmingham (England)*

and

*Research Division, Glaxo Laboratories Ltd., Greenford, Middlesex (England)*

Sodium cyanate contains varying amounts of impurities (cyanide, carbonate, etc.) when prepared by one of the usual methods from cyanide or by heating alkali metal hydroxides or carbonates with $NH_3$ and $CO_2$. Such material being unsuitable for use in biological experiments, a method has been devised for preparing sodium cyanate by isomeric transformation from urea; the resulting product contains only traces of impurities, none of them objectionable.

## EXPERIMENTAL

### *Preparation via silver cyanate*

WALKER AND HAMBLY[1] prepared silver cyanate by heating an aqueous solution of urea in the presence of silver nitrate: The latter reacted with the ammonium cyanate formed by isomerisation from urea.

An aqueous solution of *M*-urea and 0.75 *M*-silver nitrate was kept for 30 min in a boiling water bath. The precipitate was washed thoroughly with water, ethanol, then acetone, and dried. It contained approximately 80% AgCNO and up to 20% $AgCO_3$. WALKER AND HAMBLY prepared $NH_4CNO$ directly from the Ag precipitate by adding $NH_4Cl$ to an aqueous suspension of the powder. By using NaCl in slight excess in place of $NH_4Cl$ and shaking with a dense aqueous suspension of AgCNO for 1 h at room temperature, we were able to retain the NaCNO formed in solution and reject the insoluble AgCl behind. The filtered supernatant was practically free from Ag ions, however, it contained up to 14% $Na_2CO_3$. This could be eliminated as follows. DIRNHUBER AND SCHÜTZ[2] have shown that sodium or ammonium cyanate is fairly stable at $p_H > 5$, and hydrolyses rapidly at $p_H < 5$. The sample was, therefore brought to $p_H$ 6.0–6.5 by careful addition of acetic acid and was then shaken in a Warburg shaker (20 min, room temperature). Such a solution of NaCNO is suitable for many purposes. In certain experiments, however, the presence of traces of Ag had to be excluded and any contamination with carbonate or acetate seemed undesirable. The following more satisfactory method has, therefore, been developed.

### *Preparation from urea under anhydrous conditions*

It is known that sodium cyanate in aqueous solution easily undergoes hydrolysis to sodium carbonate, ammonia and carbon dioxide. Isomerisation of urea to sodium cyanate has to be carried out at a raised temperature (WALKER *et al.*), and the hydrolysis

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of cyanate must be very considerable. A method was therefore developed, still based on isomerisation from urea, but maintaining anhydrous conditions. An alcohol seemed a suitable medium, most of the lower ones being fairly good solvents for urea, while cyanate is practically insoluble in them. It is known that the isomerisation also takes place in ethanol (HALLER[3,4], EMICH[5], WALKER AND KAY[6]), the equilibrium being shifted greatly in favour of urea. If, however, urea is boiled in alcoholic KOH, an appreciable yield of KCNO is obtained.

In one experiment with alcoholic NaOH the final preparation contained 75% NaCNO, and approximately 25% $Na_2CO_3$. The heavy contamination with carbonate was obviously due to the liberation of one equivalent of water, according to the equation:

$$NH_4CNO + NaOH \rightarrow NaCNO + NH_3 + H_2O$$

Water at this temperature causes hydrolysis of a considerable part of the NaCNO present.

Hydrolysis was avoided by refluxing urea with dry butanol containing sodium butoxide in equimolecular quantity to urea. NaCNO separates from the solution in almost quantitative yield, according to the equation:

$$CO(NH_2)_2 \rightarrow NH_4CNO \xrightarrow{NaOBu} NaCNO + BuOH + NH_3$$

As known from the work of WALKER AND HAMBLY[1] and WALKER AND KAY[6], the equilibrium concentration of $NH_4CNO$ in alcohol is very small compared with that reached in aqueous solution, because of the rapid reconversion in aqueous alcohol of $NH_4CNO$ into urea. If however, as in our procedure, $NH_3$ and the sodium salt are rapidly removed, all the urea present gradually undergoes isomerisation. The removal of the sodium salt is practically instantaneous, because it is almost insoluble. NaCNO was found to dissolve in boiling ethanol only to the extent of 0.5% (w/v). Probably much less dissolves in higher alcohols.

