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Non-Glycosidically Linked Pseudodisaccharides: Thioethers, Sulfoxides, Sulfones, Ethers, Selenoethers, and Their Binding to Lectins

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Hydrolytically stable non-glycosidically linked *tail-to-tail* pseudodisaccharides are linked by a single bridging atom remote from the anomeric centre of the constituent monosaccharides. Some such pseudodisaccharides with sulfur or oxygen bridges were found to act as disaccharide mimetics in their binding to the Banana Lectin and to Concanavalin A. A versatile synthetic route to a small library of such compounds is described.

Introduction

The manner in which monosaccharides may be linked by formal condensation may be classified as follows: *head-to-head* disaccharides of the trehalose or sucrose type, where the anomeric centres of the two monosaccharides are involved in the linkage; *head-to-tail* disaccharides, where the anomeric centre of one monosaccharide is linked to a non-anomeric centre of a second monosaccharide by means of an acetal; *tail-to-tail* linked pseudodisaccharides where the anomeric centre of neither of the constituent monosaccharides is involved in the linkage (Figure 1). The first two of these groups are very common in nature; the third is almost unknown. In fact, only one example of such a motif as a substructure is known;[1] a possible second example, the All(6–6)All ether-linked structure proposed for Coyolosa, has been discredited.[2]

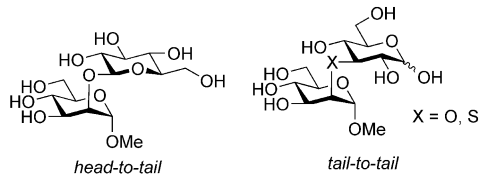

Figure 1. A *head-to-tail* disaccharide and a *tail-to-tail* pseudodisaccharide, a potential glycomimetic.

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Nevertheless, examples of such *tail-to-tail*-linked structures have attracted some synthetic interest over the years. Reports of the synthesis of *O*-,[2–5] *N*-,[6,7] or *S*-linked[5,8,9,10] compounds have appeared sporadically. It has been proposed that such pseudodisaccharides may act as disaccharide mimics, but to date, no investigation of the interaction of such molecules with carbohydrate-binding proteins appears to have been undertaken.

The key to any disaccharide mimicry of *tail-to-tail* pseudodisaccharides would be that one monosaccharide can mimic another; the two monosaccharides sharing a ring-plane and certain structural motifs such as *eq-eq-ax* orientation of hydroxy groups 2,3,4 in L-fucose and 4,3,2 in D-mannose. Related mimicry has been observed before: for example, some fucose-binding lectins (selectins) bind *C*-mannosides;[11a] Nilsson has shown that galactose-binding lectins (galectins) can bind β-mannose derivatives;[11b] Fleet has shown that some glycosidases are inhibited by the enantiomers of substrate mimics.[12] Also, Jenkins showed that 3-amino-altrosides inhibit β-glucosidases and proposed that the altrose residue binds with C-3 in the position corresponding to glucose C-1.[13]

Lectin inhibitors have possible applications as biological tools and potential therapeutics, for example, in anti-adhesion therapy (bacterial lectins),[14a] and against inflammation (selectins)[14b] or cancer (galectins).[14c] A disaccharide mimic would be expected to bind to a lectin with a higher affinity and specificity than a monosaccharide mimic, but having an inter-glycose linkage that is stable to hydrolysis is one prerequisite for such ligands, if they are to be put into an environment containing either strong acid or glycosidases. We planned to synthesise a small library of *S*-linked *tail-to-tail* pseudodisaccharides and to test the binding of these compounds (along with *O*- and *Se*-linked analogues, as well as oxidised analogues) to the lectins, Banana lectin (BanLec) and Concanavalin A (ConA). In this way,

we planned to test the theory that such hydrolytically stable *tail-to-tail* pseudodisaccharides can act as glycomimetics in their binding to carbohydrate-binding proteins. We report our results from the synthesis and binding studies in this paper.

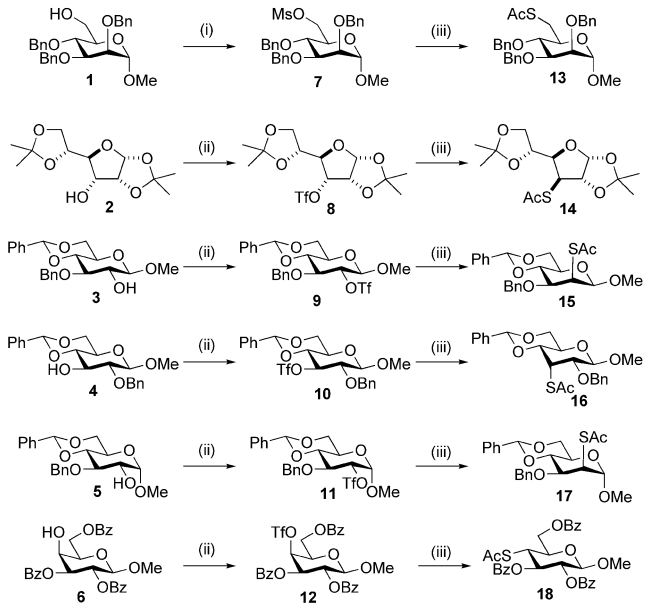
Results and Discussion

Synthesis

Our synthesis of thioether pseudodisaccharides is based on S_N2 displacement of carbohydrate sulfonates by carbohydrate thiol nucleophiles. This approach gives complete stereocontrol in the coupling reactions with inversion of configuration at the sulfonate-bearing carbon. The carbohydrate thiols are synthesised from sulfonates by S_N2 substitution with thioacetate, followed by deacetylation to reveal the thiol. By this stepwise approach, we may use the same sulfonate twice to access C_2-symmetric thioether pseudodisaccharides, or use two different sulfonates to obtain unsymmetrically substituted thioethers. Related approaches have been used for the synthesis of thiooligosaccharides; carbohydrate sulfonates have been displaced either by thioacetate to introduce sulfur, or by an anomeric thiol for thiodisaccharide formation.[15]

We converted some partially protected carbohydrates **1**–**6**[16–21] to their triflates **8**–**12**[22–26] or mesylate (**7**). In many cases, heating the sulfonates with potassium thioacetate in DMF gave a clean and high-yielding conversion to the thioacetates **13**–**17** with inversion of configuration (Scheme 1). This gave us access to *gluco* or *manno* configured monosaccharides equipped for substitution at the 2- (**15** and **17**), 3- (**14**), 4- (**18**), and 6- (**13**) positions. For the 2-substituted *manno* derivatives, we prepared both α- and β-anomers **17** and **15**, respectively, of the methyl glycoside. An allose derivative **16** equipped for 3-substitution was also prepared. For the formation of *gluco* thioacetate **18** from *galacto* triflate **12**, involving an *ax*→*eq* conversion, the yield was lower and an elimination product was also formed, presumably due to the *trans*-diaxial relationship between proton and leaving group in the ground-state conformation of the triflate starting material **12**. In some further cases, decomposition of the triflate was seen under the substitution reaction conditions and minimal product could be isolated (Figure 2). The effect of the structure and protecting group pattern of carbohydrate triflates on the success of nucleophilic displacement reactions has been noted before.[28,29]

Having established routes to suitable triflates and thioacetates, we examined coupling (thioetherification) reactions to form thioether-linked pseudodisaccharides. Cleavage of the thioacetates **13**–**17** (and **19**, synthesised earlier,[30] Figure 3) to give thiols was achieved by treatment with sodium methoxide in methanol. After aqueous workup, the crude thiols were heated with the required sulfonates **7**–**10** and sodium hydride at 50 °C in DMF, and major pseudodisaccharide products **20**–**32** were rapidly formed (Table 1, Figure 4). Small amounts of the corresponding di-



Scheme 1. Sulfonation and thioacetate formation. (i) MsCl, Et_3N, CH_2Cl_2, 0 °C;[27] (ii) Tf_2O, py, CH_2Cl_2, 0 °C, r.t.; (iii) KSAc, DMF; **13**, 73%; **14**, 84%; **15**, 84%; **16**, 80%; **17**, 88%; **18**, 58% + elimination 19% (all yields over two steps).

