PREPARATION AND CONDENSATION OF D-GLUCOPYRANOSE *N*-PHENYLCARBAMATES AND *N*-METHYL-*N*-PHENYLCARBAMATES

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ABSTRACT

A number of tri- and tetra-(*N*-phenylcarbamate) and -*N*-methyl-*N*-phenylcarbamate derivatives of methyl α-D-glucopyranoside were prepared and found resistant to acid hydrolysis. Alcoholysis and hydrolysis of the corresponding derivatives of cellulose gave oligomeric products and some loss of protecting groups. The fully substituted derivatives of benzyl β-D-glucopyranoside were resistant to hydrogenolysis. D-Glucopyranose 2,3,4-tri-(*N*-phenylcarbamate) and -(*N*-methyl-*N*-phenylcarbamate) were prepared from 1,6-anhydro-β-D-glucopyranose and, on treatment with phosphoric anhydride, gave in the first case a crosslinked polymer with a small percent of phosphorus and in the second one a monomeric diphosphate. Although carbanilates are able to act as participating groups, the reported method for polymerizing D-glucopyranose 2,3,6-tri-*O*-(*N*-phenylcarbamate) is not general for closely related compounds.

INTRODUCTION

The synthesis of a stereoregular linear polysaccharide by use of a polycondensation reaction has been reported by Husemann and Muller[1]. The monomer, D-glucopyranose 2,3,6-tri-(*N*-phenylcarbamate), was polymerized in a mixture of chloroform and dimethyl sulfoxide with phosphorus pentoxide to a multibranched derivative of $\overline{DP}_w$ 640. Branching presumably occurred by a chain transfer reaction in which the propagating D-glucosyl cation reacted with the nitrogen atom of the carbanilate groups and eliminated one proton. Removal of the *N*-phenylcarbamate groups by alkaline hydrolysis gave an unsubstituted polysaccharide of $\overline{DP}_w \sim 60$ and apparently linked β-D-(1→4). The high stereospecificity of the reaction was notable and presumed to be due to the participating character of the C-2 substituent[2].

We wished to explore the generality of this reaction with related compounds and to eliminate the chain transfer process by alkylating the carbanilate groups. The following describes our experiences in the synthesis of monomers containing *N*-phenylcarbamate and *N*-methyl-*N*-phenylcarbamate groups and their polymerization.

RESULTS AND DISCUSSION

The introduction of a *N*-phenylcarbamate group into sugar moieties involves the use of phenyl isocyanate in the presence of a base, usually pyridine. In our hands, this reaction was straightforward when high temperatures were avoided, since they led to the formation of the isocyanuric acid triphenyl ester.

The *N*-methyl-*N*-phenylcarbamate group, in contrast, has been mentioned only rarely in the carbohydrate literature and its synthesis has been in the nature of a side reaction. Several investigators have attempted to *O*-methylate a carbohydrate derivative containing *N*-phenylcarbamate blocking groups and found that *N*-methylation occurred simultaneously. The methylation procedure used in most cases was the Purdie method[8] with *N*,*N*-dimethylformamide as solvent. We chose not to use this technique since alkylation on the carbanilate oxygen atom can also occur in the presence of silver salts[9]. Therefore, the method of Dannley and Lukin[10] was used with a slight modification on a model compound. Methyl 2,3,4-6-tetra-*O*-(*N*-phenylcarbamoyl)-α-D-glucopyranoside was methylated in 1,2-dimethoxyethane with sodium hydride and methyl iodide. The isolated product was found to consist of only one compound by t.l.c. and the product was completely methylated as shown by the absence of the N-H absorption in the i.r. and n.m.r. spectra. The product was very soluble in solvents of low polarity, such as benzene and carbon tetrachloride, and it proved to be extremely difficult to crystallize. After crystallization the compound was identified from its n.m.r. spectrum and elemental analysis as the expected methyl 2,3,4,6-tetra-*O*-(*N*-methyl-*N*-phenylcarbamoyl)-α-D-glucopyranoside.