The same reaction takes place when lower alcohols are used in place of butanol, but the reaction is then much less rapid. In isoamyl alcohol the reaction proceeds still more rapidly; although the product had a satisfactory cyanate content, its physical characteristics were inferior, a hard cake resulting in place of the usual discrete crystals and, even after crushing, this material dissolved less readily in water. Since, moreover, sodium dissolves appreciably more slowly in isoamyl alcohol than in butanol, the latter has been preferred for further work.

The rate of reaction appears to be determined by the boiling point of the solvent. Thus there is a steady increase in the series methanol (b.p. 65°; 30% conversion in 40 h), ethanol (b.p. 78°; 40% conversion 40 h), propanol (b.p. 97°; 52% conversion in 15 h), butanol (b.p. 117°; 72% conversion in 2 h), isoamyl alcohol (b.p. 131°; 80% conversion in 1 h). In isopropyl alcohol, (b.p. 83°), the rate is almost identical with that in ethanol: this seems to preclude the possibility that the acceleration on ascending the series depends on the decreasing solubility of NaCNO in the solvent, since the solubility in isopropyl alcohol, a secondary alcohol, is likely to be very much less than in ethanol. Rapid removal of ammonia, brought about by passing nitrogen through the reaction mixture, does not affect the rate of cyanate formation; it would thus appear that the urea → ammonium cyanate isomerisation is the factor determining the rate of reaction. This conclusion is supported by the fact that the rate of potassium cyanate production when potassium alcoxide is used is the same as that of sodium cyanate from sodium alcoxide.

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The sodium cyanate obtained by this method always contains a small amount of carbonate, the actual quantity, when care is taken to exclude atmospheric $CO_2$ and moisture, depending on the moisture content of the alcohol used. With butanol containing 0.04% moisture, 1–2% carbonate was generally present in the sample. With butanol containing 0.3% moisture, the carbonate content rose to 10%.

The procedure finally adopted was as follows. Commercial butanol was distilled, using a column, until the distillation temperature reached 117°. The distillate, about one tenth of the total volume, was rejected. The residue was sometimes used without further distillation; it contained 0.04% moisture: at other times it was further distilled over CaO. 2.5 l of this dry butanol were placed in a 4 l round-bottomed flask, provided with a reflux condenser fitted at its upper end with a tube to carry away the ammonia produced in the reaction. A large soda-lime trap was placed between the condenser and the lead-away tube. The flask was immersed in an oil-bath.

Clean sodium (115 g) was added, leading to spontaneous boiling. Heat was applied when the vigour of the reaction abated. About 3 h were required for complete solution. Urea (300 g) was added and dissolved completely on shaking. The butoxide solution was not allowed to cool much below the boiling-point before this addition, as this is liable to cause discoloration. Evolution of ammonia follows very rapidly on the addition of urea. The solution was refluxed overnight at a bath temperature of 140°. Sodium cyanate separated as a white crystalline powder. This was filtered off and washed on the filter successively with absolute ethanol and ether. The solid retains considerable quantities of the solvent, best removed by heating *in vacuo*, raising the temperature slowly to 140°. The yield was 97–99% of the theoretical.

*Analysis*

The samples were white and odourless and gave water-clear colourless solutions. A 1 *M* solution had approximately $p_H$ 8.8. When brought to $p_H > 7$ by acetic acid, the solutions were fairly stable. At $p_H < 7$ an immediate hydrolysis of NaCNO caused the $p_H$ of unbuffered solutions to shift rapidly towards the alkaline region.

The cyanate and carbonate contents were determined manometrically according to the method recently described by DIRNHUBER AND SCHÜTZ[2], which is based on fractionated acid decomposition of carbonate and cyanate at different $p_H$ values and measurement of the evolved $CO_2$ after each acidification. 2 ml of a 0.01 *M* solution of the sample were placed into the main compartment of a WARBURG vessel, 0.3 ml of 3.0 *M* acetate buffer ($p_H$ 5) in one side bulb and 0.3 ml 10% $H_2SO_4$ in the other. After equilibration at room temperature, the acetate buffer was tipped into the main compartment. The evolved $CO_2$ was almost entirely due to the carbonate content. In experiments at 38° there was a slight continued evolution of $CO_2$ after the decomposition of carbonate was completed. This was due to very slow hydrolysis of cyanate at this $p_H$ and temperature. At room temperature, however, equilibration was easily again achieved; 10–12 min after the addition of the buffer the $H_2SO_4$, added from the other side bulb, caused rapid and complete decomposition of cyanate and a corresponding pressure change. The contents of both carbonate and cyanate were thus accurately determined in the course of one experiment.

