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RING-OPENING POLYMERIZATION OF 1,6-ANHYDRO-2,4-DI-*O*-BENZYL-3-*O*-*tert*-BUTYLDIMETHYLSILYL-β-D-GLUCOPYRANOSE AND SYNTHESIS OF α-(1→3)-BRANCHED DEXTRANS

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ABSTRACT

Ring-opening polymerization of 1,6-anhydro-2,4-di-*O*-benzyl-3-*O*-*tert*-butyldimethylsilyl-β-D-glucopyranose (**1**) with a Lewis acid catalyst and desilylation with tetrabutylammonium fluoride of the polymer obtained gave 2,4-di-*O*-benzyl-(1→6)-α-D-glucopyranan having a free hydroxyl group at C-3. Copolymerization of 3-*O*-acetyl-1,6-anhydro-2,4-di-*O*-benzyl-β-D-glucopyranose (**2**) with 1,6-anhydro-2,3,4-tri-*O*-benzyl-β-D-glucopyranose (**3**) and subsequent deacetylation of the copolymer with the use of *N,N*-dimethylformamide–methanol containing sodium methoxide also gave a partially benzylated (1→6)-α-D-glucopyranan. These polymer could be glycosylated to give branched polymers. Mannose, glucose, and galactose derivatives were used as glycosylation agents. Glycosylation by the ortho-ester method was used for mannose and the Eby and Schuerch method was used with glucose and galactose. Deprotection of the mannosylated polysaccharide was performed to give (1→6)-α-D-glucopyranan having 3-*O*-(α-D-mannopyranosyl) branches. Polymers were characterized by molecular weight, optical rotation, and by ^{1}H- and ^{13}C-n.m.r. spectroscopy.

INTRODUCTION

Such polysaccharides as heparin, an anticoagulant agent, dextran, a plasma expander, polysaccharides with antitumor activity, polysaccharides of cell-walls, and oligosaccharide chains of blood-group determinants have recognized biochemical functions in the living organism. However, in natural polysaccharides having complex structures, the relation between structure and biochemical function is not always clear.

The ring-opening polymerization of anhydro sugars provides stereoregular polysaccharides of definite structures that have been prepared from hexoses and pentoses as starting monosaccharides[1–9]. The cationic ring-opening polymerization of 1,6-anhydro sugar derivatives and subsequent deprotection gives linear (1→6)-α-D-hexopyranans[4–7]. These polymers have been used for such biochemical studies

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as the interaction of synthetic polysaccharides and proteins[10–12], antigen–antibody reactions[13–16] and the specificity of enzymes[17,18].

Most natural polysaccharides have branches that may affect their biochemical functions. For example, dextran B512, elaborated by *Leuconostoc mesenteroides* strain B512, was shown to contain 95% of its glucose residues linked α-(1→6), with the remaining 5% being linked α-(1→3); the latter are localized at branching points[19]. Chemical synthesis of some branched polysaccharides have been described[20–25].

The purpose of this research was to synthesize a (1→6)-α-D-glucopyranan having monosaccharide branches on O-3 of the glucose residues in order to investigate the interaction of synthetic, branched dextrans with anti-dextran antibodies or with such proteins as concanavalin A. For this it was first necessary to prepare polysaccharides having hydroxyl groups only at C-3. Kobayashi *et al.* prepared 2,4-di-*O*-benzyl-(1→6)-α-D-glucopyranan by polymerization of 3-*O*-acetyl-1,6-anhydro-2,4-di-*O*-benzyl-β-D-glucopyranose and by subsequent removal of the acetyl groups[26]. After obtaining the same polymer with high molecular weight by using the crotyl group at O-3 as a selectively removable group, Ito and Schuerch synthesized (1→6)-α-D-glucopyranan with various proportions of 3-*O*-(α-D-glucopyranosyl) side-chains[27].

In this investigation, we report the synthesis and cationic ring-opening polymerization of 1,6-anhydro-2,4-di-*O*-benzyl-3-*O*-*tert*-butyldimethylsilyl-β-D-glucopyranose to give a stereoregular polysaccharide that can be deprotected regioselectively. To confirm the advantage of the synthetic method using the silyl group, we undertook the polymerization of 3-*O*-acetyl-1,6-anhydro-2,4-di-*O*-benzyl-β-D-glucopyranose with subsequent deacetylation. Glycosylation followed by deprotection of the partially benzylated (1→6)-α-D-glucopyranans obtained, thus leading to branched dextrans, is reported.

