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Syntheses and reactions of saturated and 2,3-unsaturated vinyl and 1′-substituted-vinyl glycosides*,†

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ABSTRACT

Reaction of tetra-*O*-acetyl-α-D-glucopyranosyl bromide with bis(acylmethyl)mercurys [$Hg(CH_2COR)_2$] afforded acetylated vinyl [by use of bis(formylmethyl)mercury] or 1′-substituted-vinyl β-D-glucopyranosides **11–13** in high yields. When used together with phenyl 4,6-di-*O*-acetyl-2,3-dideoxy-1-thio-α-D-*erythro*-hex-2-enopyranoside, these reagents gave analogous vinyl 4,6-di-*O*-acetyl-2,3-dideoxy-D-*erythro*-hex-2-enopyranosides **20–23** which, on treatment with Lewis acids, isomerised to the corresponding *C*-glycosyl compounds, *i.e.*, (4,6-di-*O*-acetyl-2,3-dideoxy-D-*erythro*-hex-2-enopyranosyl)acetaldehyde (**24,25**) or the corresponding glycosylated methyl ketones **26, 27**. A new route to C-3-branched glycals involves treatment of the above thioglycoside or the unsaturated vinyl glycosides with bis(benzoylmethyl)-mercury.

INTRODUCTION

Mercury(II) salts have found use in carbohydrate chemistry as co-ordinating "activators" of such glycosylating agents as glycosyl halides[1] and aldosyl 1,2-(ortho esters)[2], and thioglycosides are now widely used as glycosyl donors[3], their activation for this purpose being instigated by mercury(II) compounds as was first shown in this laboratory[4]. The sulphur/mercury affinity is further applied in carbohydrate synthesis in this paper.

Otherwise, the affinity of mercury(II) salts for alkenes had frequently been used in the alkoxymercuration of glycal derivatives and, hence, the production of 2-deoxyglycosides[5] or, following homolytic cleavage of the carbon–mercury bonds, 2-deoxy 2-branched-chain analogues[6]. Extensions have led to valuable ring-closure processes involving intramolecular alkoxy- or amino-mercurations[7,8].

Unlike Grignard reagents, organomercury compounds do not readily or commonly take part in reactions as nucleophiles in the formation of C–C bonds. Thus, for example, compound **1**, on acetylation, did not undergo direct reaction at C-6, the carbanion character of this atom being expressed by formation of an alkene with cleavage of the C-5–O-5 bond followed by acylation on oxygen to give[9] compound **2**. In related fashion, the mercurial **3**, formed by hydroxymercuration of tri-*O*-acetyl-D-

* Dedicated to Professor Grant Buchanan on the occasion of his 65th birthday.
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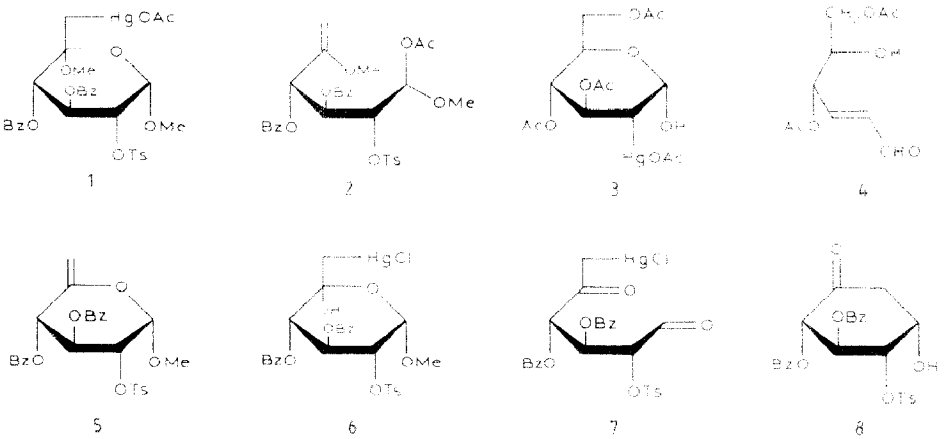
glucal, spontaneously eliminates mercury(II) acetate to give[10] the (*E*)-alkene **4** by way of a C-2 carbanion which, in this case, is stabilised by being α to the carbonyl group of the acyclic modification of **3**. In pursuing the possibility thereby suggested, that mercury-bonded carbon atoms which also have bonded carbonyl groups would serve as nucleophiles under mild conditions, we made the hemiacetal **6** by treatment of the alkene **5** with mercury(II) chloride in refluxing aqueous acetone, and obtained[11,12] the intramolecular aldol adduct **8** by way of the dicarbonyl-mercurial **7**. The reaction has become a useful entry to functionalised deoxyinososes[13], but it has not afforded access to functionalised cyclopentanes formed by attack of C-6 on C-2.

Formation of the intermediate **7** from the alkene **5** is an example of the known reaction[14] whereby (acylmethyl)mercury(II) compounds can be derived from enol ethers (or esters):

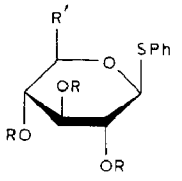
Thus, we were led to undertake a study, the results of which are now reported, of the use of simpler substances of this type as nucleophiles in conjunction with carbohydrate electrophiles. In particular, we wished to investigate the possibility of utilising such mercurials in the preparation of C-glycosyl compounds, which are of major current significance in organic synthesis[15].



RESULTS AND DISCUSSION

Initial efforts to effect nucleophilic displacements at the anomeric centre of carbohydrate derivatives involved treatment of acetonylmercury(II) chloride with the acetylated phenyl 1-thioglycoside **9**, but the sulphur–mercury affinity was insufficient to increase the electrophilicity of the anomeric centre and the nucleophilicity of the acetonyl group to cause them to react in boiling 1,4-dioxane. Likewise, phenyl 2,3,4,6-tetra-*O*-benzyl-1-thio-β-D-glucopyranoside (**10**), which would be expected to undergo

more rapid nucleophilic displacement at the anomeric centre[16], was unreactive towards this same mercurial and to bis(acetonyl)mercury in refluxing *N,N*-dimethylformamide and 1,4-dioxane, respectively.