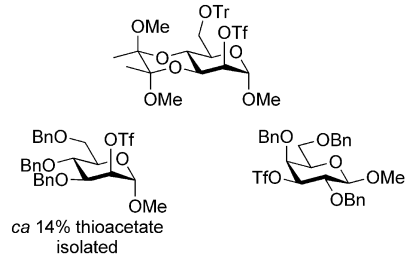


Figure 2. Some triflates that failed to give useful yields of thioacetates.

sulfides (Figure 5) and unreacted thiol or triflate could sometimes also be isolated. The formation of the thioethers always proceeded with inversion of configuration. It is also noteworthy that essentially no difference in the efficiency of the reaction between the formation of *sec*-*sec*, primary-*sec* and primary-primary linked thioethers was seen. This is in marked contrast to the behaviour of reactions for the formation of similar *N*-linked structures, where the more stringent steric and electronic demands of a secondary centre over a primary centre (in a carbohydrate) appear to strongly disfavour the formation of pseudodisaccharides with secondary amine linkages involving even just one secondary centre.[7]

We also investigated a streamlined synthesis of C_2-symmetric thioether pseudodisaccharides using a divalent sulfur anion as nucleophile to dimerise a sulfonate electrophile, based on previous work for (1–1)-linked thiodisaccharide synthesis.[31,32] Treatment of carbohydrate triflates with dried sodium sulfide in acetonitrile with molecular sieves gave the dimers in generally very good yield for those triflates that give

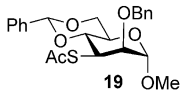
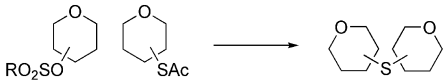


Figure 3. Thioacetate **19**.

Table 1. Thioetherification reactions for S-pseudodisaccharide synthesis.



Entry	Thioacetate [equiv.]	Sulfonate [equiv.]	Conditions[a]	Product/yield[b]
1	**13** (1)	**7** (1.5)	A	**20**/54%; **33**/15%
2	**13** (1.5)	**8** (1)[c]	A	**21**/81%
3	**15** (1)	**7** (1.5)	A	**22**/47%
4	**13** (1)	**9** (1.5)	A	**22**/42%
5	**14** (1)	**8** (1.5)	A	**23**/68%; **34**/15%
6	**14** (1)	**9** (1.6)	A	**24**/75%
7	**15** (1.5)	**8** (1)[c]	A	**24**/70%
8	**15** (2)	**9** (1)	A	**25**/73%
9	**13-SH** (1.5)[d]	**10** (1)	B	**26**/85%
10	**16** (1.5)	**9** (1)	A	**27**/60%
11	**17** (1)	**8** (1.5)[c]	A	**28**/94%
12	**19** (1)	**8** (1.6)[c]	A	**29**/81%

[a] A: Thioacetate, MeONa, MeOH then sulfonate, NaH, DMF, 50 °C; B: Thiol, sulfonate, NaH, DMF, r.t. [b] Isolated yields. [c] Purified triflate was used. [d] The purified thiol derived from **13** was used.

a clean S_N2 reaction with thioacetate (i.e. **8**–**11**), and in a somewhat lower yield for *galacto* triflate **12** (Table 2). The reaction with triflate **11** seemed rather sluggish.

Removal of the benzyl ethers from thioether pseudodisaccharides **20**–**31** was effected by treatment with sodium in liquid ammonia; acetals were removed with acid (Table 3). Following the reductive deprotection, the pseudodisaccharides were peracetylated to facilitate purification. Peracetylated pseudodisaccharides **36**–**45** (Figure 6) were subsequently deprotected with sodium methoxide to give the free thioether pseudodisaccharides **46**–**57** (Figure 7). The benzoate esters were similarly removed from **32** to give de-

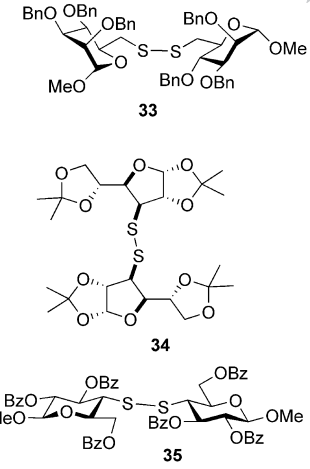
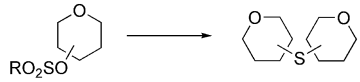


Figure 5. Disulfides.

Table 2. Approach to C_2-symmetric S-pseudodisaccharides.



Entry	Sulfonate	*t*[a]	Product/yield[b]
1	**8**	17 h	**23**/86%
2	**9**	3 h	**25**/86%
3	**10**	3 h	**30**/90%
4	**11**	3 d	**31**/64%[c]
5	**12**	1 h	**32**/46%[d]

[a] Conditions: Na_2S (2 equiv.) MeCN, sieves 4 Å, 50 °C. [b] Isolated yields. [c] Purified triflate was used. [d] Disulfide **35** (6%) and elimination products (18%) were also isolated.

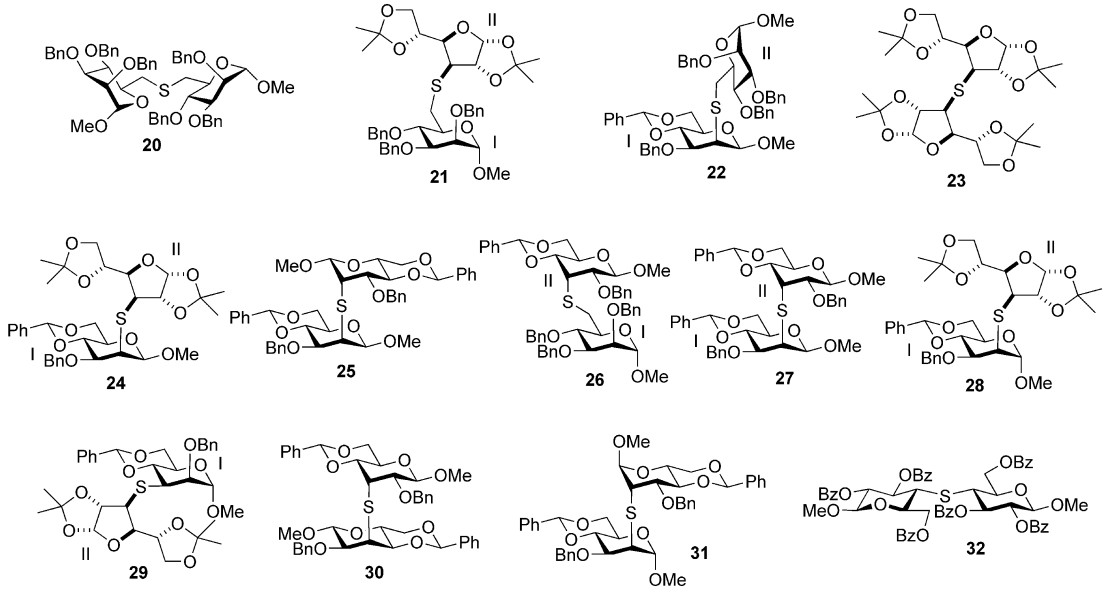


Figure 4. Protected thioethers.