RESULTS AND DISCUSSION

*Polymerization of 1,6-anhydro-2,4-di-*O*-benzyl-3-*O*-tert-butyldimethylsilyl-β-D-glucopyranose* (**1**). — Polymerization was performed with a Lewis acid as catalyst in dichloromethane at low temperature. The results are shown in Table I. Polymerization of **1** with phosphorus pentafluoride gave polymers having number-average molecular weight of 3.2–5.6 × 10^4 in high yields. Polymerization with low concentrations (1 and 2 mol%) of PF_5 catalyst gave polymers in relatively low yields, although in the polymerization of 1,6-anhydro-2,3,4-tri-*O*-benzyl-β-D-glucopyranose (**3**), the optimum PF_5 concentration was[28] 0.8–1.0 mol%. The polymer yield increased by several percent with increasing monomer-to-solvent ratio (nos. 110 and 105, nos. 107 and 109). The polymers obtained had high positive specific rotations of +118.6 to +126.8°, indicating α-specificity for the polymerization. The ^{13}C-n.m.r. spectra of the polymers showed a single peak for C-1, and therefore, poly(**1**) was a stereoregular 2,4-di-*O*-benzyl-3-*O*-*tert*-butyldimethylsilyl-(1→6)-α-D-

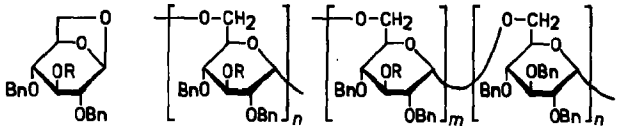
TABLE I

POLYMERIZATION OF 1,6-ANHYDRO-2,4-DI-*O*-BENZYL-3-*O*-*tert*-BUTYLDIMETHYLSILYL-β-D-GLUCOPYRANOSE[a]

Polymer no.	*Monomer (g)*	*CH_2Cl_2 (mL)*	*Catalyst (mol%)*	*Yield (%)*	*$[\alpha]_D^{25}$[b] (deg)*	*$\overline{M}_n \times 10^{-4}$[c]*
111	0.3	0.6	1	35.8	+118.6	3.4
106	0.3	0.6	2	68.7	+122.9	3.2
105	0.3	0.6	3	84.3	+122.9	3.9
110	0.3	1.0	3	78.3	+121.6	3.5
107	0.5	0.6	3	87.5	+122.8	5.6
109	0.5	0.5	3	91.1	+126.8	4.5
112	1.0	1.0	3	92.5	+124.1	3.7
104	0.3	0.6	5[d]	14.7	+109.0	0.7

[a]Temperature, −60°; time, 19.0–21.0 h; catalyst, phosphorus pentafluoride. [b]Measured in $CHCl_3$ (c = 1). [c]Determined by gel-permeation chromatography. [d]Antimony pentachloride.

glucopyranan (**4**). Antimony pentachloride was a very poor catalyst, polymerizing **1** to a polymer of a low molecular weight (0.7×10^4) in low yield (14.7%), a result similar to that of polymerization 1,6-anhydro-2,3,4-tri-*O*-benzyl-β-D-glucose.



1 R = Si(Me)(Me)-Bu^t **4** R = Si(Me)(Me)-Bu^t **6** R = Ac

7 R = H

2 R = Ac **5** R = H

3 R = Bn

It is noteworthy that **1**, which contains the *tert*-butyldimethylsilyl group, has high polymerizability, whereas 1,6-anhydro-2,3,4-tri-*O*-*tert*-butyldimethylsilyl-β-D-glucopyranose showed[29] no polymerizability in dichloromethane with PF_5 concentrations of 6 or 30 mol% at −60° or 0°; oligomers or active species were not found and most of the monomer was recovered without desilylation. Previously, Ruckel and Schuerch reported that the trimethylsilylated homolog showed absolutely no polymerizability[3].

Desilylation of poly(**1**) *to give 2,4-di-*O*-benzyl-(1→6)-α-*D*-glucopyranan.* — *tert*-Butyldimethylsilyl groups were removed from poly(**1**) (**4**) by using tetrabutylammonium fluoride in tetrahydrofuran[30]. The reaction was completed upon refluxing for 3 h. The results are shown in Table II. Fig. 1(a) shows the ^{1}H-n.m.r. spectrum of poly(**1**) and Fig. 1(b) that of the desilylated polymer. Fig. 1(b) shows, in place of the methyl group peaks of the *tert*-butyldimethylsilyl group (~0 and 0.9

TABLE II

DESILYLATION OF POLY(**1**)

Polymer no.	*Starting Polymer no.*	*Yield (%)*	$[\alpha]_D^{25}$[a] *(deg)*	$\overline{M}_n \times 10^{-4}$[b]
203	103[c]	65.7	+140.8	5.4
207	107	—	+140.6	6.0
209	109	68.2	+143.4	6.0
212	112	72.7	+143.3	4.4

[a]Measured in $CHCl_3$ (c = 1). [b]Determined by gel-permeation chromatography. [c]$\overline{M}_n$: 5.5 × 10^4.

p.p.m.), a peak for the hydroxyl group on C-3 (2.3 p.p.m.), indicating that the silyl ether linkage had been successfully cleaved to give 2,4-di-*O*-benzyl-(1→6)-α-D-glucopyranan (**5**). After the deprotection, an increase of specific rotations from +140.6° to +143.4° (lit.[26] +138.5°) was observed. Moreover, scission of the polymer backbone did not take place during the desilylation; for example, desilylation of poly(**1**) of $\overline{d.p.}_n$ 123 gave a polymer of almost the same $\overline{d.p.}_n$ (175, no. 207 in Table II). The increase in $\overline{d.p.}_n$ accompanying desilylation is probably due to molecular association by hydrogen bonding, because a polymer of $\overline{d.p.}_n$ 135 was obtained by acetylation of the desilylated polymer.

