All non-H atoms were refined anisotropically by full-matrix least-squares methods. All H atoms were experimentally positioned, with only the oxime H atom refined isotropically. All other H atoms were not refined, but their displacement parameters were kept proportional (×1.3) to those of their neighbouring non-H atoms.

Data collection: *CAD*-4 *Software* (Enraf–Nonius, 1989). Data reduction: *SDP* (B. A. Frenz & Associates Inc., 1985). Program(s) used to solve structure: *MULTAN*80 (Main *et al.*, 1980). Program(s) used to refine structure: *MolEN* (Fair, 1990). Software used to prepare material for publication: *SDP*.

Lists of structure factors, anisotropic displacement parameters, H-atom coordinates, complete geometry and torsion angles have been deposited with the IUCr (Reference: NA1176). Copies may be obtained through The Managing Editor, International Union of Crystallography, 5 Abbey Square, Chester CH1 2HU, England.

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Acta Cryst. (1996). C**52**, 155–158

Polymerizable Methacrylate Carbohydrate Derivatives: 1,2:3,4-Di-*O*-isopropylidene-6-*O*-methacryloyl-α-D-galactopyranose and 1,2:5,6-Di-*O*-isopropylidene-3-*O*-methacryloyl-α-D-glucofuranose

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Abstract

The title structures, both $C_{16}H_{24}O_7$, have been determined to investigate the possibility of using these carbohydrate-containing monomers or related compounds for solid-state polymerization. The orientation of the methacrylate groups in the galactose derivative is suitable for solid-state reaction but the distance between the potentially reacting vinyl C atoms is too great, 5.065 (5) Å, for a facile reaction. The glucose derivative is disordered, with one of the isopropylidene rings assuming two different envelope conformations in the crystal. In the glucose derivative there are no approaches of the appropriate vinyl group atoms closer than 6.439 (3) Å.

Comment

Solution free-radical polymerization of carbohydrate methacrylate derivatives leads to products consisting of a poly(methyl methacrylate) backbone with pendant carbohydrate groups. This type of polymer has been known for some time, interesting examples being the work of Black, Dewar & Rutherford (1963) and Iwakura, Imai & Yagi (1968). It has recently been recognized that such carbohydrate-containing polymers have attractive properties for use as biomaterials (Wang *et al.*, 1992). Since polymer tacticity and its control are very important for the practical application of polymeric biomaterials, we are investigating the possibility of solid-state polymerization of carbohydrate methacrylate derivatives. As a first step toward this goal, we have determined the crystal structures of the title compounds because they are

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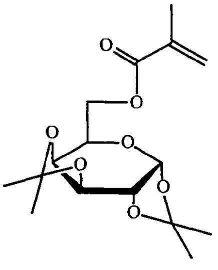
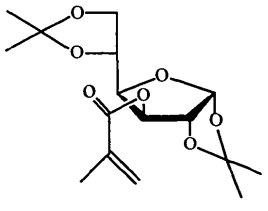
readily available derivatives of two common sugars, D-glucose and D-galactose, and also because this pair of compounds includes both pyranose and furanose ring forms.



(I)



(II)

Although solution and refinement of the structure of 1,2:3,4-di-*O*-isopropylidene-6-*O*-methacryloyl-α-D-galactopyranose, (I), proceeded without problems, the structure determination of 1,2:5,6-di-*O*-isopropylidene-3-*O*-methacryloyl-α-D-glucofuranose, (II), presented difficulties due to disorder. Initial refinement of (II) led to abnormally large anisotropic displacement parameters for the non-glycosidic isopropylidene ring. An unrestrained model for the disorder, consisting of two alternate envelope conformers, gave a reasonable fit to the experimental data although the resulting bond lengths and angles were unsatisfactory, particularly for the site of lower occupancy. The crystal structure refinement program *SHELXL*93 (Sheldrick, 1993) is particularly useful in dealing with such situations because it can be used to restrain chemically equivalent bonds without explicitly specifying a target value. Thus, for the two disordered conformers, all C—C bonds involving methyl groups in the disordered isopropylidene ring were restrained to the same target value (SADI) with a tolerance of 0.01. Similar restraints were used for the disordered isopropylidene ring C—O distances. This resulted in a model with occupancies of 0.81 and 0.19 for the major (*A*) and minor (*B*) sites and a reasonable geometry for both conformers.