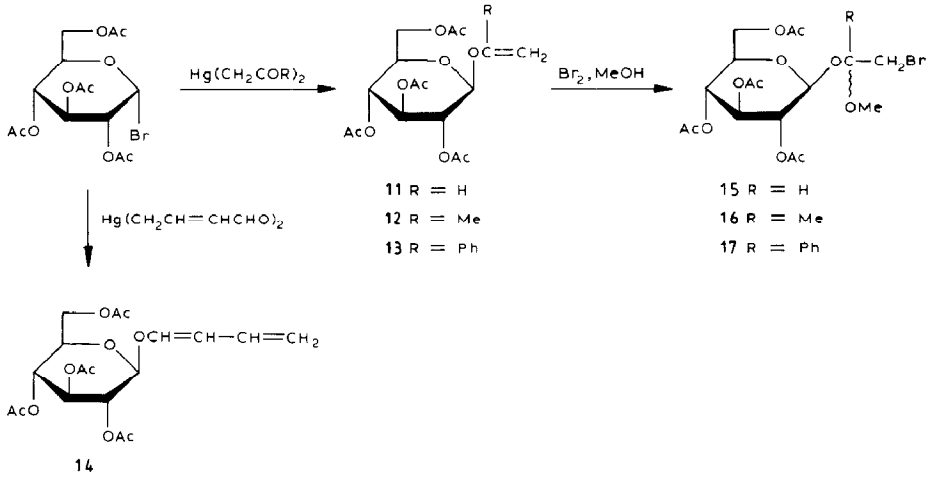


9 R = Ac, R′ = CO_2Et
10 R = Bn, R′ = CH_2OBn

By contrast, tetra-*O*-acetyl-α-D-glucopyranosyl bromide reacted readily with acetonylmercury(II) chloride in refluxing chloroform to give two products, as did acetonylmercury(II) acetate, the major compound in the latter reaction being penta-*O*-acetyl-β-D-glucopyranose, thus indicating that the counter ions were involved in the reactions. Consequently, bis(acetonyl)mercury was employed and, when used in two molar proportions in refluxing chloroform, it afforded the isopropenyl β-glycoside **12** in near quantitative yield. In analogous fashion, the known vinyl glycoside acetate **11** was obtained in 80% yield. Similarly, but with one molar equivalent of reagent (because of the release of acetophenone from excess of reagent during the isolation procedure), the styryl analogue **13** was obtained in 70% yield.

The reaction of tetra-*O*-benzyl-α-D-glucopyranosyl chloride with bis(acetonyl)-mercury proceeded readily to give mainly the isopropenyl glycoside which, however, proved to be appreciably less stable than its acetylated analogue and decomposed even on storage at low temperature.

In order to establish whether butadienyl tetra-*O*-acetyl-β-D-glucopyranoside



11 R = H
12 R = Me
13 R = Ph

15 R = H
16 R = Me
17 R = Ph

14

(**14**), which is a useful Diels–Alder diene made previously by Wittig methylenation of an aldehyde[17], could be made by the current approach. 1-trimethylsilyloxy-1,3-butadiene was treated with mercury(II) oxide and mercury(II) acetate in aqueous ethanol to give bis(4-oxo-but-2-enyl)mercury which, when used in excess with tetra-*O*-acetyl-α-D-glucopyranosyl bromide, gave **14** (51% isolated).

In the above reactions which resulted in the production of glycosides, the mercurated carbonyl compounds acted as O-nucleophiles rather than as C-nucleophiles as was the case in the intramolecular generation of cyclohexanone **8** from the mercurial **7** and in other reactions with aldehydes[18]. The nucleophilic character of the ambident α-mercurated carbonyl compounds has previously been found to be dependent upon the electrophile, the reaction solvent, and the specific nature of the organomercurial; triphenylmethyl halides tend to react with the softer carbon centres to give products of *C*-alkylation, *i.e.*, ketones[19], whereas acyl halides and reagents containing P–Cl or S–Cl bonds give enol esters following reaction with the harder oxygen centres[18]. Tetra-*O*-acetyl-α-D-glucopyranosyl bromide therefore reacted as having a hard acidic centre, but it was not determined whether the reaction took place, in the normal fashion with such compounds, by way of a cyclic 1,2-acetoxonium ion or whether the mercury assisted the halide release from the sugar in an S_N2 concerted process involving a bicyclic spiro-transition state. The experiment with tetra-*O*-benzyl-α-D-glucopyranosyl chloride, noted above, afforded mainly a β-enol glycoside which, by itself, does not establish the intermediacy of a bicyclic species. In reacting as O-nucleophiles, the (acylmethyl)-mercury compounds are complementary to silylated enol ethers which, with glycosyl halides, give good access to *C*-glycosyl compounds[20].

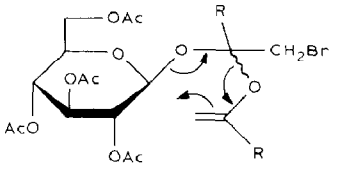
The above procedure, which has been reported briefly[21], is a convenient method for preparing vinyl and substituted-vinyl glycosides that cannot be made by conventional methods because the corresponding alcohols are not available. Such glycosides have, however, been produced by the following procedures: transvinylation to sugar derivatives unsubstituted at the anomeric centre[22–24], eliminations using 2-(trimethylammonium)ethyl glycosides[25] and 2-(phenylselenyl)ethyl glycosides[26], photolysis of 4-oxopentyl glycosides by Norrish Type II reactions[27], and isomerisation of allyl glycosides[27,28]. An alternative procedure involves the carbonyl methylenation of glycosyl esters[29].

In experiments related to those reported above, tetra-*O*-acetyl-α-D-glucopyranosyl bromide was treated separately with bis(2,2-diethoxyethyl)mercury and diphenylmercury in refluxing acetonitrile and gave a mixture of products in the former reaction and tetra-*O*-acetyl-1,5-anhydro-D-*arabino*-hex-1-enitol in the latter. The activity of the bis(acylmethyl)mercurys as nucleophiles depends, therefore, upon the existence of the free carbonyl groups, and diphenylmercury did not undergo substitution to give glucosylbenzenes, but promoted elimination. Diarylmercurials can be alkylated by reaction with organic halides[18].

