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# Reaction of 2-amino-2-deoxy-D-glucose with aryl and acyl isothiocyanates, and aryl isocyanates: structure of the intermediate products

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ABSTRACT

The structure of (4*R*)-1-aryl-5-hydroxy-4-(D-*arabino*-tetritol-1-yl)imidazolidine-2-thiones (**1–3**), obtained by reaction of 2-amino-2-deoxy-D-glucose with aryl isothiocyanates, has been confirmed by $^{1}$H- and $^{13}$C-n.m.r. spectroscopy. Likewise, the structures of 2-(3-benzoylthioureido)-2-deoxy-D-glucopyranose and 2-deoxy-2-(3-phenylureido)-D-glucopyranose, prepared by reaction of 2-amino-2-deoxy-D-glucose with benzoyl isothiocyanate and phenyl isocyanate, respectively, were also established. An X-ray analysis of **1**-5*R* (aryl = phenyl) has been carried out and its conformation in the solid state is one of the preponderant conformations in solution.

## INTRODUCTION

The reaction of amino sugars with isothiocyanates and isocyanates has been studied extensively[1–4]. The structure of 2-(3-arylthioureido)-2-deoxy-D-glucopyranose was proposed[5,6] for the first isolable products of the reaction of aryl isothiocyanates with 2-amino-2-deoxy-D-glucose. The same structrure was given[7] to the products obtained by *O*-deacetylation of 1,3,4,6-tetra-*O*-acetyl-2-(3-arylthioureido)-2-deoxy-β-D-glucopyranose. The suggestion[8] that 2-deoxy-2-thioureidoaldoses are reactive and cyclise to 5-hydroxyimidazolidine-2-thiones was based on the results of electrophoresis in borate and tungstate buffers, and u.v. and i.r. spectroscopy of the isolated products. However, the stabilities of 2-deoxy-2-ureidoaldoses and 2-acylthioureido-2-deoxyaldoses were not studied.

We now report on the structure of the first isolable compounds in the reaction of 2-amino-2-deoxy-D-glucose with aryl isothiocyanates, benzoyl isothiocyanate, and phenyl isocyanate, based mainly on $^{1}$H- and $^{13}$C-n.m.r. data.

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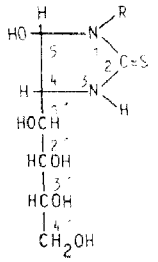
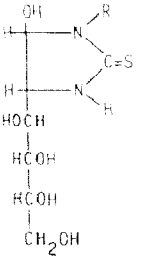




1 -5*R* R = Ph

2 -5*R* R = *p*-$MeC_6H_4$

3 -5*R* R = *p*-$ClC_6H_4$

1 -5*S* R = Ph

2 -5*S* R = *p*-$MeC_6H_4$

3 -5*S* R = *p*-$ClC_6H_4$

## RESULTS AND DISCUSSION

(4*R*)-1-Aryl-5-hydroxy-4-(D-*arabino*-tetritol-1-yl)imidazolidine-2-thiones (**1–3**) were obtained crystalline in high yield (75–85%) by the treatment of 2-amino-2-deoxy-D-glucose with aryl isothiocyanates in aqueous ethanol for two days at room temperature or under reflux for 8 min.

The intermediate 2-(3-arylthioureido)-2-deoxy-D-glucopyranoses (**8** – **10**) were too reactive to be isolated and were not detected hitherto[8]. However, **9** was detected by u.v. spectroscopy of a mixture of 2-amino-2-deoxy-D-glucose with 0.3 equiv. of *p*-tolyl isothiocyanate in ethanol–water (2:1) at room temperature. After 30 min, a band with $\lambda_{max}$ 244 nm, expected for the arylthioureido group[8], was detected together with bands at 230 and 268 nm corresponding to *p*-tolyl isothiocyanate. After 3 h, a band with $\lambda_{max}$ 238 nm, corresponding to *N*-arylimidazolidine-2-thione, was the only one detected.

Compound **2** was also obtained by *O*-deacetylation of the protected thioureidoglucose[7] **20** in methanolic sodium methoxide.

The $^1H$- and $^{13}C$-n.m.r. spectra (Tables I–III) of the hydroxyimidazolidine-2-thiones **1–3** revealed both the 5*R* and 5*S* forms. In solution in $D_2O$, these epimers were in the ratio 9:1, whereas, in methanol, the ratio was 8:2. For a sample of **2**, obtained by reacting 2-amino-2-deoxy-D-glucose with *p*-tolyl isothiocyanate for a short time (see Experimental), a 3:2 mixture of the 5*R* and 5*S* isomers was detected by $^1H$-n.m.r. spectroscopy ($D_2O$). After 4 h, a 9:1 equilibrium mixture was obtained. On the other hand, **1** crystallised from ethanol as the 5*R* form, as shown by the n.m.r. spectrum of a solution in methyl sulfoxide, a solvent in which mutarotation is expected to be slow. These results indicate that mainly the 5*S* isomer was formed kinetically, but that the 5*R* isomer was the thermodynamic product.

The 5*R* configuration of **1–3** was reflected by the $J_{4,5}$ values of 2.3–2.9 Hz, and the 5*S* configuration by a $J_{4,5}$ value of 6.8 Hz. The heterocycle was planar due to the partial double bond between N-1,3 and C-2. In the $^1H$-n.m.r. spectra ($D_2O$) of **1–3**, due to the nearly identical chemical shifts of the resonances of H-4 and H-1′ (~4.23 p.p.m.) of the 5*S* isomers, H-5 (5.58 p.p.m.) appeared to be virtually coupled to H-1′.

TABLE I

$^1$H-N.m.r. chemical shift data ($\delta$, 200 MHz) for **1–3**

| *Compound* | *Carbohydrate moiety* | | | | | *Heterocycle* | | | |
|---|---|---|---|---|---|---|---|---|---|
| | *H-1'* | *H-2'* | *H-3'* | *H-4'* | *H-4''* | *H-4* | *H-5* | *Me* | *Ar* |
| **1**-5*R*[a] | 3.98 dd | 3.60 dd | 3.72 ddd | 3.78 dd | 3.60 dd | 3.96 dd | 5.53 d | | 7.26–7.49 m |
| **2**-5*R*[a] | 4.01 dd | 3.62 dd | 3.75 ddd | 3.82 dd | 3.62 dd | 3.97 dd | 5.51 d | 2.33 s | 7.18–7.32 m |
| **2**-5*R*[b] | 3.91 dd | 3.57 dd | 3.70 ddd | 3.79 dd | 3.64 dd | 3.85 dd | 5.48 d | 2.35 s | 7.17–7.34 m |
| **2**-5*S*[b] | 4.13 dd | | | | | 4.28 dd | 5.54 d | 2.35 s | |
| **3**-5R[a] | 3.99 dd | 3.60 dd | 3.72 ddd | 3.78 dd | 3.60 dd | 3.97 dd | 5.52 d | | 7.23–7.47 m |

