

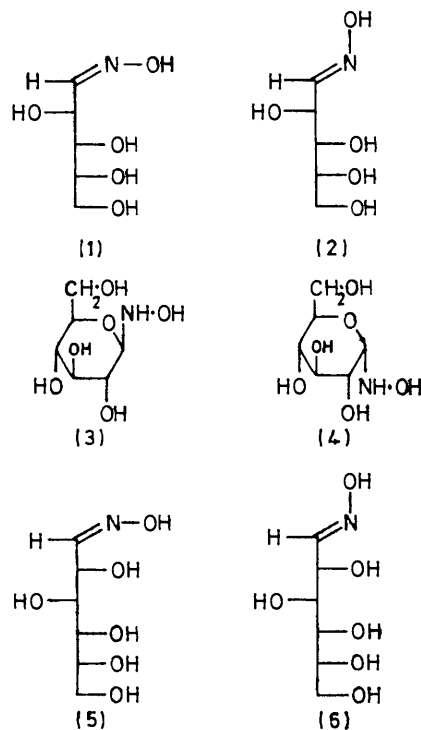
## The Structures of D-Arabinose and D-Glucose Oximes

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By means of various physical techniques D-arabinose oxime has been shown to exist in the *anti*- (*Z*-) acyclic form in the solid state and to isomerise to a mixture of *anti*- (*Z*-) (20%) and *syn*- (*E*-) (80%) forms in aqueous solution. D-Glucose oxime exists in the cyclic  $\beta$ -pyranose form in the solid state and isomerises to a mixture of  $\beta$ -pyranose (23%),  $\alpha$ -pyranose (7%), *anti*- (*Z*-) (13.5%), and *syn*- (*E*-) (56.5%) forms in aqueous solution. Conformational analysis of one cyclic ( $\beta$ -D-*gluco*-) and of one acyclic [(*E*)-D-*arabino*-] form has been carried out by  $^1\text{H}$  n.m.r. spectroscopy.

Oxime derivatives of carbohydrates prepared by reaction of hydroxylamine at the anomeric centre were first described in 1887,<sup>1</sup> and have been used for the characterisation of sugars; however the structures of these derivatives in the solid form and in solution have not been established unequivocally.<sup>2,3</sup> Since aqueous solutions exhibit mutarotation and a number of reactions such as the Wohl degradation<sup>4</sup> are best explained in terms of an open-chain structure, it has been widely presumed that equilibria between cyclic and acyclic forms exist in solution.<sup>2,5-7</sup> D-Glucose oxime has been assigned a  $\beta$ -cyclic structure on the basis of methylation,<sup>5</sup> optical rotation,<sup>6</sup> and i.r.<sup>8,9</sup> data, and arabinose oxime was thought to possess an acyclic structure on the basis of i.r. measurements.<sup>8</sup> From the results of polarographic measurements Haas *et al.*<sup>10</sup> concluded that in solution the oximes of glucose and arabinose exist in the acyclic form to the extent of 47 and 100%, respectively. Recently Szarek and his co-workers<sup>11</sup> have described the synthesis and characterisation of *O*-benzyloximes of carbohydrates, and have assigned acyclic structures on the basis of Raman and  $^1\text{H}$  n.m.r. data. We now present evidence to show that the normal  $\dagger$  crystalline form of D-arabinose oxime possesses an *anti*- (*Z*-) acyclic structure (1) which isomerises to a mixture of *syn*- (*E*-) (2) and *anti*- (*Z*-) forms in aqueous solution, and that the normal crystalline form of D-glucose oxime has a  $\beta$ -cyclic pyranosyl structure (3) which isomerises to a mixture of interconvertible

$\beta$ -cyclic,  $\alpha$ -cyclic (4), *syn*- (*E*-) (6), and *anti*- (*Z*-) (5) forms in aqueous solution.



$\dagger$  Note added in proof. It is also possible to prepare crystals of D-arabinose oxime, m.p. 136–137°, which consist of a mixture of *syn*- (80%) and *anti*- (20%) forms.