Table 3. Deprotection of thioether pseudodisaccharides.

Entry	Starting material	Conditions[a]	Peracetate/yield[b]	Deprotected/yield[c]
1	**20**	A (–40 °C, 10 min)	**36**/73%	**46**/72%
2	**21**	B	–	**47**/19%[d]
3	**22**	A (–40 °C, 10 min)	**37**/64%	**48**/92%
4	**23**	C	**38**/92%	**49**/78%
5	**24**	B	–	**50**/38%[d]
6	**25**	A (–40 °C, 10 min)	**39**/61%	**51**/97%
7	**26**	A (–78 °C, 1 h)	**40**/58%	**52**/92%
8	**27**	A (–78 °C, 30 min)	**41**/76%	**53**/77%
9	**28**	D	**42**/40%	**54**/83%
10	**29**	D	**43**/68%	**55**/75%
11	**30**	A (–40 °C, 5 min)	**44**/57%	**56**/94%
12	**31**	A (–78 °C, 7 min)	**45**/80%	**57**/76%
13	**32**	E	–	**58**/78%[d]

[a] A: Na, $NH_{3(l)}$, (T), MeOH, (t); then Ac_2O, py; B: Na, $NH_{3(l)}$, –78 °C; then TFA (90%); C: TFA (90%); then Ac_2O, NaOAc; D: Na, $NH_{3(l)}$, –78 °C, MeOH, 2 min; then TFA (90%); then Ac_2O, py; E: NaOMe, MeOH, 50 °C. [b] Isolated yields. [c] Isolated yields, from peracetates unless otherwise stated. [d] Yield from respective protected starting materials (peracetates were not formed).

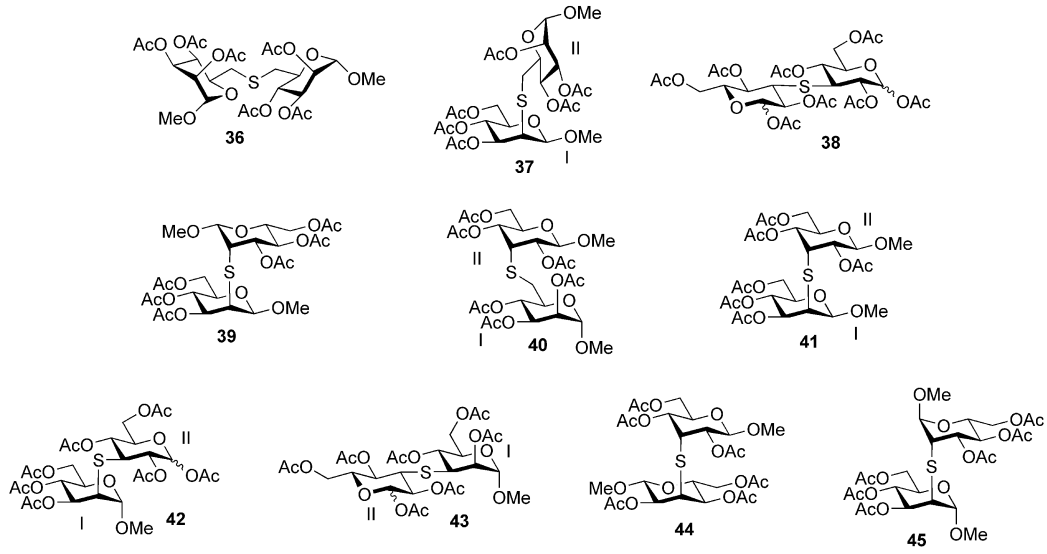


Figure 6. Thioether peracetates.

protected **58**. The deprotection procedures worked smoothly, with the exception of those compounds bearing both benzylic and isopropylidene protection (i.e. **21**, **24**, **28**, **29**). Some decomposition was seen during the first step of deprotection of these compounds (Birch reduction conditions), which could be minimised by running the reaction for very short reaction times, but the yields were not usually as high as for the fully benzylated or benzyl/benzylidene-protected thioether pseudodisaccharides.

To investigate the effect of oxidising the bridging sulfur to the sulfoxide and sulfone oxidation levels on lectin binding, the C_2-symmetric pseudodisaccharides **51**, **56** and **57** were oxidised. Treatment with *m*CPBA gave sulfoxides **59**, **61** and **63** at 0 °C and short reaction times, or sulfones **60**, **62** and **64** at room temp. after longer reaction times in good yields (Scheme 2).[29] Oxidation was best carried out on the unprotected thioether pseudodisaccharides, as attempted removal of the benzyl ether and benzylidene protection from protected sulfoxide or sulfone pseudodisaccharides (derived from e.g. **25**, not shown) by hydrogenation over palladium failed. The thioether starting materials used in these oxidations were C_2-symmetric; the sulfoxides are C_1-symmetric, i.e. the C_2 axis has been destroyed, but only one diastereomer is possible; the sulfone is once again C_2-symmetric. This is evident from the ^{1}H NMR spectra of the compounds: the C_2-symmetric thioether and sulfone have only half as many signals as the C_1-symmetric sulfoxide.

Examination of the ^3J coupling constants in the ^{1}H NMR spectra across the series thioether–sulfoxide–sulfone strongly suggests that oxidation of sulfur induces significant conformational change in the allopyranose rings away from the $^4C_1$ chair conformation. For example, the $J_{1,2}$ coupling constant changes in the *allo* series: **56**, 8.1 Hz; **61**, 4.9 Hz and 5.6 Hz; **62**, 2.7 Hz. In the sulfone (only), a $^4J_{2,4}$ coupling (1.4 Hz) is also seen. In the α (**57**, **63**, **64**) and β (**51**, **59**, **60**) *manno* series, no significant changes in the coupling constants are seen on oxidation. In general, the $^3J_{H,H}$ coupling constants of the thioether pseudodisaccharides are as

