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# Studies of the synthesis of 1,2-*cis*-(cyclic carbamates) of α-D-aldopyranosylamines *

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## ABSTRACT

Reaction of α-D-glucopyranosyl azide with triphenylphosphine and carbon dioxide gave 1-*N*,2-*O*-carbonyl-α-D-glucopyranosylamine (**7**) and its α-D-furanose analogue (**1**), and 1-*N*,3-*O*-carbonyl-α-D-allofuranosylamine (**15**) and its α-D-pyranose analogue (**17**). Similarly, α-D-xylopyranosyl azide gave 1-*N*,2-*O*-carbonyl-α-D-xylopyranosylamine (**9**) and its α-D-furanose analogue (**3**), and 1-*N*,3-*O*-carbonyl-α-D-ribopyranosylamine (**19**) and its β-D-xylopyranose analogue (**21**). The structures of the products and their acetylated derivatives were established by $^1H$ and $^{13}C$ NMR spectroscopy. 1-*N*,3-*O*-Carbonyl-β-D-xylopyranosylamine (**21**) was obtained from β-D-xylopyranosyl azide when spontaneous rearrangement of the 1,2-(cyclic carbamate) **5** into **21** occurred in water.

## INTRODUCTION

Cyclic carbamates (*N*,*O*-carbonyl derivatives) of amino sugars have attracted interest as potential components of aminoglycoside antibiotics[1,2]. They allow simultaneous protection of hydroxyl and amino groups of carbohydrates and aminocyclitols[3–5], and they are model compounds for studying conformational problems of carbohydrates[6].

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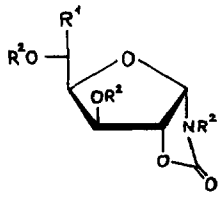
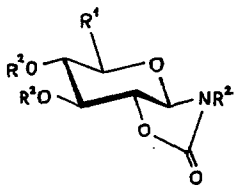
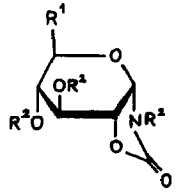
* Dedicated to Professor András Messmer on the occasion of his 70th birthday.



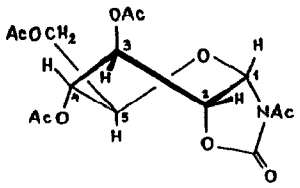
1 $R^1$ = $CH_2OH$, $R^2$ = H
2 $R^1$ = $CH_2OAc$, $R^2$ = Ac
3 $R^1$ = $R^2$ = H



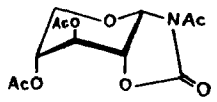
4 $R^1$ = $CH_2OH$, $R^2$ = H
5 $R^1$ = $R^2$ = H
6 $R^1$ = H, $R^2$ = Ac



7 $R^1$ = $CH_2OH$, $R^2$ = H
8 $R^1$ = $CH_2OAc$, $R^2$ = Ac
9 $R^1$ = $R^2$ = H
10 $R^1$ = H, $R^2$ = Ac



8a



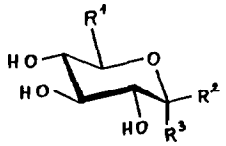
10a

Of the possible 1,2-(cyclic carbamates) (**1**, **4** and **7**) of D-glucosylamine, the furanoid compound **1** has long been known[7], but its structure was proved[8] only recently. The pyranoid 1,2-*trans*-(cyclic carbamate) **4** was isolated[9] after hydrolysis of the *N*-nitrosourea derivative and synthesised[10] from the corresponding phosphinimine. The pyranoid 1,2-*cis*-(cyclic carbamate) structure **7** was suggested[11] for the compound formed in the reaction of β-D-glucopyranosylamine and phosgene, but the product proved[10] to be **4**. The product from the acid-catalysed reaction of D-glucose and urea was also described[12] as **7**, but was shown[8,13] to be **1**.

We now report the preparation of **7** and provide evidence for its structure.

## RESULTS AND DISCUSSION

Cyclic carbamates of amino sugars are easily accessible by a one-pot procedure via phosphinimines, as described[10] for **4**, by reacting β-D-glucopyranosyl azide (**11**) with triphenylphosphine and carbon dioxide. Application of this method to the α anomer[14] **12** in dry *N*,*N*-dimethylformamide at room temperature gave a mixture of four cyclic carbamates and D-glucose. The mixture was partially fractionated by column chromatography followed by HPLC. The main fraction contained three cyclic carbamates in the ratios 75:20:5 as shown by the $^1H$ and $^{13}C$ NMR spectra.