<sup>1</sup> P. Richsbieth, *Ber.*, 1887, **20**, 2673.

<sup>2</sup> B. Capon, *Chem. Rev.*, 1969, **69**, 407.

<sup>3</sup> R. J. Ferrier and P. M. Collins, 'Monosaccharide Chemistry,' Penguin, Harmondsworth, 1972, p. 72.

<sup>4</sup> A. Wohl, *Ber.*, 1891, **24**, 994; 1893, **26**, 730.

<sup>5</sup> J. C. Irvine and R. Gilmour, *J. Chem. Soc.*, 1908, **93**, 1429.

<sup>6</sup> M. L. Wolfrom and A. Thompson, *J. Amer. Chem. Soc.*, 1931, **53**, 622.

Solid D-arabinose oxime gave a sharp, weak, i.r. band at 1680  $\text{cm}^{-1}$ , and a band of moderate intensity in the Raman at 1678  $\text{cm}^{-1}$  suggestive of the presence

<sup>7</sup> V. Deulofeu, *Adv. Carbohydrate Chem.*, 1949, **4**, 119.

<sup>8</sup> F. Legay, *Compt. rend.*, 1952, **234**, 1612.

<sup>9</sup> H. Bredereck, A. Wagner, D. Hummel, and H. Krieselmeier, *Chem. Ber.*, 1956, **89**, 1532.

<sup>10</sup> J. W. Haas, jun., J. D. Storey, and C. C. Lynch, *Analyt. Chem.*, 1962, **34**, 145.

<sup>11</sup> J. Pleniewicz, W. A. Szarek, P. A. Sipos, and M. K. Phibbs, *Synthesis*, 1974, 56.

of a C=N grouping.<sup>8,9,12-14</sup> In aqueous solution two weak bands were exhibited in the Raman at 1 656 and 1 664 cm<sup>-1</sup>, indicating the presence of two C=N species. Mutarotation was observed to be kinetically simple and to proceed at the same rate in water and deuterium oxide, indicating that, in contrast to the situation with free sugars, proton transfer is not involved in the rate-determining step.<sup>15</sup> D-Arabinose oxime in [2H<sub>6</sub>]dimethyl sulphoxide solution gave a <sup>1</sup>H n.m.r. spectrum consistent with the presence of two interconverting isomeric forms (see Tables 1 and 2). The assignment of the *Z*-structure to the initial form and of the *E*-structure to the preponderant form at equilibrium was made on the basis of chemical shift correlations. These correlations<sup>16-23</sup> state that in aldoximes the hydrogen atom

δ 10.85 and 10.66 which disappeared on addition of deuterium oxide were assigned to the NOH protons of the *Z*- (*anti*-) and *E*- (*syn*-) forms, respectively, and two doublets at δ 6.67 and 7.34 were assigned to the C-1 protons of the *Z*- (*anti*-) and *E*- (*syn*-) forms. Other assignments were made with the aid of exchange in deuterium oxide, double resonance, and computer simulation procedures. The <sup>1</sup>H n.m.r. coupling constants allow the identification of the preponderant conformation (7) of the major *E*- (*syn*-) isomer at equilibrium in [2H<sub>6</sub>]dimethyl sulphoxide-[2H<sub>2</sub>]water; the fully extended planar zig-zag form is favoured except where it would lead to parallel 1,3-diaxial interactions between substituent groups.<sup>26,27</sup> The rate of isomerisation of the initial *Z*-form of D-arabinose oxime in

