

X-Ray Structure Analysis of Methyl 2,3,4,5-tetra-*O*-acetyl- α -D-glucoside

By Jack F. McConnell* and John D. Stevens, Schools of Physics and Chemistry, University of New South Wales, Kensington, New South Wales 2033, Australia

The crystal structure of the title compound was determined by X-ray diffraction by use of the multi-solution programs, MULTAN. Crystals are monoclinic, space group $P2_1$ with $Z = 2$ in a unit cell of dimensions: $a = 12.956$, $b = 7.901$, $c = 9.438$ Å, $\beta = 106.10^\circ$. The structure was refined by full-matrix least-squares methods to a final R of 0.052 for 1666 observed diffractometer reflections. The seven-membered ring approximates to a twist-chair conformation.

As part of a programme of chemical and structural studies on septanose (seven-membered ring) forms of carbohydrates¹⁻⁶ we have determined by X-ray diffraction the crystal and molecular structure of methyl 2,3,4,5-tetra-*O*-acetyl- α -D-glucoside (1).^{7,8}

EXPERIMENTAL

Clear, prismatic crystals with well-defined faces were obtained by crystallization from aqueous alcohol. Unit cell parameters were determined from high-angle goniometric readings. The crystal used for data collection was roughly equidimensional, with *ca.* 0.022 cm between parallel faces.

Crystal Data.— $C_{15}H_{22}O_{10}$, $M = 362.3$. Monoclinic, $a = 12.956 \pm 0.015$, $b = 7.901 \pm 0.012$, $c = 9.438 \pm 0.015$ Å, $\beta = 106.10 \pm 0.02^\circ$, $U = 928$ Å³, $D_m = 1.3$ (floatation), $Z = 2$, $D_c = 1.295$ g cm⁻³. Nickel-filtered copper radiation, $Cu-K\alpha$, $\lambda = 1.54051$ Å; $\mu(Cu-K\alpha) = 10.80$ cm⁻¹. Space group $P2_1$.

X-Ray intensity data were collected on a Siemens automatic single-crystal diffractometer, by use of a θ — 2θ scan. Background was measured at each end of the scan and reflections where the net count was less than twice the background were considered unobserved. A total of 1892 independent reflections were measured, of which 226 were unobserved. Intensities were corrected for Lorentz factors, polarization, and absorption. Towards the end of refinement, an isotropic correction was also made for extinction.⁹

Structure Determination.—The first attempts at refinement were made using direct method programs.¹⁰ E -Values (normalized structure factors) were calculated and a Σ_1 calculation¹¹ gave indications with >80% probability for two structure invariants, and for two more, indications with >70% probability. By use of Σ_2 relationships for $E > 1.3$, a number of tangent refinements were made, starting from different origin-defining reflections, and supported by phases determined by a symbolic-addition procedure.¹² Many of these starting sets gave promising refinements as derived from standard figures of merit (*e.g.* mean σ of phases *ca.* 25°), with practically all phases considered determined. However, E maps from all these refined sets had two features in common: all were

unsuccessful and all had one large peak, more than four times greater than the next highest.

An attempt was then made by use of the multisolution programs, MULTAN.¹³ These gave many promising solutions, but the E maps were all unsuccessful and again contained the one large peak. One notable feature, observed also during the symbolic-addition procedure, was the existence of a group of 20 reflections, all with high E , whose phases were all determinable in terms of one of them. It is possible that this self-consistent set was responsible for the high number of refinements which were incorrect but showed a high 'figure of merit,' merely by one of the set being wrongly determined early in the refinement.

It was then noticed that one of the MULTAN solutions had a moderately high figure of merit (1.1) as compared with the highest (1.3). A feature of this solution was the change in phase from 0 to 180° of one of the origin-fixing reflections. This still gave one large peak in the E map (three times the next highest peak), but a model derived from this, and modified by difference syntheses, looked more promising. 34 Phases determined from calculated structure-factors by use of this model were then used as a starting set, and the solution was given unequivocally.