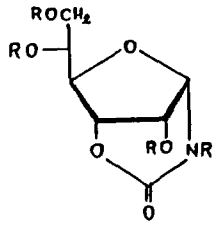


11 $R^1$=$CH_2OH$, $R^2$=$N_3$, $R^3$=H

12 $R^1$=$CH_2OH$, $R^2$=H, $R^3$=$N_3$

13 $R^1$=$R^3$=H, $R^2$=$N_3$

14 $R^1$=$R^2$=H, $R^3$=$N_3$



15 R = H

16 R = Ac

The minor component was α-D-glucofuranosylamine 1,2-(cyclic carbamate) (**1**) identified by comparison with the authentic compound[8]. The major component, which was obtained crystalline, was the expected 1-*N*,2-*O*-carbonyl-α-D-glucopyranosylamine (**7**). The structures of **7** and its *N*-acetyl-tri-*O*-acetyl derivative (**8**) were proved by their $^1H$ and $^{13}C$ NMR spectra (Tables I–IV). The signals for C-4 and C-5 were distinguished by semiselective INEPT measurements[15]. In accord with the oxazolidin-2-one structure of **7**, the chemical shift for the C=O resonance was found at δ 160.2 (Table II) and the IR spectrum contained a strong peak at 1745 $cm^{-1}$.

The $^3J_{H,H}$ values indicated a distorted pyranoid ring in **7**, as a consequence of the contribution of the $^1C_4$ conformation. The corresponding data for the tetra-acetyl derivative **8** (Table III) revealed a $^oS_2$ skew conformation (**8a**). The long-range coupling ($J_{2,4}$ 1.1 Hz) also indicated a planar arrangement of H-2 and H-4 as in the $^oS_2$ conformation. This stereochemistry of **8** was corroborated by the good agreement of the NMR data with those for the 2-*N*,1-*O*-carbonyl analogue[16] and α-D-glucopyrano[2,1-*d*]oxazolidine derivatives[17].

The third component in the mixture, which was not isolated, was probably 1-*N*,3-*O*-carbonyl-α-D-allofuranosylamine (**15**). Thus, a six-membered 1,3-(cyclic carbamate) structure was proved by the $^{13}C$ signal for C=O at δ 154.9 (Table II) that showed an upfield shift of ~ 5 ppm compared with the carbonyl signal of the oxazolidinone ring. The allofuranose structure was indicated by the resonance of C-4 at rather low field (δ 82.2), the small value of $J_{1,2}$ (0.6 Hz) and the long-range couplings ($J_{1,3}$ −1.4, $J_{2,4}$ 0.5 Hz; Table I), the small downfield shift (0.15 ppm) of the H-4 resonance, and the large shift (~ 1.3 ppm) of the H-5 resonance on the conversion of **15** into the tetra-acetyl derivative **16** (Tables I and III).

The $^1H$ NMR spectrum of the fourth product, eluted second during HPLC, indicated the structure 1-*N*,3-*O*-carbonyl-α-D-allopyranosylamine (**17**). A significant long-range coupling ($J_{1,3}$ −2.2 Hz) and a *trans*-diaxial coupling ($J_{4,5}$ 10.2 Hz),

TABLE I

$^1$H NMR data [a] for the cyclic carbamates

| Compound | Chemical shifts ($\delta$) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | H-1 | H-2 | H-3 | H-4 | H-5a | H-5b | H-6a | H-6b |
| **1** [b] | 5.876 | 5.035 | 4.466 | 3.957 | 3.942 | | 3.800 | 3.648 |
| **4** [c] | 4.895 | 3.810 | 3.939 | 3.417 | 3.582 | | 3.822 | 3.682 |
| **5** [d] | 4.80 | 3.81 | 3.87 | 3.66 | 3.39 | 4.06 | | |
| **7** [b] | 5.681 | 4.736 | 4.069 | ——— 3.63–3.65 ——— | | | 3.826 | 3.728 |
| **9** [c] | 5.55 | 4.67 | 4.18 | 3.70 | 3.77 | 3.84 | | |
| **15** [b] | 4.986 | 4.719 | 4.843 | 4.349 | ——— 3.85–3.90 ——— | | | 3.717 |
| **17** [d] | 4.89 | 3.88 | 4.67 | 3.71 | 3.43 | | 3.65 | 3.73 |
| **18** [c] | 4.899 | 3.905 | 4.689 | 3.933 | 3.278 | 3.801 | | |
| **21** [d] | 4.90 | 4.09 | 4.49 | 3.90 | 3.98 | 3.81 | | |