TABLE 1

| Compd. | <sup>1</sup> H Chemical shifts (δ values; Me <sub>4</sub> Si standard) <sup>a</sup> |                 |                   |                   |                   |                   |                   |                   |                  |                  |
|--------|---|-----------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|------------------|------------------|
|        | NOH <sup>b</sup>  | NH <sup>b</sup> | 1-H               | 2-H               | 3-H               | 4-H               | 5-H <sub>a</sub>  | 5-H <sub>b</sub>  | 6-H <sub>a</sub> | 6-H <sub>b</sub> |
| (1)    | 10.85   |                 | 6.67              | 4.93              |                   |                   |                   |                   |                  |                  |
| (2)    | 10.66   |                 | 7.34              | 5.01 <sup>c</sup> | 3.29              | 3.50 <sup>d</sup> | 3.59 <sup>d</sup> | 3.40 <sup>d</sup> |                  |                  |
| (3)    | 7.36  | 5.81            | 3.81              | 4.40 <sup>c</sup> | 3.13 <sup>d</sup> | 2.98 <sup>d</sup> | 3.04 <sup>d</sup> |                   | 3.6              | 3.38             |
| (4)    |   |                 | 4.5 <sup>c</sup>  | 2.95              |                   |                   |                   |                   |                  |                  |
| (5)    | 11.0  |                 | 6.9               | 5.04              |                   |                   |                   |                   |                  |                  |
| (6)    | 10.7  |                 | 6.64 <sup>b</sup> | 4.92 <sup>c</sup> |                   |                   |                   |                   |                  |                  |
|        |   |                 | 7.5               | 4.40              |                   |                   |                   |                   |                  |                  |
|        |   |                 | 7.24 <sup>b</sup> | 4.30 <sup>c</sup> |                   |                   |                   |                   |                  |                  |

<sup>a</sup> In (CD<sub>3</sub>)<sub>2</sub>SO-D<sub>2</sub>O except where specified. <sup>b</sup> In (CD<sub>3</sub>)<sub>2</sub>SO. <sup>c</sup> In D<sub>2</sub>O. <sup>d</sup> Obtained by computer simulation.

TABLE 2

| Compd. | <sup>1</sup> H Coupling constants (Hz) <sup>a</sup> |                     |                      |                  |                   |                      |                      |                                    |                      |                      |                                    |
|--------|---|---------------------|----------------------|------------------|-------------------|----------------------|----------------------|------------------------------------|----------------------|----------------------|------------------------------------|
|        | NOH,NH <sup>b</sup>                                 | NH,1-H <sup>b</sup> | 1-H,2-H              | 2-H,3-H          | 3-H,4-H           | 4-H,5-H <sub>a</sub> | 4-H,5-H <sub>b</sub> | 5-H <sub>a</sub> ,5-H <sub>b</sub> | 5-H,6-H <sub>a</sub> | 5-H,6-H <sub>b</sub> | 6-H <sub>a</sub> ,6-H <sub>b</sub> |
| (1)    |   |                     | 5.7 <sup>c</sup>     | 2.2 <sup>c</sup> |                   |                      |                      |                                    |                      |                      |                                    |
| (2)    |   |                     | 5.60 <sup>b</sup>    |                  |                   |                      |                      |                                    |                      |                      |                                    |
| (3)    | 2.70  | 3.24                | 7.3                  | 2.1              | 7.8               | 2.6                  | 5.9                  | -10.5                              |                      |                      |                                    |
| (4)    |   |                     | 7.28 <sup>d</sup>    | 2.8 <sup>c</sup> | 6.0 <sup>c</sup>  |                      |                      |                                    |                      |                      |                                    |
| (5)    |   |                     | 8.95                 | 8.95             | 8.95 <sup>d</sup> | 8.95 <sup>d</sup>    |                      |                                    | 7.0                  | 5.5                  | -11.5                              |
| (6)    |   |                     | 9.1 <sup>c</sup>     |                  |                   |                      |                      |                                    |                      |                      |                                    |
|        |   |                     | ca. 4.0 <sup>c</sup> |                  |                   |                      |                      |                                    |                      |                      |                                    |
|        |   |                     | 6.2                  |                  |                   |                      |                      |                                    |                      |                      |                                    |
|        |   |                     | 6.7 <sup>c</sup>     | 6.7 <sup>c</sup> |                   |                      |                      |                                    |                      |                      |                                    |
|        |   |                     | 7.8                  |                  |                   |                      |                      |                                    |                      |                      |                                    |
|        |   |                     | 7.0 <sup>c</sup>     | 7.1 <sup>c</sup> |                   |                      |                      |                                    |                      |                      |                                    |