Another very advantageous feature of the *SHELXL*93 refinement program is its employment of the Flack parameter (Flack, 1983) for assigning an absolute structure. Of course in this case the absolute configuration of both materials is known since they are derived from D-glucose and D-galactose. However, it is noteworthy that in the case of (II), routine use of the *SHELXL*93 program and the resulting value for the Flack parameter indicate reasonable confidence in the absolute structure assignment. For (I) such an assignment cannot be made with any certainty. These results are very interesting because, although the experiments were conducted using Cu $K\alpha$ radiation, both compounds contain only carbon, hydrogen and oxygen. This is encouraging for a relatively painless absolute structure determination in a difficult case. On the other hand the warning generated by *SHELXL*93 in situations where the data do not support an absolute structure assignment should serve to prevent mis-application of the method.

Figs. 1 and 2 depict the molecular structure and atom-numbering scheme adopted for (I) and (II), respectively. Of particular interest in both structures are the intermolecular bond distances and orientations of the vinyl groups. For a solid-state polymerization to occur it is necessary that the reactive monomers be packed as a chain in a head-to-tail fashion. Fig. 3 illustrates the packing of (I). Here the relative orientation of monomer units is appropriate for reaction but the distance between potentially reacting atoms is probably greater, 5.065 (5) Å, than what may be necessary for a solid-state reaction. For example, the α and β forms of cinnamic acid derivatives undergo solid-state dimerization. Here, the double-bond separation is 3.6–4.1 Å. The γ forms, with double-bond separations of 4.2–5.1 Å, are unreactive (Schmidt, 1964). Potentially reactive C atoms in (II) are separated even farther than those in (I), the closest approach being 6.439 (3) Å. Since neither of these fully blocked carbohydrate derivatives is capable of engaging in hydrogen bonding, a means of encouraging the vinyl groups to pack in closer proximity comes readily to mind. Upon removal of the isopropylidene groups, four hydroxyls will be unmasked and will engage in hydrogen bonding. The vinyl groups, unable to participate in hydrogen bonding, may well associate to form hydrophobic channels (or columns), increasing the chance that methacrylate derivatives of carbohydrates will be packed more closely. This strategy is currently being pursued.

Another interesting feature of the packing, illustrated in Fig. 3, is that the methyl groups of the methacrylate moieties are interposed almost directly between potentially reactive centers. Thus, the acrylate derivative of (I), wherein this methyl group is replaced by hydrogen, might be appropriately aligned for solid-state reaction.

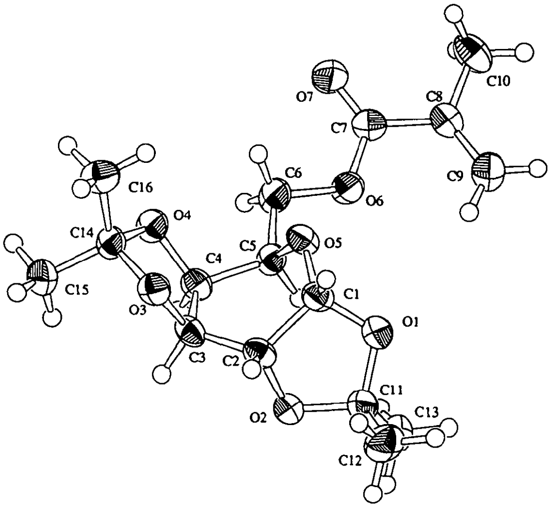


Fig. 1. *ORTEP* (Johnson, 1965) view of (I) showing 50% probability displacement ellipsoids.

Unfortunately, for biomaterials applications, methacrylate derivatives are considered superior to acrylates because of toxicity considerations.

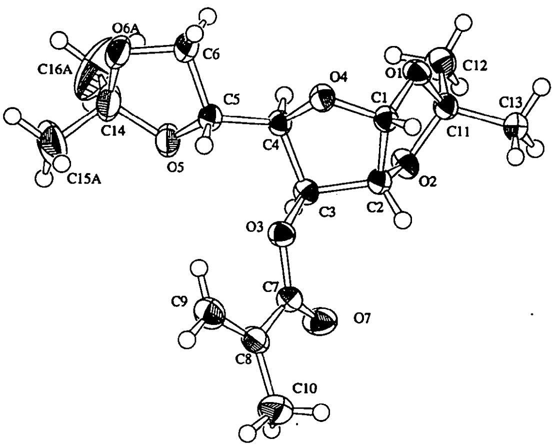


Fig. 2. *ORTEP* (Johnson, 1965) view of (II) showing 50% probability displacement ellipsoids. Only the higher occupancy conformer (site occupancy = 0.81) in this disordered structure is depicted.