Attempts at preparing cellulose tri-(*N*-methyl-*N*-phenylcarbamate) from cellulose tri-(*N*-phenylcarbamate) by use of sodium hydride and methyl iodide in 1,2-dimethoxyethane proved unsatisfactory, since the hydrogen gas evolved during the reaction produced, in the highly viscous solution, a large quantity of foam. Attempts at preventing the formation of foam by use of a very dilute solution were unsuccessful. The problem was solved by replacing sodium hydride with potassium hydroxide in acetone[11]. Although this method gave complete methylation, it was more useful for the cellulose derivative than for the methyl glucoside, since the polymeric product was more readily separated from aldol condensation products.

In another preparative sequence, *N*-methyl-*N*-phenylcarbamoyl chloride[12] was found, under a variety of conditions, to react sluggishly and incompletely with the hydroxyl groups of methyl α-D-glucopyranoside and the corresponding alkoxides. The two-step syntheses of *N*-methyl-*N*-phenylcarbamates just described were unquestionably superior to the use of this reagent.

Following these preliminary experiments, our next objective was to obtain D-glucopyranose 2,3,6-tri-(*N*-phenylcarbamate) and 2,3,6-tri-(*N*-methyl-*N*-phenylcarbamate) and the corresponding 2,3,4-derivatives. Cellulose was allowed to react with phenyl isocyanate in pyridine by the method of Hearon *et al.*[13] to give cellulose tri-(*N*-phenylcarbamate). The synthesis of D-glucopyranose 2,3,6-tri-(*N*-phenylcarbamate) from cellulose tri-(*N*-phenylcarbamate) was attempted using the methods

of depolymerization reported by Husemann and Muller[1]. This sequence involves the alcoholysis of cellulose tri-(*N*-phenylcarbamate) in 2-methoxyethanol with *p*-toluenesulfonic acid followed by hydrolysis in acetone–water–hydrochloric acid. In our hands, neither step gave a monomeric product as shown by t.l.c., vapor pressure osmometry, and n.m.r. spectroscopy (N–H to OMe groups).

A similar reaction sequence from cellulose 2,3,6-tri-(*N*-methyl-*N*-phenylcarbamate) using 2-ethoxyethanol for alcoholysis and acetone–water–hydrochloric acid or tetrahydrofuran–water–hydrochloric acid for hydrolysis gave analogous results. Loss of carbanilate groups occurred before the monomeric products could be obtained.

Since cellulose triacetate and trimethyl ether give high yields of glycosides with 2-methoxy- or 2-ethoxy-ethanol[14] and *p*-toluenesulfonic acid, the reason for the incomplete depolymerization of the cellulose carbanilate derivatives must be the presence of the slightly basic carbanilate groups. Apparently, the carbanilate group protects other glycosidic centers similarly, since hydrolysis of methyl 2,3,6- and 2,3,4-tri-*O*-(*N*-phenylcarbamoyl)-α-D-glucopyranoside[12,15] and methyl 2,3,6- and 2,3,4-tri-*O*-(*N*-methyl-*N*-phenylcarbamoyl)-α-D-glucopyranoside also failed.

Benzyl 2,3,4-tri-*O*-(*N*-methyl-*N*-phenylcarbamoyl)-β-D-glucopyranoside was also prepared by conventional methods but was found not to be cleaved by hydrogenolysis with 5% palladium-on-carbon in either acetic acid or ethanol solution.

Although the monomer used by Husemann and Muller[1] was not prepared, D-glucopyranose 2,3,4-tri-(*N*-phenyl- and *N*-methyl-*N*-phenylcarbamate) were obtained by acetolysis followed by hydrolysis of the corresponding derivatives of 1,6-anhydro-β-D-glucopyranose[16].