The literature contains few examples of the use of vinyl glycosides, but access to cyclopropyl analogues has been reported[23] and the acyl units of glycosyl aldonates, after methylenation to give subsitituted vinyl glycosides, have been cyclised to provide a new approach to disaccharides. In this way, sucrose has been impressively synthesised[30].

With the vinyl ethers **11–13** readily available, a brief investigation was undertaken of the possibility that electrophiles could render them susceptible to nucleophilic attack at the anomeric centre and thus useful as glycosylating species in a manner similar to that adopted so successfully by Fraser-Reid and colleagues with pent-4-enyl glycosides[16]. However, when **11–13** were each treated with *N*-bromosuccinimide and excess of methanol, or with bromine followed by methanol in the presence of silver perchlorate, no glycosides were formed, the products in each case being mixed stereoisomers of the glycosyl acetals **15–17**. Compounds of this type, synthesised from trimethylsilyl tetra-*O*-acetyl-β-D-glucopyranoside and aldehyde acetals, have been of interest recently as possible means of releasing cytotoxic aldehydes at sites of malignancy[30]. Similar work has examined glycosyl acetals that contained halogenated aglycons as enzyme suicide substrates[31].

Brief examination of the products of addition of bromine to the vinyl glycosides **11** and **12** indicated that they reacted with bis(formylmethyl)mercury and bis(acetonyl)-mercury to give compounds **18**, which were identified by spectroscopic methods but were too unstable for convenient use. No indication of their conversion into *C*-glycosyl compounds (see **18**) was found following heating in inert solvents.



18 R = H, Me

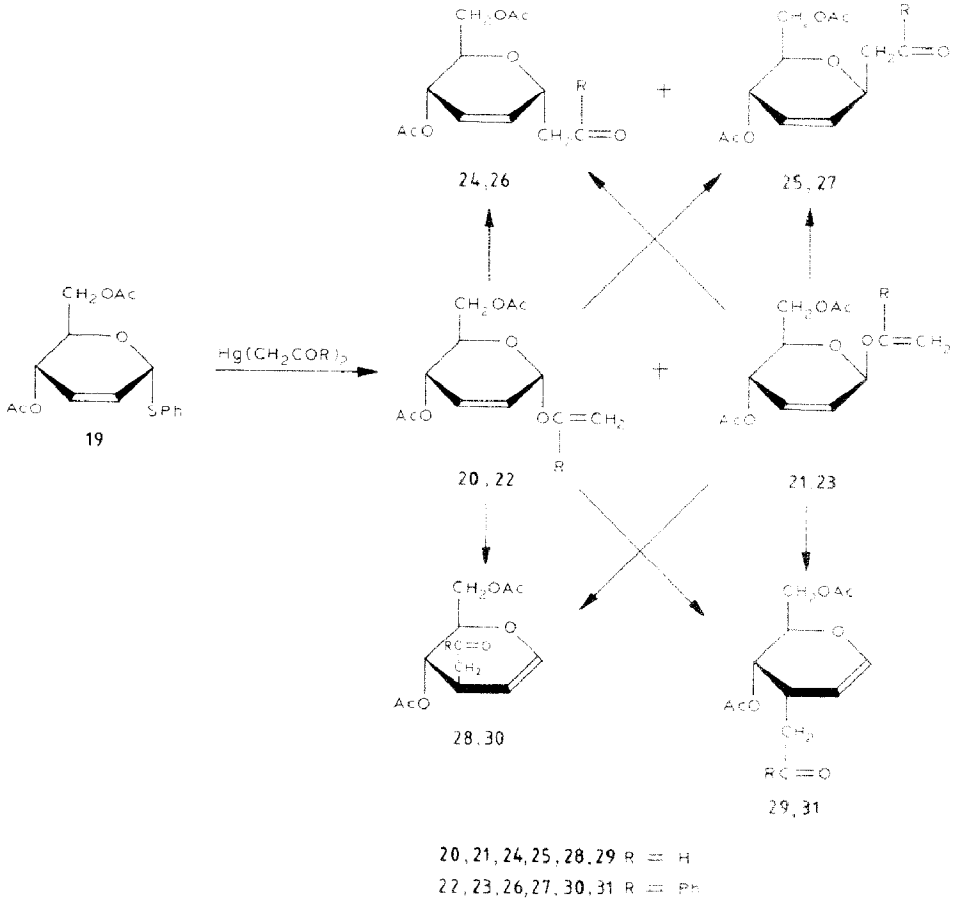
Treatment of the isopropenyl glycoside **12** with mercury(II) acetate in methanol gave neither methyl glycosides nor adducts of methoxymercuration. Instead, alkoxymercuration being reversible, rapid transvinylation from sugar to methanol took place to give 2,3,4,6-tetra-*O*-acetyl-D-glucose.

Since 2,3-unsaturated vinyl glycosides undergo Claisen thermal rearrangement to give access to synthetically useful C-3 branched glycal derivatives, their availability from phenyl 4,6-di-*O*-acetyl-2,3-dideoxy-1-thio-α-D-*erythro*-hex-2-enopyranoside (**19**) and the (acylmethyl)mercury reagents was investigated, notwithstanding the lack of reactivity shown by the latter compounds with saturated phenyl 1-thioglycosides (see above).

Compound **19** has been referred to several times in the literature[32–36], but the reaction whereby it may be obtained from tri-*O*-acetyl-D-glucal has not been described in detail, although the reaction of this glycal with other thiols has been carefully investigated[37]. Treatment of the glycal with thiophenol in benzene in the presence of catalytic amounts of boron trifluoride etherate gave a mixture of products from which the desired α-thioglycoside **19**, its β anomer, and 4,6-di-*O*-acetyl-1,5-anhydro-2-deoxy-3-*S*-phenyl-3-thio-D-*ribo*-hex-1-enitol (*cf.* ref. 37) were isolated in yields of 71, 9, and

6%, respectively; the major product was available in 65% yield following draining of the partially crystalline crude product on an unglazed tile. The glycosidic products had ^{1}H-n.m.r. spectral features consistent with literature data for analogous substances[18]. Likewise, their optical rotations (+366° and +104° for the α and β anomers, respectively) are consistent with published data for 2,3-unsaturated thioglycosides[37] and with Hudson's rules of isorotation. The 3-phenylthioglycal derivative was clearly seen from its ^{1}H-n.m.r. spectrum to have a glycal structure, and the $J_{4,5}$ and $J_{5,6}$ values of 10.0 and 4.6 Hz, respectively, revealed the *ribo* configuration.