| | Coupling constants (Hz) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $J_{1,2}$ | $J_{1,3}$ | $J_{2,3}$ | $J_{2,4}$ | $J_{3,4}$ | $J_{4,5a}$ | $J_{4,5b}$ | $J_{5a,5b}$ | $J_{5,6a}$ | $J_{5,6b}$ | $J_{6a,6b}$ |
| **1** [b] | 5.4 | −0.5 | 0.6 | | 2.4 | 9.0 | | | 2.5 | 5.6 | −12.2 |
| **4** [c] | 8.8 | | 10.8 | | 7.7 | 9.7 | | | 2.1 | 5.5 | −12.4 |
| **5** [d,e] | 8.9 | | 10.9 | 1.5 | 7.8 | 10.4 | 6.3 | −11.8 | | | |
| **7** [b] | 6.5 | | 4.7 | | 4.7 | | | | 2.2 | 3.4 | −12.4 |
| **9** [c] | 5.5 | | 5.3 | | 5.3 | 5.3 | 5.3 | −12.3 | | | |
| **15** [b] | 0.6 | −1.4 | 1.9 | 0.5 | 2.9 | 9.4 | | | 2.9 | 3.2 | −12.4 |
| **17** [d] | 3.5 | −2.2 | 1.7 | | 2.4 | 10.2 | | | 4.7 | 2.4 | −12.2 |
| **19** [c] | 3.2 | −1.8 | 2.4 | 1.2 | 2.5 | 10.8 | 6.5 | −12.0 | | | |
| **21** [d,f] | 2.2 | −2.2 | 4.0 | 1.3 | 3.7 | 2.5 | 1.0 | −14.0 | | | |

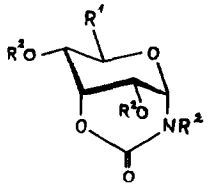
[a] For solutions in $D_2O$. [b] Recorded at 600 MHz. [c] Recorded at 300 MHz. [d] Recorded at 400 MHz. [e] $J_{1,5eq} = J_{3,5ax} = 1.5$ Hz. [f] $J_{1,5eq} \approx 1$ Hz.

TABLE II

$^{13}$C NMR data for the cyclic carbamates

| Compound | Chemical shifts ($\delta$) | | | | | | |
|---|---|---|---|---|---|---|---|
| | C-1 | C-2 | C-3 | C-4 | C-5 | C-6 | NCOO |
| **4** [a] | 85.3 | 81.8 | 73.0 | 71.5 | 80.8 | 60.7 | 160.3 |
| **5** [a] | 86.3 | 82.0 | 73.1 | 71.1 | 69.4 | | 160.3 |
| **5** [b] | 85.8 | 81.8 | 73.1 | 71.3 | 69.4 | | 157.7 |
| **7** [a] | 79.6 | 78.2 | 71.2 | 68.0 | 73.7 | 61.7 | 160.2 |
| **9** [a] | 80.4 | 78.6 | 69.6 | 67.0 | 64.0 | | 160.5 |
| **15** [c] | 83.5 | 70.6 | 79.6 | 82.2 | 70.0 | 63.4 | 154.9 |
| **17** [c] | 77.2 | 60.5 | 80.7 | 66.0 | 69.8 | 60.1 | 155.1 |
| **19** [a] | 76.6 | 60.4 | 80.3 | 65.9 | 58.3 | | 155.3 |
| **21** [a] | 76.5 | 61.9 | 71.1 | 66.2 | 61.7 | | 155.2 |
| **21** [b] | 76.5 | 62.5 | 70.2 | 66.5 | 61.2 | | 151.2 |

[a] Recorded at 75.5 MHz for a solution in $D_2O$. [b] Recorded at 75.5 MHz for a solution in $(CD_3)_2SO$. [c] Recorded at 100 MHz for a solution in $D_2O$.

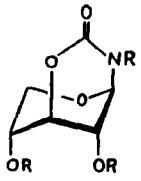


17 $R^1$ = $CH_2OH$, $R^2$ = H

18 $R^1$ = $CH_2OAc$, $R^2$ = Ac

19 $R^1$ = $R^2$ = H

20 $R^1$ = H, $R^2$ = Ac



21 R = H

22 R = Ac

as well as the small values of $J_{2,3}$ (1.7 Hz) and $J_{3,4}$ (2.4 Hz), indicated the allopyranose structure that was supported by NOE experiments which showed the proximity of H-2 to H-1 and H-3, and an *eq, ax, eq* sequence. The six-membered 1,3-(cyclic carbamate) structure was corroborated by the $^{13}C$ resonance of C=O at $\delta$ 155.1.

Treatment of **17** with hot acetic anhydride–sodium acetate gave the tetra-acetyl derivative **18** (4 s, NAc and 3 OAc; Table III). The $^1H$ NMR data of **18** accorded with those of the closely related hexa-acetylguanidine derivative[18].

Treatment of $\alpha$-D-xylopyranosyl azide[19] (**14**) with triphenylphosphine and carbon dioxide in dry acetone gave a mixture of four cyclic carbamates, which the spectroscopic data indicated to contain 1-*N*,2-*O*-carbonyl-$\alpha$-D-xylopyranosylamine (**9**), 1-*N*,3-*O*-carbonyl-$\alpha$-D-ribopyranosylamine (**19**), 1-*N*,3-*O*-carbonyl-$\beta$-D-xylopyranosylamine[9] (**21**), and 1-*N*,2-*O*-carbonyl-$\alpha$-D-xylofuranosylamine[8,20] (**3**). Compounds **9** and **19** were isolated by fractional crystallisation, and **21** by HPLC. The minor product (**3**) was identified by comparison of the $^{13}C$ NMR data with those of the authentic compound[8].