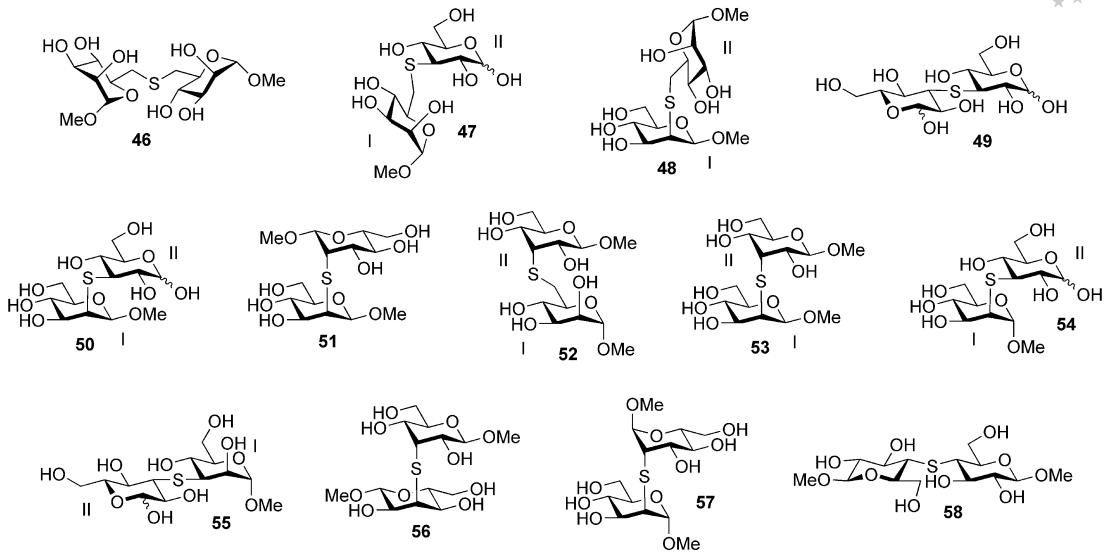
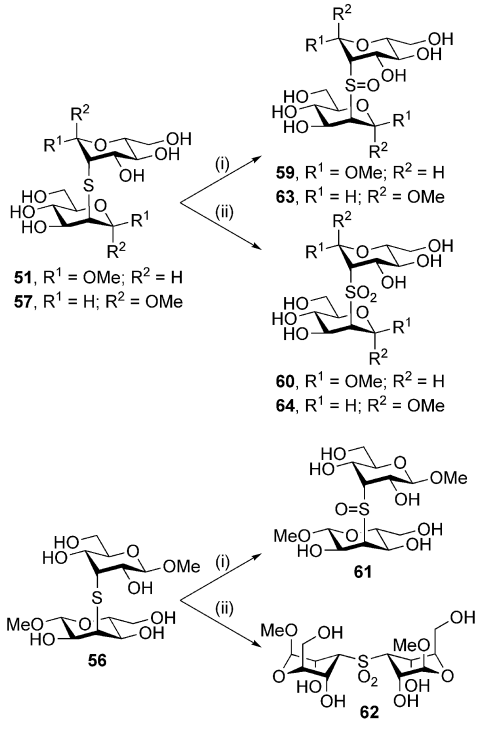


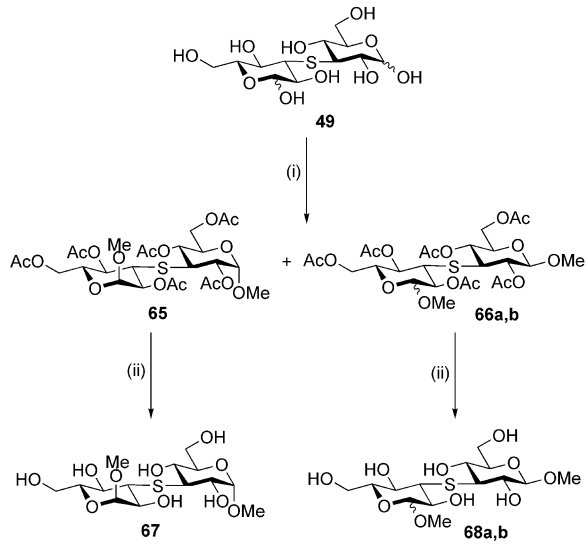
Figure 7. Unprotected thioether pseudodisaccharides.



Scheme 2. Oxidation. (i) *m*CPBA, CH_2Cl_2, MeOH, 0 °C; **59**, 99%; **61**, 89%; **63**, 72%; (ii) *m*CPBA, CH_2Cl_2, MeOH, 0 °C→r.t.; **60**, 77%; **62**, 99%; **64**, 63%.

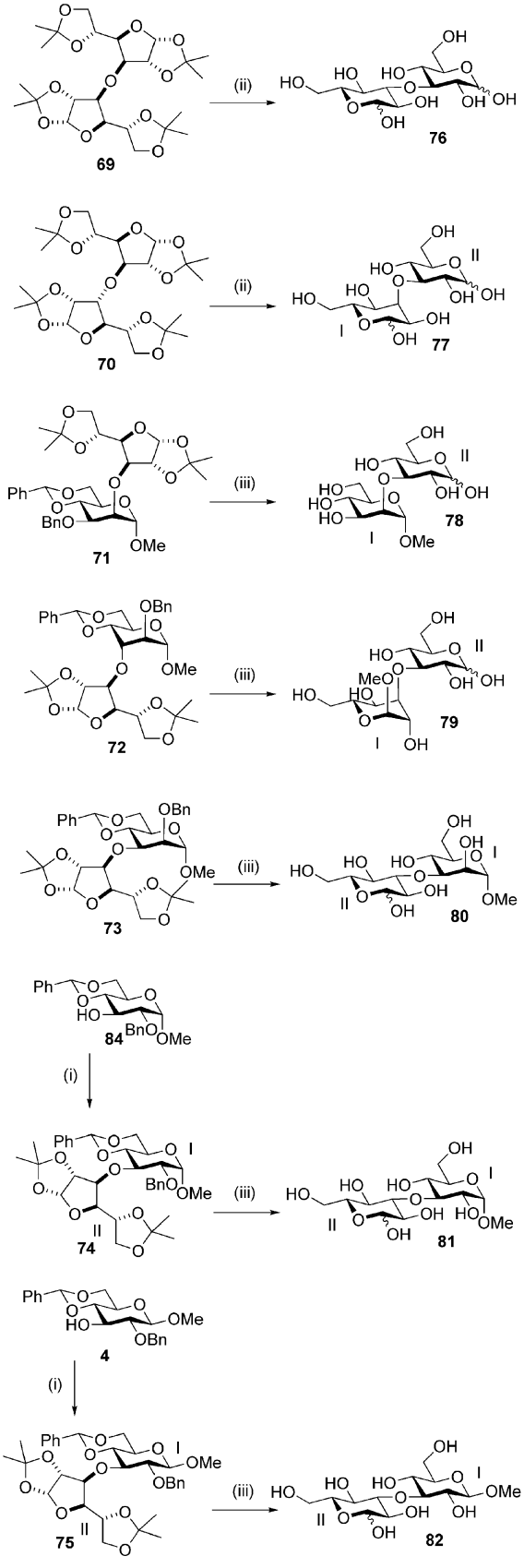
expected for the $^4C_1$ conformation of the respective contributing monosaccharides, indicating that formation of a thioether pseudodisaccharide does not appear to have a big effect on the ring conformation.