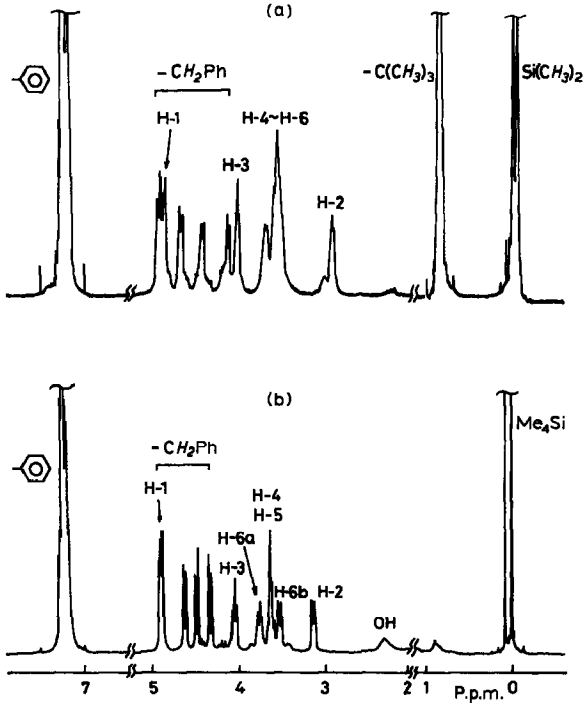


Fig. 1. ^{1}H-N.m.r. spectra of (a) 2,4-di-*O*-benzyl-3-*O*-*tert*-butyldimethylsilyl-(1→6)-α-D-glucopyranan (**4**) and (b) 2,4-di-*O*-benzyl-(1→6)-α-D-glucopyranan (**5**).

Polymerization of 3-O-*acetyl-1,6-anhydro-2,4-di-*O-*benzyl-β-*D-*glucopyranose* (**2**) *and copolymerization of* **2** *with 1,6-anhydro-2,3,4-tri-*O-*benzyl-β-*D-*glucopyranose* (**3**). — Polymerization of **2** and copolymerization of **2** with **3** were performed under high vacuum. The results are shown in Table III. When the polymerization was conducted with PF_5 as catalyst in dichloromethane (nos. 11 and 12), the yields and molecular weights of the polymers decreased with increasing mole fraction of **2** in feed. Kobayashi *et al.*[31] evaluated the monomer-reactivity ratios according to the Kelen–Tüdos method in this copolymerization system and found $r_1 = 0.10$ and $r_2 = 3.3$. This result reveals that the polymerizability of **2** was lowered by the existence of the acetyl group, probably because of interaction between PF_5 and the acetyl group of **2**. We therefore used sulfur dioxide as solvent, as it was expected that SO_2 might interact with PF_5 to lower the interaction between PF_5 and the acetyl groups in the monomer. However, the polymerization result was not improved, and the molecular weight of the polymers obtained was low (5000–9000).

Deacetylation of copoly(**2,3**). — Deacetylation of copoly(**2,3**) (**6**) by sodium methoxide in *N,N*-dimethylformamide–methanol[26] gave the results summarized in Table IV. The mole fraction of hydroxylated glucose residues was determined by

TABLE III

POLYMERIZATION AND COPOLYMERIZATION OF 3-*O*-ACETYL-1,6-ANHYDRO-2,4-DI-*O*-BENZYL-β-D-GLUCOPYRANOSE (M_1, **2**) WITH 1,6-ANHYDRO-2,3,4-TRI-*O*-BENZYL-β-D-GLUCOPYRANOSE (M_2, **3**) AT −60°

Polymer no.	*Mole fraction of M_1 in feed*	*Catalyst (mol%)*	*Solvent*	*Time (h)*	*Yield (%)*	*Mole fraction of M_1 unit in copolymer*[a]	$[\alpha]_D^{25}$[b] *(deg)*	$\overline{M}_n \times 10^{-4}$[c]
11	1.00	PF_5 5	SO_2	27	19.1	1.00	+143.7	0.9
12	1.00	$SbCl_5$ 10	SO_2	26	8.8	1.00	—	0.5
13	0.62	PF_5 5	CH_2Cl_2	16	19.4	0.63	+135.0	1.6
14	0.33	PF_5 5	CH_2Cl_2	16	79.1	0.23	+125.4	7.3
15	0.30	PF_5 10	SO_2	26	60.2	0.20	+115.8	1.5

[a]Calculated from ^{13}C-n.m.r. spectra. [b]Measured in $CHCl_3$ ($c = 1$). [c]Determined by gel-permeation chromatography.