Heating of the phenyl 1-thio-α-glycoside **19** and bis(formylmethyl)mercury in refluxing acetonitrile for 2 h resulted in its complete conversion into the known vinyl α-glycoside **20** and its β anomer **21** (ratio 5:1; 53 and 15% isolated, respectively). The ^{1}H-n.m.r. spectral features of **20** and **21** were consistent with those published for analogous compounds[38], and the ^{13}C-n.m.r. resonance of C-5 of the α anomer (δ 67.7) was characteristically upfield relative to that of the β anomer (δ 73.0) in keeping with the operation in **20** of Stothers' "γ-effect" (ref. 39). Consistent with data reported for related compounds[40], Hudson's isorotation rule was disobeyed by the glycosides **20** and **21** ($[\alpha]_D$ +78.6° and +141°, respectively).



Likewise, but using bis(benzoylmethyl)mercury and toluene as solvent at 90°, compounds **22** and **23** were produced from **19** in the ratio 5:1 (50% and 10%, respectively, isolated); **22** and **23** also disobeyed Hudson's rule.

Although the organomercury reagents under study did not give direct access to *C*-glycosyl compounds, indirect access became available on finding that the unsaturated vinyl glycosides readily isomerised to *C*-glycosyl compounds in the presence of Lewis acids. Thus, compounds **20** and **21**, treated separately in dichloromethane with catalytic amounts of zinc bromide, gave the α- and β-glycosylacetaldehyde derivatives **24,25**, in high yield and in the ratio 5:1. Boron trifluoride etherate readily effected the same rearrangement. In similar fashion, the styryl anomers **22,23** were converted into the glycosylacetophenones **26,27**, in good yield and in the ratio 3:1. These compounds have previously been prepared directly from tri-*O*-acetyl-D-glucal by reaction with 1-(trimethylsilyloxy)styrene in the presence of Lewis acids[41].

The anomeric configurations of compounds **24–27** were assigned by comparison with data reported for 4,6-*O*-benzylidene analogues of **24** and **25**, prepared by Tulshian and Fraser-Reid following sigmatropic rearrangements to 3-*O*-substituted glycal derivatives[42]. It was notable that, for the β anomers, the anomeric protons, H-5, and H-2′a,2′b all resonated at higher field than those protons of the α anomers. The $J_{4,5}$ values of 9 and 6 Hz for the β and α isomers, respectively, indicated the adoption of the $^{0}H_{5}$ conformation by the former and a distorted shape for the latter — again in keeping with data previously reported for pairs of anomers of this kind[15,43]. As with the glycosides **20–23**, the ^{13}C-n.m.r. C-5 resonances of the α anomers were upfield relative to those of the β isomers. In accordance with results observed with other anomeric pairs of 2,3-unsaturated *C*-hexopyranosyl compounds, **24,25** and **26,27** did not conform to Hudson's rules[15,43].

The rearrangement of the glycosides **20,21** to the *C*-glycosyl compounds **24,25** appears to occur by way of a common intermediate, because each anomer gave the same products without prior interconversion (^{1}H-n.m.r. evidence) and these products did not interconvert; an ion-pair intermediate is envisaged. That the rearrangement reaction is dependent upon the presence of the 2,3-double bond is indicated by the observation that the vinyl glucopyranosides **11–13** could not be induced to rearrange similarly to *C*-bonded isomers under the influence of Lewis acids. Analogous *O*- to *C*-substitution isomerisation has, however, been observed with saturated aryl glycosides: treatment of 1-naphthyl 2,3,4,6-tetra-*O*-methyl-β-D-glucopyranoside with boron trifluoride etherate gave the *C*-glycosyl product in good yield[44], and direct access to glycosylarenes is available from glycosyl acetates and phenols via unisolated aryl glycosides[45]. These isomerisations are related to the Fries rearrangement, whereby aryl esters can be converted into acylphenols.

2,3-Unsaturated vinyl glycosides undergo thermal Claisen rearrangement to give glycal derivatives having a branching group at C-3 and, in this way, compounds **20** and **21** gave the aldehydes **28** and **29**, respectively, as has been reported previously for the former by Descotes *et al.*[26]. Acetophenones **22** and **23** could not be induced to undergo analogous rearrangement prior to thermal decompositions, but, when the phenyl

1-thioglycoside **19** was treated with bis(benzoylmethyl)mercury in refluxing toluene for 42 h, the expected products of thermal rearrangement, *i.e.*, **30** and **31**, were obtained. That they were formed via **22** and **23** was shown by observing the latter pair as main products after 18 h, and by independent treatment of the former pair with bis(benzoylmethyl)mercury. Compound **22**, when heated for 18 h in refluxing toluene with the reagent, gave mainly the D-*arabino*-glycal **30** together with a small proportion of the *ribo* isomer **31**, whereas the *β* isomer **23** afforded the same products but in the inverse ratio.

It is envisaged that the bis(benzoylmethyl)mercury, which was found to be necessary for the conversion of **22,23** into the glycals **30** and **31**, attacked the relatively "soft" C-3 as a "soft" carbon nucleophile to initiate mainly *anti*-S_N2' displacement processes in reactions analogous to that by which epimeric 3-(dicyanomethyl)glycals are produced on treatment of methyl 4,6-di-*O*-acetyl-2,3-dideoxy-α-D-*erythro*-hex-2-enopyranoside with the sodium derivative of methyl dicyanoacetate in the presence of boron trifluoride[46]. In the latter reaction, no strong stereoselectivity was observed, but other S_N2' displacements carried out on 2,3- and 3,4-unsaturated hexopyranosides by organometallic carbon nucleophiles have led to allylically rearranged products formed by *anti*-processes[47,48].