<sup>a</sup> (CD<sub>3</sub>)<sub>2</sub>SO-D<sub>2</sub>O unless specified. <sup>b</sup> In (CD<sub>3</sub>)<sub>2</sub>SO. <sup>c</sup> In D<sub>2</sub>O. <sup>d</sup> Obtained by computer simulation.

on the trigonal carbon is more deshielded when *cis* (*syn*) to the oxime OH than when *trans* (*anti*), and that the hydrogen atom of the oxime OH is more deshielded when *trans* (*anti*) to that on the trigonal carbon than when *cis* (*syn*). Such correlations have been used previously<sup>24,25</sup> to assign structures of carbohydrate oxime derivatives. Thus two low-field singlets at

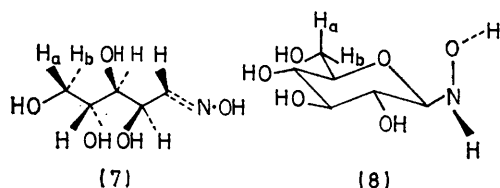
deuterium oxide was measured by monitoring the intensities of the C-1 proton n.m.r. signals with time. The same overall rate constant of 0.204 h<sup>-1</sup> was obtained as that given by observation of mutarotation, and the equilibrium (after ca. 20 h) proportions of *E*- (2) (80%) and *Z*- (1) (20%) forms yield interconversion rate

- <sup>12</sup> H. Spedding, *Adv. Carbohydrate Chem.*, 1964, **19**, 34.  
<sup>13</sup> D. Horton, K. Just, and B. Gross, *Carbohydrate Res.*, 1971, **16**, 239.  
<sup>14</sup> F. R. Dollish, W. Fateley, and F. F. Bentley, 'Characteristic Raman Frequencies of Organic Compounds,' Wiley, New York, 1974, p. 134.  
<sup>15</sup> H. S. Isbell and H. Pigman, *Adv. Carbohydrate Chem.*, 1969, **24**, 13, and references therein.  
<sup>16</sup> W. D. Phillips, *Ann. New York Acad. Sci.*, 1958, **70**, 817.  
<sup>17</sup> E. Lustig, *J. Phys. Chem.*, 1961, **65**, 491.  
<sup>18</sup> G. Slomp and W. J. Wechter, *Chem. and Ind.*, 1962, 41.  
<sup>19</sup> G. J. Karabatsos, R. A. Taller, and F. M. Vane, *J. Amer. Chem. Soc.*, 1963, **85**, 2326.

- <sup>20</sup> A. J. Durbetaki and C. Miles, 148th Meeting of the American Chemical Society, Chicago, 1964, Abstracts A-47.  
<sup>21</sup> A. Daniel and A. A. Pavia, *Tetrahedron Letters*, 1967, 1145.  
<sup>22</sup> G. G. Kleinspehn, J. A. Jung, and S. A. Studniarz, *J. Org. Chem.*, 1967, **32**, 460.  
<sup>23</sup> A. C. Huitric, D. B. Roll, and J. De Boer, *J. Org. Chem.*, 1967, **32**, 1661.  
<sup>24</sup> P. M. Collins, *Chem. Comm.*, 1966, 164.  
<sup>25</sup> A. Kampf and E. Dimant, *Carbohydrate Res.*, 1971, **16**, 212.  
<sup>26</sup> P. L. Durette, D. Horton, and J. D. Wander, 'Carbohydrates in Solution,' A.C.S. Advances in Chemistry Series No. 117, Washington, 1973, p. 147.  
<sup>27</sup> P. L. Durette and D. Horton, *Adv. Carbohydrate Chem.*, 1971, **26**, 49.