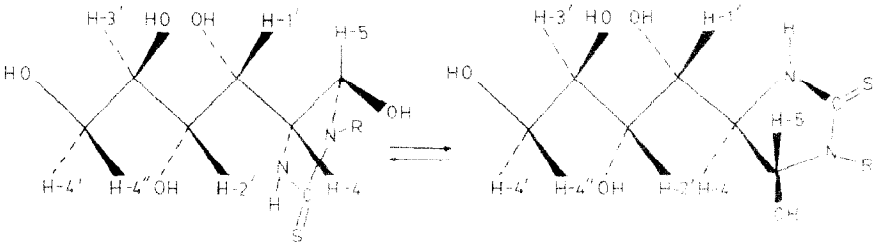
[a] In $D_2O$. [b] $CD_3OD$

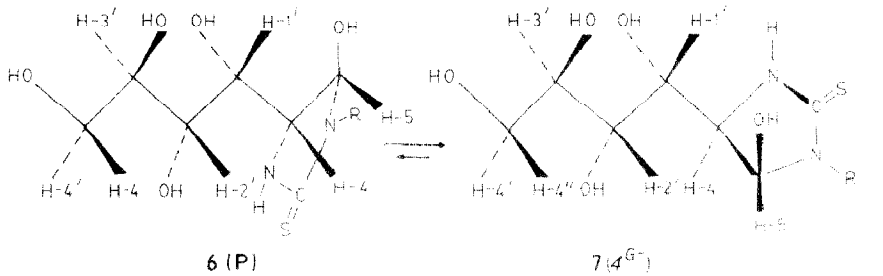
TABLE II

$^1$H-N.m.r. *J* values (Hz) for **1–3**

| *Compound* | $J_{1',2'}$ | $J_{2',3'}$ | $J_{3',4'}$ | $J_{3',4''}$ | $J_{4',4''}$ | $J_{2',5'}$ | $J_{4'',5'}$ |
|---|---|---|---|---|---|---|---|
| **1**-5*R*[a] | 1.6 | 8.5 | 2.5 | 5.0 | 10.9 | 6.0 | 2.5 |
| **2**-5*R*[a] | 1.5 | 8.4 | 2.5 | 5.2 | 11.0 | 5.9 | 2.6 |
| **2**-5*R*[b] | 1.4 | 8.1 | 2.7 | 5.1 | 11.2 | 6.1 | 2.9 |
| **2**-5*S*[a] | 1.2 | | | | | 8.3 | 6.8 |
| **3**-5*R*[a] | 1.5 | 8.7 | 2.4 | 5.1 | 11.0 | 5.9 | 2.3 |

[a] In $D_2O$. [b] In $CD_3OD$.




The 5*R* isomers of **1–3** each existed in solution as an equilibrium of the **P** (**4**) and $_4G^-$ conformations (**5**) together with those $_3G^-$ and $_4G^-{}_3G^-$ (not shown) associated with chain-end flexibility[9,10]. However, the 5*S* isomer of **2** adopted mainly the $_4G^-$ conformation **7**, due to the interaction of HO-5 and HO-1′ in the **P** form **6**.

Using ALCHEMY molecular modelling calculations[11], similar stabilities were calculated for conformations **P** and $_4G^-$ of **1**-5*R*, whereas, for **1**-5*S*, the **P** conformation **6** was 0.6 kcal/mol less stable than $_4G^-$ (**7**).

In order to confirm the structure of **1**-5*R*, an X-ray analysis was performed. The bond lengths and angles together with their estimated standard deviation are given in Table IV. A stereoview[12] of **1**-5*R* along the *b* axis together with the atomic numbering is shown in Fig. 1.

TABLE III

$^{13}$C-N.m.r. chemical shifts ($\delta$, 50.3 MHz) for **1–3**

| *Compound* | *Carbohydrate moiety* | | | | *Heterocycle* | | | *Aromatic* | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *C-1'* | *C-2'* | *C-3'* | *C-4'* | *C-4* | *C-5* | *C=S* | *C-1* | *C-2,6* | *C-3,5* | *C-4* | *Me* |
| **1**-5*R*[a] | 70.4 | 71.6[c] | 71.2[c] | 63.7 | 65.9 | 88.9 | 181.0 | 137.7 | 129.3 | 130.3 | 129.6 | |
| **1**-5*S*[a] | 68.3 | 71.7 | 70.5 | 63.8 | 61.0 | 85.9 | | | | | | |
| **1**-5*R*[b] | 69.1 | 71.4[c] | 70.3[c] | 63.3 | 65.3 | 87.4 | 179.9 | 139.2 | 127.3 | 128.3 | 126.2 | |
| **2**-5*R*[a] | 70.4 | 71.6[c] | 71.2[c] | 63.7 | 65.9 | 88.9 | 181.1 | 140.1 | 129.1 | 130.9 | 135.1 | 21.2 |
| **2**-5*S*[a] | 68.3 | 71.7 | 70.5 | 63.8 | 61.0 | 85.9 | 181.8 | | | | | |
| **3**-5*R*[b] | 69.0 | 71.4[c] | 70.2[c] | 63.3 | 65.2 | 87.2 | 179.6 | 138.1 | 128.2 | 128.8 | 130.3 | |
| **3**-5*S*[b] | 67.6 | 71.1 | | 63.4 | 60.5 | 85.5 | 180.4 | | | | | |

[a] In $D_2O$. [b] In $(CD_3)_2SO$. [c] Assignments may be interchanged.

TABLE IV

Bond lengths (Å) and angles (°) for **1**-5*R*

| | | | |
|---|---|---|---|
| S–C-2 | 1.697(18) | C-5–N-1–C-1″ | 122.0(9) |
| O-5–C-5 | 1.386(20) | C-2–N-1–C-1″ | 123.9(9) |
| O-1′–C-1′ | 1.439(15) | C-2–N-1–C-5 | 112.1(9) |
| O-2′–C-2′ | 1.431(22) | C-2–N-3–C-4 | 110.6(9) |
| O-3′–C-3′ | 1.436(21) | N-1–C-2–N-3 | 109.4(9) |
| O-4′–C-4′ | 1.419(14) | S–C-2–N-3 | 126.1(9) |
| N-1–C-2 | 1.335(23) | S–C-2–N-1 | 124.3(7) |
| N-1–C-5 | 1.437(19) | N-3–C-4–C-1′ | 116.3(6) |
| N-1–C-1″ | 1.455(15) | N-3–C-4–C-5 | 103.1(6) |
| N-3–C-2 | 1.337(15) | C-5–C-4–C-1′ | 112.1(6) |
| N-3–C-4 | 1.455(15) | N-1–C-5–C-4 | 102.7(8) |
| C-4–C-5 | 1.510(16) | O-5–C-5–C-4 | 109.2(8) |
| C-4–C-1′ | 1.529(15) | O-5–C-5–N-1 | 114.4(8) |
| C-1″–C-2″ | 1.397(20) | N-1–C-1″–C-6″ | 118.6(8) |
| C-1″–C-6″ | 1.343(18) | N-1–C-1″–C-2″ | 119.2(9) |
| C-2″–C-3″ | 1.378(23) | C-2″–C-1″–C-6″ | 121.6(9) |
| C-3″–C-4″ | 1.360(26) | C-1″–C-2″–C-3″ | 117.2(9) |
| C-4″–C-5″ | 1.396(25) | C-2″–C-3″–C-4″ | 121.3(9) |
| C-5″–C-6″ | 1.367(21) | C-3″–C-4″–C-5″ | 120.0(9) |
| C-1′–C-2′ | 1.514(16) | C-4″–C-5″–C-6″ | 118.7(9) |
| C-2′–C-3′ | 1.512(18) | C-1″–C-6″–C-5″ | 120.7(9) |
| C-3′–C-4′ | 1.547(18) | O-1′–C-1′–C-4 | 109.8(8) |
| | | C-4–C-1′–C-2′ | 113.8(8) |
| | | O-1′–C-1′–C-2′ | 111.4(8) |
| | | O-2′–C-2′–C-1′ | 109.7(9) |
| | | C-1′–C-2′–C-3′ | 111.2(9) |
| | | O-2′–C-2′–C-3′ | 110.8(9) |
| | | O-3′–C-3′–C-2′ | 109.4(9) |
| | | C-2′–C-3′–C-4′ | 114.3(9) |
| | | O-3′–C-3′–C-4′ | 105.3(9) |
| | | O-4′–C-4′–C-3′ | 108.8(8) |