The $^1H$ and $^{13}C$ chemical shift data for the main product (**9**) showed a close relation to those of the D-glucopyranose derivative **7** (Tables I and II). The medium $^3J_{H,H}$ values ($J_{1,2}$ 5.5, $J_{2,3} = J_{3,4} = J_{4,5a} = J_{4,5b}$ = 5.3 Hz) of a solution of **9** in $D_2O$ suggested an equilibrium of the $^4C_1$ and $^1C_4$ conformations. However, for the triacetate **10**, the $^3J_{H,H}$ values (Table III) correspond well with the $^1C_4$ conformation (**10a**) not unusual for D-*xylo* compounds[21].

The D-ribose derivative **19** had a structure analogous to that of the allopyranose derivative **17**, as shown by their $^1H$ and $^{13}C$ NMR data (Tables I and II) and those of the respective acetylated derivatives **20** and **18** (Tables III and IV). The structure of **19** was proved by X-ray diffraction[22].

The $^1H$ NMR spectrum of **21** afforded vicinal and long-range couplings which agreed well with the $^1C_4$ conformation of the xylopyranoid ring. NOE experiments showed that the intensity of the signal for H-2 ($\delta$ 4.09) was increased by irradiation

TABLE III

$^1$H NMR data [a] for the acetylated derivatives of cyclic carbamates

| Compound | Chemical shifts ($\delta$) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | H-1 | H-2 | H-3 | H-4 | H-5a | H-5b | H-6a | H-6b | NAc | OAc |
| **6** [b] | 5.08 | 4.00 | 5.44 | 5.10 | 3.65 | 4.34 | | | 2.53 | 2.12, 2.08 |
| **8** [c] | 6.161 | 4.629 | 5.282 | 4.981 | 3.810 | | 4.160 | 4.234 | 2.575 | 2.150, 2.112, 2.064 |
| **10** [c] | 5.921 | 4.851 | 5.329 | 4.375 | 3.791 | 4.029 | | | 2.520 | 2.155, 2.119 |
| **16** [c] | 6.384 | 5.304 | 4.851 | 4.500 | 5.207 | | 4.663 | 4.135 | 2.581 | 2.183, 2.092, 2.072 |
| **18** [b] | 6.21 | 5.19 | 4.99 | 5.00 | 3.82 | | 4.19 | 4.30 | 2.70 | 2.14, 2.13, 2.03 |
| **20** [c] | 6.140 | 5.108 | 4.963 | 5.050 | 3.447 | 4.000 | | | 2.68 | 2.09(2) |
| **22** [d] | 6.09 | 4.85 | 4.84 | 4.96 | 3.92 | 3.96 | | | 2.66 | 2.20, 2.13 |
| | Coupling constants (Hz) | | | | | | | | | |
| | $J_{1,2}$ | $J_{1,3}$ | $J_{2,3}$ | $J_{2,4}$ | $J_{3,4}$ | $J_{4,5a}$ | $J_{4,5b}$ | $J_{5a,5b}$ | $J_{5,6a}$ | $J_{5,6b}$ | $J_{6a,6b}$ |
| **6** [b] | 9.1 | | 11.0 | | 8.0 | 9.9 | 6.3 | −12.0 | | | |
| **8** [c] | 6.5 | | 3.1 | 1.1 | 2.2 | 8.6 | | | 3.4 | 6.0 | −12.2 |
| **10** [c] | 4.8 | | 2.4 | 0.8 | 2.4 | 4.3 | 3.9 | −13.2 | | | |
| **16** [c] | ~0 | −1.3 | 1.8 | | 2.3 | 8.6 | | | 3.0 | 4.3 | −12.5 |
| **18** [b] | 4.0 | −2.1 | 1.7 | | | 10.7 | | | 2.8 | 3.7 | −12.5 |
| **20** [c] | 3.8 | −2.1 | 1.6 | | 2.1 | 10.8 | 6.4 | −12.0 | | | |
| **22** [d] | | | | | | 2.4 | 1.0 | −14.7 | | | |

[a] For solutions in $CDCl_3$. [b] Recorded at 250 MHz. [c] Recorded at 300 MHz. [d] Recorded at 400 MHz.