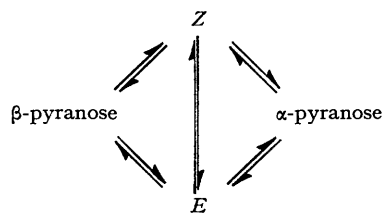
constants of 0.168 and 0.036 h<sup>-1</sup>. The specific rotations of the diastereoisomers (1) and (2) were calculated to be -83.6 and +3.15°, respectively. The equilibration of non-carbohydrate oximes has been noted previously,<sup>28</sup> and the preponderance of the *E*-form at equilibrium is in accord with steric considerations.

Solid D-glucose oxime gave no band in the 1 650—1 690 cm<sup>-1</sup> region in i.r. or Raman spectra, suggesting the absence of a C=N group<sup>8,9,12-14</sup> and the presence of a cyclic structure. Some evidence in support of a β-D-configuration was provided by an i.r. band at 891 cm<sup>-1</sup>.<sup>29</sup> The occurrence of mutarotation in aqueous solution was confirmed and observed to be kinetically complex. As has been observed with other carbohydrates having a cyclic structure<sup>15</sup> mutarotation was slower in deuterium oxide than in water. The formation of acyclic forms was suggested by two bands of moderate intensity in the C=N region of the Raman spectrum of an aqueous 20% solution. The occurrence of isomerisation was confirmed and further studied by <sup>1</sup>H n.m.r. spectroscopy.



The spectrum of D-glucose oxime freshly dissolved in [<sup>2</sup>H<sub>6</sub>]dimethyl sulphoxide was completely analysable (apart from the precise assignment of C-OH signals) in terms of a β-cyclic structure in the normal <sup>4</sup>C<sub>1</sub> conformation (8). Spectral assignments and parameters (Tables 1 and 2) were checked by double resonance experiments, exchange in deuterium oxide, and computer simulation of the C-H signals. The preponderant conformation of the exocyclic hydroxymethyl substituent is proposed to be that shown (8) on the basis of the observed coupling constants and chemical shifts of the C-6 protons. The fact that one vicinal coupling constant, *J*<sub>5,6</sub>, is larger (7.0 Hz) than the other (5.5 Hz) suggests the presence of a rotamer with a diaxial relationship between C-5 and C-6 protons, and since the smaller coupling is not associated with the downfield signal which would arise from deshielding by the opposing C-4 hydroxy-group<sup>30</sup> the major rotamer is thought to be that shown. In a survey<sup>31</sup> of the conformation of the primary alcohol group in 23 carbohydrate structures the arrangement having OH *anti* to C was most favoured. The small value of *J*<sub>NCH,NH</sub> (2.7 Hz) suggests that the torsion angle between the NO-H and N-H bonds must be within about 30° of 90°. The rotamer having a diparallel arrangement of the

NO-H bond and the nitrogen lone pair as shown in (8) is predicted to have minimum energy by molecular orbital calculations on *N*-methylhydroxylamine.<sup>32</sup> The low value of *J*<sub>NH,1-H</sub> (3.24 Hz) suggests a preponderance of a rotamer having a torsion angle between the N-H and C(1)-H bonds of about 60° (as distinct from 180°), and of the two possible rotamers that having a 1,3-diparallel relationship of C(2)-OH and N-OH bonds is proposed to be disfavoured as compared with that shown in (8). The spectrum of the solution in [<sup>2</sup>H<sub>6</sub>]dimethyl sulphoxide showed a slow decrease in intensity of the signals attributed to NOH, 1-H, and NH while new signals appeared at δ 11.0, 10.7, 7.24, 6.64, 4.40, and 5.04 and the remaining part of the spectrum became more complex. The signals (doublets) at δ 7.24 and 6.64 were assigned, according to correlations<sup>15-22</sup> referred to above, to C-1 protons of the *E*- (6) and *Z*- (5) forms of acyclic D-glucose, respectively. On addition of deuterium oxide the singlets at δ 11.0 and 10.7 disappeared; they were assigned to NOH of the *Z*- and *E*-forms, respectively. At equilibrium in deuterium oxide four doublets attributable to the C-1 protons of α-, β-, *E*-, and *Z*-forms were visible at 200 MHz. The observations are consistent with Scheme 1. The preponderance of the *E*- (*syn*-) (56.5%) over the *Z*- (*anti*-) form (13.5%) is consistent with steric considerations, and steric factors appear to outweigh electronic factors in controlling the position of equilibrium between β- (23%) and α- (7%) cyclic forms.