Refinement.—All non-hydrogen atoms were located and the structure was refined to R 15%, with individual isotropic temperature factors. Refinement was by the least-squares program ORFLS¹⁴ which minimises the function $\Sigma w(|F_o| - |F_c|)^2$. Reflections were given weights equal to σ^{-2} , where σ is the standard deviation determined from counting statistics. Anisotropic temperature factors reduced R to 10.8%. A cycle of refinement using high-angle ($\sin \theta > 0.3$) data only, was then used to help locate the hydrogen atoms. These 'high-angle' parameters were then used to calculate structure factors for all data, from which a difference synthesis revealed all hydrogen atom positions. As expected, the methyl hydrogens were less clearly indicated, showing larger thermal motion, but were nevertheless identifiable. All hydrogen atoms were given anisotropic temperature parameters equal to those of the carbon atom to which they are attached and two more cycles of refinement were carried out varying positional parameters for the hydrogen atoms and all parameters for

† All errors quoted are *ca.* 3 σ .

¹ J. Jackobs and M. Sundaralingam, *Chem. Comm.*, 1970, 157.

² J. Jackobs, M. A. Reno, and M. Sundaralingam, in the press.

³ J. P. Beale, N. C. Stephenson, and J. D. Stevens, *Chem. Comm.*, 1971, 484.

⁴ J. P. Beale, N. C. Stephenson, and J. D. Stevens, *Acta Cryst.*, 1972, **B28**, 3115.

⁵ E. T. Pallister, N. C. Stephenson, and J. D. Stevens, *Chem. Comm.*, 1972, 98.

⁶ J. F. McConnell and J. D. Stevens, *Crystal Struct. Comm.*, 1973, **2**, 619.

⁷ J. D. Stevens, *Chem. Comm.*, 1969, 1140.

⁸ J. F. McConnell and J. D. Stevens, 9th Internat. Congr. Internat. Union Crystallography, Kyoto, Japan, August, 1972.

⁹ A. C. Larson in 'Crystallographic Computing,' ed. F. R. Ahmed, Munksgaard, Copenhagen, 1970, p. 291.

¹⁰ C. T. Grainger, personal communication.

¹¹ H. Hauptmann and J. Karle, Amer. Chem. Assoc. Monograph No. 3, 1953.

¹² J. Karle and I. L. Karle, *Acta Cryst.*, 1966, **21**, 849.

¹³ G. Germain, P. Main, and M. M. Woolfson, *Acta Cryst.*, 1971, **A27**, 368.

¹⁴ W. B. Busing, K. O. Martin, and A. A. Levy, Report ORNL TM 305, Oak Ridge National Laboratory, Tennessee, 1962.

TABLE I
Atomic co-ordinates and thermal parameters* (all $\times 10^4$)