D-Glucopyranose 2,3,4-tri-(*N*-phenylcarbamate) was polymerized by use of the technique described by Husemann and Muller[1] for the 2,3,6 isomer. The product that was isolated by pouring the reaction mixture into methanol was found to be completely insoluble in all organic solvents and swelled only in dimethyl sulfoxide. The limited swelling indicated that the material was probably cross-linked. Elemental analysis of the polymer showed that it contained 2.94% phosphorus, possibly in the form of phosphate linkages. Husemann and Muller[1] reported no phosphorus in the polymers that they obtained from the 2,3,6 isomer under the same reaction conditions. A reason for the higher phosphorus content in our product may be the higher reactivity of the C-6 hydroxyl group as compared to that of the C-4 hydroxyl group. Attempts to remove the blocking groups were not made.

The polymerization of D-glucopyranose tri-(*N*-methyl-*N*-phenylcarbamate) under the same conditions as those used for the polymerization of the *N*-phenylcarbamate derivative gave a solid gel after a reaction time of 24 h. The gel was dissolved in chloroform and worked up in the conventional manner. The structure of D-glucopyranose 2,3,4-tri-*O*-(*N*-methyl-*N*-phenylcarbamate)-1,6-diphosphate is consistent with the optical rotation, elemental analysis, and n.m.r. spectrum. The formation of the 6-phosphate ester must be much more rapid than polymerization, for no polymeric product was found. It is clear, therefore, that the polymerization method

reported by Husemann and Muller[1] cannot be applied to closely related compounds. We have found[16], however, in other glycoside-forming reactions that the *N*-phenylcarbamate group acts as a powerful participating group inducing β-D-glucoside formation, as was expected from the work of Husemann and Muller[1]. In the course of this work a number of new compounds were prepared and are described below.

EXPERIMENTAL

Synthesis of the N-*methyl*-N-*phenylcarbamate group. — Sodium hydride method.* Methyl 2,3,4,6-tetra-*O*-(*N*-phenylcarbamoyl)-α-D-glucopyranoside[15] (4.0 g, dried *in vacuo* at 70°) was added to anhyd. 1,2-dimethoxyethane (20 ml). Except for the solvent used, the methylation method was similar to that of Dannley and Lukin[10] and the yield of pure methyl 2,3,4,6-tetra-*O*-(*N*-methyl-*N*-phenylcarbamoyl)-α-D-glucopyranoside was 6.25 g (76%), m.p. 116–117°, $[\alpha]_D^{25}$ +50.2° (*c* 1, chloroform); n.m.r. data: δ 7.3 (4 phenyl groups) and 3.1–3.3 (4 *N* and 1 O–Me); no N–H protons could be observed.

Anal. Calc. for $C_{35}H_{34}N_4O_{10}$: C, 64.48; H, 5.78; N, 7.71. Found: C, 64.70; H, 5.83; N, 7.77.

Potassium hydroxide method. The method of Pachter and Kloetzel[11] applied to methyl 2,3,4,6-tetra-*O*-(*N*-phenylcarbamoyl)-α-D-glucopyranoside (4.7 g) gave methyl 2,3,4,6-tetra-*O*-(*N*-methyl-*N*-phenylcarbamoyl)-α-D-glucopyranoside in the same yield and with the same physical constants and i.r. and n.m.r. spectra as the compound prepared by the sodium hydride method.

N-*Methyl*-N-*phenylcarbamoyl chloride method.* *N*-Methyl-*N*-phenylcarbamoyl chloride was prepared by the method of Weygand and Mitgau[17]. Methyl α-D-glucopyranoside (2.0 g, dried for 2 h at 100°) was suspended in 1,2-dimethoxyethane (20 ml). The mixture was stirred under an atmosphere of nitrogen and sodium hydride (1.0 g) was added slowly. After the evolution of hydrogen ceased, *N*-methyl-*N*-phenylcarbamoyl chloride (5.2 g) was added. The solution was stirred for 24 h, and then methanol (1.0 ml) was added to destroy the excess sodium hydride. The reaction mixture was poured into water (500 ml) and an oil precipitated. The water was decanted and the oil dissolved in carbon tetrachloride. The solution was worked up in the usual fashion and evaporated to dryness. The residue was dissolved in hot ethanol, and the solution was seeded and cooled to give a product (3.5 g, 50%) having the same physical constants and spectra as the compound prepared by the sodium hydride method.