SCHEME 1

The structures of the oximes are supported but not unequivocally confirmed by mass spectrometry and g.l.c. of the *per-O*-trimethylsilyl derivatives. Both oximes gave small *M* + 1 peaks which were shown to have the expected molecular formulae by accurate mass measurements. Other peaks could be accounted for in terms of breakdown patterns based on previous work on carbohydrates<sup>33</sup> and aliphatic oximes.<sup>34</sup> The majority of the peaks in the mass spectrum of arabinose oxime could be attributed to simple cleavage as shown in (9). The base peak at *m/e* 75 probably arises from a McLafferty rearrangement (Scheme 2) as has been observed for other oximes.<sup>34</sup> This

<sup>31</sup> D. C. Fries, S. T. Rao, and M. Sundaralingam, *Acta Cryst.*, 1971, **B27**, 994.

<sup>32</sup> L. Radom, W. J. Hehre, and J. A. Pople, *J. Amer. Chem. Soc.*, 1972, **94**, 2371.

<sup>33</sup> N. K. Kochetkov and O. S. Chizov, *Adv. Carbohydrate Chem.*, 1966, **21**, 39.

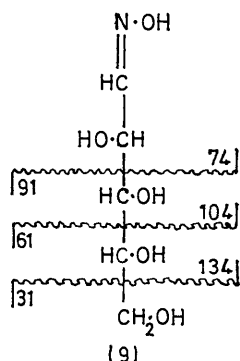
<sup>34</sup> H. Budzikiewicz, C. J. Djerassi, and D. H. Williams, 'Mass Spectrometry of Organic Compounds,' Holden-Day, San Francisco, 1967, pp. 367-379.

<sup>28</sup> G. E. Hawkes, K. Herwig, and J. D. Roberts, *J. Org. Chem.*, 1974, **39**, 1017.

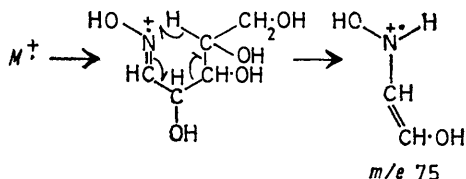
<sup>29</sup> S. A. Barker, E. J. Bourne, and D. H. Whiffen, *Methods Biochem. Analysis*, 1956, **3**, 213.

<sup>30</sup> R. U. Lemieux and J. T. Brewer, 'Carbohydrates in Solution,' A.C.S. Advances in Chemistry Series No. 117, Washington, 1973, p. 121.

peak is of lower intensity in the mass spectrum of D-glucose oxime, but the breakdown pattern is similar to that arising from D-arabinose oxime. A number of



workers have proposed<sup>35-37</sup> the use of *O*-trimethylsilyl derivatives of oximes for analysis of carbohydrate mixtures, and in general it has been presumed that each



SCHEME 2

sugar gives rise to a mixture of *syn*- and *anti*-acyclic forms. However we observed an additional component to be present in the *O*-trimethylsilyl derivative prepared from crystalline D-glucose oxime. This slowly disappeared as was observed by Sweeley,<sup>38</sup> and was presumed to be an *O*-trimethylsilyl derivative of the  $\beta$ -cyclic oxime.

The results (see Experimental section) of periodate oxidation studies on the freshly dissolved oximes supported the structural assignments for the solid compounds; in particular the lower rate of oxidation of D-glucose oxime and the lack of production of formaldehyde were considered to indicate a cyclic structure.

The preference of one of a number of isomeric forms of similar energy in the solid state is presumably related to crystal lattice forces, and it is hoped to investigate the crystal structures in the near future. However there is no obvious reason why a cyclic structure should be more favoured in the case of D-glucose oxime than in the case of D-arabinose oxime.