Locking the anomeric position of the (*S*3–3)-linked glucose dimer **49** would give information on which anomer bound more strongly to the lectins. Thus we heated **49** with HCl in methanol to form two glycosidic bonds.[33] The initially formed mixture contained furanosides as expected, but leaving the reaction longer to equilibrate to the pyranosides also gave some decomposition and low yields (Scheme 3). The α,α-dimer **65** could be separated from the α,β- and β,β-compounds **66a**,**b** (which could not be separated) after acetylation. Deacetylation gave the deprotected α,α-compound **67** and a mixture of the deprotected α,β and β,β compounds **68a**,**b** (10:1).



Scheme 3. Fischer glycosylation of thioether pseudodisaccharides and deprotection. (i) MeOH, AcCl, 65 °C; then Ac_2O, py; **65**, 8%; **66a**,**b**, 10%; (ii) NaOMe, MeOH; **67**, 92%; **68a**,**b**, 99%.

The synthesis of ether-linked pseudodisaccharides **69**–**73** has been described previously.[4] Two further examples **74** and **75** were synthesised in the same manner by alkylation of the alcohols **4** and **84** with the *allo* triflate **8** (Scheme 4). These compounds **69**–**75** were deprotected by catalytic hydrogenolysis (to remove benzyl ethers) or acid treatment (to remove acetals) as necessary, followed by peracetylation to allow purification. Peracetylated pseudodisaccharides were deprotected with sodium methoxide to give the free ether-linked pseudodisaccharides **76**–**82** (Scheme 4).



Scheme 4. Ether synthesis and deprotection. (i) **8**, NaH, DMF; **74**, 19%; **75**, 45%; (ii) TFA (90%); **76**, 83%; **77**, 78%; (iii) a) TFA (90%); b) H_2, Pd (C), AcOH, H_2O; c) Ac_2O, pyridine; d) NaOMe, MeOH; **78**, 79%; **79**, 72%; **80**, 78%; **81**, 66%; **82**, 61%.

Lectin Binding Studies

Banana lectin (BanLec) from *Musa acuminata* is a tetramer composed of 15 kDa subunits[34] with a somewhat unusual carbohydrate binding specificity. It recognises 2- or 3-substituted glucose or mannose residues,[35,36] including internal (α1→3)-linked glucose, but it will not tolerate substitution (or deoxygenation) at the 4- or 6-positions. It will, though, bind the *terminal* glucose residues in (α1→6)-branched glucans and mannans.[37] BanLec has been crystallised and its X-ray structure determined with two disaccharide ligands, Glc(β1→3)Glc and Xyl(β1→3)ManαMe,[38] revealing two similar sugar-binding sites.

The pseudodisaccharides [thioether-linked **46**–**58**, **67**, **68**; sulfoxide-linked **59**, **61**, **63**; sulfone-linked **60**, **62**, **64**; ether-linked **76**–**82**; and selenoether-linked **83** (Figure 8)[39]] were assayed for binding to BanLec using isothermal titration microcalorimetry (ITC). The results are summarised in Table 4. Some mannose and glucose derivatives (mono- and disaccharides) were included as standards (Table 4, Entries 1–6). The pseudodisaccharides had a range of binding affinities, with many failing to bind at all. The compounds that bound most strongly to BanLec are 2- or 3- substituted methyl α-mannosides: MeαMan(3–3)Glc (ether **80** and thioether **55**), MeαMan(2–3)Glc (ether **78** and thioether **54**), MeαMan(2–2)ManαMe (thioether **57**, sulfoxide **63** and sulfone **64**). Changing between a bridging sulfur and oxygen appears to have a relatively small effect on the affinity, which may be surprising, given the differences in C–O vs. C–S bond lengths and C–O–C vs. C–S–C bond-angles, and in hydrogen-bond acceptor capability between oxygen and sulfur. Wherever 2-substituted α-Man and β-Man derivatives are compared (**50** vs. **54**; **51** vs. **57**), the α derivatives tend to bind more strongly, which is not surprising, given BanLec's preference for α-configured glucose and mannose derivatives over their β anomers. We can envisage two possible binding orientations for the pseudodisaccharides. 3-Substituted glucose and both 2- and 3-substituted mannose bind to BanLec, and it is difficult to speculate regarding the binding mode based on our data. Only one of these compounds, the MeαMan(3–3)Glc ether-linked derivative **80** binds more strongly than methyl α-mannoside.

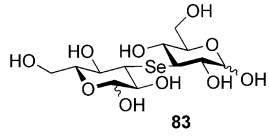


Figure 8. Selenoether **83**.

For the Glc(3–3)Glc compounds, the thioether **49** binds most strongly, the ether **76** slightly less so, and the selenoether **83** does not bind at all. The glucose residues in the unprotected pseudodisaccharides exist as mixtures of the pyranoses, as judged by their ^{1}H NMR spectra, α/β approximately 1:1. The ether-linked α-monomethyl glycoside **81** bound more strongly than did the β compound **82**. The α,α bis-methyl glycoside **67** bound more strongly than the 10:1 mixture of α,β and β,β bis-methyl glycosides **68a**,**b**. These

Table 4. Binding of pseudodisaccharides to banana lectin and Concanavalin A.[a]

Entry	Compound	Structure	Binding constant K_a [M^{-1}] BanLec	Con A
1		MeαMan	520 ± 22	8960±280
2		Man(α1→2)Man		35700±970
3		Man(α1→3)Man	372	11000±130
4		Glc	141	
5		3-*O*-benzyl-Glc	269	
6		3-*O*-methyl-Glc	268	
7	**76**	Glc(3–3)Glc	141 ± 21	n.b.
8	**49**	Glc(*S*3–3)Glc	241 ± 16	n.b.
9	**83**	Glc(*Se*3–3)Glc	n.b.	n.d.
10	**81**	MeaGlc(3–3)Glc	95 ± 2	n.d.
11	**82**	MeβGlc(3–3)Glc	n.b.	n.d.
12	**67**	MeαGlc(*S*3–3)GlcαMe	223 ± 2	n.d.
13	**68a**,**b**	MeαGlc(*S*3–3)GlcβMe [+MeβGlc(*S*3–3)GlcβMe]	186 ± 2	n.d.
14	**80**	MeαMan(3–3)Glc	691 ± 78	n.b.
15	**55**	MeαMan(*S*3–3)Glc	519 ± 7	n.b.
16	**78**	MeαMan(2–3)Glc	474 ± 35	7950±390
17	**54**	MeαMan(*S*2–3)Glc	446 ± 10	32400±600
18	**50**	MeβMan(*S*2–3)Glc	276	n.d.
19	**79**	MeαAlt(3–3)Glc	n.b.	n.d.
20	**77**	All(3–3)Glc	75 ± 2	n.d.
21	**58**	MeβGlc(*S*4–4)GlcβMe	n.b.	n.d.
22	**52**	MeαMan(*S*6–3)AllβMe	n.b.	n.d.
23	**46**	MeαMan(*S*6–6)ManαMe	n.b.	n.d.
24	**48**	MeαMan(*S*6–2)ManβMe	119 ± 31	n.d.
25	**47**	MeαMan(*S*6–3)Glc	120 ± 2	n.d.
26	**51**	MeβMan(*S*2–2)ManβMe	70 ± 2	n.d.
27	**59**	MeβMan(*SO*2–2)ManβMe	n.b.	n.d.
28	**60**	MeβMan($SO_2$2–2)ManβMe	186 ± 2	n.b.
29	**57**	MeαMan(*S*2–2)ManαMe	529 ± 42	59300±2800
30	**63**	MeαMan(*SO*2–2)ManαMe	274 ± 17	13100±142
31	**64**	MeαMan($SO_2$2–2)ManαMe	576 ± 34	26900±1300
32	**56**	MeβAll(*S*3–3)AllβMe	n.b.	n.d.
33	**61**	MeβAll(*SO*3–3)AllβMe	n.d.	n.d.
34	**62**	MeβAll($SO_2$3–3)AllβMe	n.b.	n.d.
35	**53**	MeβMan(*S*2–3)AllβMe	< 50	n.d.