Bis(benzoylmethyl)mercury applied to the vinyl glycoside **20** again gave the branched-chain glycals **30** and **31**, but, to illustrate that there are factors yet to be assessed in these processes, the reverse reaction, *i.e.*, treatment of the styryl glycoside **22** with bis(formylmethyl)mercury, did not yield the expected branched aldehydic glycals; instead, a 2:1 mixture of the vinyl glycosides **20** and **21** was obtained in high yield.

EXPERIMENTAL

General procedures. — The ^{1}H- and ^{13}C-n.m.r. data given in Tables I and II were recorded for solutions in $CDCl_3$ with a Varian XL200 and a Varian FT80A spectrometer, respectively. Optical rotations were determined for 0.5–1% solutions in deuteriochloroform (unless otherwise stated), using a 1-dm cell and a Perkin Elmer 241 polarimeter.

Preparation of the mercurial reagents. — Bis(formylmethyl)mercury was made by dropwise addition of butyl vinyl ether (24 g, 240 mmol) to a stirred suspension of yellow mercury(II) oxide (21.6 g, 100 mmol) and mercury(II) acetate (0.8 g, 2.5 mmol) in ethanol (8 mL) and water (4 mL). The mixture was filtered hot and the filtrate on cooling gave the mercurial, m.p. 81–83°; lit.[49] m.p. 93–95°. N.m.r. data: ^{1}H, δ 2.58 (dd, 2 H, J 5, 92.9 Hz), 9.52 (t, 1 H); ^{13}C, δ 52.4 (J 662 Hz), 199.5. Bis(acetonyl)mercury was prepared by the method of Lutsenko and Khomutov[49], and bis(benzoylmethyl)mercury by that of House *et al.*[50]. Bis(4-oxo-but-2-enyl)mercury was also made following the method of House *et al.*[50]. The product had m.p. 80–82° (dec.). ^{1}H-N.m.r. data: δ 2.38 (dd, 2 H, J 9, 175 Hz), 5.94 (dd, 1 H, J 8, 15 Hz), 7.13 (dt, 1 H), 9.37 (d, 1 H).

Vinyl 2,3,4,6-tetra-O-*acetyl-β*-D-*glucopyranoside* (**11**). — Tetra-*O*-acetyl-α-D-glucopyranosyl bromide (7.6 g, 18 mmol) in chloroform (15 mL) was added to bis(formylmethyl)mercury (10.0 g, 35 mmol) in chloroform (200 mL), and the mixture was

TABLE I

^{1}H-N.m.r. data for solutions in $CDCl_3$

Compound Chemical shifts (δ)[a]

	H-1	*H-2*	*H-3*	*H-4*	*H-5*	*H-6a*	*H-6b*	*H-1′*	*H-2′a*	*H-2′b*
11	4.82	5.16	5.26	5.12	3.78	4.28	4.14	6.40	4.58	4.29
12	4.93	5.15	5.28	5.11	3.79	4.27	4.15		4.15	4.15
13	5.09	5.32	5.35	5.17	3.89	4.30	4.18		4.96	4.60
19	5.77	6.08	5.87	5.39	4.48	4.31	4.22			
19β	5.65	5.97	5.82	5.19	3.92	4.29	4.28			
20	5.35	5.89	5.99	5.38	4.10	4.29	4.20	6.48	4.59	4.59
21	5.43	6.02	6.10	5.16	——4.11–4.33——			6.47	4.57	4.22
22	5.69	6.03	6.03	5.41	——4.18–4.33——				4.90	4.76
23	5.78	6.17	6.17	5.17	——4.23–4.29——				4.89	4.75
24	4.84	5.97	5.88	5.13	3.96	4.29	4.13	9.81	2.81	2.64
25	4.73	5.88	5.80	5.28	3.78	4.23	4.14	9.80	2.73	2.61
26	4.95	6.09	5.86	5.16	4.00	4.26	4.13		3.49	3.15
27	4.86	6.00	5.77	5.30	3.79	4.19	4.19		3.42	3.09
28	6.38	4.62	3.00	4.97	4.02	4.38	4.16	9.77	2.65	2.44
29	6.36	4.70	3.15	5.20	4.13	4.34	4.21	9.77	2.66	2.46
30	6.37	4.70	3.15	5.08	4.07	4.42	4.18		3.14	2.96
31	6.37	4.77	3.33	5.27	4.21	4.35	4.22		3.22	2.90

Compound Coupling constants (Hz)

	$J_{1,2}$	$J_{1,3}$	$J_{1,4}$	$J_{2,3}$	$J_{2,4}$	$J_{3,4}$	$J_{4,5}$	$J_{5,6a}$	$J_{5,6b}$	$J_{6a,6b}$	$J_{1',2'a}$	$J_{1',2'b}$	$J_{2'a,2'b}$
11	7.6			9.2		9.2	9.6	4.9	2.5	12.3	14.0	6.5	2.1
12	7.8			9.2		9.2	9.9	5.4	2.5	12.3			
13	7.9			9.0		9.8	9.8	5.4	2.5	12.2			3.0
19	3.2	1.8	1.9	10.1	1.9	1.9	9.5	5.6	2.7	12.1			
19β	1.7	2.4	2.5	10.2	1.7	2.5	7.6	4.5	5.2				
20	2.4			10.2	1.8		9.2	4.8	2.3	12.2	14.0	6.4	1.7
21											14.1	6.5	1.8
22							9.4	4.9		11.4			2.6
23													2.9
24	2.2	1.7	2.0	10.4	1.0	2.6	6.1	6.9	3.6	12.0	2.8	1.4	16.6
25	1.0	1.6	2.8	10.3	1.5	1.6	9.1	3.2	5.5	12.1	1.8	1.8	15.5
26	2.5	2.0	1.8	10.5	1.5	3.0	6.5	6.6	3.6	11.9			16.4
27	1.6	2.1	2.9	10.4	1.6	2.1	9.1	4.4	4.4				16.9
28	6.0	2.5		2.0		9.5	9.5.	4.6	2.3	12.3	1.3	1.3	17.7
29	6.1	1.8		4.3		5.6	7.6	5.7	3.3	12.0	1.2	1.2	17.8
30	5.9	2.1		1.8		9.4	9.8	4.7	2.2	12.4			17.8
31	6.1	1.7		4.1		5.4	7.3	6.4	2.6	12.4			16.7

[a] Appropriate resonances were observed for all of the groups in the assigned structures.