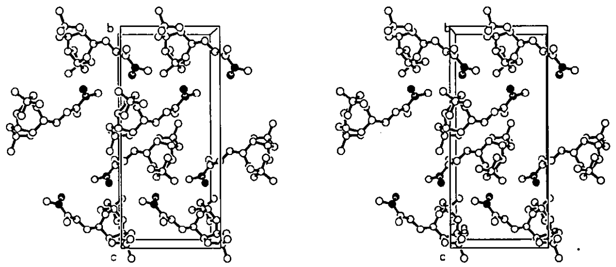


Fig. 3. *PLUTON* (Spek, 1992) view of the packing of (I). Vinyl C atoms are shown as black spheres.

Experimental

The syntheses of both methacrylate derivatives were accomplished by slight modifications of the procedures of Bird, Black, Colquhoun, Dewar & Rutherford (1966) for (I) and Black *et al.* (1963) for (II). For (I) the product mixture was extracted with light petroleum of b.p. 303–333K and the extract washed with distilled water (3 x 100 ml) after sodium hydroxide washes. 4-Methoxyphenol (0.01 g) was used as inhibitor and the concentrated syrup was distilled once to give the methacrylate (I) in 65% yield. The same procedure was followed to obtain (II) in 65% yield. Crystallization of (II) was from methanol–water. This compound also crystallized upon standing after distillation. Crystallization of (I) occurred while attempting to co-crystallize (I) and (II). Equal amounts of (I) and (II) were dissolved in ethanol. Water was added until the solution was turbid (3:2 ratio of alcohol:water). The system was allowed to stand in a closed vessel at room temperature resulting in crystallographic quality needles of (I).

Compound (I)

Crystal data

$C_{16}H_{24}O_7$
$M_r = 328.35$
Orthorhombic
$P2_12_12_1$
$a = 9.375\,(5)$ Å
$b = 20.676\,(5)$ Å
$c = 8.866\,(5)$ Å
$V = 1718.5$ Å^3
$Z = 4$
$D_x = 1.269$ Mg m^{-3}

Cu $K\alpha$ radiation
$\lambda = 1.54178$ Å
Cell parameters from 25 reflections
$\theta = 22–25°$
$\mu = 0.834$ mm^{-1}
$T = 173\,(2)$ K
Needle
0.4 × 0.1 × 0.1 mm
Colorless

Data collection

Rigaku AFC-6S diffractometer
θ–2θ scans
Absorption correction: ψ scans (North, Phillips & Mathews, 1968)
$T_{\min} = 0.91$, $T_{\max} = 1.00$
2860 measured reflections
2522 independent reflections
1651 observed reflections $[I > 2\sigma(I)]$

$R_{\rm int} = 0.029$
$\theta_{\max} = 70.29°$
$h = -9 \rightarrow 0;\ 0 \rightarrow 11$
$k = -20 \rightarrow 0;\ 0 \rightarrow 25$
$l = -8 \rightarrow 0;\ 0 \rightarrow 10$
3 standard reflections monitored every 150 reflections
intensity decay: none

Refinement

Refinement on F^2
$R[F^2 > 2\sigma(F^2)] = 0.0406$
$wR(F^2) = 0.1032$
$S = 1.079$
2522 reflections
213 parameters
H atoms treated using riding model
$w = 1/[\sigma^2(F_o^2) + (0.0648P)^2]$ where $P = (F_o^2 + 2F_c^2)/3$
$(\Delta/\sigma)_{\max} < 0.001$

$\Delta\rho_{\max} = 0.183$ e Å^{-3}
$\Delta\rho_{\min} = -0.205$ e Å^{-3}
Extinction correction: none
Atomic scattering factors from *International Tables for Crystallography* (1992, Vol. C, Tables 4.2.6.8 and 6.1.1.4)
Absolute configuration: Flack (1983)
Flack parameter = −0.38 (34)