	X/A	Y/B	Z/C	B ₁₁	B ₂₂	B ₃₃	B ₁₂	B ₁₃	B ₂₃
O(1)	5969(2)	3535(0)	8666(3)	68(2)	164(6)	135(4)	12(3)	12(2)	3(4)
O(2)	4912(2)	6061(6)	7366(3)	71(2)	107(5)	96(3)	-7(3)	33(2)	-12(3)
O(3)	2881(2)	5647(6)	5220(3)	84(2)	144(6)	88(3)	25(3)	31(2)	9(4)
O(4)	1457(2)	3509(7)	5620(3)	64(2)	253(8)	144(4)	4(4)	26(2)	-13(5)
O(5)	2045(3)	3486(6)	8601(3)	90(2)	179(6)	156(4)	-36(3)	71(3)	-34(5)
O(6)	4351(2)	2945(6)	9108(3)	86(2)	140(5)	85(3)	-14(3)	31(2)	-2(3)
O(7)	5597(3)	6220(6)	5434(3)	144(3)	213(8)	130(4)	-53(5)	82(3)	-24(5)
O(8)	2638(3)	8032(7)	6376(4)	137(4)	185(7)	164(5)	54(4)	36(4)	-28(6)
O(9)	1547(4)	2264(8)	3538(5)	131(4)	334(12)	178(6)	62(6)	-27(4)	-96(7)
O(10)	612(6)	1881(11)	8449(10)	200(7)	459(18)	663(20)	-185(10)	259(11)	-274(17)
C(1)	4908(3)	3081(7)	8107(4)	66(3)	136(7)	87(4)	5(4)	22(3)	-6(5)
C(2)	4422(3)	4441(6)	6867(4)	75(3)	101(7)	82(4)	-5(4)	32(3)	-18(4)
C(3)	3217(4)	4719(7)	6572(4)	73(3)	125(7)	78(4)	4(4)	26(3)	3(5)
C(4)	2558(3)	3066(8)	6370(4)	60(3)	161(8)	105(5)	-6(4)	22(3)	-13(6)
C(5)	2504(4)	2244(8)	7800(5)	90(4)	149(8)	116(5)	-28(5)	45(4)	-10(6)
C(6)	3561(4)	1663(8)	8799(5)	99(4)	149(9)	116(5)	-30(5)	30(4)	6(6)
C(7)	6547(6)	2310(10)	9688(6)	105(5)	213(12)	158(8)	41(7)	-11(5)	17(9)
C(8)	5502(4)	6786(7)	6591(4)	84(3)	130(8)	89(4)	-7(4)	28(3)	16(5)
C(9)	6000(5)	8396(9)	7286(6)	126(6)	174(11)	122(6)	-35(6)	31(4)	7(7)
C(10)	2625(4)	7299(8)	5264(5)	66(3)	147(8)	161(7)	18(4)	31(4)	14(7)
C(11)	2295(6)	8020(10)	3741(7)	120(6)	212(13)	193(9)	31(8)	31(6)	78(9)
C(12)	1041(4)	3009(10)	4248(5)	83(4)	234(12)	139(6)	-17(6)	-14(4)	6(8)
C(13)	-111(7)	3528(16)	3680(11)	87(5)	455(28)	254(13)	37(10)	-16(7)	64(17)
C(14)	1142(6)	3124(11)	8908(8)	140(6)	310(16)	266(11)	-92(9)	124(7)	-91(12)
C(15)	732(7)	4562(15)	9643(11)	144(8)	472(26)	397(19)	-59(12)	180(11)	-145(19)

Hydrogen atoms: thermal parameters were equal to those of the atom to which each was bonded

	X/A	Y/B	Z/C		X/A	Y/B	Z/C
H(1)	4880(45)	1911(79)	7636(56)	H(12)	6497(61)	7788	7590(80)
H(2)	4598(41)	3937(71)	5795(52)	H(13)	5846(54)	9155(92)	6382(70)
H(3)	2931(44)	5327(81)	7166(57)	H(14)	2673(68)	8314	3375(83)
H(4)	2795(46)	2283(82)	5813(58)	H(15)	1657(71)	7518	3390(84)
H(5)	1797(46)	1380(85)	7486(56)	H(16)	1981(60)	9572	3884(77)
H(6)	3957(48)	487(91)	8539(60)	H(17)	-255(80)	4371	3615
H(7)	3365(50)	1575(86)	9752(66)	H(18)	-551(64)	2913	2712(97)
H(8)	6314(66)	2291	1.0413(85)	H(19)	-329(60)	4337	4637(95)
H(9)	7219(61)	2752(97)	1.0223(76)	H(20)	1376(69)	5415	9754
H(10)	6848(54)	1055	9303(68)	H(21)	-513(69)	3998	8976(96)
H(11)	6083(60)	8454	8202(75)	H(22)	478(73)	4407	1.0388

* Figures in parentheses are estimated standard deviations (e.s.d.) (σ). Where no e.s.d. appears for a hydrogen atom, the calculated value exceeded 99, but in no case was greater than 130.

the other atoms. The final R value was 5.2%, with all shifts $< 0.1\sigma$.