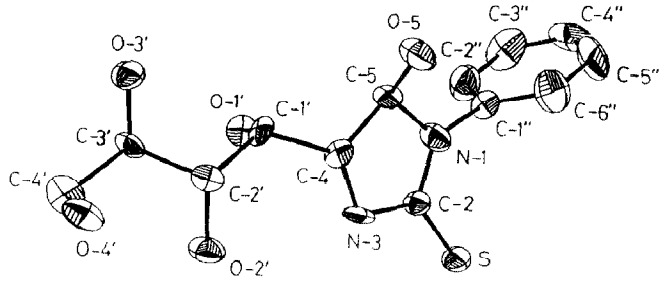



Fig. 1. ORTEP view of **1**-5*R* along the *b* axis, showing the atomic numbering. The ellipsoids enclose 50% probability.

The value of 1.697(18) Å observed for the length of the S–C bond is intermediate of the values for single (1.81 Å) and double bonds (1.56 Å), and this partial double-bond character is a normal feature of these compounds. The average distances (C-2–N-1 and

C-2–N-3 of 1.336(23), C-4–N-3 and C-5–N-1 of 1.446(19), and the C-5–C-4 distance of 1.510(16) Å agree well with the mean values reported for analogous compounds[13,14]. The average angles C–N–C and N–C–C are 111(1) and 103(1)°, respectively, and the N–C–N angle is 109(1)°. The exocyclic bonds C-5–O-5, N-1–C-1″, and C-4–C-1′ are 1.386(20), 1.455(15), and 1.529(15) Å, respectively.

The imidazolidine ring is planar [maximum deviation from the best plane is 0.088(12) Å]. The S atom is in this plane with a deviation of −0.016(4) Å, but C-1′, C-1″, and O-5 are out of this plane, at −0.879(11), −0.174(11), and 0.923(9) Å, respectively. The corresponding bonds are bent by 42(1), 14(1), and −52(1)°.

The mean value of the C–C bond length in the phenyl ring is 1.374(20) Å and the mean C–H bond length is 1.09 (2) Å. The N substituent is at −0.108(16) Å from the least squares calculated plane.

The polyhydroxyalkyl chain C-1′/4′ is nearly planar [maximum deviation from the least squares plane, 0.034(14) Å]. The average C–C and C–O bond lengths of 1.524(17) and 1.431(18) Å, respectively, and the average bond angles C–C–C and C–C–O of 113(1) and 109(1)°, respectively, are normal.

The Newman projections along the backbone carbons, shown in Fig. 2, accord with a ${}_3G^+$ conformation, one of the conformers found in solution. According to the Klyne and Prelog rules[15], the configuration for the chiral centres C-5, C-4, C-1′, C-2′, and C-3′ are *R*, *R*, *R*, *S*, and *R*, respectively.

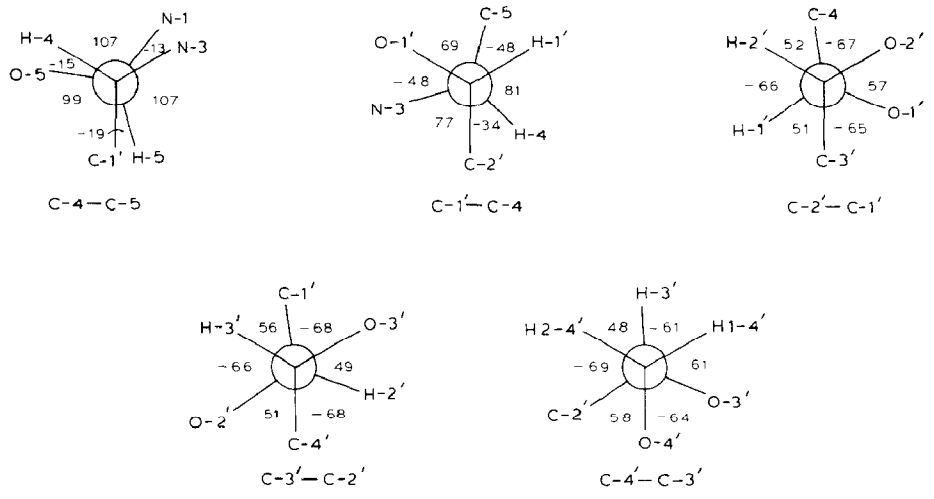



Fig. 2. Newman projections along the carbon backbone of **1**-5*R*.

The dihedral angles between the phenyl and imidazolidine ring and between the sugar-chain plane and the imidazolidine ring are 44.4(8) and 88.7(6)°, respectively.

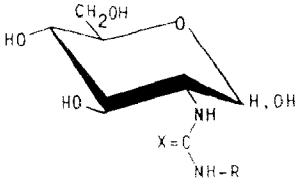
The molecules in the crystal were closely stacked through van der Waals forces and there were three possible hydrogen bonds:

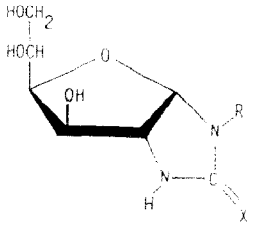
O-1′···O-2′($-x + 1, y + 1/2, -z + 1$) = 2.716(17) Å,
O-1′···O-3′($-x + 1, y + 1/2, -z + 1$) = 2.862(15) Å, and
O-5···S($x, y + 1, z$) = 3.084(17) Å.

Compounds **2** and **3** were dehydrated easily by heating without solvent at 155° for 10–20 min, to give the glucofuranoimidazolidine-2-thiones **13** and **14**, respectively. This dehydration can proceed through **16**, which might also be the intermediate in the isomerisation between the 5*R* and 5*S* forms of **1**–**3** and in the acid-catalysed isomerisation[5] of glucofuranoimidazolidine-2-thiones into tetritol-1-yl-dihydroimidazole-2-thiones.

The peaks with the highest *m/z* detected in the mass spectra of **1**–**3** corresponded to the loss of $H_2O$ (relative intensity 4–8%), whereas the molecular ion $M^+$ (17%) was detected for the bicyclic compound **13**.

The n.m.r. data for **13**–**15** are given in Tables V–VII. The *J* values of **13** and **14** indicated[16,17] (Table VI) a conformational equilibrium between conformers **18** and **19**, with the furan ring in the $E_4$ form[18] and the backbone C-4,1′,2′,3′,4′ in a planar conformation and showing the usual chain-end flexibility. These conformations accord with those deduced for 1-alkyl(aryl)-(1,2-dideoxy-α-D-glucofurano)[2,1-*d*]imidazolidine-2-thiones from X-ray diffraction data[19].