The results obtained by this method are liable to be somewhat high for carbonate, as a small part of the $CO_2$ evolved on addition of the buffer ($p_H$ 5) was due to $CO_2$ from the atmosphere absorbed by the solution, which was originally at about $p_H$ 8. The results

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for cyanate were liable to be slightly low, partly because very small amounts of cyanate were hydrolysed before addition of the $H_2SO_4$, and partly because of a small loss of cyanic acid. When a concentrated aqueous solution of cyanate is strongly acidified, the immediate formation of a white precipitate can be observed; this is a mixture of cyanuric acid and cyamelide, two polymerisation products of cyanic acid. One can, moreover, for a few seconds after acidification, detect the pungent smell of HCNO. Polymerisation occurs to an appreciable extent in concentrated solutions only. At the concentrations used in the manometric determination of cyanate, the loss through polymerisation is negligible.

The urea content was determined manometrically according to the urease method of KREBS AND HENSELEIT[7]. The action of cyanate on urease will be the subject of a future publication. It should be noted, however, that in the above method cyanate is eliminated before the addition of urease. A solution of the sample to be analysed, approximately 2 *M* for NaCNO, was brought to $p_H$ 5 by electrometric titration with acetic acid. An equivalent of 0.1 ml of the original 2 *M* solution was then placed in the main compartment of a WARBURG vessel filled up to a volume of 2.5 ml with 3 *M* acetate buffer ($p_H$ 5). This was then shaken in a WARBURG apparatus at 38°. Cyanate decomposed slowly; from time to time the manometer-taps were opened to release the pressure due to the evolved $CO_2$. When equilibrium was obtained, the urease solution in *M* acetate buffer ($p_H$ 5), was added from the side bulb. The urease solution was freshly made from benzene extracted jack bean meal.

*Cyanide.* Although cyanide was unlikely to be present in a cyanate preparation made from urea, tests were made on a number of samples. The test described by FEIGL[8] seemed the most suitable, since the reaction, carried out with the vapour obtained from the material, permitted the use of relatively huge quantities of the sample to be analysed, without any intereference from other non-volatile substances present. This point seemed important, since in preliminary experiments it was found that cyanate, present in large amounts, greatly interferred with, *e.g.*, the prussian blue test for cyanide carried out in solution.

The test was carried out as follows. The dry sample was placed in a large conical flask, and water added until all had dissolved. A few ml conc. $H_2SO_4$ were added, and the conical flask was covered by a filter paper, soaked in the benzidine-copper acetate reagent and placed in a Petri dish. There was no need to add Zn dust to evolve a gas in the early stages, as prescribed by FEIGL, since there was much $CO_2$ evolved after acidification through hydrolysis of NaCNO. Gradually more conc. $H_2SO_4$ was added. When finally the evolution of gas stopped, Zn dust was added and after a further 2–3 min the flask was transferred into a water bath at 50°. The temperature of the water bath was then slowly raised to 75°.

Negative results were always obtained by subjecting 30–100 g of different samples, made as described above, to this test. When 100 $\mu$g KCN were added to 50 g of the sample, or, on another occasion, 30 $\mu$g KCN to 60 g, strongly positive results were obtained almost immediately after placing the soaked filter paper over the newly acidified solution.

It seems highly improbable that any cyanide was present in the samples, made according to the method described above. If only 0.00005% $CN'$ had been present, it would have been easily detected.

This finding is in harmony with the conception that no cyanide is likely to be

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produced under the described conditions. It could result only from reduction of cyanate, and no indication of this was obtained even when the conditions were modified so as to favour it. Thus, while the sodium was always allowed to dissolve completely before urea was added, no cyanide could be detected even after sodium was added to a solution of urea in butanol.

Table I shows typical results obtained with samples made by different methods. It can be seen that samples prepared by the method described above contained 97–99% NaCNO, usually 1–1.5% carbonate, and no urea or less than 0.2%. Cyanide was not detected, whereas up to 0.4% of it was found in commercial samples.