Attempted preparation of D-*glucopyranose 2,3,6-tri-*(N-*methyl*-N-*phenyl- and* N-*phenylcarbamate*) *from cellulose. — Cellulose tri-*(N-*phenylcarbamate*). To a solution of anhyd. pyridine (670 ml) and phenyl isocyanate (170 g) was added dried cellulose powder (50 g). The solution was stirred and heated for 24 h on a steam bath. The brown, viscous reaction mixture was diluted with acetone and then poured into methanol (4 l). The white precipitate was filtered off, washed with methanol, extracted with methanol in a Soxhlet extractor for 2 days, and dried *in vacuo* at 50° (150 g, 94%), $[\alpha]_D^{25}$ −144.5° (*c* 1, pyridine); i.r. data: 3400 (amide) and 1725 cm^{-1} (CO).

Cellulose tri-(N-*methyl*-N-*phenylcarbamate*). Cellulose tri-(*N*-phenylcarbamate)[13] (30 g) was dissolved in dry acetone (600 ml). To the solution was added powdered potassium hydroxide (39 g), the mixture stirred for 30 min, and then methyl iodide (30 ml) was added dropwise. After the solution was stirred for 6 h, it was poured into water (4 l) and the white precipitate filtered off. The precipitate was washed with water and methanol and dried *in vacuo* at 50° to give 31.6 g (99%), $[\alpha]_D^{25}$ −62.9° (*c* 1, chloroform); the i.r. spectrum showed a loss of the amide protons and the presence of the *N*-methyl group absorption at 1350 and 1150 cm^{-1}.

Alcoholysis of cellulose tri-(N-*phenylcarbamate*). The alcoholysis of cellulose tri-(*N*-phenylcarbamate) was performed with the method described by Husemann and Muller[1] (yield 87.6 g, 76.5%), $[\alpha]_D^{23}$ −92.5 to −120° (*c* 0.5, pyridine); the n.m.r. spectrum showed the ratio of protons of the *N*-phenylcarbamate group to the *O*-methyl protons to be larger than calculated for a product containing only monomeric species. Vapor pressure osmometry of the product showed it to contain oligosaccharides and t.l.c. did not show the presence of monomeric species.

Alcoholysis of cellulose tri-(N-*methyl*-N-*phenylcarbamate*). *p*-Toluenesulfonic acid (6.0 g) and cellulose tri-(*N*-methyl-*N*-phenylcarbamate) (10.0 g) were dissolved in dry 2-ethoxyethanol (150 ml). The solution was stirred under an atmosphere of nitrogen for 48 h at 102°. The dark-brown solution was poured into water (1 l), the water was decanted, and the oil was dissolved in chloroform. The solution was extensively washed, dried, decolorized, and evaporated to a syrup that formed a hard glass upon cooling (9.7 g) $[\alpha]_D^{23}$ +3.4° (*c* 1, chloroform). The alcoholysis was incomplete since the number of methyl protons (from the 2-ethoxyethyl group by n.m.r.) was less than would be expected for a product of complete alcoholysis. T.l.c. and vapor pressure osmometry also indicated that the reaction gave products that were mostly trimers and higher-molecular-weight oligomers.

Acid hydrolysis of the alcoholysis product of cellulose tri-(N-*phenylcarbamate*). The method of Husemann and Muller[1] applied to 10.0 g gave 8.3 g showing a very wide melting point range (180–220°) and a variable specific rotation. Although the n.m.r. spectrum showed a loss of the 2-methoxyethyl group, the spectrum was not consistent with that of a monomeric product. T.l.c. and vapor pressure osmometry proved the product to be composed of oligosaccharides, the one having the lowest mol. wt. being a dimer.

