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FORMATION OF 6-DEOXY-6-IODOHEXOPYRANOSIDES AS SUBSTRATES FOR THE HEX-5-ENOSE DEGRADATION

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ABSTRACT

The synthesis of 6-deoxy-6-iodohexopyranosides as potential substrates for the hex-5-enose degradation has been examined for a range of mono-, di-, and poly-saccharide derivatives. It is shown that (*1*) unsubstituted D-glucopyranosides undergo selective, primary iodination without unwanted side-reactions; (*2*) primary iodination of D-galactopyranosides is accompanied by 3,6-anhydride formation, so that the desired reaction is only possible with protection of secondary hydroxyl groups; and (*3*) the extent of iodination in substrates of higher molecular weight is conveniently determined by reaction of acetylated (or methylated) derivatives with tributylstannane, followed by analysis of the resulting 6-deoxyhexopyranosides. The formation of 6-deoxy-6-iodohexopyranosyl residues in otherwise methylated plant galactomannans proceeds satisfactorily for (terminal) α-D-galactopyranosyl groups but incompletely for unbranched β-D-mannopyranosyl residues.

INTRODUCTION

The Bernet–Vasella reaction of 6-deoxy-6-iodohexopyranosides with zinc dust to give 5,6-dideoxyhex-5-enoses[1] has been developed as a new procedure for the selective cleavage of glycosidic linkages in otherwise permethylated oligo- and poly-saccharides[2,3]. The original objective was to achieve specific fragmentation at former α-D-galactopyranosiduronic acid linkages, and, in the case of methylated tragacanthic acid, the carboxyl-reduced polysaccharide was iodinated and the product heated with zinc to cause it to undergo cleavage at the modified glycosidic linkages. In this way, depolymerization was effected at sites where other selective-fragmentation methods had proved unsatisfactory. In our first studies[2,3], iodide displacement at primary hydroxyl groups in otherwise methylated derivatives was performed by the method of Binkley *et al.*[4], involving the formation of highly reactive triflic esters followed by treatment with tetrabutylammonium iodide. In reaction of other polysaccharide derivatives, the triflic ester intermediates have proved to be rather unstable, and i.r.-spectroscopic monitoring of triflate formation through the appearance of sulfonic ester bands and of their conversion into iodides through disappea-

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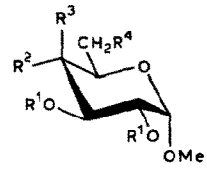
rance of these bands has been found to be insufficiently sensitive to confirm completeness of reaction in the two steps. As an alternative, we have found that reaction by the procedure of Hanessian *et al.*[5], using *N*-iodosuccinimide (NIS) and triphenylphosphine in pyridine, is satisfactory for iodination. The analysis of 6-deoxy-6-iodohexose residues in complex substrates is conveniently performed after reaction of acetylated (or methylated) derivatives with tributylstannane[6] to give the corresponding 6-deoxyhexopyranosides. With the intention of initiating the hex-5-enose degradation at 6-deoxy-6-iodohexopyranose residues generated from hexopyranose residues originally present, we have re-examined the foregoing[5], and other established methods for selective iodination at primary hydroxyl groups, for potential application to polysaccharides, directly without, or indirectly with, protection of secondary hydroxyl groups.

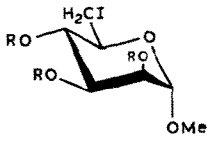
RESULTS AND DISCUSSION

Well established procedures for selective, primary iodination in hexopyranosides are those of Hanessian *et al.*[5] (see the foregoing) which uses *N,N*-dimethylformamide as the solvent, Anisuzzaman and Whistler[7] using carbon tetraiodide and triphenylphosphine in pyridine, and Garegg *et al.*[8,9] using iodine, imidazole, and triphenylphosphine in toluene, or toluene and acetonitrile. Reactions in the first two of these procedures are reported to take place under somewhat milder conditions with limited quantities of reagents, and in solvents more likely to be suitable for unsubstituted polysaccharides. They were therefore re-examined to ensure that selective primary iodination proceeds to completion without detectable reaction at secondary hydroxyl groups. To the best of our knowledge, the only reported examples of iodination at secondary as well as primary positions in unsubstituted glycosides are those of Garegg *et al.*[9] using a substantial excess of the last-mentioned reagents. In order to ensure that the products of secondary iodination would not escape detection in a polysaccharide substrate, a sample of methyl 2,3-di-*O*-acetyl-4,6-dideoxy-4,6-diiodo-α-D-galactopyranoside[9] (**1**) was treated with tributylstannane[6], to give methyl 2,3-di-*O*-acetyl-4,6-dideoxy-α-D-*xylo*-hexopyranoside (**2**). Although some deoxyhexoses undergo considerable decomposition on hydrolysis of their glycosides, in this instance hydrolysis proceeded satisfactorily, and conversion of the sugar into the corresponding 4,6-dideoxyhexitol tetraacetate gave a product whose sites of deoxygenation were established from characteristic fragment-ions in the mass spectrum. However, only primary substitution was observed when limited quantities of iodinating reagent were used in the Garegg procedure[8]. In the preparation of methyl 6-deoxy-6-iodo-α-D-glucopyranoside (**3**), where isolation of the product was best effected after acetylation, the subsequent catalytic *O*-deacetylation of the triacetate **4** with sodium methoxide was performed with no detectable formation of 3,6-anhydride.

Direct iodination of unsubstituted methyl α-D-glucopyranoside and methyl α-D-mannopyranoside was carried out with NIS–triphenylphosphine in pyridine

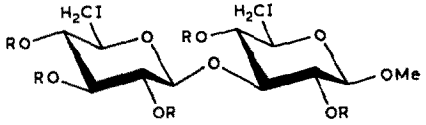


1 R^1 = Ac, R^2 = H, R^3 = R^4 = I
2 R^1 = Ac, R^2 = R^3 = R^4 = H
3 R^1 = H, R^2 = OH, R^3 = H, R^4 = I
4 R^1 = Ac, R^2 = OAc, R^3 = H, R^4 = I