**8** R = Ph, X = S
**9** R = p-$MeC_6H_4$, X = S
**10** R = p-$ClC_6H_4$, X = S
**11** R = Bz, X = S
**12** R = Ph, X = O

**13** R = p-$MeC_6H_4$, X = S
**14** R = p-$ClC_6H_4$, X = S
**15** R = Ph, X = O

2-(3-Benzoylthioureido)-2-deoxy-D-glucopyranose[20] (**11**) and 2-deoxy-2-(3-phenylureido)-D-glucopyranose (**12**) were prepared by treating 2-amino-2-deoxy-D-glucose with benzoyl isothiocyanate and phenyl isocyanate, respectively. The glucopyranosyl structures of **11** and **12** were confirmed by the $^{13}C$-n.m.r. data (Table VIII). In solution in methyl sulfoxide, **11** was present only as the α anomer, whereas **12** existed as a 3:2 α,β-mixture.

Conventional acetylation of **11** and **12** gave the corresponding tetra-acetates **21** and **22** (α,β-ratio 9:1), and **23** and **24** (α,β-ratio 3:2) as deduced from their $^1H$- and $^{13}C$-n.m.r. data (Tables VIII–X). Signal assignments were facilitated by the spectra of

TABLE V

$^1$H-N.m.r. chemical shift data[a] ($\delta$, 200 MHz) for **13–15**

| *Compound* | *H-1* | *H-2* | *H-3* | *H-4* | *H-5* | *H-6* | *H-6'* | *NH* | *Aromatic* | *OH-3* | *OH-5* | *OH-6* | *Me* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **13** | 5.91 d | 4.15 d | 4.10 dd | 3.64 dd | 3.72 dtd | 3.56 ddd | 3.39 dt | 9.08 s | 7.14–7.32 m | 5.36 d | 4.77 d | 4.55 t | 2.30 s |
| **14** | 5.97 d | 4.17 d | 4.14 dd | 3.62 dd | 3.71 dtd | 3.56 ddd | 3.35 dt | 9.28 s | 7.42–7.54 m | 5.58 d | 5.10 d | 4.59 t | |
| **15** | 5.97 d | 4.00 dd | 4.07 dd | 3.72 dd | 3.76 dtd | 3.58 ddd | 3.40 dt | 7.53 d | 7.00–7.63 m | 5.31 d | 4.74 d | 4.50 t | |

[a] In $(CD_3)_2SO$.

TABLE VI

$^1$H-N.m.r. *J* values[a] (Hz) for **13–15**

| *Compound* | $J_{1,2}$ | $J_{2,3}$ | $J_{3,4}$ | $J_{4,5}$ | $J_{5,6}$ | $J_{5,6'}$ | $J_{6,6'}$ | $J_{2,NH}$ | $J_{3,OH}$ | $J_{5,OH}$ | $J_{6,OH}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **13** | 6.5 | ~0 | 2.2 | 8.6 | 2.6 | 5.6 | 11.2 | | 5.0 | 5.8 | 5.6 |
| **14** | 6.3 | ~0 | 2.0 | 8.9 | 2.0 | 5.6 | 11.0 | | 4.8 | 5.6 | 5.7 |
| **15** | 6.1 | ~0 | 2.1 | 8.2 | 2.6 | 5.4 | 11.1 | 1.3 | 4.7 | 5.6 | 5.5 |

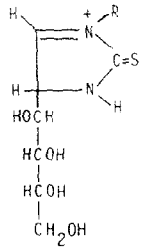
[a] Conditions described in Table V.

TABLE VII

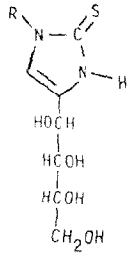
$^{13}$C-N.m.r. chemical shift data[a] ($\delta$, 50.3 MHz) for **13** and **15**

| *Compound* | *C-1* | *C-2* | *C-3* | *C-4* | *C-5* | *C-6* | *C=O* | *C=S* | *Aromatic* | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | *C-1* | *C-2,6* | *C-3,5* | *C-4* | *Me* |
| **13** | 94.7 | 65.2 | 73.9 | 79.4 | 68.3 | 63.9 | | 181.2 | 136.4[b] | 127.1 | 129.0 | 136.0[b] | 20.8 |
| **15** | 89.7 | 60.6 | 74.2 | 79.4 | 68.7 | 63.9 | 157.3 | | 139.4 | 119.3 | 128.7 | 123.0 | |

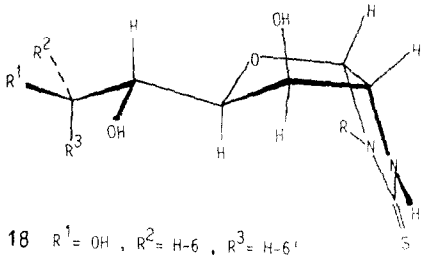
[a] In $(CD_3)_2SO$. [b] Assignments may be interchanged.



16

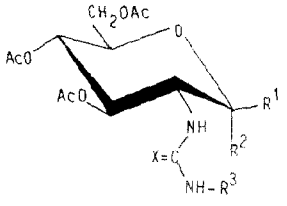


17 R = p-$MeC_6H_4$



18 $R^1$= OH , $R^2$= H-6 , $R^3$= H-6'

19 $R^1$= H-6, $R^2$= H-6', $R^3$= OH



20 $R^1$= OAc , $R^2$= H, $R^3$= p-$MeC_6H_4$, X = S

21 $R^1$= H, $R^2$= OAc, $R^3$= Bz, X = S

22 $R^1$= OAc, $R^2$= H, $R^3$= Bz, X = S

23 $R^1$= H, $R^2$= OAc, $R^3$= Ph, X = O

24 $R^1$= OAc, $R^2$= H, $R^3$= Ph, X = O

the $\beta$ anomers **22** and **24** obtained from 1,3,4,6-tetra-*O*-acetyl-2-amino-2-deoxy-$\beta$-D-glucopyranose by reaction with benzoyl isothiocyanate and phenyl isocyanate[21], respectively.

*O*-Deacetylation of **24** in methanolic sodium methoxide gave the glucofuranoimidazolidin-2-one **15** instead of the expected **12**.

Conventional acetylation of **2** gave a mixture of at least three compounds, in which **20** was not detected. Treatment of the mixture with silica gel in refluxing toluene[22] followed by *O*-deacetylation gave **17**, presumably through the tetra-acetate of **17**. This method is a new route to tetritol-1-yldihydroimidazole-2-thiones.