TABLE IV

$^{13}C$ NMR data [a] for the acetylated derivatives of cyclic carbamates

| Compound | Chemical shifts ($\delta$) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | C-1 | C-2 | C-3 | C-4 | C-5 | C-6 | NCOO | Others |
| **6** [b] | 85.5 | 76.6 | 71.0 | 69.5 | 67.1 | | 151.5 | 171.2 (CON), 169.6(2) (COO)<br>24.2 (*Me*CON), 20.6(2) (*Me*COO) |
| **8** [c] | 78.7 | 70.7 | 68.0 | 67.3 | 68.1 | 63.0 | 151.9 | 170.3 (CON), 169.4, 169.0, 168.8 (COO)<br>23.6 (*Me*CON), 20.6, 20.5(2) (*Me*COO) |
| **10** [d] | 78.3 | 71.0 | 65.8 [e] | 65.6 [e] | 61.4 | | 151.9 | 169.8 (CON), 169.2, 168.5 (COO)<br>23.5 (*Me*CON), 20.7, 20.6 (*Me*COO) |
| **16** [d] | 81.1 | 72.2 | 77.2 | 80.2 | 68.1 | 61.9 | 148.0 | 170.6 (CON), 170.3, 169.0, 168.8 (COO)<br>26.0 (*Me*CON), 20.6(3) (*Me*COO) |
| **18** [b] | 75.0 | 62.2 | 75.3 | 66.9 | 66.4 | 61.1 | 148.8 | 172.2 (CON), 170.4, 169.4, 168.9 (COO)<br>27.1 (*Me*CON), 20.6(2), 20.5 (*Me*COO) |
| **20** [d] | 74.6 [e] | 62.6 | 75.4 [e] | 67.0 | 57.2 | | 148.8 | 172.3 (CON), 169.4(2), (COO)<br>27.1 (*Me*CON), 20.6(2), (*Me*COO) |
| **22** [c] | 74.2 | 62.7 | 68.0 | 66.1 | 59.2 | | 148.5 | 171.5 (CON), 169.6, 169.4 (COO)<br>26.7 (*Me*CON), 20.8, 20.6 (*Me*COO) |

[a] For solutions in $CDCl_3$. [b] Recorded at 62.5 MHz. [c] Recorded at 100 MHz. [d] Recorded at 75.5 MHz. [e] Assignments may have to be reversed.

of H-1 (δ 4.90). Similarly, the proximity of H-3 (δ 4.49) to H-2 (δ 4.09) and H-4 (δ 3.90) was established. The $^1$H NMR data for **21** accord with those reported[9], except that the signals of H-2 and H-3 were assigned incorrectly; the chemical shift of the H-2 resonance (δ 4.09) is smaller than that of H-3 (δ 4.49) as a consequence of the 1,3-(cyclic carbamate) structure.

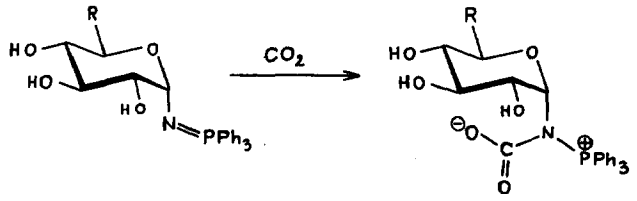
The formation of **21**, as a stable β-D-xylopyranosyl derivative, from the α-azide **14** must involve anomerisation. Indeed, in the reaction of β-D-xylopyranosyl azide (**13**) with triphenylphosphine and carbon dioxide in dry acetone, 20% of **21** was obtained in addition to the 1,2-*trans*-(cyclic carbamate) **5**. The $^{13}$C C=O signal was found at δ 155.2 for **21** but at δ 160.3 for **5**, in accord with the six- and five-membered cyclic carbamate structures, respectively. The large $^3J_{H,H}$ values revealed a $^4C_1$ conformation for **5** in contrast to the $^1C_4$ conformation for **21**.

Conventional acetylation of **5** and **21** afforded the known triacetyl derivatives **6** and **22**, respectively. Compound **6** was obtained earlier[6] as the sole product of the same reaction sequence. An unambiguous assignment of the $^{13}$C NMR spectrum of the triacetyl compound[9,23] **22** was achieved by 1D semi-selective INEPT[15].

The 1,2-(cyclic carbamate) **5** was unstable in water and rearranged into the thermodynamically more stable[23] 1,3-(cyclic carbamate) **21**. Consequently, only **21** was obtained by the same transformation of **13** when the product was extracted with water.

The rearrangement **5** → **21** can be explained by the opening and recyclisation of the cyclic carbamate system accompanied by inversion of the pyranoid ring. A similar transformation with a conformational change of the cyclitol ring occurs for fortimicin derivatives[5].

The formation of several cyclic carbamates in the reaction of α-D-glycopyranosyl azides with triphenylphosphine and carbon dioxide suggests that the zwitterionic oxycarbonylaminophosphonium intermediate (**24**), generated from the phosphinimine **23** and carbon dioxide, may give the products without formation of the isocyanate as was assumed earlier[10].