#### EXPERIMENTAL

<sup>1</sup>H N.m.r. spectra were recorded on Varian EM 360 or HR 220 (P.C.M.U.) spectrometers; spectrum simulation

<sup>35</sup> R. A. Laine and C. C. Sweeley, *Carbohydrate Res.*, 1973, **27**, 199.

<sup>36</sup> G. Petersson, *Carbohydrate Res.*, 1974, **33**, 47.

<sup>37</sup> T. W. Orme, C. W. Boone, and P. P. Poller, *Carbohydrate Res.*, 1974, **37**, 261.

<sup>38</sup> C. C. Sweeley, R. Bentley, M. Makita, and W. W. Wells, *J. Amer. Chem. Soc.*, 1963, **85**, 2497.

<sup>39</sup> R. C. Hockett and C. W. Maynard, jun., *J. Amer. Chem. Soc.*, 1939, **61**, 2111.

was carried out using program UEA NMR BASIC filed at the University of London Computer Centre in conjunction with a plotting routine LIBRARY RHC PLOT developed at Royal Holloway College Central Computer Services. Optical rotations were recorded on a Perkin-Elmer 141 polarimeter. I.r. spectra were recorded with a Perkin-Elmer 337 spectrometer. Raman spectra were taken with a Coderg PHO spectrometer and CR Argon Krypton mixed gas laser at 6 471 Å (D-glucose oxime), and a Cary 81 instrument on the yellow line (D-arabinose oxime). G.l.c. was carried out with a Perkin-Elmer F11 chromatograph (9 ft column of 3% OV-225 on Chromosorb Q, 80–100 mesh, at 168 °C). Mass spectra were taken on an A.E.I. MS 902 spectrometer (P.C.M.U.).

**D-Arabinose Oxime.**—D-Arabinose oxime was prepared essentially according to the method of Hockett,<sup>39,40</sup> except that 28 g of hydroxylamine hydrochloride was used. The concentration of hydroxylamine after neutralisation was found to be 66% of the original by reaction with an excess of 0.016M-potassium bromate followed by reduction of the excess of bromate with hydrogen iodide and titration of the liberated iodine with 0.1N-sodium thiosulphate. The crude product was concentrated under vacuum, dried by adding sodium-dried ether, and distilled under vacuum. The solid crystallised as plates from 60% aqueous ethanol; yield 60%; m.p. 140° (lit.,<sup>41</sup> 138–139°; lit.,<sup>39</sup> 136–137°) (Found: C, 36.7; H, 6.5; N, 8.2. Calc. for C<sub>5</sub>H<sub>11</sub>NO<sub>5</sub>: C, 36.4; H, 6.7; N, 8.5%); for <sup>1</sup>H n.m.r. data see Tables 1 and 2; [ $\alpha$ ]<sub>D</sub><sup>25</sup> initial –83.6°, final –14.2° (*c* 1.3 in H<sub>2</sub>O) {lit.,<sup>39</sup> [ $\alpha$ ]<sub>D</sub><sup>20</sup> initial –84.0°, final –13.50 (*c* 2.05 in H<sub>2</sub>O)}, simple mutarotation constant (*k*<sub>1</sub> + *k*<sub>2</sub>) 0.204 h<sup>-1</sup> at 25 °C in D<sub>2</sub>O and H<sub>2</sub>O [lit.,<sup>39</sup> 0.07–0.19 h<sup>-1</sup> (calculated from data given)]; D-arabinose oxime had consumed<sup>42</sup> 4.6, 4.7, and 4.7 mol. equiv. of periodate after 0.5, 2.0, and 4.2 h respectively and liberated 0.8 mol. equiv. of formaldehyde<sup>43</sup> and 2.9 mol. equiv. of formic acid; *m/e* 166 (C<sub>5</sub>H<sub>12</sub>NO<sub>5</sub>, *M* + 1), 134 (C<sub>4</sub>H<sub>8</sub>NO<sub>4</sub>), 104, 103 (C<sub>4</sub>H<sub>7</sub>O<sub>3</sub>), 91, 75 (C<sub>2</sub>H<sub>5</sub>NO<sub>2</sub>), 74, 61, and 31; i.r.  $\nu_{\max}$ . (KBr) 1 680w cm<sup>-1</sup> (C=N); Raman  $\nu_{\max}$ . (solid) 1 678m cm<sup>-1</sup> (C=N), (sat. aq. soln.) 1 656 and 1 664 cm<sup>-1</sup> (C=N).