Table 1. *Fractional atomic coordinates and equivalent isotropic displacement parameters* (Å^2) *for* (I)

$$U_{\rm eq} = (1/3)\Sigma_i\Sigma_j U_{ij}a_i^*a_j^*\mathbf{a}_i.\mathbf{a}_j.$$

	x	y	z	$U_{\rm eq}$
O5	0.3404 (2)	0.36410 (10)	0.5749 (3)	0.0390 (6)
O2	0.4766 (2)	0.40480 (11)	0.8973 (3)	0.0366 (6)
O1	0.3648 (3)	0.31605 (11)	0.8077 (3)	0.0484 (7)
O3	0.6174 (2)	0.45353 (11)	0.5372 (3)	0.0386 (6)
O4	0.4102 (2)	0.49314 (11)	0.4475 (3)	0.0392 (6)
O6	0.0426 (3)	0.38751 (13)	0.5563 (3)	0.0477 (7)
O7	−0.0555 (3)	0.39138 (14)	0.3290 (3)	0.0579 (8)
C1	0.4371 (4)	0.3421 (2)	0.6827 (4)	0.0380 (8)
C2	0.5334 (4)	0.3954 (2)	0.7500 (4)	0.0365 (8)
C3	0.5292 (3)	0.4596 (2)	0.6664 (4)	0.0359 (8)
C4	0.3830 (4)	0.4787 (2)	0.6027 (4)	0.0359 (8)
C5	0.2745 (3)	0.4245 (2)	0.6140 (4)	0.0351 (8)
C6	0.1510 (4)	0.4332 (2)	0.5087 (5)	0.0441 (9)
C7	−0.0507 (4)	0.3681 (2)	0.4527 (4)	0.0383 (8)
C11	0.4175 (4)	0.3443 (2)	0.9432 (4)	0.0413 (9)
C14	0.5624 (3)	0.4964 (2)	0.4272 (4)	0.0368 (8)
C13	0.2963 (4)	0.3563 (2)	1.0489 (5)	0.0490 (10)
C12	0.5343 (5)	0.3015 (2)	1.0089 (5)	0.0569 (11)
C15	0.6147 (4)	0.5648 (2)	0.4516 (4)	0.0478 (9)
C16	0.5981 (4)	0.4705 (2)	0.2733 (4)	0.0477 (10)
C8	−0.1472 (4)	0.3159 (2)	0.5067 (4)	0.0368 (8)
C9	−0.1209 (5)	0.2854 (2)	0.6333 (4)	0.0506 (10)
C10	−0.2684 (4)	0.2994 (2)	0.4040 (5)	0.0508 (11)

Compound (II)

Crystal data

$C_{16}H_{24}O_7$
$M_r = 328.35$
Monoclinic
$P2_1$
$a = 7.275$ (2) Å
$b = 8.945$ (2) Å
$c = 13.486$ (2) Å
$\beta = 97.148$ (15)°
$V = 870.7$ (3) Å^3
$Z = 2$
$D_x = 1.252$ Mg m^{-3}

Cu $K\alpha$ radiation
$\lambda = 1.54178$ Å
Cell parameters from 25 reflections
$\theta = 23–25°$
$\mu = 0.823$ mm^{-1}
$T = 173$ (2) K
Prism
0.50 × 0.45 × 0.10 mm
Colorless

Data collection

Rigaku AFC-6S diffractometer
$\theta–2\theta$ scans
Absorption correction: ψ scans (North, Phillips & Mathews, 1968)
$T_{\min} = 0.78$, $T_{\max} = 1.00$
3789 measured reflections
3290 independent reflections
3013 observed reflections $[I > 2\sigma(I)]$

$R_{\rm int} = 0.017$
$\theta_{\max} = 69.93°$
$h = 0 \rightarrow 8$; $-8 \rightarrow 0$
$k = 0 \rightarrow 10$; $-10 \rightarrow 0$
$l = -16 \rightarrow 16$; $-16 \rightarrow 0$
3 standard reflections monitored every 150 reflections intensity decay: 2.7%

Refinement

Refinement on F^2
$R[F^2 > 2\sigma(F^2)] = 0.0364$
$wR(F^2) = 0.0949$
$S = 1.022$
3290 reflections
223 parameters
H atoms treated using riding model
$w = 1/[\sigma^2(F_o^2) + (0.0573P)^2 + 0.1917P]$ where $P = (F_o^2 + 2F_c^2)/3$
$(\Delta/\sigma)_{\max} = 0.001$