Final positional and thermal parameters are listed in Table 1. Observed and calculated structure factors are listed in Supplementary Publication No. SUP 20883 (2 pp., 1 microfiche).*

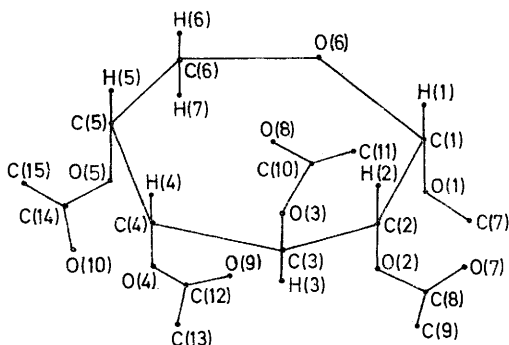


FIGURE 1 Atom numbering system

DISCUSSION

Bond lengths and angles involving non-hydrogen atoms are listed in Table 2. The atom numbering

* See Notice to Authors No. 7 in *J.C.S. Dalton*, 1972, Index issue.

system used in this study is given in Figure 1. In keeping with studies on other glycosides,^{15,16} the

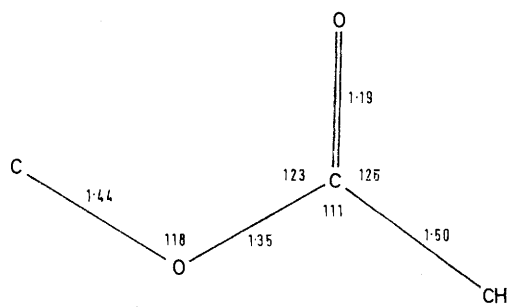


FIGURE 2 Mean values of bond lengths and angles in acetate groups

C(1)-O(1) bond length is significantly shorter than the C(1)-O(6) and C(6)-O(6) bond lengths, which are roughly equal; the values correspond more closely with those observed for pyranosides in which O(1) is equatorially oriented on the six-membered ring than with those for pyranosides in which O(1) is axially oriented. Bond

¹⁵ S. Arnott and W. E. Scott, *J.C.S. Perkin II*, 1972, 324.

¹⁶ G. A. Jeffrey, J. A. Pople, and L. Radom, *Carbohydrate Res.*, 1972, 25, 117.

TABLE 2

(a) Interatomic distances (Å) and standard deviations

C(1)-C(2)	1.533(6)	C(8)-O(2)	1.326(5)
C(2)-C(3)	1.524(6)	C(10)-O(3)	1.350(6)
C(3)-C(4)	1.542(7)	C(12)-O(4)	1.318(6)
C(4)-C(5)	1.517(6)	C(14)-O(5)	1.312(6)
C(5)-C(6)	1.503(7)	C(8)-C(9)	1.493(7)
C(6)-O(6)	1.411(6)	C(10)-C(11)	1.494(8)
C(1)-O(6)	1.415(4)	C(12)-C(13)	1.497(9)
C(1)-O(1)	1.388(5)	C(14)-C(15)	1.502(11)
C(2)-O(2)	1.448(5)	C(8)-O(7)	1.218(5)
C(3)-O(3)	1.431(5)	C(10)-O(8)	1.195(6)
C(4)-O(4)	1.494(5)	C(12)-O(9)	1.212(7)
C(5)-O(5)	1.462(6)	C(14)-O(10)	1.208(9)
C(7)-O(1)	1.425(6)		