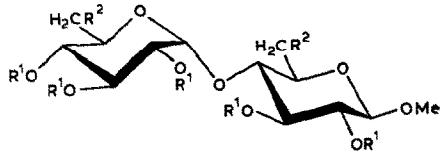


5 R = Ac

with no observable secondary substitution, and, in each case, the methyl 2,3,4-tri-*O*-acetyl-6-deoxy-6-iodo-α-D-hexopyranosides (**4** and **5**) were obtained in satisfactory, preparative yields. Likewise, selective iodination at both primary hydroxyl groups occurred when methyl β-laminarabioside and methyl β-maltoside reacted with NIS-triphenylphosphine in pyridine. Complete disappearance of starting material was observed, with no detectable formation of products of incomplete, or too extensive, reaction, and the resulting methyl 6,6′-dideoxy-6,6′-diiodoglycosides were isolated as crystalline pentaacetates (**6** and **7**) in overall yields of 68 and 66%, respectively. Previously reported yields of these compounds[10,11] from alternative syntheses involving selective primary tosylation, acetylation, and iodide displacement were 57 and 37%. In the case of methyl β-maltoside, a more detailed analysis of the iodination reaction was performed, to provide evidence for selectivity of substitution. The complete reaction-mixture after iodination was acetylated, treated with tributylstannane, and *O*-deacetylated. That this product contained methyl 6,6′-dideoxy-β-maltoside (**8**) as the sole detectable disaccharide derivative was shown by the results of the following two experiments. A portion of this material was hydrolyzed and, after reduction and acetylation, it gave 6-deoxyglucitol pentaacetate with no observable glucitol hexaacetate or dideoxyhexitol tetraacetate. The remainder of the material was methylated, and examination of the product by g.l.c.–m.s. showed a single component whose mass spectrum had characteristic fragment-ions for methyl 6,6′-dideoxy penta-*O*-methyl-β-maltoside (**9**).



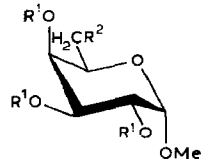
6 R = Ac



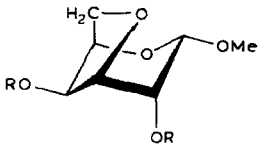
7 R^1 = Ac, R^2 = I
8 R^1 = R^2 = H
9 R^1 = Me, R^2 = H

In contrast to D-glucopyranosides, which show a high degree of selectivity in halogenation, D-galactopyranosides have been reported by other laboratories[9,12] to

give rise, under similar reaction-conditions, to 3,6-anhydro-D-galactopyranosides, as well as to the desired 6-deoxy-6-halo-D-galactopyranosides. Our results are in full agreement. Thus, reaction of methyl α-D-galactopyranoside with NIS–triphenylphosphine in pyridine, followed by acetylation, gave methyl 2,3,4-tri-*O*-acetyl-6-deoxy-6-iodo-α-D-galactopyranoside (**10**), together with methyl 2,4-di-*O*-acetyl-3,6-anhydro-α-D-galactopyranoside (**14**). Similiarly, as reported previously[12], reaction of methyl α-D-galactopyranoside with carbon tetrabromide–triphenylphosphine in pyridine afforded methyl 6-bromo-6-deoxy-α-D-galactopyranoside (**11**) with methyl 3,6-anhydro-α-D-galactopyranoside (**15**). Treatment of **11** with the same reagents under the conditions of its formation gave no anhydride **15**, suggesting that the formation of the latter compound takes place by intramolecular displacement (by O-3) of the intermediate phosphonium ion in competition with nucleophilic substitution by halide ion. Preliminary evidence showed that the corresponding iodination was also accompanied by anhydride formation. Attention was therefore turned to a less direct preparation of 6-deoxy-6-iodo-D-galactopyranosides that involved protection of secondary hydroxyl groups.



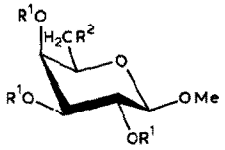
10 R^1 = Ac, R^2 = I
11 R^1 = H, R^2 = Br
12 R^1 = Ac, R^2 = OTr
13 R^1 = Ac, R^2 = OH



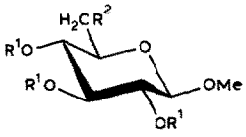
14 R = Ac
15 R = H

Preparation of methyl 2,3,4-tri-*O*-acetyl-β-D-galactopyranoside (**17**) by mild hydrolysis of the corresponding 6-*O*-trityl derivative (**16**) with acid has been shown by Kováč *et al.*[13] to be complicated by acetyl migration from O-4 to O-6 and, if reaction is performed with acetic acid, by acetylation at O-6. These complications were avoided by using the recently reported procedure of Klemer *et al.*[14] in which selective *O*-detritylation occurs on brief treatment with iodotrimethylsilane at room temperature. Kováč and Glaudemans[15] also showed that *O*-detritylation is not accompanied by acetyl migration. Using this procedure, followed by reaction with either carbon tetraiodide–triphenylphosphine or NIS–triphenylphosphine, we have shown that methyl 2,3,4-tri-*O*-acetyl-6-*O*-tritylhexopyranosides in the β-D-*gluco*, and α-D- and β-D-*galacto*, series may be cleanly converted into the corresponding methyl 2,3,4-tri-*O*-acetyl-6-deoxy-6-iodohexopyranosides.

The formation of syrupy methyl 2,3,4-tri-*O*-acetyl-α-D-galactopyranoside (**13**) took place without accompanying acetyl migration, as shown by its ^{1}H-n.m.r. spectrum, and by its complete disappearance on treatment with iodinating reagents, with formation of the 6-deoxy-6-iodo compound (**10**) in good yields. Similarly, in

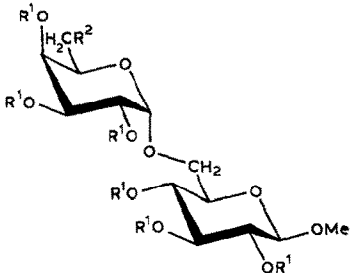


16 R^1 = Ac, R^2 = OTr
17 R^1 = Ac, R^2 = OH
18 R^1 = Ac, R^2 = I



19 R^1 = Ac, R^2 = OTr
20 R^1 = Ac, R^2 = OH
21 R^1 = Ac, R^2 = I

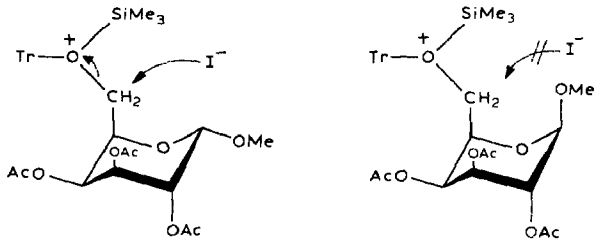
the melibiose series, the acetylated disaccharide glycoside trityl ether (**22**) was converted into the corresponding 6′-deoxy-6′-iodo compound (**24**) in high yield *via* the intermediate, hexa-*O*-acetyl derivative **23**.