TABLE II

^{13}C-N.m.r. chemical shifts for solutions in $CDCl_3$

Compound	*Chemical shifts (δ)*[a]							
	C-1	*C-2*	*C-3*	*C-4*	*C-5*	*C-6*	*C-1'*	*C-2'*
11	99.2	68.5[b]	71.2[b]	72.5[c]	72.9[c]	62.1	148.8	93.2
12	97.5	68.7[b]	71.3[b]	72.2[c]	73.0[c]	62.3	158.2	87.3
13	98.5	68.7[b]	71.3[b]	72.3[c]	73.0[c]	62.2	158.7	88.3
19	83.6	128.9[c]	131.8[c]	65.2	67.4	63.1		
19β	81.5	128.8[c]	132.7[c]	64.6	74.9	63.3		
20	93.5[b]	126.6	130.3	65.0	67.7	62.6	149.0	92.3[c]
21	93.4[b]	126.3	129.0	63.7	73.0	63.3	148.7	92.2[c]
22	92.3	125.4	128.2	65.2	68.1	62.7	158.2	88.2
23	91.7	125.4	128.2	63.8	73.0	63.4	158.0	87.2
24	70.4	124.6	131.9	64.5	67.0	62.4	199.6	46.9
25	70.5	126.4	131.2	65.3	74.5	63.5	199.9	48.2
26	70.4	124.1	132.8	64.9	68.5	62.8	197.0	42.2
27	71.7	125.5	132.4	65.5	74.5	63.6	197.2	43.9
28	143.4	102.0	33.2	68.9	75.0	62.1	182.2	46.7
29	142.9	101.2	27.8	67.0	71.4	62.3	199.8	45.6
30	142.9	102.9	34.6	69.3	75.0	62.2	184.2	41.3
31	142.5	102.1	28.9	67.2	71.6	62.5	197.7	39.9

[a] Appropriate resonances were observed for all of the groups in the assigned structures. [b] May be interchanged.

heated under reflux for 22 h. After cooling, the solution was extracted with aqueous sodium thiocyanate, washed with water, and dried ($MgSO_4$). Removal of the solvent gave a solid residue (6.3 g, 92%) that was shown to be a single compound by ^{1}H-n.m.r. spectroscopy. Recrystallisation from dichloromethane–light petroleum afforded **11** as white needles (5.5 g, 80%), m.p. 95–97°, $[\alpha]_D$ −5.3; lit.[26], m.p. 96°, $[\alpha]_D$ −5.2°. The ^{1}H-n.m.r. spectrum was also in agreement with literature data[26].

Isopropenyl 2,3,4,6-tetra-O-acetyl-β-D-glucopyranoside (**12**). — The procedure used was as for compound **11**, and employed bis(acetonyl)mercury (15.9 g, 51 mmol), tetra-*O*-acetyl-α-D-glucopyranosyl bromide (10.1 g, 25 mmol), and chloroform (150 mL). After recrystallisation from dichloromethane–light petroleum, **12** (8.8 g, 90%) had m.p. 107–108°, $[\alpha]_D$ −11.4°.

Anal. Calc. for $C_{17}H_{24}O_{10}$: C, 52.5; H, 6.2. Found: C, 52.2; H, 6.2.

Styryl 2,3,4,6-tetra-O-acetyl-β-D-glucopyranoside (**13**). — Tetra-*O*-acetyl-α-D-glucopyranosyl bromide (9.2 g, 22 mmol) in acetonitrile (20 mL) was heated under reflux for 18 h with bis(benzoylmethyl)mercury (10.0 g, 23 mmol) in the same solvent (160 mL). After evaporation of the solvent and dissolution of the product in dichloromethane (50 mL), the mixture was filtered and treated as for compound **11**. Recrystallisation of the pale-yellow solid residue (9.8 g, 97%) from ether–light petroleum gave **13** (7.0 g, 70%), m.p. 105–107°, $[\alpha]_D$ −50.3°.

Anal. Calc. for $C_{22}H_{28}O_{10}$: C, 58.6; H, 5.8. Found: C, 58.4; H, 5.8.

But-1,3-dienyl 2,3,4,6-tetra-O-acetyl-β-D-glucopyranoside (**14**). — Tetra-*O*-ace-

tyl-α-D-glucopyranosyl bromide (50 mg, 0.12 mmol) in chloroform (1 mL) was heated under reflux for 18 h with a suspension of bis(4-oxo-but-2-enyl)mercury (412 mg, 1.2 mmol) in chloroform (3 mL). The mixture was washed with aqueous sodium sulphide, then with water, and dried ($MgSO_4$). The residue obtained by removing the solvent was purified by radial chromatography to give a solid (25 mg, 51%) which, on recrystallisation from dichloromethane–light petroleum, gave the butadienyl glycoside **14**, m.p. 135–137°, $[\alpha]_D$ −10.3° (dichloromethane); lit.[17], m.p. 152–153°, $[\alpha]_D$ −13.3° (dichloromethane). The ^{1}H-n.m.r. spectrum was consistent with published data[17].

Treatment of tetra-O-acetyl-α-D-glucopyranosyl bromide with diphenylmercury. — The bromide (1.0 g, 2.5 mmol) in acetonitrile (2 mL) was added to diphenylmercury (1.76 g, 5.0 mmol) in refluxing acetonitrile (22 mL), and heating under reflux was continued for 60 h. The main product (0.48 g, 60%) gave a ^{1}H-n.m.r. spectrum identical to that of 2,3,4,6-tetra-*O*-acetyl-1,5-anhydro-D-*arabino*-hex-1-enitol.