TABLE VIII

$^{13}$C-N.m.r. chemical shift data ($\delta$, 50.3 MHz) for **11**, **12** and **21–24**

| *Compound* | *C-1* | *C-2* | *C-3* | *C-4* | *C-5* | *C-6* | *C=O* | *C=S* | *OAc* | | *Aromatic* | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | *Me* | *COO* | *C-1* | *C-2,6* | *C-3,5* | *C-4* |
| **11**[a] | 89.3 | 60.1 | 71.0[c] | 70.8[c] | 72.6 | 61.1 | 168.6 | 180.7 | | | 132.4 | 128.7 | 128.7 | 133.3 |
| **12**$\alpha$[a] | 91.3 | 54.5 | 71.6 | 71.2 | 72.4 | 61.3 | 155.3 | | | | 140.7 | 128.9 | 117.6 | 121.2 |
| **12**$\beta$[a] | 96.2 | 58.1 | 74.8 | 71.1 | 76.9 | 61.3 | 156.3 | | | | 140.5 | 128.9 | 117.9 | 121.4 |
| **21**[b] | 89.4 | 56.3 | 70.5 | 67.3 | 69.6 | 61.3 | 166.6 | 181.3 | 20.5 | 168.7 | 133.7 | 127.5 | 129.0 | 131.2 |
| | | | | | | | | | 20.6(2) | 169.1 | | | | |
| | | | | | | | | | 20.7 | 170.6(2) | | | | |
| **22**[b] | 92.0 | 57.6 | 72.1 | 67.4 | 72.6 | 61.5 | 166.1 | 181.7 | 20.5 | 169.1 | 133.7 | 127.0 | 129.0 | 130.9 |
| | | | | | | | | | 20.6(2) | 169.2 | | | | |
| | | | | | | | | | 20.9 | 170.2 | | | | |
| | | | | | | | | | | 170.5 | | | | |
| **23**[b] | 91.2 | 51.7 | 70.9 | 67.5 | 69.8 | 61.6 | 154.9 | | | 168.7 | 138.3 | 120.3 | 129.2 | 123.8 |
| | | | | | | | | | | 169.1 | | | | |
| | | | | | | | | | | 170.8 | | | | |
| | | | | | | | | | | 171.7 | | | | |
| **24**[b] | 92.9 | 53.8 | 72.7 | 67.9 | 72.8 | 61.7 | 154.9 | | 20.5 | 169.3 | 137.8 | 121.2 | 129.4 | 124.5 |
| | | | | | | | | | 20.6(2) | 169.7 | | | | |
| | | | | | | | | | 20.8 | 170.8 | | | | |
| | | | | | | | | | | 171.3 | | | | |

[a] In $(CD_3)_2SO$. [b] In $CDCl_3$. [c] Assignments may be interchanged.

The failure of **11** to form a hydroxyimidazolidine may be due to the weak nucleophilicity of the acylated N-3, which also explains why no glucofuranoimidazolidine-2-thiones have been obtained from 2-(3-*N*-acylthioureido)-2-deoxy-D-glucopyranose[20]. On the other hand, the lesser tendency of **12**, compared to **8–10**, to form a hydroxyimidazolidine may reflect the weaker nucleophilicity of N-3 in the ureido group compared to that in the thioureido group.

To our knowledge, no 2-aminothiazoline or 2-amino-oxazoline has been detected hitherto in the reaction of 2-amino-2-deoxyaldoses with isothiocyanates and isocyanates, reflecting the fact that the thioureas and ureas **8–10** and **12** react preferentially *via* N-3 and not *via* S. This situation accords with the general reactions of thioureas and ureas with aldehydes and ketones to form *N*-hydroxyalkyl-thioureas[21] and -ureas[24], respectively. On treatment with phosphoric acid, *N*-phenacylthioureas cyclised to aminothiazoles[25,26], and 2-(3-*N*-methylthioureido)propionacetal gave a mixture of imidazoline-2-thione and aminothiazole on acid hydrolysis[27].

Thioureas react *via* S in nucleophilic displacement reactions[28]. Thus, glucopyranothiazolines[28] were obtained from 1,3,4,6-tetra-*O*-acetyl-2-[3-alkyl(aryl)thioureido]-2-deoxy-α-D-glucopyranose by hydrogen bromide-promoted cyclisation, through a nucleophilic displacement of Br-1 by the S of the thiourea moiety. Similarly, glucopyrano-oxazolines[29] were obtained from 1,3,4,6-tetra-*O*-acetyl-2-[3-alkyl(aryl)ureido]-2-deoxy-α-D-glucopyranose.

As for **1**-5*R*, the imidazolidine structure of **14** (ref. 30), **15** (ref. 31), and related compounds[32,33] have been established by X-ray crystallography.

## EXPERIMENTAL

*General methods.* — Melting points are uncorrected. Optical rotations were measured with a Perkin–Elmer 241 polarimeter. I.r. spectra (KBr discs) were recorded with an FT-IR Bomem MB-120 spectrophotometer. U.v. spectra were recorded with a Hewlett–Packard 8450A spectrophotometer on aqueous solutions. $^1$H-N.m.r. spectra (200 MHz) were recorded with a Varian XL-200 instrument at 20° (internal $Me_4Si$ in organic solvents; internal DOH at 4.75 p.p.m. in $D_2O$). The $^{13}$C-n.m.r. spectra (50.3 MHz) were recorded with the same spectrometer (internal 1,4-dioxane at 67.4 p.p.m.). Proton-decoupled APT[34] (Attached Proton Test) spectra were obtained to assist in signal assignments. E.i.-mass spectra were obtained at 70 eV, using an MS-80 RFA Kratos instrument, an ionising current of 100 μA, an accelerating voltage of 4 kV, and a resolution of 1000 (10% valley definition). T.l.c. was performed on Silica Gel $HF_{254}$ (Merck) with detection by charring with sulfuric acid.

*(4*R*)-5-Hydroxy-1-phenyl-4-(*D*-arabino-tetritol-1-yl)-imidazolidine-2-thione* (**1**). — A mixture of 2-amino-2-deoxy-D-glucose (180 mg, 1 mmol) and phenyl isothiocyanate (0.12 mL, 1.1 mmol) in aqueous 95% ethanol (5 mL) was boiled for 8 min under reflux, then concentrated. Treatment of the syrupy residue with ether gave a crystalline product (270 mg, 85%). Recrystallisation from ethanol gave **1**, m.p. 152–156° (dec.); $[\alpha]_D^{35}$ +31°, $[\alpha]_{578}^{35}$ +32°, $[\alpha]_{546}^{35}$ +37°, $[\alpha]_{436}^{35}$ +76° (*c* 1, pyridine) {lit.[3] m.p. 154°, $[\alpha]_D$ +46.6

TABLE IX

$^1$H-N.m.r. chemical shift data[a] ($\delta$, 200 MHz) for **21–24**

| *Compound* | *H-1* | *H-2* | *H-3* | *H-4* | *H-5* | *H-6* | *H-6'* | *NH* | *Ar-NH* | *OAc* | *Aromatic* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **21**[b] | 6.42 d | 5.16 ddd | 5.51 dd | 5.27 t | 4.10 ddd | 4.33 dd | 4.09 dd | 10.88 d | 9.03 s | 2.05s<br>2.06 s<br>2.11 s<br>2.25 s | 7.27–7.87 m |
| **22** | 6.01 d | 5.12 td | 5.46 dd | 5.23 t | 3.93 ddd | 4.34 dd | 4.17 dd | 10.91 d | 9.00 s | 2.05 s<br>2.07 s<br>2.11 s<br>2.14 s | 7.45–7.80 m |
| **23**[b] | 6.26 d | 4.43 m | ———5.2 m——— | | 4.00 m | 4.26 dd | 4.07 dd | | 6.96 s | | |
| **24** | 5.84 d | 4.12 ddd | 5.32 dd | 5.14 dd | 3.87 ddd | 4.29 dd | 4.13 dd | 5.63 d | 7.39 s | 2.03 s<br>2.04 s<br>2.08 s<br>2.10 s | 7.00–7.29 m |

[a] In $CDCl_3$. [b] Data taken from $\alpha,\beta$-mixtures.