22 R^1 = Ac, R^2 = OTr
23 R^1 = Ac, R^2 = OH
24 R^1 = Ac, R^2 = I

Klemer and Bieber[16] reported that iodotrimethylsilane may also be used for the direct displacement of specific ether groups by iodo substituents. The reaction conditions were considerably more drastic (1 h at 60–70° with 10–20 mol. equiv. of reagent) than those required for *O*-detritylation alone (10 min at room temperature with only 3 mol. equiv. of reagent). All methyl glycosides examined[16] for which good preparative yields were reported had the α-D-*gluco* configuration. An attempt was made to convert the β-D-galactopyranoside trityl ether (**16**) into the 6-deoxy-6-iodo compound (**18**), but, under the foregoing conditions required for iodide displacement, ^{1}H-n.m.r. spectroscopy of the product showed that the desired substitution had been accompanied by considerable anomerization, with the formation of α-D and β-D isomers in the ratio of ~3:1. Surprisingly, the reaction of methyl 2,3,4-tri-*O*-acetyl-6-*O*-trityl-α-D-galactopyranoside (**12**) with iodotrimethylsilane took place at room temperature, and the isolated iodo compound (**10**) showed no accompanying β-D anomer. No observable iodide displacement occurred when the β-D- trityl ether (**16**) was treated under these conditions. A possible explanation for this unusual observation is that iodide displacement at C-6 of the bulky (trimethylsilyl)trityloxonium ion requires a change to the $^1C_4$ conformation in order to relieve

unfavorable steric interaction with O-4 and its substituent, and that, in that conformation (see Scheme 1), the absence of an axial substituent at C-1 in the α-D-galactoside, as opposed to the presence of such a substituent in the β-D-galactoside, results in a relative lowering of the activation energy. The information obtained from these model-compound studies shows clearly that the introduction of iodo substituents at C-6 of galactopyranose residues must involve protection at secondary hydroxyl groups, and that the necessary protection–deprotection steps to expose primary hydroxyl groups must be performed with care in order to avoid migration of substituent groups.

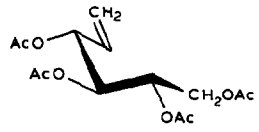


Scheme 1

In some of the aforementioned experiments, 6-deoxy-6-iodo compounds were converted into the corresponding 6-deoxy compounds by reduction with tributylstannane in the presence of a radical initiator. This procedure is satisfactory as a general method for the analysis of the extent of iodination in polysaccharide substrates. With some compounds, however, the reaction has been found to give traces (2–3%) of products which are oxygenated at C-6. G.l.c. analysis of the reaction of methyl 2,3,4-tri-*O*-acetyl-6-deoxy-6-iodo-α-D-glucopyranoside (**4**) with tributylstannane in the presence of an internal standard, followed by treatment of the reaction product with acetic anhydride in pyridine, showed 97% conversion into the deoxyglycoside, but some accompanying formation of methyl 2,3,4,6-tetra-*O*-acetyl-α-D-glucopyranoside as a minor by-product (~2%) occurred.

Quantitative aspects of the hexenose degradation were also examined. Reaction of acetylated iodo glycoside **4** with activated zinc dust in ethanol–water at 70° (conditions employed for methylated carbohydrates) in the presence of an internal standard, followed by reduction with sodium borohydride, acetylation, and g.l.c.–m.s. analysis, showed the formation of 3,4,5,6-tetra-*O*-acetyl-1,2-dideoxy-L-*xylo*-hex-1-enitol (**25**; 92%) with some (~5%) methyl 2,3,4-tri-*O*-acetyl-6-deoxy-α-D-glucopyranoside. The ^{1}H-n.m.r. spectrum of a preparative sample of **25** confirmed its identity. Unsubstituted methyl 6-deoxy-6-iodo-α-D-glucopyranoside (**3**) underwent a similar reaction with activated zinc dust, giving slightly less of compound **25** (87%) and slightly more deoxyglycoside (10%). Hutchinson *et al.*[17] reported the formation of the deoxyglycoside as a by-product during the reaction of the iodoglycoside **3** with the even-more-reactive, Riecke zinc preparation. To the extent

that this minor, competing reaction takes place in polysaccharide substrates, no glycoside cleavage, and thus no depolymerization, would take place.



25

In principle, the hex-5-enose degradation is not restricted to carboxyl-reduced glycuronans, because reaction could be initiated wherever selective iodination of primary hydroxyl groups can be achieved. Galactomannans from leguminous seeds[18] constitute a group of polysaccharides in which the main features are well established. Until recently, however, there has been a lack of definitive evidence for the distribution of α-D-galactopyranosyl side-chains attached to the 4-linked β-D-mannan backbone. Contradictory conclusions have been reported from several chemical approaches to the problem[19-22], but recently, McCleary and co-workers[23,24] obtained much more convincing results from the characterization of oligosaccharides formed by the action of *endo*-β-D-mannanases. Although these studies have given more-detailed information on side-chain distribution in galactomannans than is likely to be obtained from chemical degradations, the polysaccharides appeared to be suitable neutral glycan substrates on which to explore experimental difficulties in, and to evaluate potential applications of, the hexenose degradation. The hex-5-enose degradation has potential advantages over other chemical approaches[19,20] which also involve structural modification of primary hydroxyl groups, in that these methods give degradation products in which no recognizable segments arise from modified, unbranched D-mannosyl residues. In contrast, the hexenose reaction would be expected to furnish oligosaccharides in which sequences of branched, unmodified D-mannosyl residues would be terminated, after reduction, by base-stable hexitol units.

In their approach to galactomannan fragmentation, Baker and Whistler[19] reported the selective iodination of all primary hydroxyl groups on using the reaction with NIS–triphenylphosphine in hexamethylphosphoric triamide as the first step in the structural-modification sequence. In our hands, no detectable reaction occurred in this solvent under the conditions reported, even after addition of further quantities of reagents or when using a polysaccharide sample which had been freeze-dried from dimethyl sulfoxide to expose maximum surface area. In *N,N*-dimethylformamide, a solvent in which guaran was more swollen, some reaction took place, but it did not yield a soluble derivative. The modified polysaccharide was analyzed by hydrolysis, after acetylation, and treatment with tributylstannane. The results showed that no detectable change in D-mannosyl residues had occurred, ~50% of the D-galactosyl residues were unaltered, and only a very small proportion of the altered units had undergone iodination. Colorimetric analysis[25] indicated that near-

ly all of the modified D-galactosyl residues had been converted into those of the 3,6-anhydride. The nature of these modified residues was confirmed by g.l.c.-m.s. analysis of the products of methanolysis followed by acetylation, the products of which were identical to those similarly derived from methyl 3,6-anhydro-α-D-galactopyranoside. Because our results confirmed the susceptibility of galactopyranosides to 3,6-anhydride formation on attempted iodination[9,12], we examined an indirect procedure for the iodination of galactomannan with protection of secondary hydroxyl groups.