(1RS)-2-Bromo-1-methoxyethyl 2,3,4,6-tetra-O-acetyl-β-D-glucopyranoside (**15**). — *N*-Bromosuccinimide (14 mg, 0.08 mmol) and compound **11** (30 mg, 0.08 mmol), each in methanol (2 mL), were stirred together for 15 min at 20° in the dark. Dichloromethane (50 mL) was added, the solution was extracted with water (× 2) and dried, and the solvent was removed to give a solid (36 mg, 93%) which, on recrystallisation from dichloromethane–light petroleum, gave **15** (31 mg, 81%), m.p. 105–110°, $[\alpha]_D$ −34.1°; lit.[51] $[\alpha]_D$ −30.4°. The ^{1}H-n.m.r. spectrum was identical to that previously published[51] and indicated that the *R,S* stereoisomers were present in the ratio 2:1.

(1RS)-2-Bromo-1-methoxy-1-methylethyl 2,3,4,6-tetra-O-acetyl-β-D-glucopyranoside (**16**). — *N*-Bromosuccinimide (0.49 g, 2.75 mmol) in methanol (20 mL) was added with stirring to compound **12** (1.05 g, 2.7 mmol) in methanol (20 mL), and the mixture was stirred at 20° in the dark for 20 min. The residue produced on removal of the solvent was extracted with chloroform (300 mL), and the extract was washed (× 3) with water and dried. Evaporation of the chloroform gave **16** as a solid (1.15 g, 85%) which, on recrystallisation from dichloromethane–light petroleum, gave **16** (0.95 g, 70%), m.p. 102–111°, $[\alpha]_D$ −23.9°, shown by ^{1}H- and ^{13}C-n.m.r. spectroscopy to be a 1:1 mixture of *R* and *S* stereoisomers.

Anal. Calc. for $C_{18}H_{27}BrO_{11}$: C, 43.3; H, 5.5; Br, 16.0. Found: C, 43.2; H, 5.6; Br, 15.9.

(1RS)-2-Bromo-1-methoxy-1-phenethyl 2,3,4,6-tetra-O-acetyl-β-D-glucopyranoside (**17**). — Compound **13** (29 mg, 0.06 mmol) in methanol (2 mL) and *N*-bromosuccinimide (12 mg, 0.07 mmol) in methanol (1 mL) were stirred together in the dark at 20° for 15 min. Dichloromethane (50 mL) was added, the solution was washed with water and dried ($MgSO_4$), and removal of the solvent gave **17** (32 mg, 89%), $[\alpha]_D$ −27.3°, shown by ^{1}H- and ^{13}C-n.m.r. spectroscopy to be a 2.5:1 mixture of stereoisomers.

Anal. Calc. for $C_{23}H_{29}BrO_{11}$: C, 49.2; H, 5.2. Found: C, 49.2; H, 5.2.

Reaction of tri-O-acetyl-D-glucal with thiophenol. — Thiophenol (10 mL, 98 mmol) and boron trifluoride etherate (0.5 mL, 4 mmol) were added sequentially to a stirred solution of tri-*O*-acetyl-D-glucal (21.8 g) in benzene (50 mL) at 20°. Stirring was continued for 10 min, and the solution was washed with aqueous sodium hydrogen

carbonate, followed by water, and dried ($MgSO_4$). Removal of the solvent gave a syrup which solidified on standing. A portion (1.02 g) was resolved by radial chromatography to yield three isomeric products (in order of elution):

4,6-Di-*O*-acetyl-1,5-anhydro-2-deoxy-3-*S*-phenyl-3-thio-D-*ribo*-hex-1-enitol (57 mg, 6%), m.p. 79–80° (from dichloromethane–light petroleum), $[\alpha]_D$ +279°.

Anal. Calc. for $C_{16}H_{18}O_5S$: C, 59.6; H, 5.6; S, 9.9. Found: C, 59.6; H, 5.6; S, 10.0.

Phenyl 4,6-di-*O*-acetyl-2,3-dideoxy-1-thio-α-D-*erythro*-hex-2-enopyranoside (**19**; 690 mg, 71%), m.p. 64.5–66° (from dichloromethane–light petroleum), $[\alpha]_D$ +366°.

Anal. Found: C, 59.6; H, 5.6; S, 10.0.

Phenyl 4,6-di-*O*-*acetyl*-2,3-*dideoxy*-1-*thio*-β-D-*erythro*-hex-2-enopyranoside (**19**β; 88 mg, 9%), $[\alpha]_D$ +104°.

Anal. Found: C, 59.9; H, 5.7; S, 10.0.

The remaining, unfractionated, partly crystalline product was placed on an unglazed porcelain tile to afford **19** (16.1 g, 65%, following recrystallisation from dichloromethane–light petroleum).

Reaction of α-thioglycoside **19** *with bis(formylmethyl)mercury.* — Bis(formylmethyl)mercury (3.44 g, 12.0 mmol) in acetonitrile (25 mL) was added to **19** (1.92 g, 6.0 mmol) in the same solvent (7 mL), and the solution was heated under reflux for 2 h. After being cooled, it was washed with aqueous sodium sulphate followed by water and dried. Removal of the solvent gave a syrupy mixture of compounds **20** and **21** (1.45 g, 95%; 5:1, ^{1}H-n.m.r. analysis), a portion of which (334 mg) was purified by radial chromatography to give vinyl 4,6-di-*O*-acetyl-2,3-dideoxy-α-D-*erythro*-hex-2-enopyranoside (**20**; 186 mg, 53%), m.p. 26–34°, $[\alpha]_D$ +78.6°; lit.[25,26] $[\alpha]_D$ +83.7° and +78°. The ^{1}H-n.m.r. spectrum was in agreement with published data[26].

Anal. Calc. for $C_{12}H_{16}O_6$: C, 56.2; H, 6.3. Found: C, 56.0; H, 6.4.

The second product isolated was vinyl 4,6-di-*O*-acetyl-2,3-dideoxy-β-D-*erythro*-hex-2-enopyranoside (**21**; 54 mg, 15%), $[\alpha]_D$ +141°.

Anal. Found: C, 56.5; H, 6.4.