TABLE IV

DEACETYLATION OF COPOLYMER OF **2** WITH **3**

Polymer no.	*Starting polymer no. (g)*	*$HCONMe_2$ (mL)*	*Na/CH_3OH (mg)/(mL)*	*Yield (%)*	*Mole fraction of hydroxylated glucose residues*[a]	$[\alpha]_D^{25}$[b] *(deg)*	$\overline{M}_n \times 10^{-4}$[c]
23	13 0.3	20	10/15	63.5	0.63	+123.4	2.5
24	14 0.5	30	100/30	80.1	0.23	+119.7	4.1
21	11 0.2	15	45/13	74.7	0.20	+111.9	1.8

[a]Calculated from ^{13}C-n.m.r. spectra. [b]Measured in $CHCl_3$ ($c = 1$). [c]Determined by gel-permeation chromatography.

^{13}C-n.m.r. spectroscopy. Acetyl groups were removed without scission of the main chain, as was the *tert*-butyldimethylsilyl group, and a partially benzylated (1→6)-α-D-glucopyranan (**7**) was obtained. However, deacetylation required five days for completion, whereas desilylation was completed in 3 h.

Branching of partially benzylated (1→6)-α-D-glucopyranan. — The partially benzylated (1→6)-α-D-glucopyranan containing hydroxyl groups, obtained by desilylation of poly(**1**) (**5**) or deacetylation of copoly(**2**,**3**) (**7**), was glycosylated to form branched polymers. Derivatives of mannose, glucose, and galactose were used as glycosylation agents. To form α-linked hexose branches, it is convenient to use the orthoester method for mannose and the method of Eby and Schuerch[32] employing 1-*O*-tosyl derivatives for glucose and galactose. Thus, 3,4,6-tri-*O*-acetyl-β-D-mannose-1,2-(methyl orthoacetate), 2,3,4-tri-*O*-benzyl-6-*O*-(*N*-phenylcarbamoyl)-1-*O*-tosyl-α-D-glucopyranose, and 2,3,4,6-tetra-*O*-benzyl-1-*O*-tosyl-α-D-galactopyranose were used for the glycosylation.

Glycosylation of 2,4-di-*O*-benzyl-(1→6)-α-D-glucopyranan (**5**) with 3,4,6-tri-*O*-acetyl-β-D-mannose-1,2-(methyl orthoacetate) was carried out with mercuric bromide as catalyst in nitromethane–dichloromethane[33] (Table V, no. 303). In contrast to reactions with alcohols of low molecular weight, 10 equivalents of the orthoester (based on the polymer) and 50 mol% of the catalyst were required to effect the reaction. The reaction for 24 h at 60° under high vacuum caused glycosylation and gave the branched polysaccharide **8**, whereas no reaction occurred at 25 or 40°. Despite use of 10 equivalents of the orthoester, the mole fraction of glycosylated residues in the main chain was only 0.34 per glucose residue, as calculated from ^{1}H-n.m.r. spectra.

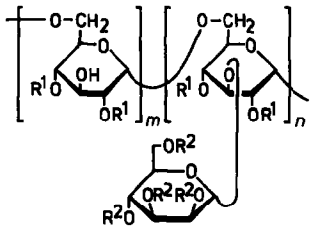
Accordingly, 2,6-lutidinium perchlorate was used as the catalyst and chlorobenzene as solvent for the glycosylation reaction[33]. The solution was boiled under reflux at atmospheric pressure for 45 min. The mole ratio of the glucose residues in the polymer to the orthoester used is shown in Table V, and 1 mol% of

TABLE V

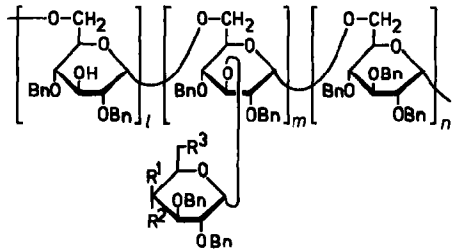
GLYCOSYLATION BY THE ORTHOESTER METHOD[a]

Polymer no.	*Starting polymer no.*	*Mole ratio of reactants*[b]	$[\alpha]_D^{25,c}$ *(deg)*	$\overline{M}_n \times 10^{-4,d}$	*Mole fraction of glycosylated residues in main chain*[e]
303[f]	203	1:10	—	6.8	0.34
403	203	1:1	+127.4	5.5	0.56
407	207	1:2	+132.3	8.2	0.98
409	209	1:3	+133.1	4.7	1.01
412	212	1:2	+135.3	4.5	0.91

[a]Polymer, 0.1–0.5 g; solvent, chlorobenzene (20 w/v%); catalyst, 2,6-lutidinium perchlorate (1mol% to polymer). [b]The mole ratio of 2,4-di-*O*-benzyl-(1→6)-α-D-glucopyranan and 3,4,6-tri-*O*-acetyl-β-D-mannose-1,2-(methyl orthoacetate). [c]Measured in $CHCl_3$ (c = 1). [d]Determined by gel-permeation chromatography. [e]Calculated from ^{1}H-n.m.r. spectra. [f]Solvent, nitromethane–dichloromethane; catalyst, mercuric bromide.