Acid hydrolysis of the alcoholysis product of cellulose tri-(N-*methyl*-N-*phenylcarbamate*). The syrup obtained from the alcoholysis of cellulose tri-(*N*-methyl-*N*-phenylcarbamate) (9.7 g) was dissolved in tetrahydrofuran (100 ml) containing 6M hydrochloric acid (40 ml) and water (40 ml). The solution was heated for 24 h to reflux and then neutralized with barium carbonate. The solution was filtered and carbon tetrachloride was added to the filtrate. The organic phase was well washed, dried, and concentrated to a syrup (8.9 g),[$\alpha]_D^{23}$ −45.3 to −48.6° (*c* 1, chloroform); although the n.m.r. spectrum showed a loss of the 2-ethoxyethyl group, t.l.c. and vapor pressure osmometry showed the product to be composed of low-molecular-weight oligosaccharides.

Attempted synthesis of D-*glucopyranose 2,3,6-tri-*(N-*methyl*-N-*phenyl- and* N-*phenylcarbamate*) *and 2,3,4-tri-*(N-*methyl*-N-*phenyl- and* N-*phenylcarbamate*) *from* D-*glucopyranosides.* — *Methyl 4-tetrahydropyranoyl-2,3,6-tri-*O-(N-*phenylcarbamoyl*)-α-D-*glucopyranoside.* Methyl 2,3,6-tri-*O*-(*N*-phenylcarbamoyl)-α-D-glucopyranoside (4.0 g), prepared by the method of Hearon[18], was dissolved in a solution containing *p*-dioxane (25 ml) and dichloromethane (25 ml). Dihydropyran (1.3 g) and 5M hydrochloric acid (2 ml) were added and the solution was stirred for 2 days at room temperature. The reaction mixture was shaken with potassium carbonate (4.0 g) and then poured into a 10% solution of sodium carbonate. The mixture was extracted with four 20-ml portions of chloroform, and the chloroform extract was washed with water and dried with anhyd. potassium carbonate. After evaporation, benzene was added and the resulting mixture heated to dissolve the syrup. Upon cooling, a white amorphous powder precipitated (4.0 g, 87%); n.m.r. data: δ 1.09–2.07 and 3.02–3.70 (3 *N*-phenylcarbamate and one tetrahydropyranyl groups).

Methyl 2,3,6-tri-(N-*methyl*-N-*phenylcarbamoyl*)-α-D-*glucopyranoside.* Methyl 4-tetrahydropyranyl-2,3,6-tri-(*N*-phenylcarbamoyl)-α-D-glucopyranoside (4.0 g) was dissolved in anhyd. 1,2-dimethoxyethane (70 ml). Sodium hydride (0.47 g) was added slowly under a stream of nitrogen. After the evolution of hydrogen had ceased, methyl iodide (2.8 g) was added and the solution stirred for 3 h. Methanol was then added to destroy the excess sodium hydride. A mixture of carbon tetrachloride and water was added and the organic layer washed with water until colorless and neutral. The organic phase was dried with magnesium sulfate and evaporated to a syrup, which was dissolved in acetone (20 ml). Water (10 ml) and conc. hydrochloric acid (1.0 ml) were added, and the solution was heated for 15 min to reflux, after which carbon tetrachloride was added. The organic phase was washed with aqueous sodium hydrogen carbonate and water, dried with magnesium sulfate, decolorized with activated charcoal, and evaporated to yield a clear, colorless syrup (2.8 g, 75%); the n.m.r. spectrum showed the loss of the tetrahydropyranyl group and the presence of 3 *N*-methyl and 1 *O*-methyl groups.

Anal. Calc. for $C_{31}H_{35}N_3O_9$: C, 62.72; H, 5.94; N, 7.08. Found: C, 62.58; H, 6.04; N, 6.79.

*Methyl 2,3,4-tri-*O-(N-*phenyl- and* N-*methyl*-N-*phenylcarbamoyl*)-α-D-*glucopyranoside.* Methyl 2,3,4-tri-*O*-(*N*-phenylcarbamoyl)-α-D-glucopyranoside was prepared with the method of Hearon[12]. Methyl 2,3,4-tri-*O*-(*N*-methyl-*N*-phenylcarbamoyl)-α-D-glucopyranoside was prepared by *N*-methylation of the corresponding 2,3,4-tri-*O*-(*N*-phenylcarbamoyl)-6-trityl derivative, followed by detritylation with hydrobromic acid in acetic acid[19].