TABLE X

$^1$H-N.m.r. *J* values[a] (Hz) for **21–24**

| *Compound* | $J_{1,2}$ | $J_{2,3}$ | $J_{3,4}$ | $J_{4,5}$ | $J_{5,6}$ | $J_{5,6'}$ | $J_{6,6'}$ | $J_{2,NH}$ |
|---|---|---|---|---|---|---|---|---|
| **21** | 3.8 | 10.6 | 9.5 | 9.5 | 4.2 | 2.1 | 12.6 | 8.9 |
| **22** | 8.2 | 9.6 | 9.0 | 9.0 | 4.6 | 2.6 | 12.4 | 9.4 |
| **23** | 3.5 | | | | 4.2 | 2.4 | 12.4 | |
| **24** | 8.8 | 10.4 | 9.3 | 9.7 | 4.7 | 2.2 | 12.5 | 9.3 |

[a] Conditions described in Table IX.

(pyridine)}; $R_L$ 0.53 (dichloromethane–methanol, 5:1); $\lambda_{max}^{H_2O}$ 237 nm ($\varepsilon_{mM}$ 17.5); $\nu_{max}$ 3425, 3290 (NH, OH), 1460 (NH), 1255 (C=S), 1595, 1495, 1450, 695, and 735 cm$^{-1}$ (phenyl). Mass spectrum: *m/z* 296 ($M^+ - H_2O$, 7%), 295 ($M^+ - H_2O - H$, 5), 278 ($M^+ - 2H_2O$, 1), 194 ($M^+ - C_4H_8O_4$, 5), 193 ($M^+ - C_4H_9O_4$, 3), 176 ($B^+ + H$, 99), 175$B^+$, 100, where B = 1-phenyl-2-thioxo-imidazolinyl), and 135 ($PhNCS^+$, 68). The $^1$H- and $^{13}$C-n.m.r. data are given in Tables I–III.

*Anal.* Calc. for $C_{13}H_{18}N_2O_5S$: C, 49.67; H, 5.77; N, 8.91; S, 10.20. Found: C, 49.46; H, 5.80; N, 8.70; S, 9.96.

(*4*R)-*5-Hydroxy-4-(*D-arabino-*tetritol-1-yl)-1-*p-*tolylimidazolidine-2-thione* (**2**). — (*a*) A solution of 2-amino-2-deoxy-D-glucose (0.5 g, 2.79 mmol) and *p*-tolyl isothiocyanate (0.4 g, 3.35 mmol) in ethanol–water (2:1, 15 mL) was kept for 48 h at room temperature, then concentrated. The syrupy residue was treated with ether to give chromatographically pure **2** (668 mg, 74%). Recrystallisation from ethanol gave material which bubbled at 153–155°, resolidified, and melted at 204–208° (dec.); $[\alpha]_D^{35}$ +23°, $[\alpha]_{578}^{35}$ +23°, $[\alpha]_{546}^{35}$ +25°, $[\alpha]_{435}^{35}$ +44° (*c* 1, *N*,*N*-dimethylformamide) {lit.[7] m.p. 154–157°, $\alpha_D$ +10.2° (*N*,*N*-dimethylformamide)}; $R_L$ 0.57 (dichloromethane–methanol; 5:1); $\lambda_{max}^{H_2O}$ 238 nm ($\varepsilon_{mM}$ 17.6); $\nu_{max}$ 3370, 3300 (OH, NH), 1460 (NH), 1250 (C=S), 1580, 1515, 1495, and 820 cm$^{-1}$ (aryl, *p*-substituted). Mass spectrum: *m/z* 310 ($M^+ - H_2O$, 4%), 309 ($M^+ - H_2O - H$, 3), 292 ($M^+ - 2H_2O$, 13), 208 ($M - C_4H_8O_4$, 10), 190 ($B^+ + H$, 8), 189 ($B^+$, 8, where B = 1-*p*-tolyl-2-thioxo-imidazolinyl), and 149 ($CH_3C_6H_4NCS^+$, 12). The $^1$H- and $^{13}$C-n.m.r. data are given in Tables I–III.

*Anal.* Calc. for $C_{14}H_{20}N_2O_5S$: C, 51.20; H, 6.14; N, 8.53; S, 9.76. Found: C, 51.32; H, 6.01; N, 8.83; S, 9.21.

(*b*) A solution of 1,3,4,6-tetra-*O*-acetyl-2-deoxy-[3-(*p*-tolyl)thioureido]-β-D-glucopyranose[7] (0.6 g, 1.2 mmol) in methanolic 0.1% sodium methoxide (10 mL) was kept for 30 min at room temperature, then deionised with Amberlite IR-120 ($H^+$) resin, filtered, and concentrated. Crystallisation of the syrupy residue from ethanol gave 1-*p*-tolyl-(1,2-dideoxy-α-D-glucofurano)[2,1-*d*]imidazolidine-2-thione (37 mg, 10%). From the mother liquor, **2** (215 mg, 55%) was obtained.

(*c*) A mixture of 2-amino-2-deoxy-D-glucose (360 mg, 2 mmol) and *p*-tolyl isothiocyanate (480 mg, 3 mmol) in aqueous 95% ethanol (10 mL) was boiled for 3 min under reflux, then filtered immediately, and concentrated to a syrupy residue that

solidified on treatment with ether. The solid was washed with aqueous 90% ethanol, to give a 3:2 mixture [130 mg, 20%; m.p. 180° (dec.)] of **2**-5*R* and **2**-5*S*, as deduced from the $^1$H-n.m.r. spectrum of a solution in $D_2O$ recorded immediately. After 4 h, the ratio had become 9:1.

*(4R)-1-p-Chlorophenyl-5-hydroxy-4-(*D-arabino-*tetritol-1-yl)imidazolidine-2-thione* (**3**). — A mixture of 2-amino-2-deoxy-D-glucose (180 mg) and *p*-chlorophenyl isothiocyanate (255 mg) was treated as described for the preparation of **1**, to give **3** (294 mg, 84%), m.p. 144–148°; $[\alpha]_D^{26}$ +42°, $[\alpha]_{578}^{26}$ +45°, $[\alpha]_{546}^{26}$ +50°, $[\alpha]_{435}^{26}$ +92° (*c* 1, pyridine) {lit.[7] m.p. 144–147°, $[\alpha]_D$ +30° (ethanol)}; $R_F$ 0.52 (dichloromethane–methanol, 5:1); $\lambda_{max}^{H_2O}$ 236 nm ($\varepsilon_{mM}$ 19.5); $\nu_{max}$ 3360 (NH, OH), 1450 (NH), 1260 (C=S), 1495, 1450, and 830 cm$^{-1}$ (aryl, *p*-substituted). Mass spectrum: *m/z* 330 ($M^+ - H_2O$, 8%), 228 ($M^+ - C_4H_8O_4$, 3), 212 ($C_7H_7{}^{37}ClN_2S^+$, 36), 211 ($C_7H_6{}^{37}ClN_2S^+$, 47), 210 ($B^+ + H$, 90), 209 ($B^+$, 100, where B = 1-*p*-chlorophenyl-2-thioxo-imidazolinyl), 178 ($B^+ + H - S$, 68), and 169 ($ClC_6H_4NCS^+$, 40). The $^1$H- and $^{13}$C-n.m.r. data are given in Tables I–III.

*Anal.* Calc. for $C_{13}H_{17}ClN_2O_5S$: C, 44.76; H, 4.91; Cl, 10.16; N, 8.03. Found: C, 44.48; H, 4.90; Cl, 10.00; N, 8.01.