8 R^1 = Bn , R^2 = Ac
9 R^1 = R^2 = H



10 R^1 = H , R^2 = OBn , R^3 = OCONH⟨◎⟩
11 R^1 = R^3 = OBn , R^2 = H

catalyst was used in all experiments. In no. 403, although only 1 equivalent of orthoester to polymer was used, the mole fraction of glycosylated residues was 0.56, which was about twice as high as that of no. 303.

It was found that the latter was the superior method in this glycosylation reaction. When the quantity of the orthoester was increased, reaction readily occurred and glycosylation became essentially quantitative. The ^{13}C-n.m.r. spectrum of the glycosylated polymer **8** (Fig. 2) shows carbonyl-group peaks at 170

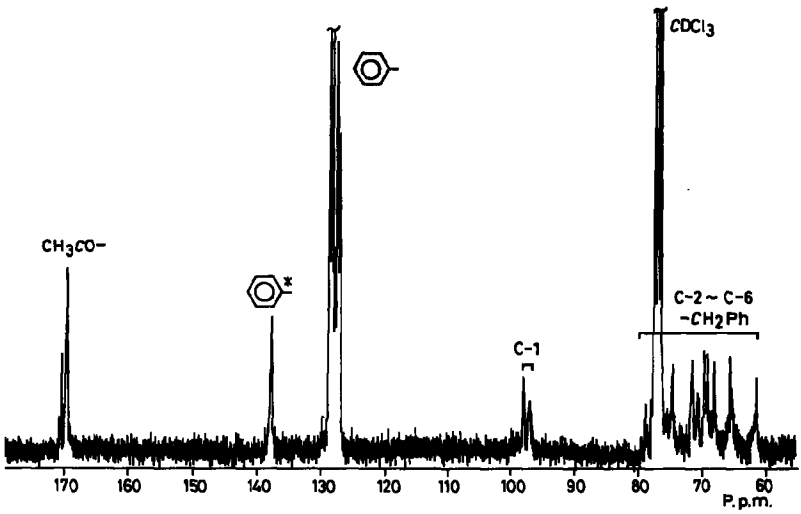


Fig. 2. ^{13}C-N.m.r. spectrum of mannosylated polysaccharide (**8**).

TABLE VI

GLYCOSYLATION WITH 1-*O*-TOSYL DERIVATIVES[a]

Polymer no.	*Starting polymer no.*	*1-O-Tosyl derivatives*	$\overline{M}_n \times 10^{-4}$[b]	*Mole fraction of glycosylated residues in main chain*[c]	*Branching efficiency*[d]
33	23	glucose[e]	3.0	0.53	0.84
34	24	glucose[e]	6.6	0.14	0.61
31	21	galactose[f]	5.5	0.11	0.47

[a]Solvent, 1:2 dimethoxyethane–acetonitrile; temperature, 27°; time, 24 h. [b]Determined by gel-permeation chromatography. [c]Calculated from ^{13}C-n.m.r. spectra. [d]Molar ratio of glycosylated glucose residues to hydroxyl-containing glucose residues. [e]2,3,4-Tri-*O*-benzyl-6-*O*-(*N*-phenylcarbamoyl)-1-*O*-tosyl-α-D-glucopyranose. [f]2,3,4,6-Tetra-*O*-benzyl-1-*O*-tosyl-α-D-galactopyranose.

p.p.m. from the acetylated mannosyl branches, indicating that glycosylation had taken place. Of two C-1 peaks, the one at higher field (97 p.p.m.) may be attributed to glucose residues in the main chain and the lower one (98 p.p.m.) to the mannose branches.

Polysaccharides containing glucose and galactose as branches were next synthesized by the procedure of Eby and Schuerch[32]. 2,3,4-Tri-*O*-benzyl-6-*O*-(*N*-phenylcarbamoyl)-α-D-glucopyranosyl bromide or 2,3,4,6-tetra-*O*-benzyl-α-D-galactopyranosyl bromide were treated with silver *p*-toluenesulfonate in acetonitrile, and the resultant 1-*O*-tosyl derivatives were directly treated with the partially benzylated (1→6)-α-D-glucopyranan (**7**) in dimethoxyethane–acetonitrile. Both reactions were performed under high vacuum. About 7–9 equiv. of the glycosyl bromides to the polymer were used, so that glycosylation occurred readily. The results are shown in Table VI and Figs. 3 and 4 show ^{13}C-n.m.r. spectra of the