Reaction of α-thioglycoside **19** *with bis(benzoylmethyl)mercury.* — Bis(benzoylmethyl)mercury (2.19 g, 5.0 mmol) in toluene (170 mL) and **19** (756 mg, 2.3 mmol) in this solvent (6 mL) were heated together at 85–90° for 18 h. Following cooling, the mixture was reduced in volume to 15 mL and filtered, and the filtrate was washed with aqueous sodium sulphide, followed by water, and dried. Removal of the solvent gave a syrupy mixture of compounds **22** and **23** (632 mg, 81%; 5:1, ^{1}H-n.m.r. spectroscopy), which was fractionated by radial chromatography to give styryl 4,6-di-*O*-acetyl-2,3-dideoxy-α-D-*erythro*-hex-2-enopyranoside (**22**; 370 mg, 48%), m.p. 86–87° (from dichloromethane–light petroleum), $[\alpha]_D$ +57.4°.

Anal. Calc. for $C_{18}H_{20}O_6 \cdot 0.3H_2O$: C, 64.0; H, 6.1. Found: C, 63.9; H, 6.1.

The second product isolated was styryl 4,6-di-*O*-acetyl-2,3-dideoxy-β-D-*erythro*-hex-2-enopyranoside (**23**; 60 mg, 8%), $[\alpha]_D$ +112.5°.

Reaction of compound **20** *with zinc bromide.* — The vinyl α-glycoside **20** (466 mg, 1.8 mmol) was stirred in dichloromethane (20 mL) in the presence of molecular sieve for 2 h. Zinc bromide (38 mg, 0.17 mmol) was added and, after 18 h, the solution was

extracted with aqueous sodium hydrogen carbonate, washed with water, and dried ($MgSO_4$). Removal of the solvent gave compounds **24** and **25** (395 mg, 85%; 5:1, ^{1}H-n.m.r. spectroscopy), which were separated by radial chromatography. The first product eluted was (4,6-di-*O*-acetyl-2,3-dideoxy-β-D-*erythro*-hex-2-enopyranosyl)acetaldehyde (**25**; 51 mg, 11%), $[\alpha]_D$ +111°.

Anal. Calc. for $C_{12}H_{16}O_6$: C, 56.2; H, 6.3. Found: C, 56.2; H, 6.4.

The second product isolated was (4,6-di-*O*-acetyl-2,3-dideoxy-α-D-*erythro*-hex-2-enopyranosyl)acetaldehyde (**24**; 186 mg, 40%), $[\alpha]_D$ +81°.

Anal. Found: C, 56.1; H, 6.4.

Reaction of compound **22** *with boron trifluoride.* — The styryl α-glycoside **22** (44 mg, 0.13 mmol) was stirred in dichloromethane (3 mL) in the presence of molecular sieve for 2 h, boron trifluoride etherate (0.01 mL, 0.08 mmol) was added, and, after 15 min, the solution was shaken with aqueous sodium hydrogen carbonate, washed with water, and dried ($MgSO_4$). Removal of the solvent gave compounds **26** and **27** (30 mg, 70%; 3:1, ^{1}H-n.m.r. spectroscopy), which were isolated by radial chromatography. The first product eluted was α-(4,6-di-*O*-acetyl-2,3-dideoxy-β-D-*erythro*-hex-2-enopyranosyl)-acetophenone (**27**; 9 mg, 21%), $[\alpha]_D$ +128°; lit.[41] $[\alpha]_D$ +111°. The ^{1}H-n.m.r. spectrum was consistent with published data[41]. The second compound eluted was α-(4,6-di-*O*-acetyl-2,3-dideoxy-α-D-*erythro*-hex-2-enopyranosyl)acetophenone (**26**; 18.1 mg, 41%), $[\alpha]_D$ +36.2°; lit.[41] $[\alpha]_D$ +35.7°. The ^{1}H-n.m.r. spectrum was consistent with published data[41].

Thermal rearrangements of the vinyl glycosides **20** *and* **21**. — Following the procedure of Descotes *et al.*[26], **20** (73 mg) and **21** (25 mg) were heated separately in nitrobenzene (2 mL and 1 mL, respectively) in the presence of *N,N*-dimethylaniline (0.08 mL and 0.05 mL, respectively) at 155–165° for 18 and 6 h, respectively. The products were isolated by column chromatography on silica gel. From the α-glycoside **20**, the product (42 mg, 58%) was 4,6-di-*O*-acetyl-1,5-anhydro-2,3-dideoxy-3-*C*-formylmethyl-D-*ribo*-hex-1-enitol (**29**), $[\alpha]_D$ +154°; lit.[26] +124°. The ^{1}H-n.m.r. spectrum was consistent with published data[26]. From the β-glycoside **21**, the product (21 mg, 84%) was 4,6-di-*O*-acetyl-1,5-anhydro-2,3-dideoxy-3-*C*-formylmethyl-D-*arabino*-hex-1-enitol (**28**), $[\alpha]_D$ −12.6°.

Anal. Calc. for $C_{12}H_{16}O_6$: C, 56.2; H, 6.3. Found: C, 56.1; H, 6.3.

Reaction of the α-thioglycoside **19** *with bis(benzoylmethyl)mercury in refluxing toluene.* — Compound **19** (870 mg, 2.7 mmol) in toluene (9 mL) was added to a solution of bis(benzoylmethyl)mercury (2.4 g, 5.5 mmol) in the same solvent (70 mL) and heating under reflux was continued for 42 h. After being cooled, the solvent was removed, the residue was extracted with dichloromethane, and the extract was washed with aqueous sodium sulphide, then water, and dried. Following removal of the solvent, the product was purified by radial chromatography to give a white solid (576 mg, 64%). Recrystallisation (toluene–light petroleum) gave 4,6-di-*O*-acetyl-1,5-anhydro-3-*C*-benzoylmethyl-2,3-dideoxy-D-*arabino*-hex-1-enitol (**30**), m.p. 60.5–61.5°, $[\alpha]_D$ −87.5°

Anal. Calc. for $C_{18}H_{20}O_6$: C, 65.0; H, 6.1. Found: C, 65.0; H, 6.0.

The second compound eluted was 4,6-di-*O*-acetyl-1,5-anhydro-3-*C*-benzoylmethyl-2,3-dideoxy-D-*ribo*-hex-1-enitol (**31**; 78 mg, 9%). $[\alpha]_D$ +121.6°.

Anal. Found: C, 64.7; H, 6.1.

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