23 R = $CH_2OH$, H 24

Thus, **24** can afford the 1,2-(cyclic carbamate) by the participation of HO-2 or the 1,3-(cyclic carbamate) by an intramolecular nucleophilic attack at C-3. The mechanism of the formation and transcarbamoylation of cyclic carbamates of amino sugars is being investigated further.

## EXPERIMENTAL

*General.*—TLC was performed on Silica Gel $F_{254}$ (Merck) with *A*, EtOAc–EtOH–water (7:2:1); *B*, EtOAc–EtOH–water (8:2:1); *C*, $CHCl_3$–acetone (9:1); *D*, EtOAc–MeOH (8:1); and *E*, $CHCl_3$–acetone (95:5); and detection by charring with $H_2SO_4$. Silica gel (40–63 μm) was used for column chromatography and dry-column flash chromatography[24]. HPLC was carried out on a Waters Deltaprep 3000 apparatus, using a column (15 × 250 mm) of silica gel (10–15 μm). Melting points are uncorrected. Optical rotations were measured with a Zeiss Polamat A polarimeter and IR spectra with a Nicolet 205FT spectrometer. Bruker AMX-600, AM-400, AM-300, and AC-250 spectrometers were used to obtain $^1H$ (solutions in $D_2O$, internal HOD; solutions in $CDCl_3$, internal $Me_4Si$) and $^{13}C$ NMR spectra (solutions in $D_2O$, internal acetone; solutions in $CDCl_3$ and $(CD_3)_2SO$, internal $Me_4Si$). The assignments of most $^1H$ and $^{13}C$ resonances were proved by spin-decoupling and by 2D $^{13}C$–$^1H$ correlation maps, obtained with the Bruker software package. CI (isobutane)-mass spectra were obtained with a Finnegan-MAT 212 instrument and an SS 200 data system.

*Acetylation of cyclic carbamates.*—The *N*-acetyl-di- and -tri-*O*-acetyl derivatives were prepared as follows, except where noted otherwise. A mixture of the cyclic carbamate (1 mmol) and anhyd NaOAc (0.5 g, 6 mmol) in acetic anhydride (5 mL) was boiled under reflux for 2 h, then poured into ice–water (50 mL), and extracted with $CHCl_3$. The extract was dried and concentrated, a solution of the residue in EtOH was clarified with charcoal, then concentrated, and toluene was evaporated from the residue.

*Reaction of α-D-glucopyranosyl azide* (**12**) *with triphenylphosphine and carbon dioxide.*—To a solution of **12**[14b] (0.82 g, 4 mmol) in dry *N*,*N*-dimethylformamide (14 mL) saturated with $CO_2$ was added a solution of triphenylphosphine (1.31 g, 5 mmol) in *N*,*N*-dimethylformamide (15 mL) at room temperature during 20 min, and the flow of $CO_2$ was continued for 12 h. TLC (solvent *A*) then revealed no **12** but several products ($R_f$ 0.4–0.5, 0.3, and 0.15), triphenylphosphine oxide ($R_f$ 0.8), and triphenylphosphine ($R_f$ 0.9). The solution was concentrated and the residue was extracted with $CHCl_3$ (15 mL) to dissolve the phosphorus containing by-products (1.33 g). Column chromatography (solvent *A*) of the residue (0.74 g) then HPLC (solvent *B*) gave fractions I–III.

Fraction I (191 mg), *T* 20.5 min (solvent *B*), $R_f$ 0.4–0.5 (solvent *A*) was a mixture of 1-*N*,2-*O*-carbonyl-α-D-glucopyranosylamine (**7**, 17%), 1-*N*,3-*O*-carbonyl-α-D-allofuranosylamine (**15**, 5%), and 1-*N*,2-*O*-carbonyl-α-D-glucofuranosylamine[8] (**1**, 1%) in the ratios 75:20:5 (NMR data). Fraction I was treated with EtOH to give **7** (107 mg, 13%); $R_f$ 0.45; mp 151–152°C; $[\alpha]_D$ +37° (*c* 2, $H_2O$); $\nu_{max}^{KBr}$ 1745 $cm^{-1}$ (C=O). Mass spectrum: *m/z* 206 $(M+1)^+$. Anal. Calcd for $C_7H_{11}NO_6$: C, 40.98; H, 5.40; N, 6.83. Found: C, 41.05; H, 5.58; N, 6.75.

The tetra-acetyl derivative (**8**, 85%) of **7** was a syrup; $R_f$ 0.4 (solvent *C*); $[\alpha]_D$ +82° (*c* 1, $CHCl_3$). Anal. Calcd for $C_{15}H_{19}NO_{10}$: C, 48.26; H, 5.13; N, 3.75. Found: C, 48.12; H, 5.10; N, 3.54.