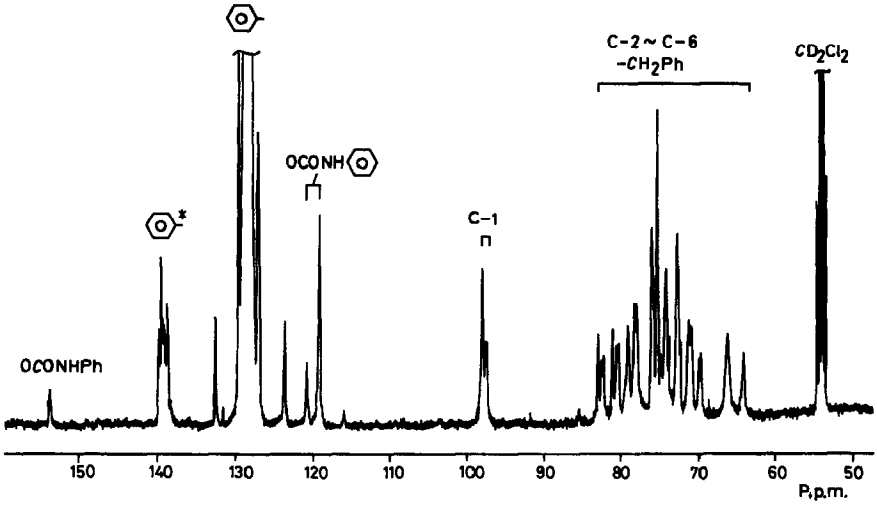


Fig. 3. ^{13}C-N.m.r. spectrum of glucosylated polysaccharide (**10**).

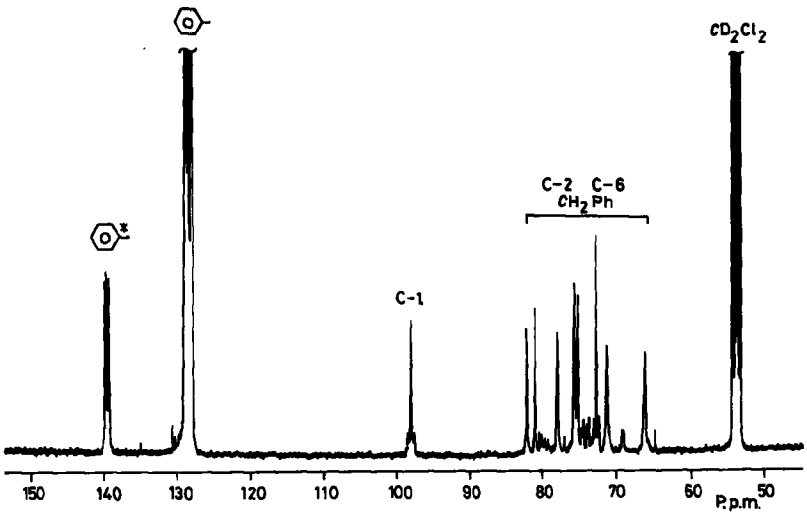


Fig. 4. ^{13}C-N.m.r. spectrum of galactosylated polysaccharide (**11**).

branched polysaccharides **10** and **11**. The mole fraction of glycosylated units in the main chain was calculated by ^{13}C-n.m.r. spectroscopy. The branching efficiency is defined as the molar ratio of the glycosylated glucose residues to hydroxyl-containing residues. For glucosylation, the branching efficiency of no. 31 was higher than of no. 32. As the concentration of hydroxyl groups of the starting polymer no. 21 was higher and its molecular weight was lower than those of no. 22, the reactivity of no. 21 may be higher than that of no. 22. For galactosylation, the branching efficiency was lower than for glucosylation. The difficulty in tosylation, the difference of the protective group at C-6, and/or the configuration on C-4 could be the reason for the observed lower reactivity in galactosylation.

Deprotection of mannosylated polysaccharides. — The mannosylated polysaccharide **8** was deprotected by sodium in liquid ammonia at −78° to remove benzyl groups from the main chain and acetyl groups from the side chains (Table VII). Fig. 5 shows ^{13}C-n.m.r. spectrum of the resultant polymer, which indicates the formation of a mannose-branched, (1→6)-α-D-glucopyranan (**9**) with complete

TABLE VII

DEPROTECTION OF MANNOSYLATED POLYSACCHARIDES TO GIVE BRANCHED DEXTRANS

Polymer no.	*Starting polymer no.*	$[\alpha]_D^{25}$[a] *(deg)*	$\overline{M}_n \times 10^{-4}$[b]	*Mole fraction of glycosylated residues in main chain*[c]
503	303	+161.0	2.1	0.37
512	412	+176.4	1.7	0.93

[a]Measured in $CHCl_3$ (c = 1). [b]Determined by gel-permeation chromatography. [c]Calculated from ^{13}C-n.m.r. spectra.

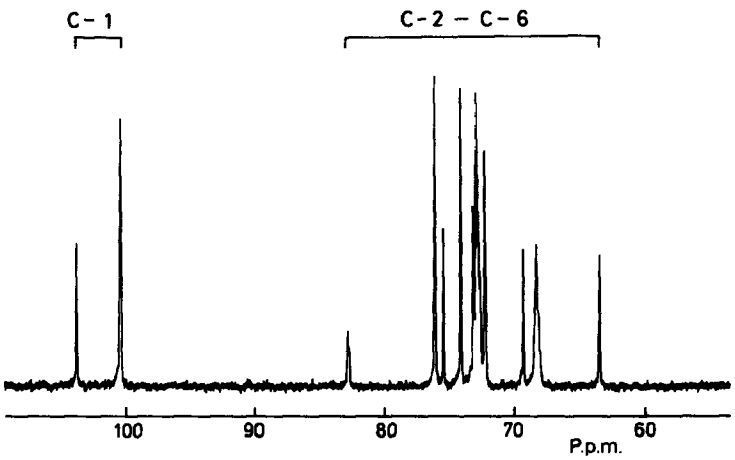


Fig. 5. ^{13}C-N.m.r. spectrum of (1→6)-α-D-glucopyranan with 3-*O*-(α-D-mannopyranosyl) branches (**9**).

removal of benzyl and acetyl groups. These polymers had high specific rotations of +161.0° to +176.4°. In this way, a synthetic dextran having 3-*O*-(α-D-mannopyranosyl) side-chains (**9**) was prepared.