[a] n.b. = no binding; n.d. = not determined. Error values are for curve fitting of the single titration, not variance of replicates, which were not done.

data suggest that BanLec prefers the α-Glc configuration over the β-Glc, which is consistent with the reported binding preferences for reducing terminal glucose.[36] Comparing the affinities of different 3-substituted glucose compounds: ethers **76**, **79**, **77** and thioether **47**, we see a wide range of binding, which leads us to speculate that both monosaccharide residues are interacting with the protein. The thioether **49** does bind more strongly than the monosaccharide glucose. However, the binding affinities of these pseudodisaccharides do not come up to the level of the most strongly binding disaccharides, e.g. Glc(β1→3)Glc (K_a = 830 M^{-1}), Glc(β1→3)GlcαMe (K_a = 2400 M^{-1}),[36] and even some simple 3-*O*-alkylglucose derivatives (Table 4, Entries 5,6) bind more strongly to BanLec.

Some thioether-linked 6-substituted mannose derivatives (**47**, **48**) bind, whereas others (**46**, **52**) do not. Those derivatives that bind have a second monosaccharide that consistently shows some binding (ManβMe **48** or Glc **47**), whereas one that does not bind has a second monosaccharide that tends not to bind (All **52**). For the (*S*6–6)-linked compound **46**, the inter-ring linkage is, at four bonds, longer than any inter-ring linkage in a disaccharide. Given the non-tolerance of BanLec for C-6 substitution at glucose and the fact that in the crystal structures of the complexed Glc(β1→3)Glc and Xyl(β1→3)ManαMe, 6-OH of the reducing end glucose and mannose residues are buried in the protein, it seems likely that the 6-substituted mannose derivatives bind in the orientation with the 2-substituted Man or 3-substituted Glc residues, respectively, in the primary binding subsite.

Concanavalin A (ConA) is an extensively studied plant lectin from Jack Bean (*Canavalia ensiformis*). The monomeric subunit has a molecular weight of 27 kDa, and binds mono- and disaccharides with a 1:1 stoichiometry. The requirements for binding are free equatorial hydroxy groups at C-3 and C-4, and a free hydroxy group at C-6.[40] Mannose binds more strongly than glucose and GlcNAc, although these two monosaccharides do bind. Man(α1→2)Man binds more strongly than the other mannobioses (which have binding affinities not much enhanced over monosaccharidic mannose).[41] The crystal structure of ConA in complex with Man(α1→2)ManαMe reveals two binding modes, one with the reducing end mannose in the monosaccharide binding site and the non-reducing end

mannose in a second binding subsite; the other with the non-reducing end mannose in the monosaccharide binding site and the reducing end mannose in a third binding subsite.[42]

Some of the pseudodisaccharides were also tested for binding to ConA (Table 4). Two thioether-linked pseudodisaccharides, MeαMan(*S*2–3)Glc **54** and MeαMan(*S*2–2)ManαMe (**57**) bound with high affinity: **54** bound with similar affinity to the best-known natural disaccharide ligand Man(α1→2)Man, while **57** bound approximately twice as well. Changing the bridging group from sulfur to oxygen (**54→78**) gave a fourfold loss in affinity. Oxidising the bridging sulfur in **57** to sulfoxide **63** or sulfone **64** levels also gave some loss of affinity. Man(3–3)Glc (**55**, **80**) or Glc(3–3)Glc (**49**, **76**) derivatives did not bind to ConA, as may be expected from the low binding affinities of ConA for 3-substituted carbohydrates. It is possible that the highest affinity binder MeαMan(*S*2–2)ManαMe benefits from a favourable entropy factor. Its C_2 symmetry leads to double the number of *degenerate* binding modes, which ought to lead to a more favourable entropy of binding, although the many other unpredictable factors contributing to the binding event may render this contribution irrelevant.

Conclusions

Thioether-linked pseudodisaccharides are available stereospecifically by S_N2 displacement of carbohydrate sulfonates by carbohydrate thiol nucleophiles. The reactions can be as efficient for the formation of *sec–sec* linkages as for the formation of linkages involving a primary carbon (C-6), with the caveat that the efficiency of the S_N2 displacements are dependent on the individual monosaccharide substrates and their protecting groups.

Some of the unprotected pseudodisaccharides with ether, thioether, sulfoxide and sulfone linkages bound to the lectins, Banana lectin and Concanavalin A. Binding to banana lectin was in many cases similar to or worse than binding of monosaccharides, but the very best ligands did bind to the lectin with enhanced binding affinity over monosaccharides. Binding to ConA occurred in general with much higher affinities than to the BanLec. In this case, the best pseudodisaccharide ligands bound with affinities similar to or enhanced over the strongest known disaccharide ligand, suggesting an interaction involving both halves of the pseudodisaccharide and a mimicry of the disaccharide binding event. The binding of the hydrolytically stable pseudodisaccharides to lectins opens up the field to further research. The mode of binding of these structures, the effect of the linking heteroatom and the possibility of extending the work to binding animal or bacterial lectins would all now be relevant topics for investigation.

Experimental Section

General: Melting points were recorded with a Gallenkamp melting point apparatus and are uncorrected. Proton nuclear magnetic resonance (^{1}H) spectra were recorded with Bruker Avance II 400 (400 MHz) or 500 (500 MHz) or Varian Mercury 300 (300 MHz) or 400 (400 MHz) spectrometers; multiplicities are quoted as singlet (s), broad singlet (br. s), doublet (d), doublet of doublets (dd), triplet (t), apparent triplet (at), apparent triplet of doublets (atd), doublet of apparent triplets (dat), quartet (q), apparent quartet (aq), or multiplet (m). Carbon nuclear magnetic resonance (^{13}C) spectra were recorded with Bruker Avance II 400 (100 MHz) or 500 (125 MHz) or Varian Mercury 300 (75 MHz) or 400 (100 MHz) spectrometers, and multiplicities were assigned by DEPT. Spectra were assigned using COSY, HSQC and DEPT experiments. All chemical shifts are quoted on the δ scale in parts per million (ppm). Residual solvent signals were used as an internal reference. Low- and high-resolution (HRMS) electrospray (ES) mass spectra were recorded using a Bruker Microtof instrument. MALDI spectra were recorded on a Bruker Biflex III spectrometer using 2′,4′,6′-trihydroxyacetophenone trihydrate (THAP) as matrix. Infra-red spectra were recorded with a Perkin–Elmer Spectrum One FT-IR spectrometer using the thin film method on NaCl plates. Optical rotations were measured with a Perkin–Elmer 241 polarimeter with a path length of 1 dm; concentrations are given in g/100 mL. Thin layer chromatography (TLC) was carried out on Merck kieselgel sheets, pre-coated with $60F_{254}$ silica. Plates were visualised with UV light and developed using 10% sulfuric acid, or an ammonium molybdate (10% w/v) and cerium(IV) sulfate (2% w/v) solution in 10% sulfuric acid. Flash column chromatography was carried out on silica gel (35–70 micron, Grace). CMAW means chloroform/MeOH/acetic acid/water, 60:30:3:5. Acetonitrile (puriss.) was purchased from Riedel-de Haën and used without purification. DMF was from VWR (AnalaR normapur) and used without purification. Reactions performed under hydrogen or nitrogen were maintained by an inflated balloon.