*1-p-Tolyl-(1,2-dideoxy-α-*D-*glucofurano)[2,1-*d*]imidazolidine-2-thione* (**13**). — Compound **2** (100 mg) was heated for 20 min at 155–160°. Crystallisation of the product from aqueous 50% ethanol gave **13** (58 mg, 61%). Recrystallisation from aqueous 95% ethanol gave material having m.p. 242–244° (dec.); $[\alpha]_D^{24}$ +64°, $[\alpha]_{578}^{24}$ +68°, $[\alpha]_{546}^{24}$ +76°, $[\alpha]_{435}^{24}$ +111° (*c* 1, pyridine) {lit.[6] m.p. 239–240°, $[\alpha]_D^{17}$ +64° (pyridine)}; $R_F$ 0.68 (dichloromethane–methanol, 5:1); $\nu_{max}$ 3430, 3355, 3205, 3150 (NH, OH), 1480 (NH), 1235 (C=S), 1580, 1515, 1445, and 820 cm$^{-1}$ (aryl, *p*-substituted). Mass spectrum: *m/z* 310 ($M^+$, 17%), 309 ($M^+ - H$, 7), 292 ($M^+ - H_2O$, 2), 208 ($M^+ - C_4H_6O_3$, 15), 190 ($B^+ + H$, 95), 189 ($B^+$, 100, where B = 1-*p*-tolyl-2-thioxo-imidazolinyl), 149 ($CH_3C_6H_4NCS^+$, 5), and 91 ($C_7H_7^+$, 15). The $^1$H- and $^{13}$C-n.m.r. data are given in Tables V–VII.

*1-p-Chlorophenyl-(1,2-dideoxy-α-*D-*glucofurano)[2,1-*d*]*imidazolidine-2-thione (**14**). — Compound **3** (100 mg) was heated for 10 min at 155–160°. Crystallisation of the product from aqueous 50% ethanol gave **14** (60 mg, 63%), m.p. 240–241° (lit.[35] m.p. 250°), $R_F$ 0.65 (dichloromethane–methanol, 5:1); $\nu_{max}$ 3430, 3355, 3210 (NH, OH), 1495, 1430, 830 (aryl, *p*-substituted), 1480 (NH), and 1235 cm$^{-1}$ (C=S). The $^1$H-n.m.r. data are given in Tables V and VI.

*2-(3-Benzoylthioureido)-2-deoxy-*D-*glucopyranose* (**11**). — A stirred mixture of ammonium thiocyanate (200 mg, 2.6 mmol) and benzoyl chloride (0.3 mL, 2.6 mmol) in acetone (2.5 mL) was boiled for 15 min under reflux, then filtered, and added to a solution of 2-amino-2-deoxy-D-glucose (0.45 g, 2.5 mmol) in water (0.75 mL). The mixture was kept for 24 h at ~0°, then concentrated. Preparative t.l.c. (dichloromethane–methanol, 5:1) of the syrupy residue and crystallisation from ethanol gave **11** (0.45 g, 53%), m.p. 188–190° (dec.); $[\alpha]_D^{31}$ +80°, $[\alpha]_{578}^{31}$ +83°, $[\alpha]_{546}^{31}$ +90°, $[\alpha]_{435}^{31}$ +126° (*c* 1, pyridine) {lit.[20] m.p. 185°, $[\alpha]_D^{24}$ +82.7° (pyridine)}; $R_F$ 0.72 (dichloromethane–methanol, 5:1); $\nu_{max}$ 3480, 3395, 3225, 3170 (NH, OH), 1650 (C=O), 1600, 1455, 725, 690 (phenyl), 1535, 1470 (NH), and 1275 cm$^{-1}$ (C=S). Mass spectrum: *m/z* 194 ($PhCONHCSNHCH_3$, 16%), 122 ($PhCO\overset{+}{N}H_3$, 14), 121 ($PhCO\overset{+}{N}H_2$, 33), 106 ($PhC\overset{+}{O}H$,

9), 105 ($PhCO^+$, 100), 77 ($Ph^+$, 36). $^1$H-N.m.r. data (200 MHz, $D_2O$): $\delta$ 5.38 (d, 1 H, $J_{1,2}$ 3.9 Hz, H-1), 4.58 (dd, 1 H, $J_{2,3}$ 9.6 Hz, H-2), 3.46 (t, 1 H, $J_{3,4}$ 9.5, $J_{4,5}$ 9.5 Hz, H-4). The $^{13}$C-n.m.r. data are given in Table VIII.

*2-Deoxy-2-(3-phenylureido)*-D-glucopyranose (**12**). — To a stirred solution of 2-amino-2-deoxy-D-glucose (1 g, 5.58 mmol) in water (5 mL) at 0° was added a solution of phenyl isocyanate (0.61 mL, 5.6 mmol) in 1,4-dioxane (5 mL). A white precipitate was formed immediately, the mixture was stirred vigorously for 30 min and then filtered, and the insoluble material was washed with water (5 mL). The solid was treated with water (4 × 25 mL) at room temperature, and the combined extracts were lyophilised to give **12** (380 mg, 23%). Crystallisation from aqueous 95% ethanol gave material having m.p. 186–187°, $[\alpha]_D^{23}$ +74° (*c* 1, pyridine); $\lambda_{max}^{H_2O}$ 236 nm ($\varepsilon_{mM}$ 13.4); $\nu_{max}$ 3360, 3320 (NH, OH), 1630 (C=O), 1525 (NH), 1595, 1580, 1445, 735, and 695 cm$^{-1}$ (phenyl). $^1$H-N.m.r. data (200 MHz, $D_2O$), $\delta$ 5.18 (d, 1 H, $J_{1,2}$ 2.9 Hz, H-1). The $^{13}$C-n.m.r. data are given in Table VIII.

*Anal.* Calc. for $C_{13}H_{18}N_2O_6$: C, 52.34; H, 6.08; N, 9.39. Found: C, 52.34; H, 6.22; N, 9.26.

*1-Phenyl-(1,2-dideoxy-α-D-glucofurano)[2,1-d]imidazolidin-2-one* (**15**). — A solution of 1,3,4,6-tetra-*O*-acetyl-2-deoxy-2-(3-phenylureido)-β-D-glucopyranose[21] (**24**; 400 mg, 0.81 mmol) in methanolic 0.1% sodium methoxide (20 mL) was kept for 20 min at room temperature, then deionised with Amberlite IR-120 ($H^+$) resin, filtered, and concentrated. The syrupy residue was crystallised from ethanol to give **15** (85 mg, 27%), m.p. 210–211°, $[\alpha]_D^{26}$ +90° (*c* 1, pyridine) {lit.[4] m.p. 214–216°, $[\alpha]_D$ +93° (pyridine)}; $\lambda_{max}^{H_2O}$ 232 nm ($\varepsilon_{mM}$ 14.2); $\nu_{max}$ 3375 (NH, OH), 1665 (C=O), 1440 (NH), 1605, 1505, 690, and 760 cm$^{-1}$ (phenyl). The $^1$H- and $^{13}$C-n.m.r. are given in Tables V–VII.