(b) Interatomic angles (deg.) and standard deviations

O(6)-C(1)-C(2)	112.1(3)	C(4)-C(3)-O(3)	107.7(3)
C(1)-C(2)-C(3)	115.4(3)	C(3)-O(3)-C(10)	119.0(4)
C(2)-C(3)-C(4)	113.9(4)	O(3)-C(10)-O(8)	123.5(4)
C(3)-C(4)-C(5)	114.4(3)	O(3)-C(10)-C(11)	110.3(5)
C(4)-C(5)-C(6)	115.5(4)	O(8)-C(10)-C(11)	126.2(5)
C(5)-C(6)-O(6)	113.1(4)	C(3)-C(4)-O(4)	107.0(4)
C(6)-O(6)-C(1)	113.0(3)	C(5)-C(4)-O(4)	104.8(4)
O(6)-C(1)-O(1)	109.9(3)	C(4)-O(4)-C(12)	119.1(4)
C(2)-C(1)-O(1)	107.0(3)	O(4)-C(12)-O(9)	123.5(5)
C(1)-O(1)-C(7)	113.2(4)	O(4)-C(12)-C(13)	111.4(7)
C(1)-C(2)-O(2)	109.4(3)	O(9)-C(12)-C(13)	125.0(6)
C(3)-C(2)-O(2)	105.5(3)	C(4)-C(5)-O(5)	107.3(4)
C(2)-O(2)-C(8)	118.0(3)	C(6)-C(5)-O(5)	108.1(4)
O(2)-C(8)-O(7)	123.6(4)	C(5)-O(5)-C(14)	118.9(4)
O(2)-C(8)-C(9)	111.8(4)	O(5)-C(14)-O(10)	123.4(6)
O(7)-C(8)-C(9)	124.6(4)	O(5)-C(14)-C(15)	112.8(6)
C(2)-C(3)-O(3)	106.2(3)	O(10)-C(14)-C(15)	122.8(7)

(c) Torsion angles * (deg.) and standard deviations

C(7)-O(1)-C(1)-C(2)	-175.6(4)
O(7)-C(8)-O(2)-C(2)	4.9(6)
O(8)-C(10)-O(3)-C(3)	-1.8(7)
O(9)-C(12)-O(4)-C(4)	-4.0(9)
O(10)-C(14)-O(5)-C(5)	-7.0(12)
C(8)-O(2)-C(2)-C(1)	114.9(4)
C(10)-O(3)-C(3)-C(2)	-107.0(4)
C(12)-O(4)-C(4)-C(3)	110.6(5)
C(14)-O(5)-C(5)-C(4)	119.4(5)

* Ring torsion angles are in Table 3.

angles within the seven-membered ring are greater than the value for the tetrahedral angle. Similar large bond

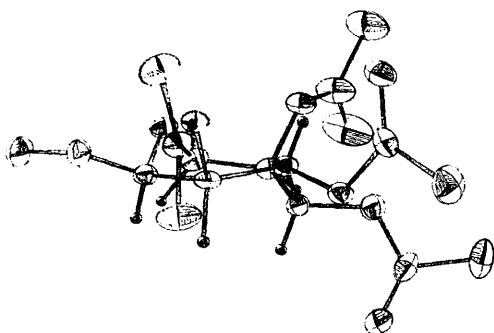


FIGURE 3 Stereoscopic pair of views of the molecule

angles were found in 5-*O*-chloroacetyl-1,2,3,4-di-*O*-isopropylidene- α -D-glucoseptanose^{1,2} and in the β -anomer of (1).³

Bond angles and distances in the four acetate groups in (1) show a regularity of magnitude. A comparison

¹⁷ J. P. Beale, N. C. Stephenson, and J. D. Stevens, *Chem. Comm.*, 1971, 25.

¹⁸ J. B. Hendrickson, *J. Amer. Chem. Soc.*, 1967, **89**, 7036.

of these values with those observed in the acetate groups in methyl 2,3,4,5-tetra-*O*-acetyl- β -D-glucoseptanose,³ 3-*O*-acetyl-1,2:4,5-di-*O*-isopropylidene- α -D-glucoseptanose,⁵ 4,5-di-*O*-acetyl-1,2-*O*-isopropylidene-3-*O*-methyl- α -D-glucoseptanose,⁶ and methyl 1,2,3,5-tetra-*O*-acetyl- β -D-galactofuranuronate,¹⁷ showed the regularity to be general and a statistical analysis of the values of each bond length and angle gave the mean values in Figure 2.