Attempted acid hydrolysis of the methyl glucopyranoside derivatives. The four methyl glucosides, methyl 2,3,4- and 2,3,6-tri-*O*-(*N*-phenylcarbamoyl)- and methyl 2,3,4- and 2,3,6-tri-*O*-(*N*-methyl-*N*-phenylcarbamoyl)-α-D-glucopyranoside, were hydrolyzed with a variety of solvents and acids. The solvent mixtures used were: acetone–water, *p*-dioxane–water, and tetrahydrofurane–water (1:1, v/v). The acids used were conc. hydrochloric acid, conc. hydrobromic acid, and conc. sulfuric acid.

The amount of acid used was varied from 5 to 40% by volume. A typical reaction sequence using acetone–water–conc. hydrochloric acid is described as follows:

Methyl 2,3,4-tri-*O*-(*N*-methyl-*N*-phenylcarbamoyl)-α-D-glucopyranoside (1.0 g) was dissolved in acetone–water (1:1, v/v, 4.0 ml). Conc. hydrochloric acid (2.0 ml) was added and the solution heated to reflux. A sample of the reaction mixture was removed immediately and its rotation determined. After 24 h of reflux, another sample was withdrawn and its rotation was compared with the initial sample. The composition of the sample was also checked by use of t.l.c. with the starting methyl glucoside as a reference. Where no change was detected, the reaction mixture was heated for an additional 48 h to reflux. At the end of 72 h, the solution was poured into water and the precipitate filtered off, washed with water, and dried. The product was checked by t.l.c. and n.m.r. spectroscopy. In every case the product was found to be identical with the starting material. No cleavage of the C-1 methoxyl group could be detected.

Benzyl 2,3,4-tri-O-(N-*phenylcarbamoyl*)-*6-trityl-β-D-glucopyranoside.* — Benzyl β-D-glucopyranoside (1.0 g, prepared from 2,3,4,6-tetra-*O*-acetyl-α-D-glucopyranosyl bromide[20]) was dissolved in dry pyridine (20 ml) and chlorotriphenylmethane (1.3 g) was added. The solution was stirred for 1 h on a steam bath, cooled to room temperature, and phenyl isocyanate (2.0 g) was added. The mixture was heated for 1 h on a steam bath, then cooled to room temperature, and methanol (1.0 ml) was added. The solution was again heated for 10 min on a steam bath and then poured into water. The white precipitate was filtered off, washed with water, dried, and dissolved in hot acetone. Benzene was added and acetone removed by boiling. The product crystallized from the benzene solution as a fluffy, white solid (2.4 g, 70%), m.p. 231–233°, $[\alpha]_D^{23}$ −20.1° (*c* 1, acetone).

Anal. Calc. for $C_{53}H_{47}N_3O_9$: C, 73.18; H, 5.41; N, 4.83. Found: C, 73.08; H, 5.38; N, 4.68.

Benzyl 2,3,4-tri-O-(N-*methyl*-N-*phenylcarbamoyl*)-*6-trityl-β-D-glucopyranoside.* — Benzyl 2,3,4-tri-*O*-(*N*-phenylcarbamoyl)-6-trityl-β-D-glucopyranoside (1.0 g) was dissolved in anhyd. 1,2-dimethoxyethane (30 ml). Sodium hydride (0.16 g of a 52% suspension in oil) was added and then, after the evolution of hydrogen ceased, methyl iodide (0.51 g). The suspension was stirred for 2 h at room temperature and methanol was added to destroy the excess sodium hydride. After addition of carbon tetrachloride, the organic phase was worked up in the usual fashion, dried, decolorized, and evaporated to a syrup. This was dissolved in a minimum volume of hot ether and the solution was poured into petroleum ether. The liquid was decanted from the white precipitate and the amorphous solid dried (0.7 g, 70%), $[\alpha]_D^{23}$ −10.7° (*c* 1, acetone).