TABLE I

ANALYSIS OF SAMPLES OF SODIUM CYANATE, PREPARED ACCORDING TO DIFFERENT METHODS

| | % Found | | | |
|---|---|---|---|---|
| | NaCNO | Carbonate | Urea | CN |
| Batch RB5 | 97.5 | 2.0 | 0.2 | — |
| Batch RB8 | 98.0 | 1.5 | 0.1 | — |
| Batch PD1 | 99.0 | 1.0 | — | — |
| Batch GL | 99.0 | 1.0 | — | — |
| Commercial samples *A* | 88.0 | 10.5 | — | 0.4 |
| Commercial sample *B* | 78.0 | 14.0 | 0.8 | 0.2 |
| Commercial sample *C* | 82.0 | 17.0 | 0.5 | — |

*Stability.* If kept *in vacuo* over $P_2O_5$ or $CaCl_2$ the samples are very stable. If kept without special precautions, gradual but considerable decomposition takes place. One sample had immediately after preparation a carbonate content of 1%, but after 8 months storage in the laboratory, when the container was frequently opened, 8% were found. Even small amounts of urea were slowly formed in this way, and after one year the sample smelled of $NH_3$.

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## SUMMARY

1. When prepared from cyanide, or by heating alkali metal hydroxides or carbonates with $NH_3$ and $CO_2$, sodium cyanate samples contain impurities (cyanide, carbonate, etc.), which preclude their use for biological experiments.

2. When prepared by isomerisation from urea in the presence of alkali hydroxide in water or alcohol, the samples contain large amounts of carbonate, due to hydrolysis of cyanate in the presence of water.

3. A method of preparing pure NaCNO is described, based on isomerisation of urea to $NH_4CNO$ under anhydrous conditions. Sodium metal is dissolved in dry butanol and urea is then added in equimolecular quantities; the mixture is refluxed. Insoluble NaCNO separates in almost theoretical yield.

4. Details are given of the method of preparation, of the manometric determination of the cyanate, carbonate and urea content, of the tests for cyanide and of the stability of the samples.

## RÉSUMÉ

1. Les échantillons de cyanate de sodium préparés soit à partir de cyanure, soit par chauffage

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des hydroxydes ou des carbonates des métaux alcalins avec $NH_3$ et $CO_2$, contiennent des impuretés (cyanure, carbonate, etc.) qui empêchent leur utilisation pour des expériences biologiques.

2. Préparés par isomérisation de l'urée en présence d'hydroxydes alcalins dans l'eau ou l'alcool, les échantillons de cyanate de sodium contiennent des quantités importantes de carbonate, dû à l'hydrolyse du cyanate en présence de l'eau.

3. Une méthode de préparation de NaCNO pure est décrite; cette méthode est basée sur l'isomération de l'urée en $NH_4CNO$ en milieu anhydre. Du sodium métallique est dissous dans du butanol sec et de l'urée est ensuite ajoutée en quantité équimoléculaire; le mélange est traité à l'ébullition à reflux. Le NaCNO se sépare avec un rendement presque théorique.

4. Des détails sont donnés concernant la méthode de préparation, le dosage manométrique du cyanate, du carbonate et de l'urée, la caractérisation du cyanure et la stabilité des échantillons.

## ZUSAMMENFASSUNG

1. Wenn Natriumzyanat aus Zyanid oder durch Erhitzen von Alkalihydroxiden bzw. -karbonaten mit $NH_3$ und $CO_2$ bereitet wird, enthält es Verunreinigungen (Zyanid, Karbonat usw.), die seine Benutzung für biologische Experimente ausschliessen.

2. Wenn die Bereitung durch Isomerisierung aus Harnstoff bei Anwesenheit von Alkalihydroxid in Wasser oder Alcohol erfolgt, enthalten die Präparate grosse Mengen Karbonat, das durch die Hydrolyse des Zyanats bei Vorhandensein von Wasser entsteht.

3. Eine Methode zur Bereitung von reinem NaCNO wird beschrieben, die auf der Isomerisierung von Harnstoff zu $NH_4CNO$ unter wasserfreien Umständen beruht. Natriummetall wird in trockenem Butanol gelöst und Harnstoff in aequimolekularer Menge zugefügt; das Gemisch wird am Rückflusskühler erhitzt. Das unlösliche NaCNO wird in beinahe theoretischer Menge abgetrennt.

4. Einzelheiten über die Bereitungsmethode, die manometrische Zyanat-, Karbonat- und Harnstoffbestimmung, die Proben auf Zyanid, sowie über die Stabilität der Präparate werden angegeben.

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