**D-Glucose Oxime.**—Powdered hydroxylamine hydrochloride (70 g) in dry methanol (300 cm<sup>3</sup>) was neutralised with a solution of sodium methoxide [from sodium (20 g)] in methanol (100 cm<sup>3</sup>). The neutralised solution was cooled in ice and filtered, and the residue was washed with dry methanol (200 cm<sup>3</sup>). The combined filtrate and washings were shown to contain 0.64 mol of hydroxylamine (64% of the original) by titration as described above. The methanolic hydroxylamine solution was refluxed in a water-bath and powdered anhydrous D-glucose (110 g, 0.61 mol) was added slowly. The solution was concentrated, left at room temperature overnight, and dried in a desiccator. The dry solid was powdered, dissolved in 80% aqueous methanol, and allowed to crystallise in a freezer. Recrystallisation was carried out from 70% methanol and 60% methanol, and gave truncated prisms (53 g, 45%), m.p. 141° (lit.,<sup>4</sup> 137.5°; lit.,<sup>44</sup> 141°; lit.,<sup>45</sup> 136–137°) (Found: C, 36.7; H, 6.8; N, 7.2. Calc. for

<sup>40</sup> R. C. Hockett, *J. Amer. Chem. Soc.*, 1935, **57**, 2265.

<sup>41</sup> O. Ruff, *Ber.*, 1898, **31**, 1576.

<sup>42</sup> G. O. Aspinall and R. J. Ferrier, *Chem. and Ind.*, 1957, 1216.

<sup>43</sup> J. C. Speck, *Methods Carbohydrate Chem.*, 1962, **1**, 441.

<sup>44</sup> Pejkovic-Tadic, M. Hranisavljevic-Jakovljevic, and M. Maric, *Enzymologia*, 1970, **33**, 89.

<sup>45</sup> H. Jacobi, *Ber.*, 1891, **24**, 696.

$C_6H_{13}NO_6$ : C, 36.9; H, 6.7; N, 7.2%); for  $^1H$  n.m.r. data see Tables 1 and 2;  $[\alpha]_D^{25}$  initial  $-8.04^\circ$ , final  $-1.92^\circ$  (*c* 2.6 in  $H_2O$ ) {lit.,<sup>45</sup>  $[\alpha]_D$  final  $-2.2^\circ$  (*c* 9.4 in  $H_2O$ )} (the mutarotation was observed to be complex, *i.e.* initially the rotation decreased but after 0.5 h it increased until it reached a constant value after about 10 h; the mutarotation in  $D_2O$  was similar except that equilibrium was reached after about 36 h; equilibration was also observed by  $^1H$  n.m.r. to be a complex process; the areas of the 1-H signals of the acyclic forms did not increase at the same rate nor by a simple first-order process); D-glucose oxime consumed<sup>42</sup> 2.4, 3.2, 4.2, and 4.2 mol. equiv. of periodate after 0.5, 1.25, 4, and 5 h, respectively, and liberated no

formaldehyde<sup>43</sup> and 1.95 mol. equiv. of formic acid after 4 h; *m/e* 196 ( $C_6H_{14}NO_6$ ,  $M + 1$ ); i.r.  $\nu_{max}$  (KBr) 980s (N-O<sup>46</sup>) and 891sharp and  $m\text{ cm}^{-1}$  (ring breathing<sup>29</sup>); Raman  $\nu_{max}$ . (20% aq. solution) 1 648m and 1 653m (C=N) not given by powdered crystals or water alone.

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<sup>46</sup> A. Palm and H. Werbin, *Canad. J. Chem.*, 1954, **32**, 858.