Parallel experiments were performed on water-soluble galactomannan preparations (**26**) from guar gum and locust-bean gum (see Table I and II). Reaction of

TABLE I

GUAR GALACTOMANNAN AND DERIVATIVES

Sugar constituents	*Compositions (%) of galactomannan derivatives*[a]					
	26	**27**	**29**	**31**	**32**	**33**
Gal	36					
Man	64					
2,3,4,6-Me_4Gal		35	2	34	< 1	2
2,3,4-Me_3Gal			35		1	31
2,3,6-Me_3Man		30	< 1	29		< 1
2,3-Me_2Man		34	65	36	62	65
2,3,4-Me_3Fuc					32	
2,3-Me_2Rha					4	

[a]**26**, water-soluble galactomannan; **27**, permethylated galactomannan; **29**, *O*-methyl-*O*-tritylgalactomannan; **31**, partially methylated galactomannan from *O*-detritylation of **29** followed by remethylation; **32**, 6-deoxy-6-iodo-*O*-methylgalactomannan from iodination of **29**; compound **33**, reconstituted *O*-methyl-*O*-tritylgalactomannan from tritylation of **29**, followed by further treatment with methylating reagents.

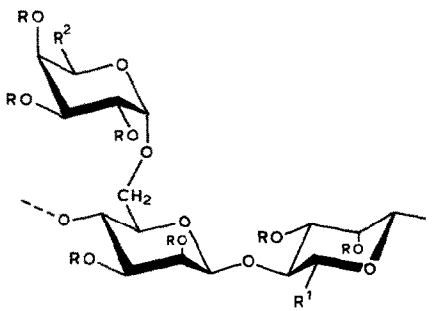
TABLE II

LOCUST BEAN GALACTOMANNAN AND DERIVATIVES

Sugar constituents	*Compositions (%) of galactomannan derivatives*[a]					
	26	**27**	**29**	**31**	**32**	**33**
Gal	29					
Man	70					
2,3,4,6-Me_4Gal		28	2	29	1	2
2,3,4-Me_3Gal			26		1	25
2,3,6-Me_3Man		44	< 1	44		1
2,3-Me_2Man		26	69	26	58	70
2,3,4-Me_3Fuc					26	
2,3-Me_2Rha					12	

[a]As in Table I.

galactomannan with trityl chloride in pyridine resulted in virtually complete *O*-tritylation of primary hydroxyl groups, as shown by methylation of *O*-tritylgalactomannan (**28**) and comparison of the sugars formed on hydrolysis of *O*-methyl-*O*-tritylgalactomannan (**29**) and fully methylated galactomannan (**27**). Treatment of *O*-methyl-*O*-tritylglycan (**29**) with iodotrimethylsilane resulted in complete *O*-detritylation, as shown by re-alkylation of samples of partially methylated galactomannan (**30**) to give a product (**31**) of methylated-sugar composition identical to that of the fully methylated derivative (**27**). Partially methylated galactomannan (**30**) was treated with NIS–triphenylphosphine in large excess. Analysis of 6-deoxy-6-iodo-*O*-methylgalactomannan (**32**) after reaction with tributylstannane showed that >95% of the galactopyranose residues had undergone iodination, but that only a very small proportion (~3%) of unbranched D-mannosyl residues were modified. Repeated reaction with NIS–triphenylphosphine, or treatment with triflic anhydride followed by tetrabutylammonium iodide[4], failed to increase the degree of substitution. Incompleteness of iodination appears to be genuinely attributable to steric factors in which galactopyranosyl residues afford protection to primary hydroxyl groups of unbranched mannopyranosyl residues. The lack of reaction is apparently limited to direct displacement at C-6 of these residues, as *O*-tritylation of partially methylated galactomannan (**30**), with the re-introduction of the bulky substituent at O-6, gave back a sample (**33**), identical to the original *O*-methyl-*O*-tritylgalactomannan (**29**), in which no further methylation could be effected.



26 R = H, R^1 = R^2 = CH_2OH
27 (= **31**) R = Me, R^1 = R^2 = CH_2OMe
28 R = H, R^1 = R^2 = CH_2OTr
29 (= **33**) R = Me, R^1 = R^2 = CH_2OTr
30 R = Me, R^1 = R^2 = CH_2OH
32 R = Me, R^1 = CH_2OH (+ some CH_2I), R^2 = CH_2I

These experiments have revealed unsuspected problems in the introduction of iodo substituents into these neutral glycans, a step which is necessary for the successful application of the hex-5-enose degradation. Despite the difficulties often encountered in effecting SN2 displacements at C-6 of individual galactopyranosyl

residues[26], a high degree of substitution was achieved in galactopyranosyl end-groups when the secondary hydroxyl groups were protected.

EXPERIMENTAL

General methods. — Evaporations were conducted under diminished pressure at 40° or lower. Optical rotations were measured with a Perkin–Elmer model 141 polarimeter at ~20°. N.m.r. spectra (^1H and ^{13}C) were recorded with a Bruker AM 300 spectrometer for solutions in $CDCl_3$ or D_2O with Me_4Si, MeCN, or 1,4-dioxane as internal standards. G.l.c. was performed with a Perkin–Elmer 3B chromatograph, using (*A*) a packed column of 3% of silicone gum Silar 10 CP on Chromasorb W-HP (100–200 mesh), or (*B*) a S.C.O.T. column coated with silicone gum OV-225. A Perkin–Elmer Data System Sigma 10B instrument was used for peak integration. Column *B* was used in a Pye–Unicam series 204 gas chromatograph connected by a jet separator to a VG Micromass 16F mass spectrometer and VG data system 2000, operated with an inlet temperature of ~250°, an ionization potential of 70 eV, and an ion-source temperature of ~250°.

Examination of products from reaction of methyl α-D-glucopyranoside with iodine, imidazole, and triphenylphosphine. — Tributylstannane (0.01 mL) and 2,2′-azobis(2-methylpropanonitrile) as initiator (catalytic amount) were added to methyl 2,3-di-*O*-acetyl-4,6-dideoxy-4,6-diiodo-α-D-galactopyranoside[9] (**1**) (10 mg) in toluene at 100° under nitrogen. T.l.c. showed disappearance of starting material after 10 min, and the solution was evaporated, the residual syrup was partitioned between acetonitrile and light petroleum, and the acetonitrile layer was washed four times with light petroleum and evaporated, to give syrupy methyl 2,3-di-*O*-acetyl-4,6-dideoxy-α-D-*xylo*-hexopyranoside (**2**), whose ^1H-n.m.r. spectrum was identical to that reported by Garegg *et al.*[9]. A sample of **2** was hydrolyzed with M trifluoroacetic acid for 1 h at 100°, the sugars reduced with sodium borohydride, and the alditols acetylated. Examination of the product by g.l.c.–m.s. on column *B* (120°, 4°/min → 200°) showed fragment-ions at *m/z* 173, 131, and 113, diagnostic for a 4,6-dideoxyhexitol tetraacetate, but none at *m/z* 231, 171, 129, and 111 which would be characteristic for the 3,6-dideoxy isomer. Iodination of methyl α-D-glucopyranoside with limited quantities of reagents, as described by Garegg *et al.*[9], followed by acetylation, gave crystalline methyl 2,3,4-tri-*O*-acetyl-6-deoxy-6-iodo-α-D-glucopyranoside (**4**), m.p. and mixed m.p. 148–149°, $[\alpha]_D$ +114° (*c* 1.0, chloroform), in 78% yield, with no detectable products of further iodination.