Anal. Calc. for $C_{56}H_{53}N_3O_9$: C, 73.76; H, 5.82; N, 4.61. Found: C, 73.87; H, 5.99; N, 4.57.

Benzyl 2,3,4-tri-O-(N-*methyl*-N-*phenylcarbamoyl*)-*β-D-glucopyranoside.* — Benzyl 2,3,4-tri-*O*-(*N*-methyl-*N*-phenylcarbamoyl)-6-trityl-β-D-glucopyranoside (0.7 g) was dissolved in glacial acetic acid (5.0 ml) and the solution cooled in an ice bath. To the cooled solution was added 30% hydrogen bromide in acetic acid (0.3 ml) and the flask swirled until the precipitation of bromotriphenylmethane stopped. The

mixture was filtered and the filtrate poured into ice–water. The oily precipitate was dissolved in carbon tetrachloride and the solution washed with dilute base and water. After being dried with magnesium sulfate, the solution was evaporated to a syrup that formed a glass upon cooling (0.35 g, 70%), $[\alpha]_D^{23}$ −22.3° (*c* 1, acetone); the n.m.r. spectrum showed the loss of the trityl group and the presence of 1 benzyl and 3 *N*-methyl-*N*-phenylcarbamoyl groups.

Anal. Calc. for $C_{37}H_{39}N_3O_9$: C, 66.36; H, 5.87; N, 6.27. Found: C, 66.48; H, 5.79; N, 6.11.

*Hydrogenolysis of benzyl 2,3,4-tri-*O-(N-*methyl*-N-*phenylcarbamoyl*)-*β*-D-*glucopyranoside.* — Benzyl 2,3,4-tri-*O*-(*N*-methyl-*N*-phenylcarbamoyl)-*β*-D-glucopyranoside (0.35 g) was dissolved in glacial acetic acid (5 ml) and one drop of conc. hydrochloric acid was added. To the solution was added 5% palladium-on-carbon (0.5 g); the flask was sealed and the air flushed out with hydrogen. The content of the flask was stirred for 24 h under an atmosphere of hydrogen at a pressure of 1 to 2 atm. The reaction mixture was filtered and the filtrate evaporated under reduced pressure. The last traces of acetic acid were removed by azeotropic distillation with toluene. The residue (0.34 g) was analyzed by t.l.c. and n.m.r. spectroscopy, and the results showed only the presence of the starting material in the hydrogenolysis product.

The reaction was repeated with both abs. ethanol and ethanol containing one drop of conc. hydrochloric acid as the solvent, instead of glacial acetic acid. The reaction time was also increased to 48 h. In every case tried, the results were the same, *i.e.* isolation of the starting material only.

*2,3,4-Tri-*O-(N-*phenylcarbamoyl*)-D-*glucopyranose.* — To a solution of 1,6-di-*O*-acetyl-2,3,4-tri-(*N*-phenylcarbamoyl)-α-D-glucopyranose[16] (1.0 g) in acetone (5 ml) and abs. ethanol (10 ml) was added dry hydrogen chloride (1% by weight). After being stirred for 17 h at room temperature, the solution was evaporated under reduced pressure. Addition of carbon tetrachloride to the syrup and evaporation removed the last traces of hydrogen chloride. The residue was dissolved in hot ethanol and the solution allowed to cool to give 0.6 g (70%), m.p. 227–229°, $[\alpha]_D^{23}$ +37.4° (*c* 1, acetone).

Anal. Calc. for $C_{27}H_{27}N_3O_9$: C, 60.33; H, 5.06; N, 7.82. Found: C, 60.17; H, 5.31; N, 7.59.