*1,3,4,6-Tetra-O-acetyl-2-(3-benzoylthioureido)-2-deoxy-α-* (**21**) and *-β-D-glucopyranose* (**22**). — (*a*) A mixture of ammonium thiocyanate (0.4 g, 5.2 mmol) and benzoyl chloride (0.6 mL, 5.2 mmol) in dry acetone (5 mL) was boiled for 10 min under reflux. A solution of 1,3,4,6-tetra-*O*-acetyl-2-amino-2-deoxy-β-D-glucopyranose (1.7 g, 4.9 mmol) was added and boiling under reflux was continued for 5 min. The mixture was stored for 1 h at room temperature, then filtered, and concentrated. The residue was treated with ether and the product was recrystallised from ethanol to give **22** (1.85 g, 74%), m.p. 167–169°; $[\alpha]_D^{23}$ +23°, $[\alpha]_{578}^{23}$ +22°, $[\alpha]_{546}^{23}$ +23°, $[\alpha]_{435}^{23}$ +18° (*c* 1, dichloromethane); $R_F$ 0.71 (dichloromehane–methanol, 40:1); $\nu_{max}$ 3390, 3365, 3170 (NH), 1765, 1220 (C=O, ester); 1690 (C=O, amide), 1545 (NH), 1245 (C=S), 1605, 1580, 1495, 740, and 690 cm$^{-1}$ (phenyl). Mass spectrum: *m/z* 450 ($M^+$ – AcOH, 3%), 390 ($M^+$ – PhCONH, 11), 330 $M^+$ – $PhCONHCSNH_2$, 11), 106 ($PhC\overset{+}{O}H$, 10), 105 ($PhCO^+$, 100), 77 ($Ph^+$, 16), 60 ($AcOH^+$, 12), 43 ($Ac^+$, 9). The $^1$H- and $^{13}$C-n.m.r. data are given in Tables VIII–X.

*Anal.* Calc. for $C_{22}H_{26}N_2O_{10}S$: C, 51.75; H, 5.13; N, 5.48. Found: C, 51.66; H, 5.14; N, 5.15.

(*b*) Conventional acetylation of **11** (80 mg, 0.23 mmol) with acetic anhydride (0.5 mL) in pyridine (0.5 mL) gave a 9:1 mixture (72 mg, 62%) of **21** and **22** as deduced from the $^1$H- and $^{13}$C-n.m.r. spectra, $R_F$ 0.79 for **21** and 0.71 for **22** (dichloromethane–methanol, 40:1).

*1,3,4,6-Tetra-*O*-acetyl-2-deoxy-2-(3-phenylureido)-α-* (**23**) *and β-*D*-glucopyranose* (**24**). — Conventional acetylation of **12** (40 mg, 0.13 mmol) with acetic anhydride (0.3 mL) in pyridine (0.3 mL) gave a 3:2 mixture (59 mg, 94%) of **23** and **24**, as deduced from the $^1$H- and $^{13}$C-n.m.r. spectra, $R_F$ 0.79 for **23** and 0.71 for **24** (dichloromethane–methanol, 40:1). Signal assignments of the mixture were facilitated by the $^1$H- and $^{13}$C-n.m.r. spectra of **24** obtained as described[21].

*4-*(D-arabino-*Tetritol-1-yl)-1-*p-*tolyl-4-imidazoline-2-thione* (**17**). — Conventional acetylation of **2** (380 mg, 1.16 mmol) with acetic anhydride (2 mL) in pyridine (2 mL) gave a mixture of three main compounds, $R_F$ 0.77, 0.64, and 0.45 (t.l.c.; ether–hexane, 10:1); **20** was not detected. To a solution of the mixture in toluene (10 mL) was added Silica Gel 60 (Merck, 1 g) and the stirred mixture was boiled for 1 h under reflux, then filtered. The filtrate, which gave one main spot in t.l.c. ($R_F$ 0.45; ether–hexane, 10:1), was concentrated. A solution of the residue in methanolic 0.1% sodium methoxide (10 mL) was deionised with Amberlite IR-120 ($H^+$) resin and concentrated. The syrupy residue was crystallised from aqueous 95% ethanol to give **17** (121 mg, 34%). Recrystallisation from ethanol gave material with m.p. 210–212°, $[\alpha]_D^{22}$ −30°, $[\alpha]_{578}^{22}$ −31°, $[\alpha]_{546}^{22}$ −36°, $[\alpha]_{435}^{22}$ −68° (*c* 2, pyridine) {lit.[6] m.p. 211–212°, $[\alpha]_D$ −30° (pyridine)}.

*Crystal analysis**. — Compound **1**-5*R* crystallised as colourless prisms. Rather poor crystals were obtained with approximate dimensions 0.39 × 0.42 × 0.20 mm, which belonged to the monoclinic system with systematic absences consistent with $P2_1$. Accurate cell dimensions and crystal orientation matrix, determined on a CAD-4 diffractometer by a least-squares treatment of the setting angles of 25 reflections in the range $2 < \theta < 14°$, were *a* 6.978(9), *b* 7.125(2), *c* 14.694(5)Å, and $\beta$ 94.4(3)°. The unit-cell volume ($V$) was 728.3(4)Å$^3$, and the absorption coefficient ($\mu$) was 0.23 mm$^{-1}$.

An Enraf–Nonius CAD-4 diffractometer was used with monochromated Mo-$K_\alpha$ radiation (0.7107Å), the $\omega/2\theta$ mode, and $2\theta_{max} = 50°$ ($0 \leqslant h \leqslant 8, 0 \leqslant k \leqslant 8, -17 \leqslant l \leqslant 17$). Two reference reflections were measured every hour to monitor crystal stability, and were re-centred after every hundred measured reflections in order to monitor crystal orientation. No significant changes in the intensities were noted. From 1435 measured reflections, 1042 were observed with $I \geqslant 2\sigma(I)$; $F(000) = 332$. Corrections were made for Lorentz-polarisation effects, but not for extinction and absorption. The last effect was not taken into account because the crystal absorption with Mo radiation was negligible.

The structure was solved by direct methods with the MULTAN-80 program[36], and 234 reflections with $|E| > 1.62$ and 5 reflections in the starting set were used to determine the structure. The initial $E$ map revealed most of the non-hydrogen atoms and the remainder were located from subsequent electron-density maps. After anisotropic refinement by full-matrix least squares of all the 21 non-hydrogen atoms in the asymmetric unit, the hydrogen atoms were located at geometrical positions and were

* Lists of the observed and calculated structure factors, the anisotropic thermal parameters, and non-hydrogen and hydrogen atomic co-ordinates are deposited with, and can be obtained from, Elsevier Science Publishers B.V., BBA Data Deposition, P.O. Box 1527, Amsterdam, The Netherlands. Reference should be made to No. BBA/DD/451 *Carbohydr. Res.*, 210(1991) 125–143.

assigned the same isotropic thermal parameters as the atoms to which they were bonded, and were included, but not refined, in the final stage of refinement.

Refinement was based on $F$ (structure amplitudes) to minimise the function $\Sigma w(|F_o|-|F_c|)^2$ with $w = 1/\sigma^2(F_o)$; 189 parameters were refined (9 parameters per atom plus 1 for the scale); the over-determination ratio was 5.5 reflections/parameter. The refinement led to a final convergence with $R = 0.07$. All parameter shifts during the final cycle of refinement were $< 0.07\,\sigma$. Atomic scattering factors were from the International Tables for X-Ray Crystallography[37] and all calculations performed with the X-Ray System of crystallographic programs[38]. The $y$ co-ordinate of C-4 was held fixed in order to define the origin.

The bond lengths (Å) and angles (°) in Table IV were calculated by the program PARST, written by Nardelli[39].

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