Selective primary iodination with NIS–triphenylphosphine. — (*a*) *Methyl 2,3,4-tri-O-acetyl-6-deoxy-6-iodo-α-D-glucopyranoside* (**4**). Triphenylphosphine (540 mg, 2.06 mmol) was added with stirring to a cooled solution of methyl α-D-glucopyranoside (200 mg, 1.03 mmol) and freshly prepared *N*-iodosuccinimide[27] (NIS; 464 mg, 2.06 mmol) in pyridine (10 mL). The solution was heated for 2 at 50°; t.l.c. then showed complete disappearance of starting material and no products of disubstitution. Methanol was added to the cooled solution which was evaporated

to a syrup. This was dissolved in dichloromethane (10 mL), and the solution was extracted with water (3 × 20 mL); the aqueous extracts were combined, and evaporated to a syrup which was treated overnight with 1:1 acetic anhydride–pyridine. The reaction mixture was worked up in the usual way, and crystallization from ethanol furnished the iodoglycoside **4** (293 mg, 66%); m.p. 148–149°, $[\alpha]_D$ +114° (*c* 1.0, chloroform) (lit.[8] m.p. 148–149°, $[\alpha]_D$ +114°). The iodoglycoside triacetate **4** (100 mg) in dry methanol was treated with sufficient methanolic sodium methoxide to maintain permanent alkalinity, until complete *O*-deacetylation had taken place. The solution was shaken with Amberlite IR-120 (H^+) resin to remove sodium ions, and then evaporated to a syrup which crystallized from ethanol, to yield methyl 6-deoxy-6-iodo-α-D-glucopyranoside (**3**, 66 mg, 94%); m.p. 146–147°, $[\alpha]_D$ +101.5° (*c* 1.0, water) (lit.[28] m.p. 146–147°, $[\alpha]_D$ +101.5°).

(*b*) *Methyl 2,3,4-tri-*O*-acetyl-6-deoxy-6-iodo-*α*-*D*-mannopyranoside* (**5**). Methyl α-D-mannopyranoside (100 mg) was treated as in (*a*) and, on acetylation, the product afforded the acetylated iodoglycoside **5** (149 mg, 68%); m.p. 90–91°, $[\alpha]_D$ +37° (*c* 1.0, chloroform) (lit.[29] m.p. 91–92°, $[\alpha]_D$ +37°).

(*c*) *Methyl 2,4,2',3',4'-penta-*O*-acetyl-6,6'-dedeoxy-6,6'-diiodo-β-laminarabioside* (**6**). Methyl β-laminarabioside[10] (100 mg, 0.28 mmol) was allowed to react with triphenylphosphine (294 mg, 1.12 mmol) and freshly prepared NIS (252 mg, 1.12 mmol) in pyridine (10 mL) as described in (*a*). Normal work-up, followed by acetylation, and crystallization from ethanol, afforded the disaccharide derivative **6** (151 mg, 68%); m.p. 219–220°, $[\alpha]_D$ −7.0° (*c* 2.2, chloroform) (lit.[10] m.p. 220–221°, $[\alpha]_D$ −7.2°).

(*d*) *Methyl 2,2',3,3',4'-penta-*O*-acetyl-6,6'-dedeoxy-6,6'-diiodo-β-maltoside* (**7**). Methyl β-maltoside (100 mg) was treated as in (*c*), and, on acetylation, afforded disaccharide derivative **7** (144 mg, 66%); m.p. 195–196°, $[\alpha]_D$ +48° (*c* 7.6, chloroform) (lit.[11] m.p. 196–197°, $[\alpha]_D$ +48°).

A second portion (25 mg) of methyl β-maltoside was treated similarly, but after acetylation, the whole product (without crystallization) in boiling toluene under nitrogen was treated with tributylstannane (0.02 mL) and a catalytic amount of 2,2'-azobis(2-methylpropanonitrile) for 10 min. Catalytic *O*-deacetylation of the product with methanolic sodium methoxide afforded a syrupy disaccharide glycoside. Hydrolysis of a portion of this material with trifluoroacetic acid, followed by reduction ($NaBH_4$), acetylation, and g.l.c. analysis on column *A* (210°, isothermal), showed the formation of 6-deoxyglucitol pentaacetate and no observable glucitol hexaacetate or dideoxyhexitol tetraacetate. The remaining portion of the disaccharide glycoside was methylated by the Hakomori procedure[30], to give a product which showed a single component on examination by g.l.c.–m.s. using column *B* (160°, 4°/min → 210°). The mass spectrum showed fragment ions at *m/z* 363, 350, 275, 249, 189, and 157, indicating the presence of methyl 6,6'-dideoxypenta-*O*-methyl-β-maltoside (**9**).

(*e*) *Methyl 2,3,4-tri-*O*-acetyl-6-deoxy-6-iodo-*α*-*D*-galactopyranoside* (**10**) *and methyl 2,4-di-*O*-acetyl-3,6-anhydro-*α*-*D*-galactopyranoside* (**14**). Methyl α-D-galac-

topyranoside (300 mg from dehydration of the crystalline monohydrate) was treated as in (*a*), and, after acetylation, the mixture was chromatographed on silica gel using 10:1 chloroform–acetone, to give anhydro compound **14** (103 mg, 26%); m.p. 80–82°, $[\alpha]_D$ +57.9° (*c* 1.0, chloroform) {lit.[31] m.p. 83–84°, $[\alpha]_D$ +58.8° (chloroform)}, and acetylated iodoglycoside **10** as a syrup (365 mg, 55%); $[\alpha]_D$ +144° (*c* 1.0, chloroform) lit.[32] $[\alpha]_{578}$ +143° (chloroform); ^{1}H-n.m.r. (chloroform-*d*): δ 1.99, 2.09, 2.16 (s, each 3 H, 3 OAc), 3.15 (m, 2 H, CH_2I), 3.48 (s, 3 H, OMe), 4.13 (m, 1 H, H-5), 4.99 (d, 1 H, $J_{1,2}$ 3.6 Hz, H-1), 5.13 (dd, 1 H, $J_{2,3}$ 10.9 Hz, H-2), 5.34 (dd, 1 H, $J_{3,4}$ 3.3 Hz, H-3), and 5.54 (dd, 1 H, $J_{4,5}$ 1.1 Hz, H-4); ^{13}C-n.m.r.: δ_C 0.49 (C-6), 55.78 (OCH_3), 97.13 (C-1,α), and 169.8, 170.14, and 170.3 (3 $OCOCH_3$).

Anal. Calc. for $C_{13}H_{19}IO_8$: C, 36.30; H, 4.45; I, 29.50. Found: C, 36.43; H, 4.27; I, 29.90.