The above mother liquor was concentrated to give an inseparable mixture (65 mg) of **15**, **7**, and **1** (in the ratios 56:24:20). Acetylation gave an inseparable syrupy mixture (86%) of the corresponding tetra-acetyl derivatives **16**, **8**, and **2**; $R_f$ 0.4–0.45 (solvent *C*).

Fraction II was 1-*N*,3-*O*-carbonyl-α-D-allopyranosylamine (**17**; 69 mg, 8%); *T* 26 min (solvent *B*); $R_f$ 0.3 (solvent *A*); mp 180–182°C (from MeOH); $[\alpha]_D$ +46° (*c* 2.3, $H_2O$); $\nu_{max}^{KBr}$ 1690 $cm^{-1}$ (C=O). Anal. Calcd for $C_7H_{11}NO_6$: C, 40.98; H, 5.40; N, 6.83. Found: C, 41.10; H, 5.50; N, 6.74.

The tetra-acetyl derivative (**18**, 85%) of **17** was a syrup; $R_f$ 0.7 (solvent *C*); $[\alpha]_D$ +61° (*c* 2, $CHCl_3$). Anal. Calcd for $C_{15}H_{19}NO_{10}$: C, 48.26; H, 5.13; N, 3.75. Found: C, 48.10; H, 5.00; N, 3.58.

Fraction III (254 mg, 35%) was identical with glucose, $R_f$ 0.15 (solvent *A*). Conventional acetylation gave a mixture of α,β-D-glucopyranose penta-acetate (66%, α,β-ratio 1:2); mp 128–131°C (from EtOH), identified by $^{13}C$ NMR spectroscopy[25].

*Reaction of α-D-xylopyranosyl azide* (**14**) *with triphenylphosphine and carbon dioxide.*—To a solution of **14**[19] (0.875 g, 5 mmol) in dry acetone (29 mL) was added triphenylphosphine (1.64 g, 6.25 mmol) in dry acetone (18 mL), in the presence of $CO_2$, and the reaction was carried out as described for **12**. TLC (solvent *B*) then revealed triphenylphosphine ($R_f$ 0.9), triphenylphosphine oxide ($R_f$ 0.7), several products in the region $R_f$ 0.45–0.6, and xylose ($R_f$ 0.2). The solution was concentrated and the residue was extracted with water (15 mL) to leave insoluble phosphorus compounds (1.67 g). The extract was concentrated, and the residue was treated with ether to give an amorphous solid (0.64 g), dry-column flash chromatography[24] (solvent *B*) of which gave, first, a mixture (275 mg, 31%) of four compounds, $R_f$ 0.6, 0.5–0.55, and 0.45 (solvent *B*), and then xylose (245 mg, 33%).

The first fraction (275 mg) crystallised spontaneously after 2 weeks and, when treated with a little EtOH, yielded 1-*N*,2-*O*-carbonyl-α-D-xylopyranosylamine (**9**; 64 mg, 7%) as colourless prisms; $R_f$ 0.55 (solvent *B*); mp 153–155°C (from EtOH); $[\alpha]_D$ +34° (*c* 1.6, $H_2O$); $\nu_{max}^{KBr}$ 1720 $cm^{-1}$ (C=O). Mass spectrum: *m/z* 176 $(M+1)^+$. Anal. Calcd for $C_6H_9NO_5$: C, 41.15; H, 5.18; N, 8.00. Found: C, 41.01; H, 5.10; N, 7.87.

The ethanolic filtrate of **9** was cooled to give 1-*N*,3-*O*-carbonyl-α-D-ribopyranosylamine (**19**; 29 mg, 3%); $R_f$ 0.45 (solvent *B*); mp 194°C; $[\alpha]_D$ +49° (*c* 1, EtOH); $\nu_{max}^{KBr}$ 1690, 1660 $cm^{-1}$ (C=O). Mass spectrum: *m/z* 176 $(M+1)^+$. Anal. Found: C, 41.33; H, 5.23.

The mother liquor was concentrated to give a four-component mixture (178 mg) which, on the basis of $^1H$ and $^{13}C$ NMR spectra, contained 1-*N*,3-*O*-carbonyl-β-D-xylopyranosylamine[9] (**21**) and 1-*N*,2-*O*-carbonyl-α-D-xylofuranosylamine[8,20] (**3**), **9**, and **19**, in the ratios 2:1:1:1. Thus, the calculated total yields were **9** 11.5%, **19** 7.5%, **21** 8%, and **3** 4%. HPLC (solvent *B*) of the mixture gave **21** (52 mg, 6%); *T* 12 min, $R_f$ 0.6 (solvent *B*); 0.4 (solvent *D*); mp 168–169°C (from EtOH); $[\alpha]_D$ +8°

(*c* 2.3, $H_2O$); $\nu_{max}^{KBr}$ 1700 $cm^{-1}$ (C=O); lit.[9] mp 155–167°C; $[\alpha]_D$ + 6.4° ($H_2O$). Anal. Found: C, 41.40; H, 5.30; N, 7.78.