Methyl 2,3,4-Tri-*O*-benzyl-6-*O*-methylsulfonyl-α-D-mannopyranoside (7): Alcohol **1**[16] (600 mg, 1.30 mmol) was dissolved in CH_2Cl_2 (3 mL) and cooled to 0 °C under N_2. Triethylamine (0.27 mL, 1.95 mmol) and mesyl chloride (0.11 mL, 1.42 mmol) were added, and the mixture was stirred at 0 °C. After 90 min, TLC (pentane/EtOAc, 2:1) showed the formation of a product (R_f = 0.3) and little starting material remaining (R_f = 0.2). Further triethylamine (0.13 mL, 1.0 mmol) and mesyl chloride (55 μL, 0.7 mmol) were added. After a further 20 min, TLC showed the complete conversion of starting material into a major product. The mixture was diluted with CH_2Cl_2 (50 mL) and washed with ice-water (50 mL) then NH_4Cl (satd. aq., 50 mL). The organic phase was dried ($MgSO_4$), filtered, and concentrated in vacuo to give the crude mesylate **7** as a pale yellow oil, which was used without further purification. The material could be purified by column chromatography (pentane/EtOAc, 2:1) for characterisation: colourless oil. $[\alpha]_D^{23}$ = +42.2 (c = 1.0, in $CHCl_3$). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.37–7.27 (m, 15 H, Ar-H), 4.97 (d, J = 10.8 Hz, 1 H, PhC*H*H′), 4.77 (d, J = 11.9 Hz, 1 H, PhC*H*H′), 4.71 (d, $J_{1,2}$ = 1.8 Hz, 1 H, 1-H), 4.67–4.63 (m, 4 H, 2 PhC*H*H′, PhCH_2), 4.53 (dd, $J_{5,6'}$ = 2.0, $J_{6,6'}$ = 11.5 Hz, 1 H, 6′-H), 4.43 (dd, $J_{5,6}$ = 4.4, $J_{6,6'}$ = 11.5 Hz, 1 H, 6-H), 3.98–3.90 (m, 2 H, 3-H, 4-H), 3.80 (at, J = 2.3 Hz, 1 H, 2-H), 3.76 (m, 1 H, 5-H), 3.32 (s, 3 H, OCH_3), 3.00 (s, 3 H, SO_2CH_3) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 138.3, 138.2 (2 s, Ar-C), 128.6, 128.6, 128.5, 128.2, 128.0, 127.8, 127.7 (7 d, Ar-CH), 99.4 (d, C-1), 80.1, 74.7, 74.1, 70.4 (4 d, C-2, C-3, C-4, C-5), 75.4, 73.2, 72.3, 69.6 (4 t, 3 PhCH_2, C-6), 55.2 (q, OCH_3), 38.0 (q, SO_2CH_3) ppm. MS (ES^+): m/z (%) = 560 (100) [M + NH_4^+]. HRMS: calcd. for $C_{29}H_{38}NO_8S$ [MNH_4^+] 560.2313; found 560.2320.

Preparation of Triflates 8–12: Alcohol **2**[17] (403 mg, 1.6 mmol) was dissolved in CH_2Cl_2 (14 mL) and the mixture cooled to 0 °C under

N_2. Pyridine (0.50 mL, 6.2 mmol) and triflic anhydride (0.51 mL, 3.1 mmol) were added, and the mixture was stirred at 0 °C. After 2 h, TLC (pentane/EtOAc, 1:1) showed complete conversion of the starting material into a single product. The mixture was poured into ice-water (100 mL) and extracted with CH_2Cl_2 (2 × 50 mL). The organic extracts were dried (Na_2SO_4), filtered, and concentrated in vacuo to give the crude triflate **8** (610 mg),[22] which was used without further purification.

Alcohol **3**[18] (1.0 g, 2.7 mmol) was converted with pyridine (0.54 mL, 6.7 mmol) and triflic anhydride (0.55 mL, 3.4 mmol) in CH_2Cl_2 (10 mL) by the same procedure as described for compound **8**, into the crude triflate **9**,[23] which was used without further purification, or purified by flash column chromatography (toluene/EtOAc, 5:1, 1% Et_3N).

Alcohol **4**[19] (2.0 g, 5.4 mmol) was converted with pyridine (1.08 mL, 13.4 mmol) and triflic anhydride (1.10 mL, 6.7 mmol) in CH_2Cl_2 (10 mL) by the same procedure as described for compound **8**, into the crude triflate **10**,[24] which was used without further purification.

Alcohol **5**[20] (224 mg, 0.60 mmol) was converted with pyridine (0.29 mL, 3.6 mmol) and triflic anhydride (0.2 mL, 1.2 mmol) in CH_2Cl_2 (5 mL, freshly distilled) by the same procedure as described for compound **8** into the crude triflate **11** (318 mg)[25] as a yellow solid, which was used without further purification.

Alcohol **6**[21] (228 mg) was converted with pyridine (0.15 mL, 1.8 mmol) and triflic anhydride (0.15 mL, 0.9 mmol) in CH_2Cl_2 (6 mL) by the same procedure as described for compound **8**, into the crude triflate **12**,[26] which was used without further purification.