CONCLUSIONS

Both the *tert*-butyldimethylsilyl group and acetyl group adversely influenced the cationic ring-opening polymerization by Lewis acid catalysts, and tri-*O*-substituted 1,6-anhydroglucose derivatives showed no polymerizabilities at all at low temperature[5,29]. However, compounds **1** and **2**, which contain these groups only at O-3, are polymerizable. In particular, compound **1** gave polymers **1** of higher molecular weights and in higher yields than did **2**, and the *tert*-butyldimethylsilyl group could be readily removed.

Desilylation of poly(**1**) and deacetylation of copoly(**2,3**) gave partially benzylated (1→6)-α-D-glucopyranans (**5** and **7**) containing free hydroxyl groups at specific positions, and these could be glycosylated to give branched polymers.

Glycosylation of the partially benzylated (1→6)-α-D-glucopyranans gave branched polysaccharides having mannopyranosyl, glucopyranosyl, and galactopyranosyl side-chains (**8, 10**, and **11**). Subsequent deprotection of the mannosylated polysaccharides gave an α-(1→3)-branched product, namely, a (1→6)-α-D-glucopyranan bearing 3-*O*-(α-D-mannopyranosyl) side-chains (**9**).

EXPERIMENTAL

General methods. — The ^{1}H- and ^{13}C-n.m.r. spectra of monomers and polymers were recorded with JEOL GX-400 and GX-270 spectrometers for solutions in chloroform-*d* using tetramethylsilane as internal standard, except for

the debenzylated polysaccharides, whose spectra were recorded for solutions in deuterium oxide with sodium 4,4-dimethyl-4-silapentane-1-sulfonate as the internal reference. Gel-permeation chromatography employed 1% solutions of polymers in tetrahydrofuran with a Toyo Soda high-speed liquid chromatograph (model HLC 802UR). The number-average molecular weights determined by gel-permeation chromatography were based on standard polystyrene samples. For the debenzylated polysaccharides, the number-average molecular weights were determined by high-performance liquid chromatography, performed with a combination of Toyo Soda Model HLC-803D and Toyo Soda Model RI-8 instruments in conjunction with standard dextran samples. Optical rotations were measured in chloroform at 25° with Perkin–Elmer Model 241 polarimeter using a 1-dm cell.

*1,6-Anhydro-2,4-di-*O*-benzyl-3-*O*-tert-butyldimethylsilyl-β-*D*-glucopyranose* (**1**). — Compound **1** was prepared from 1,6-anhydro-2,4-di-*O*-benzyl-β-D-glucopyranose[34] according to the method of Hakimelahi and coworkers[35]. To a solution of 1,6-anhydro-2,4-di-*O*-benzyl-β-D-glucopyranose (1.03 g, 3 mmol) in tetrahydrofuran (10 mL), pyridine (1.21 mL, 15 mmol), silver nitrate (0.77 g, 4.5 mmol), and *tert*-butylchlorodimethylsilane (0.68 g, 4.5 mmol) were added and the mixture was stirred for 14 h at room temperature. The mixture was filtered, the filtrate was mixed with aqueous sodium hydrogencarbonate, and the aqueous solution was extracted with chloroform. The combined chloroform extract was evaporated and the residue purified on a column of silica gel with 20:1 benzene–ethyl acetate as eluant. Evaporation gave a clear syrup; yield 1.20 g (87.5%); $[\alpha]_D^{25}$ −32.9° (*c* 1, chloroform).

Anal. Calc. for $C_{26}H_{36}O_5Si$: C, 68.39; H, 7.95. Found: C, 68.44; H, 8.03.

*3-*O*-Acetyl-1,6-anhydro-2,4-di-*O*-benzyl-β-*D*-glucopyranose* (**2**). — Compound **2** was synthesized and purified according to the procedure of Zemplén[36], $[\alpha]_D^{25}$ −45.7° (*c* 1, chloroform); lit.[26] −31.8° (*c* 1, chloroform).

*1,6-Anhydro-2,3,4-tri-*O*-benzyl-β-*D*-glucopyranose* (**3**). — Compound **3** was synthesized and purified as previously described[28], m.p. 90.0–91.0°, $[\alpha]_D^{25}$ −31.6° (*c* 2.7, chloroform); lit.[37], m.p. 89.5–90.5°, $[\alpha]_D^{25}$ −30.8° (*c* 2.7, chloroform).