Reaction of methyl α-D-galactopyranoside with triphenylphosphine and carbon tetrahalides. — Triphenylphosphine (163 mg, 1.21 mmol) and carbon tetrabromide (103 mg, 0.62 mmol) were added to methyl α-D-galactopyranoside (60 mg, 0.62 mmol) in pyridine (5 mL) at 0°, and the solution was heated for 1.5 h at 60°; there was then complete disappearance of starting material. After addition of methanol (2 mL) to quench the reaction, the solution was evaporated and the residue was chromatographed on silica gel. Elution with chloroform, and then with chloroform–methanol, yielded (*i*) methyl 6-bromo-6-deoxy-α-D-galactopyranoside (**11**) (15 mg, 19%); m.p. 172–174° (from 1:1 chloroform–hexane); $[\alpha]_D$ +156° (*c* 1.0, chloroform) {lit.[33] m.p. 174–175°, $[\alpha]_D$ +157° (chloroform)}, and (*ii*) methyl 3,6-anhydro-α-D-galactopyranoside (**15**; 42 mg, 78%); m.p. 138–139° (from ethanol), $[\alpha]_D$ +82° (*c* 1.0, water) {lit.[31] m.p. 140°, $[\alpha]_D$ +84° (water)}. A sample of methyl α-D-galactopyranoside was treated with carbon tetraiodide–triphenylphosphine under the same conditions, and t.l.c. showed that iodination was accompanied by 3,6-anhydride formation. In a further experiment, methyl 6-bromo-6-deoxy-α-D-galactopyranoside (**11**) was treated with carbon tetrabromide–triphenylphosphine under the conditions of its formation, but no 3,6-anhydride (**15**) could be detected.

Conversion of methyl tri-O-acetyl-6-O-tritylhexopyranosides into methyl 2,3,4-tri-O-acetyl-6-deoxy-6-iodohexopyranosides. A. Two-step procedure via *methyl 2,3,4-tri-O-acetylhexopyranosides.* — (*a*) *Methyl 2,3,4-tri-O-acetyl-6-deoxy-6-iodo-β-D-glucopyranoside* (**21**). Chlorotrimethylsilane (0.024 mL, 1.92 mmol) was added with stirring to methyl 2,3,4-tri-*O*-acetyl-6-*O*-trityl-β-D-glucopyranoside[34] (**19**; 350 mg, 0.64 mmol) and sodium iodide (288 mg, 1.92 mmol) in acetonitrile (7.5 mL) under nitrogen. Examination by t.l.c. showed disappearance of starting material after ~10 min; water (5.0 mL) was then added and the mixture was stirred for 15 min at 0°. Precipitated tritanol was removed by filtration, the filtrate was diluted with dichloromethane (7 mL), the organic phase was washed with aqueous 10% sodium thiosulfate, the aqueous phase was extracted with dichloromethane, and the extracts were combined, dried, and evaporated. Crystallization of the residue from ether–light petroleum afforded methyl 2,3,4-tri-*O*-acetyl-β-D-glucopyranoside (**20**; 128 mg, 84%); m.p. 134–135°, $[\alpha]_D$ −19.0° (*c* 1.0, chloroform) {lit.[35] m.p. 134–

135°, $[\alpha]_D$ −19.0° (chloroform)}. Compound **20** (100 mg, 0.31 mmol) was allowed to react with triphenylphosphine (162 mg, 0.62 mmol) and freshly prepared NIS (140 mg, 0.62 mmol) in pyridine (10 mL) as described previously. Normal work-up followed by column chromatography using 10:1 chloroform–acetone, and crystallization from ethanol, furnished the acetylated iodoglycoside **21** (83 mg, 62%); m.p. 111–112°, $[\alpha]_D$ −0.9 (*c* 1.0, chloroform) {lit.[36] m.p. 111–112°, $[\alpha]_D$ +0.9 (chloroform)}.

(*b*) *Methyl 2,3,4-tri-*O*-acetyl-6-deoxy-6-iodo-β-*D*-galactopyranoside* (**18**). Methyl 2,3,4-tri-*O*-acetyl-6-*O*-trityl-β-D-galactopyranoside[37] (1.08 g, 1.92 mmol) was treated with iodotrimethylsilane generated *in situ*, as in (*a*), and furnished methyl 2,3,4-tri-*O*-acetyl-β-D-galactopyranoside (**17**); (514 mg, 84%); m.p. 108–109°, $[\alpha]_D$ +5.0° (*c* 1.0, chloroform) {there are discrepancies between these values and those reported by Kováč *et al.*[13], m.p. 125–126°, $[\alpha]_D$ +5.0° (chloroform), and by Klemer *et al.*[14], m.p. 122°, $[\alpha]_D$ −4.3° (chloroform), but the ^{1}H- and ^{13}C-n.m.r. data for our sample were identical to those reported by Kováč *et al.*[13]}. Further reaction of **17** (96 mg, 0.3 mmol) with NIS (135 mg, 0.6 mmol) and triphenylphosphine (158 mg, 0.6 mmol) in pyridine, as in (*a*), gave acetylated iodoglycoside **18** (89 mg, 69%) as a syrup; $[\alpha]_D$ +19.5° (*c* 1.2, chloroform) {lit.[32] $[\alpha]_{578}$ +20° (chloroform)}; ^{1}H-n.m.r. (chloroform-*d*): δ 1.99, 2.09, 2.16 (s, each 3 H, 3 OAc), 3.21 (m, 2 H, CH_2I), 3.57 (s, 3 H, OMe), 3.85 (m, 1 H, H-5), 4.40 (d, 1 H, $J_{1,2}$ 7.95 Hz, H-1), 5.02 (dd, 1 H, $J_{3,4}$ 3.4 Hz, H-3), 5.18 (dd, 1 H, $J_{2,3}$ 10.5 Hz, H-2), and 5.54 (dd, 1 H, $J_{4,5}$ 1.0 Hz, H-4); ^{13}C-n.m.r.: δ_C −0.1 (C-6), 57.2 (OCH_3), 101.9 (C-1,β), and 169.4, 170.0, and 170.2 (3 $OCOCH_3$).

Anal. Calc. for $C_{13}H_{19}IO_8$: C, 36.30; H, 4.45; I, 29.50. Found: C, 36.37; H, 4.66; I, 29.10.