$\Delta\rho_{\max} = 0.199$ e Å^{-3}
$\Delta\rho_{\min} = -0.261$ e Å^{-3}
Extinction correction: none
Atomic scattering factors from *International Tables for Crystallography* (1992, Vol. C, Tables 4.2.6.8 and 6.1.1.4)
Absolute configuration: Flack (1983)
Flack parameter = −0.01 (17)

Table 2. *Fractional atomic coordinates and equivalent isotropic displacement parameters* (Å^2) *for* (II)

$U_{\rm eq} = (1/3)\Sigma_i\Sigma_j U_{ij}a_i^*a_j^*\mathbf{a}_i.\mathbf{a}_j$.

	x	y	z	$U_{\rm eq}$
O1	1.3027 (2)	0.9600	1.01990 (10)	0.0335 (3)
O2	1.2883 (2)	0.7425 (2)	0.93370 (10)	0.0349 (3)
O3	0.8566 (2)	0.8414 (2)	0.78337 (10)	0.0300 (3)
O4	1.0733 (2)	1.0619 (2)	0.90532 (10)	0.0301 (3)
O5	1.0766 (2)	1.0511 (2)	0.63693 (11)	0.0423 (4)
O7	0.8637 (2)	0.5917 (2)	0.77170 (13)	0.0444 (4)
C1	1.1151 (3)	0.9485 (2)	0.97684 (13)	0.0280 (4)
C2	1.1042 (3)	0.7984 (3)	0.92074 (13)	0.0285 (4)
C3	1.0542 (2)	0.8422 (2)	0.81129 (13)	0.0269 (4)
C4	1.1179 (2)	1.0047 (3)	0.81128 (14)	0.0273 (4)
C5	1.0258 (3)	1.1049 (3)	0.72954 (14)	0.0309 (4)
C6	1.0955 (3)	1.2661 (3)	0.73316 (15)	0.0387 (5)
C7	0.7793 (3)	0.7064 (3)	0.76100 (13)	0.0312 (4)
C8	0.5782 (3)	0.7189 (3)	0.72015 (14)	0.0347 (4)
C9	0.5085 (3)	0.8475 (3)	0.6863 (2)	0.0432 (5)
C10	0.4717 (3)	0.5766 (3)	0.7189 (2)	0.0559 (7)
C11	1.3872 (3)	0.8161 (2)	1.01820 (13)	0.0300 (4)
C12	1.5856 (3)	0.8357 (3)	1.0004 (2)	0.0429 (5)
C13	1.3643 (3)	0.7313 (3)	1.11367 (15)	0.0407 (5)
C14	1.0924 (4)	1.1779 (3)	0.5733 (2)	0.0553 (6)
O6*A*	1.0721 (5)	1.3084 (3)	0.63104 (14)	0.0499 (9)
C15*A*	0.9428 (9)	1.1782 (5)	0.4874 (4)	0.103 (2)
C16*A*	1.2874 (8)	1.1791 (7)	0.5416 (5)	0.113 (3)
O6*B*	1.1777 (16)	1.2772 (13)	0.6440 (6)	0.050 (3)
C15*B*	0.8917 (16)	1.214 (3)	0.5337 (18)	0.087 (7)
C16*B*	1.197 (3)	1.121 (2)	0.4913 (12)	0.073 (5)

For both compounds, data collection: AFC-6S control software (Molecular Structure Corporation, 1988); cell refinement: AFC-6S control software; data reduction: *TEXSAN* (Molecular Structure Corporation, 1990); program(s) used to solve structures: *SHELXS*86 (Sheldrick, 1985); program(s) used to refine structures: *SHELXL*93 (Sheldrick, 1993); molecular graphics: *ORTEP* (Johnson, 1965); *PLUTON* (Spek, 1992); software used to prepare material for publication: *SHELXL*93.

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Lists of structure factors, anisotropic displacement parameters, H-atom coordinates and complete geometry have been deposited with the IUCr (Reference: SX1002). Copies may be obtained through The Managing Editor, International Union of Crystallography, 5 Abbey Square, Chester CH1 2HU, England.

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