Other materials for polymerization. — Phosphorus pentafluoride was prepared by thermal decomposition of *p*-chlorobenzenediazonium hexafluorophosphate (Ozark–Mahoning Co.), which had been recrystallized from water. Antimony pentachloride was purified by trap-to-trap distillation. Dichloromethane was purified conventionally[8]. Sulfur dioxide was dried over phosphorus pentaoxide and purified by trap-to-trap distillation *in vacuo*.

Polymerization and copolymerization. — High-vacuum techniques were used for polymerization and copolymerization[28]. Compound **1** was polymerized in dichloromethane. Polymerization conditions are shown in Table I. Purification of polymers was performed as previously described[28].

Desilylation of poly(**1**). — Desilylation of 2,4-di-*O*-benzyl-3-*O*-*tert*-butyldimethylsilyl-(1→6)-α-D-glucopyranan was accomplished with tetrabutyl-

ammonium fluoride in tetrahydrofuran[31]. To a solution of 2,4-di-*O*-benzyl-3-*O*-*tert*-butyldimethylsilyl-(1→6)-α-D-glucopyranan (1.46 g) in 10 mL of tetrahydrofuran was added commercial M tetrabutylammonium fluoride (10 mL) in tetrahydrofuran, and the mixture was boiled under reflux for 3 h. The solvent was evaporated and the polymer was precipitated by the addition of methanol. The polymer was purified by reprecipitation from chloroform solution into methanol three times and by freeze-drying from benzene; yield 0.72 g (65.7%), $[\alpha]_D^{25}$ +140.8° (*c* 1, chloroform); lit.[26] $[\alpha]_D^{25}$ +138.5°.

Deacetylation of copoly(**2,3**). — Deacetylation of copoly(**2,3**) was performed with sodium methoxide in *N,N*-dimethylformamide–methanol for 120 h at room temperature; conditions are shown in Table IV.

*Glycosylation with 3,4,6-tri-*O*-acetyl-β-*D*-mannose-1,2-(methyl orthoacetate).* — 3,4,6-Tri-*O*-acetyl-β-D-mannose-1,2-(methyl orthoacetate) was prepared from D-mannose according to the literature[38–40] m.p. 108.5–110.0°; lit.[40] m.p. 109–110°.

Two orthoester methods for glycosylation were used; the first employed mercuric bromide in nitromethane–dichloromethane[33]. 2,4-Di-*O*-benzyl-(1→6)-α-D-glucopyranan (0.41 g, 1.2 mmol), 3,4,6-tri-*O*-acetyl-β-D-mannose-1,2-(methyl orthoacetate) (4.34 g, 12 mmol), and mercuric bromide (0.21 g, 0.6 mmol) were placed in the reaction vessel and dried under high vacuum for 1 h. Nitromethane (14 mL) and dichloromethane (6 mL) were distilled into the vessel. The mixture was allowed to react for 24 h at 60°. Chloroform was then added and the solution was washed with aqueous sodium hydrogencarbonate. The organic layer was dried over anhydrous sodium sulfate and purified by reprecipitation three times and freeze-drying from benzene.

In the second method, chlorobenzene was used as solvent and 2,6-lutidinium perchlorate as catalyst[33]. 2,4-Di-*O*-benzyl-(1→6)-α-D-glucopyranan and 3,4,6-tri-*O*-acetyl-β-D-mannose-1,2-(methyl orthoacetate) were dissolved in chlorobenzene, and the solution was distilled at atmospheric pressure. After distillation of a few mL of solvent, 2,6-lutidinium perchlorate was added and the mixture boiled under reflux for 40 min. The mixture was evaporated and the product purified by reprecipitation using chloroform–methanol three times and freeze-drying from benzene.

*Glycosylation with 1-*O*-tosyl-*D*-glucose and* D*-galactose derivatives.* — For glucosylation, 2,3,4-tri-*O*-benzyl-6-*O*-(*N*-phenylcarbamoyl)-1-*O*-tosyl-α-D-glucopyranose, which had been prepared by the reaction of 2,3,4-tri-*O*-benzyl-6-*O*-(*N*-phenylcarbamoyl)-α-D-glucopyranosyl bromide (2.2 mmol) and silver *p*-toluenesulfonate (2.5 mmol), was treated with partially benzylated (1→6)-α-D-glucopyranan (0.3 mmol) in 12 mL of 2:1 dimethoxyethane–acetonitrile according to the method of Eby and Schuerch[32,36,41]. For galactosylation, 2,3,4,6-tetra-*O*-benzyl-1-*O*-tosyl-D-galactopyranose was used[42,43].

Deprotection of mannosylated polysaccharides. — The mannosylated polymer (~0.3 g) dissolved in 10 mL of dimethoxyethane was added dropwise to a solution of sodium (0.43 g) in 30 mL of liquid ammonia, and the reaction was allowed to

proceed for 2 h, with subsequent addition of ammonium chloride and water. The solution of free polysaccharide was dialyzed against running water for 5 days, concentrated to 1–2 mL, and freeze-dried from water.

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