(*c*) *Methyl 2,3,4-tri-*O*-acetyl-6-deoxy-6-iodo-α-*D*-galactopyranoside* (**10**). As in (*b*), methyl 2,3,4-tri-*O*-acetyl-6-*O*-trityl-α-D-galactopyranoside[38] (**12**; 56 mg, 0.10 mmol) was converted into methyl 2,3,4-tri-*O*-acetyl-α-D-galactopyranoside (**13**; 31 mg, 95%); ^{1}H-n.m.r. (chloroform-*d*): δ 2.08, 2.09, and 2.10 (s, each 3 H, 3 OAc), 3.41 (s, 3 H, OMe), 3.52–3.71 (m, 2 H, CH_2OH), 4.99 (d, 1 H, $J_{1,2}$ 3.6 Hz, H-1), 5.18 (dd, 1 H, $J_{2,3}$ 10.6 Hz, H-2), and 5.38 (d, 1 H, H-4). Carbon tetraiodide (50 mg, μmol) was added in several portions to the glycoside triacetate **13** (30 mg, 94 μmol) and triphenylphosphine (51 mg, 0.19 mmol) in pyridine at 0°. The solution was heated for 45 min at 60°; t.l.c. then showed disappearance of all of the starting material. Methanol was added to quench the reaction, the solution was evaporated, and a solution of the residue in dichloromethane was washed with aqueous 10% sodium thiosulfate, dried, and evaporated to a syrup, which was chromatographed on silica gel using 20:1 chloroform–acetone, to give acetylated iodoglycoside **10** (20 mg, 64%), identical to the sample previously prepared.

(*d*) *Methyl 2,3,4,2',3',4'-hexa-*O*-acetyl-6'-deoxy-6'-iodo-β-melibioside* (**24**). Methyl 2,3,4,2',3',4'-hexa-*O*-acetyl-6'-*O*-trityl-β-melibioside (**22**) was prepared from methyl 6-*O*-trityl-β-melibioside[39] in the usual way, and had m.p. 110–112°.

Anal. Calc. for $C_{44}H_{50}O_{17}$: C, 62.12; H, 5.88. Found: C, 62.27; H, 6.22.

Compound **22** (50 mg) was treated with iodotrimethylsilane as in (*a*), to give methyl 2,3,4,2′,3′,4′-hexa-*O*-acetyl-β-melibioside (**23**) as a syrup (29 mg, 81%); ^{1}H-n.m.r. (chloroform-*d*): δ 2.01–2.15 (18 H, 6 OAc), 3.49 (s, 3 H, OMe), 3.61–3.75 (m, 2 H, C*H*$_2$OH), 4.42 (d, 1 H, $J_{1,2}$ 7.9 Hz, H-1), 5.36 (dd, 1 H, $J_{2,3}$ 10.6, $J_{3,4}$ 3.3 Hz, H-3′), and 5.36 (br d, H-4′). Hexaacetate **23** (29 mg) was treated with NIS–triphenylphosphine in pyridine as described previously, with complete disappearance of starting material, and the crude product was chromatographed as in (*c*), to give acetylated iodoglycoside **24** (22 mg, 64%); ^{1}H-n.m.r. (chloroform-*d*): δ 1.99–2.15 (6 s, 18 H, 6 OAc), 3.48 (s, 3 H, OMe), 4.45 (d, 1 H, $J_{1,2}$ 7.8 Hz, H-1), 5.31 (br d, H-4′), and 5.37 (dd, 1 H, $J_{2,3}$ 10.6, $J_{3,4}$ 3.3 Hz, H-3′); ^{13}C-n.m.r.: δ_C 0.8 (C-6′), 20.61–20.85 (6 CO*C*H$_3$), 56.8 (O*C*H$_3$), 96.3 (C-1′), and 101.2 (C-1).

Anal. Calc. for $C_{25}H_{35}IO_{16}$: C, 41.78; H, 4.87; I, 17.69. Found: C, 41.74; H, 5.03; I, 17.89.

B. Direct transformation. (*a*) *Methyl 2,3,4-tri-O-acetyl-6-deoxy-6-iodo-α-*D*-galactopyranoside* (**10**) (with B. A. Williams). Chlorotrimethylsilane (1.2 mL, 9.0 mmol) in freshly distilled acetonitrile (5 mL) was added dropwise, with stirring, to methyl 2,3,4-tri-*O*-acetyl-6-*O*-trityl-α-D-galactopyranoside (**12**; 499 mg, 0.88 mmol) and sodium iodide (1.34 g, 8.9 mmol) in acetonitrile (15 mL), and the mixture was kept at room temperature. T.l.c. showed that reaction was complete after 1 h; the mixture was poured into ice–water (50 mL) and extracted with chloroform, and the extracts were washed successively with aqueous sodium hydrogencarbonate, aqueous sodium thiosulfate, and water, dried, and evaporated. The resulting syrup was chromatographed on silica gel with chloroform–acetone mixtures, and furnished the acetylated iodoglycoside **10** (248 mg, 65%) with spectral properties identical to those of other samples.

(*b*) *Attempted preparation of the β anomer* (**18**). Methyl 2,3,4-tri-*O*-acetyl-6-*O*-trityl-β-D-galactopyranoside (**16**) was treated with iodotrimethylsilane (generated *in situ*) at room temperature as before, but no formation of iodoglycosides **18** was observed. Treatment of **16** with 20 mol. equiv. of reagent for 1 h at 60°, followed by chromatography on silica gel with 20:1 chloroform–acetone, gave a syrupy product (~70%) whose ^{1}H-n.m.r. spectrum showed signals corresponding to those of a mixture of α-D (**12**) and β-D (**18**) acetylated iodoglycosides in the ratio of ~3:1.

Conversion of O-acetyl-6-deoxy-6-iodohexopyranosides into O-acetyl-6-deoxyhexopyranosides. — For quantitative analysis, 6-deoxy-6-iodohexopyranosides as simple glycosides, or as constituents of polysaccharides, were acetylated (if not already fully substituted) and then processed as in the following experiment. Tributylstannane (0.02 mL, 0.05 mmol) and 2,2′-azobis(2-methylpropanonitrile (~2 mg) as radical initiator were sequentially added to methyl 2,3,4-tri-*O*-acetyl-6-deoxy-6-iodo-α-D-glucopyranoside (**4**; 21.5 mg) and methyl 2,3,4-tri-*O*-acetyl-β-D-xylopyranoside (as internal standard; 14.5 mg, 0.05 mmol) in boiling, dry oxolane (2 mL), and boiling was continued for 1 h. The solution was cooled and evaporated, the residue was partitioned between acetonitrile and light petroleum, the acetonitrile layer was evaporated, and the product was treated with acetic anhydride–pyridine

before g.l.c. analysis on column *A* (200°, isothermal). The results showed the formation of methyl 2,3,4-tri-*O*-acetyl-6-deoxy-α-D-glucopyranoside (97%) and methyl 2,3,4,6-tetra-*O*-acetyl-α-D-glucopyranoside (2%). For polysaccharide substrates, the product from the work-up of the tributylstannane treatment was directly hydrolyzed, and the reducing sugars liberated were converted into alditol acetates for analysis.