The triacetyl derivative (**10**, 91%) of **9** was a syrup; $R_f$ 0.45 (solvent *C*); $[\alpha]_D$ +29° (*c* 2.3, $CHCl_3$). Anal. Calcd for $C_{12}H_{15}NO_8$: C, 47.84; H, 5.02; N, 4.65. Found: C, 47.61; H, 4.83; N, 4.46.

The triacetyl derivative (**20**) of **19**, after column chromatography (solvent *C*), was obtained as a syrup (65%); $R_f$ 0.6 (solvent *C*); $[\alpha]_D$ +15° (*c* 1, $CHCl_3$). Anal. Found: C, 48.05; H, 5.09; N, 4.61.

The triacetyl derivative[9,23] (**22**, 66%) of **21** had $R_f$ 0.35 (solvent *E*); mp 210–211°C; $[\alpha]_D$ −17° (*c* 2, $CHCl_3$); $\nu_{max}^{KBr}$ 1740 (Ac), 1720 $cm^{-1}$ (carbamate C=O); lit.[9] mp 182–188°C; $[\alpha]_D$ −11.5° ($CHCl_3$).

*Reaction of β-D-xylopyranosyl azide with triphenylphosphine and carbon dioxide.* —(*a*) A solution of β-D-xylopyranosyl azide (**13**; 1.75 g, 10 mmol) in dry acetone (40 mL) was treated with triphenylphosphine (3.0 g, 11.45 mmol) in dry acetone (30 mL), in the presence of $CO_2$, as described for **12**. TLC (solvent *D*) revealed products with $R_f$ 0.5 (major) and 0.4 together with triphenylphosphine oxide ($R_f$ 0.65). The solution was concentrated, and the residue was extracted with $CHCl_3$ (30 mL) to leave a mixture (1.46 g, 83%) of 1-*N*,2-*O*-carbonyl-β-D-xylopyranosylamine (**5**) and 1-*N*,3-*O*-carbonyl-β-D-xylopyranosylamine[9] (**21**) in the ratio 4:1 (NMR data). Dry-column flash chromatography (EtOAc) of the crude product (0.3 g) gave **5** (39 mg); $R_f$ 0.5 (solvent *D*); mp 149°C; $[\alpha]_D$ +19° (initial) to +9° (24 h) (*c* 2, $H_2O$); $[\alpha]_D$ +23.5° (*c* 1.5, MeOH); $\nu_{max}^{KBr}$ 1745 $cm^{-1}$ (C=O). Anal. Calcd for $C_6H_9NO_5$: C, 41.15; H, 5.18; N, 8.00. Found: C, 41.32; H, 5.41; N, 7.79.

The above chloroform extract was concentrated and the residue was extracted with water to leave triphenylphosphine oxide (3.0 g), $R_f$ 0.65 (solvent *D*), contaminated with triphenylphosphine ($R_f$ 0.85). Concentration of the water extract (0.25 g) and recrystallisation from EtOH gave **21** (120 mg, 7%); $R_f$ 0.4 (solvent *D*); mp 168–170°C; $[\alpha]_D$ +7.5° (*c* 2, $H_2O$), identical with the product obtained from **14**.

Conventional acetylation of crude **5** with acetic anhydride and pyridine for 5 days gave **6** (43%); $R_f$ 0.35 (solvent *E*); mp 190–191°C (from EtOH); $[\alpha]_D$ −24° (*c* 1.5, $CHCl_3$); $\nu_{max}^{KBr}$ 1780 (carbamate C=O), 1740, 1730 $cm^{-1}$ (Ac); lit.[6] mp 190–192°C; $[\alpha]_D$ −25° (*c* 1, $CHCl_3$).

*(b)* Compound **13** (1.0 g, 5.71 mmol) was treated with triphenylphosphine (1.71 g, 6.53 mmol) and $CO_2$, as in *(a)*, the mixture was concentrated, and the residue was extracted with water (10 mL) for 5 h and then stored at room temperature overnight to leave the phosphorus compounds. The extract was concentrated to give crude **21** (0.95 g, 95%), $R_f$ 0.4 (solvent *D*). Recrystallisation from EtOH yielded **21** (0.48 g, 48%); mp 168–169°C, identical with the product described above.

*Isomerisation of* **5** *into* **21**.—A solution of crude **5** (0.7 g, 4 mmol) in water (14 mL) was stored at room temperature for 2 days. TLC then showed, in accord with the $^{13}C$ NMR data, the total conversion of **5** ($R_f$ 0.5, solvent *D*) into **21** ($R_f$ 0.4).

Concentration of the solution and recrystallisation of the residue from EtOH gave **21** (0.38 g, 54%); mp 167–169°C, identical with the product described above.

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