*2,3,4-Tri-*O-(N-*methyl*-N-*phenylcarbamate*)-D-*glucopyranose.* — To a solution of 1,6-di-*O*-acetyl-2,3,4-tri-*O*-(*N*-methyl-*N*-phenylcarbamoyl)-*β*-D-glucopyranose[16] (1.0 g) in acetone (5 ml) and abs. ethanol (10 ml) was added dry hydrogen chloride gas (1% by weight). The solution was stirred at room temperature for 24 h and then neutralized with aqueous sodium hydrogen carbonate. Chloroform was added and the organic phase separated and washed with water until neutral. The chloroform solution was dried with magnesium sulfate and evaporated to a syrup (0.7 g, 81%), $[\alpha]_D^{23}$ +30.0° (*c* 1, acetone); the n.m.r. spectrum showed the loss of the acetyl groups and the presence of 3 *N*-methyl-*N*-phenylcarbamoyl groups and two protons that could be exchanged with deuterium oxide.

Anal. Calc. for $C_{30}H_{33}N_3O_9$: C, 62.17; H, 5.74; N, 7.25. Found: C, 62.45; H, 5.87; N, 7.32.

Polymerization of 2,3,4-tri-O-(N-*phenylcarbamoyl*)-D-*glucopyranose.* — The method used for the polycondensation was the same as that used for the polymerization of 2,3,6-tri-*O*-(*N*-phenylcarbamoyl)-D-glucopyranose reported by Husemann and Muller[1]. 2,3,4-Tri-*O*-(*N*-phenylcarbamoyl)-D-glucopyranose (1.0 g) was dissolved in a mixture of chloroform (10 ml) and dimethyl sulfoxide (1 ml). The chloroform was dried over phosphorus pentoxide and distilled before use. Dimethyl sulfoxide was dried over 4 Å molecular sieves. To the mixture was added phosphorus pentoxide powder (1.0 g). The flask was sealed against atmospheric moisture and stirred vigorously by means of a magnetic stirrer. The phosphorus pentoxide was at first a fine powder but, after 24 h, it formed small clumps in the reaction mixture. Only the rapid stirring prevented the material from forming a solid mass. After being stirred for 7 days, the reaction mixture was poured into methanol (100 ml) and the precipitate filtered off and washed with methanol. Attempts at dissolving the product in organic solvents such as acetone, dioxane, tetrahydrofurane, and dimethyl sulfoxide were unsuccessful. The material did swell in dimethyl sulfoxide, which suggests that it was cross-linked and was not a linear polymer. Elemental analysis showed the product to contain 2.94% phosphorus.

Polymerization of 2,3,4-tri-O-(N-*methyl*-N-*phenylcarbamoyl*)-D-*glucopyranose.* — 2,3,4-Tri-*O*-(*N*-methyl-*N*-phenylcarbamoyl)-D-glucopyranose (1.0 g) was dissolved in dry chloroform (10 ml) and dry dimethyl sulfoxide (1.0 ml) was added. To this solution was added phosphorus pentoxide (1.0 g) and the resulting mixture was stirred at room temperature. After 24 h, the reaction mixture formed a solid gel; the gel was broken up and the stirring continued for 6 days. The semi-solid mixture was then poured into chloroform. The chloroform solution was washed with water, aqueous sodium hydrogen carbonate, and water, dried with magnesium sulfate, and evaporated to yield a light yellow syrup. This was dissolved in a small amount of chloroform and the solution poured into petroleum ether. The precipitate was collected by centrifugation (570 mg), $[\alpha]_D^{23}$ +3.7° (*c* 0.5, acetone); n.m.r. data δ 3.2–3.3 and 7.25 (3 *N*-methyl-*N*-phenylcarbamate groups), 3.4–6.0 (9 protons in the region of the glucose ring protons), mol. wt. (vapor pressure osmometry) 763. Found: C, 48.57; H, 4.70; P, 8.53%. Calc. for 2,3,4-tri-*O*-(*N*-methyl-*N*-phenylcarbamoyl)-D-glucopyranose 1,6-diphosphate: mol. wt. 740; C, 48.72; H, 4.50; P, 8.65%. Presumably, the rest of the product was extracted and lost as the sodium salt in the hydrogen carbonate solution.

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