Treatment of 6-deoxy-6-iodoglycosides and their acetylated derivatives with zinc. — Freshly activated zinc dust (300 mg) was added to acetylated 6-deoxy-6-iodoglycoside **4** (150 mg) in 4:1 ethanol–water, and the mixture was heated, with stirring, at 70°. When t.l.c. showed complete disappearance of starting material (~40 min), the mixture was filtered through a pad of Celite, the filtrate was treated with sodium borohydride, and, after normal work-up, the product was acetylated, to give 3,4,5,6-tetra-*O*-acetyl-1,2-dideoxy-L-*lyxo*-hex-1-enitol (**25**; 61 mg, 71%); ^{1}H-n.m.r. (chloroform-*d*): δ 2.05–2.17 (4 s, 12 H, 4 OAc), 3.98 (dd, 1 H, H-6), 4.29 (dd, 1 H, H-6), 5.30 (m, 4 H, H-4, H-5, and CH_2=CH), 5.44 (t, 1 H, H-3), and 5.74 (m, 1 H, CH=CH_2). For quantitative analysis, a sample of **19** (10 mg) was treated with zinc dust in the same way, in the presence of added methyl 2,3,4,6-tetra-*O*-acetyl-β-D-glucopyranoside (3.5 mg) as an internal reference. Examination by g.l.c. on column *B* of the products after reduction and acetylation showed formation of **25** (92%), together with methyl 2,3,4-tri-*O*-acetyl-6-deoxy-α-D-glucopyranoside (5%). The identities of these products were confirmed by g.l.c.–m.s. In a similar manner, methyl 6-deoxy-6-iodo-α-D-glucopyranoside (**3**) was heated with zinc dust in 4:1 ethanol–water in the presence of methyl β-D-glucopyranoside as an internal standard, and g.l.c. analysis of the products showed 87% and 10% conversion into the same two compounds.

Isolation and structural modifications of galactomannans. — Water-soluble galactomannan fractions (**26**) were isolated from commercial samples of guar and locust-bean gums (Sigma Chemical Company) by heating 0.8% aqueous suspensions in an autoclave for 3 h at 100°, removal of insoluble material by centrifugation, addition of ethanol (0.67 vol.), redispersion of the precipitated polysaccharides in water, and lyophilization. Galactomannan samples were hydrolyzed[40] in sealed tubes for 2 h at 120°, D-allose was added as an internal standard, and the sugars were converted into the corresponding alditol acetates[41] for g.l.c. analysis. Galactomannans were methylated by the Hakomori procedure as described by Lindberg[30], methylated galactomannans (**27**) were hydrolyzed, and methylated sugars were converted into partially methylated alditol acetates for g.l.c. analysis, with confirmation of identities by g.l.c.–m.s. where necessary.

Freshly prepared trityl chloride (2.56 g) was added with stirring to a suspension of galactomannan (0.5 g) in pyridine (50 mL), and the mixture was kept for 12 h at 100°. Addition of methanol (20 mL) to the cooled solution gave a precipitate which was washed several times with methanol and then acetone, and dried, to give *O*-tritylgalactomannan (**28**) (~1 g). This derivative (0.45 g) was methylated by the Hakomori procedure, and the product was purified by chromatography on Sepha-

dex LH-20, to give *O*-methyl-*O*-tritylgalactomannan (**29**; 0.47 g). Methylated sugars formed on hydrolysis of this derivative were analyzed in the usual way.

Iodotrimethylsilane (440 mg; from chlorotrimethylsilane and sodium iodide[13]) in acetonitrile (4 mL) was added, with stirring, to *O*-methyl-*O*-tritylgalactomannan (**29**; 300 mg) in chloroform (12 mL). The solution was kept for 8 min at room temperature; the reaction was then quenched by the addition of a few drops of aqueous 10% sodium thiosulfate until the iodine coloration disappeared. The mixture was evaporated to dryness, and the residue was extracted with pyridine, to give a solution of partially methylated galactomannan (**30**), the major portion of which was used for the next transformation. The remaining solution was evaporated, and the crude **30** was remethylated, to give a product (**31**) having the same composition as methylated galactomannan (**27**).

Triphenylphosphine (580 mg) was added to a cooled solution of partially methylated galactomannan (**30**) and NIS (498 mg) in pyridine, and the solution was heated for 6 h at 60°. Further quantities of NIS (498 mg) and triphenylphosphine (580 mg) were added, and the solution was kept for 12 h at 60°. The reaction was quenched by the addition of methanol (2 mL), and the solution was evaporated. The residue was partitioned between dichloromethane and aqueous sodium thiosulfate, and the aqueous layer was repeatedly extracted with chloroform. The organic layers were combined, dried, concentrated, and purified by passage through a column of Sephadex LH-20 with dichloromethane as eluant, to yield 6-deoxy-6-iodo-*O*-methylgalactomannan (**32**; 140 mg). The extent of iodination was determined by treatment of a sample of **32** with tributylstannane in boiling oxolane for 1 h, followed by hydrolysis and analysis of the resulting methylated sugars in the usual way.

Attempted direct iodination of guar galactomannan. — Analysis, as described later, of guaran samples recovered from attempted iodinations in hexamethylphosphoric triamide[19] showed unaltered ratios of galactose and mannose residues, and the absence of 6-deoxyhexoses from iodinated residues.

Triphenylphosphine (420 mg) was added with stirring to a cooled suspension of swollen guar galactomannan (101 mg) and NIS (360 mg) in *N*,*N*-dimethylformamide (10 mL), and the mixture was heated for 8 h at 90°. Two further batches of NIS (each 360 mg) and triphenylphosphine (each 420 mg) were added after 8 and 16 h. The reaction was quenched by the addition of methanol (2 mL) after 24 h, and the further addition of methanol (35 mL) to the cooled reaction-mixture gave a precipitate, which was washed several times with methanol and then acetone, to give modified galactomannan (94 mg). A portion of the modified glycan was acetylated in 1:1 acetic anhydride–pyridine and the product was treated with tributylstannane in boiling oxolane for 1 h, and then hydrolyzed to give component sugars which were converted into alditol acetates for g.l.c.–m.s. analysis. The results showed the presence of galactose (16%), fucose (1%), and mannose (66%). Colorimetric analysis of the modified glycan with the resorcinol reagent[25] showed the presence of 17% of 3,6-anhydrogalactose. The identity of the modified sugar constituent was confirmed

by treating the polysaccharide with boiling, methanolic 7% hydrogen chloride for 4 h, followed by acetylation and g.l.c.-m.s. analysis of the products using column *B*. The results showed the presence *inter alia* of three compounds which were formed in a similar manner by methanolysis followed by acetylation of methyl 3,6-anhydro-α-D-galactopyranoside, and whose mass spectra[42] showed that they were methyl 2,4-di-*O*-acetyl-3,6-anhydro-α-D-galactopyranoside (with fragment ions at *m/z* 229, 200, 157, 140, and 127), the corresponding β-D anomer (with the same fragment ions), and 2,4,5-tri-*O*-acetyl-3,6-anhydro-β-galactose dimethyl acetal (with fragment ions at *m/z* 303, 243, 187, 183, 169, and 127).

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