An examination of the torsion angles (Table 3) in conjunction with those computed for the various minimum-energy conformations of cycloheptane¹⁸ shows that the seven-membered ring exists in a twist-chair conformation in which the corresponding cycloheptane axis of symmetry passes through C(2), the ^{4,5}TC_{6,0} conformation.¹⁹ Table 3 gives the comparative values

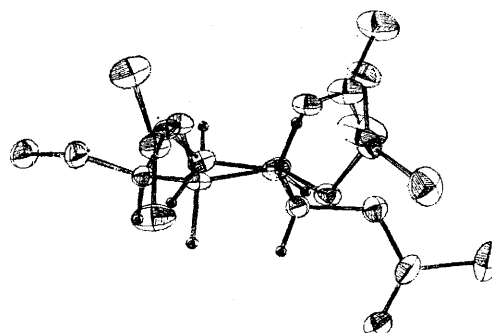
TABLE 3

Ring torsion angles (deg.)

Angle	(1)	(2)	Cycloheptane twist-chair
O(6)-C(1)-C(2)-C(3)	-31	-32	-39
C(1)-C(2)-C(3)-C(4)	-46	-48	-39
C(2)-C(3)-C(4)-C(5)	84	92	88
C(3)-C(4)-C(5)-C(6)	-63	-65	-72
C(4)-C(5)-C(6)-O(6)	53	50	54
C(5)-C(6)-O(6)-C(1)	-85	-84	-72
C(6)-O(6)-C(1)-C(2)	95	97	88

for the twist-chair form of cycloheptane as well as the torsion angle values for 5-*O*-chloroacetyl-1,2,3,4-di-*O*-isopropylidene- α -D-glucoseptanose (2). It is apparent that both (1) and (2) adopt remarkably similar conformations in the solid state, although the ring torsion angles in both compounds deviate somewhat from the calculated values for cycloheptane. These deviations may result from the septanose ring C-O bond lengths being shorter than C-C bond lengths, but computations on the energies of different conformations of the parent oxygen heterocyclic compound, oxepan, have yet to be reported.

Table 4 gives the displacements of atoms C(4)-(6)



and O(6) from both the three-atom plane C(1)-(3), and from the least-squares plane through C(1)-(3) and the midpoint of C(5) and C(6). The former values show clearly the distortion of the septanose ring from the twist-chair form of cycloheptane. Interestingly, the

¹⁹ J. F. Stoddart, 'Stereochemistry of Carbohydrates,' Wiley-Interscience, New York, 1971, p. 102.

TABLE 4
Distances from planes (Å)

Plane (1): C(1)—(3)

[C(4) -1.012, C(5) -0.513, C(5) -0.208, O(6) 0.668]

Plane (2): C(1)—(3), midpoint C(5)—C(6)

[C(1) 0.042, C(2) -0.061, C(3) 0.040, C(4) -0.819, C(5) -0.165, midpoint C(5)—C(6) -0.021, C(6) 0.124, O(6) 0.856]

β -anomer of (1) exists in the solid state in a conformation between the chair ${}^1,{}^2C_5$ and twist-chair, ${}^5,{}^6TC_{3,4}$ the latter

²⁰ V. J. James and J. D. Stevens, *Carbohydrate Res.*, 1972, **21**, 334.

corresponding to the cycloheptane twist-chair in which the axis of symmetry passes through C(1).

In common with a number of glycosides **3**, **6**, **16**,²⁰ which have been subjected to X-ray examination, the methoxy-group is oriented such that the methyl group is anti-periplanar to C(2). Figure 3 is a stereoscopic pair²¹ of views of the molecule which shows clearly all the conformational features.

[3/1565 Received, 25th July, 1973]

²¹ C. K. Johnson, USAEC Report ORNL 3794, Oak Ridge National Laboratory, Tennessee, 1965.