Methyl 6-*S*-Acetyl-2,3,4-tri-*O*-benzyl-6-deoxy-6-thio-α-D-mannopyranoside (13): Crude mesylate **7** (200 mg, 0.37 mmol) was dissolved in DMF (2 mL). Potassium thioacetate (84 mg, 0.74 mmol) was added, and the mixture was stirred at 90 °C. After 3 h, TLC (pentane/EtOAc, 3:1) showed complete conversion of starting material (R_f = 0.2) into a single product (R_f = 0.8). The reaction mixture was cooled, then ether (50 mL) was added, and the mixture washed with brine (50 mL). The aqueous phase was re-extracted with diethyl ether (30 mL) and the combined organic extracts dried ($MgSO_4$), filtered, and concentrated in vacuo. The residue was purified by flash column chromatography (pentane/EtOAc, 8:1) to give the thioacetate **13** (170 mg, 88%) as a yellow oil. $[\alpha]_D^{23}$ = +35.7 (c = 1.0, in $CHCl_3$). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.42–7.26 (m, 15 H, Ar-H), 4.96, 4.68 (2 d, J = 10.8 Hz, 2 H, PhCH_2), 4.77, 4.72 (2 d, J = 12.3 Hz, 2 H, PhCH_2), 4.69 (d, $J_{1,2}$ = 2.0 Hz, 1 H, 1-H), 4.63 (s, 2 H, PhCH_2), 3.88 (dd, $J_{2,3}$ = 3.0, $J_{3,4}$ = 9.0 Hz, 1 H, 3-H), 3.82–3.78 (m, 2 H, 2-H, 4-H), 3.71 (atd, J_{at} = 8.7, $J_{5,6'}$ = 2.7 Hz, 1 H, 5-H), 3.60 (dd, $J_{5,6'}$ = 2.7, $J_{6,6'}$ = 13.5 Hz, 1 H, 6′-H), 3.31 (s, 3 H, OCH_3), 3.11 (dd, $J_{5,6}$ = 8.1, $J_{6,6'}$ = 13.5 Hz, 1 H, 6-H), 2.36 [s, 3 H, SC(O)CH_3] ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 195.3 (s, C=O), 138.5, 138.4, 138.3 (3 s, 3 Ar-C), 128.5, 128.5, 128.5, 128.3, 127.9, 127.8, 127.8, 127.7, 127.7 (9 d, Ar-CH), 99.1 (d, C-1), 80.1 (d, C-3), 77.7, 74.7 (2 d, C-2, C-4), 75.3, 72.9, 72.3 (3 t, 3 PhCH_2), 71.0 (d, C-5), 54.8 (q, OCH_3), 31.4 (t, C-6), 30.6 [q, SC(O)CH_3] ppm. IR (film): $\tilde{\nu}$ = 1694 (C=O) cm^{-1}. MS (ES$^+$): m/z (%) = 1067 (20) [2M + Na$^+$], 545 (100) [M + Na$^+$]. HRMS: calcd. for $C_{30}H_{34}O_6S$ [MNa$^+$] 545.1968; found 545.1952.

3-*S*-Acetyl-1,2:5,6-di-*O*-isopropylidene-3-deoxy-3-thio-α-D-glucofuranose (14): Triflate **8** (244 mg, 0.62 mmol), KSAc (142 mg, 1.24 mmol) in DMF (2 mL) at 90 °C for 4 h gave, by the same procedure as described for **13** and chromatography (CH_2Cl_2/diethyl ether, 49:1) the thioacetate **14** (175 mg, 84%) as a pale brown oil.[43]

Methyl 2-*S*-Acetyl-3-*O*-benzyl-4,6-*O*-benzylidene-2-deoxy-2-thio-β-D-mannopyranoside (15): Triflate **9** (1.15 g, 2.7 mmol), KSAc (790 mg, 6.9 mmol) in DMF (10 mL) at room temp. for 19 h gave, by the same procedure as described for **13** and chromatography (pentane/EtOAc, 4:1) the thioacetate **15** (969 mg, 84%) as a pale yellow oil. $[\alpha]_D^{23}$ = –67.4 (c = 1.0, in $CHCl_3$). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.51–7.26 (m, 10 H, Ar-H), 5.57 (s, 1 H, PhCH), 4.72 (d, J = 12.4 Hz, 1 H, PhCHH'), 4.64–4.57 (m, 3 H, PhCHH′, 1-H, 2-H), 4.30 (dd, $J_{5,6'}$ = 4.7, $J_{6,6'}$ = 10.4 Hz, 1 H, 6′-H), 3.94 (dd, $J_{2,3}$ = 4.4, $J_{3,4}$ = 9.6 Hz, 1 H, 3-H), 3.80 (at, J = 10.3 Hz, 1 H, 6-H), 3.66 (at, J = 9.5 Hz, 1 H, 4-H), 3.50 (s, 3 H, OCH_3), 3.38 (atd, J_{at} = 9.6, $J_{5,6'}$ = 4.7 Hz, 1 H, 5-H), 2.42 [s, 3 H, SC(O)CH_3] ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 194.2 (s, C=O), 137.7, 137.3 (2 s, 2 Ar-C), 129.0, 128.4, 128.2, 127.7, 126.1 (5 d, Ar-CH), 101.6 (d, PhCH), 101.4 (d, C-1), 80.2 (d, C-4), 75.3 (d, C-3), 71.7 (t, PhCH_2), 68.5 (t, C-6), 67.7 (d, C-5), 57.3 (q, OCH_3), 49.2 (d, C-2), 30.7 [q, SC(O)CH_3] ppm. IR (film): $\tilde{\nu}$ = 1692 (C=O) cm^{-1}. MS (ES$^+$): m/z (%) = 453 (100) [M + Na$^+$]. HRMS: calcd. for $C_{23}H_{26}O_6SNa$ [MNa$^+$] 453.1342; found 453.1345.

Methyl 3-*S*-Acetyl-2-*O*-benzyl-4,6-*O*-benzylidene-3-deoxy-3-thio-β-D-allopyranoside (16): Triflate **10** (2.31 g, 5.4 mmol), KSAc (1.03 g, 9.0 mmol) in DMF (10 mL) at room temp. for 6 h gave, by the same procedure as described for **13** and chromatography (pentane/EtOAc, 4:1 → 2:1) followed by trituration with ether, the thioacetate **16** (1.85 g, 80%) as an off-white solid, which was recrystallised; Colourless crystals, m.p. 146–150 °C (EtOAc/pentane). $[\alpha]_D^{21}$ = –109 (c = 1.0, in $CHCl_3$). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.44–7.28 (m, 10 H, Ar-H), 5.53 (s, 1 H, PhCH), 4.76 (at, J = 4.4 Hz, 1 H, 3-H), 4.72, 4.66 (2 d, J = 11.9 Hz, 2 H, PhCH_2), 4.41 (d, $J_{1,2}$ = 7.9 Hz, 1 H, 1-H), 4.33 (dd, $J_{5,6'}$ = 5.0, $J_{6,6'}$ = 10.5 Hz, 1 H, 6′-H), 3.78 (dd, $J_{3,4}$ = 4.0, $J_{4,5}$ = 9.3 Hz, 1 H, 4-H), 3.72 (at, J = 10.1 Hz, 1 H, 6-H), 3.65 (dd, $J_{1,2}$ = 7.9, $J_{2,3}$ = 4.7 Hz, 1 H, 2-H), 3.59 (m, 1 H, 5-H), 3.57 (s, 3 H, OCH_3), 2.41 [s, 3 H, C(O)CH_3] ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 31.0 [q, C(O)CH_3], 46.6 (d, C-3), 57.4 (q, OCH_3), 66.7 (d, C-5), 69.1 (t, C-6), 72.3 (t, PhCH_2), 75.6 (d, C-2), 76.7 (d, C-4), 101.1 (d, PhCH), 103.6 (d, C-1), 129.1, 128.5, 128.3, 128.1, 127.9, 126.2 (6 d, Ar-CH), 137.6, 137.2 (2 s, 2 Ar-C), 193.6 (s, C=O) ppm. MS (ES$^+$): m/z (%) = 453 (100) [M + Na$^+$]. HRMS: calcd. for $C_{23}H_{26}O_6SNa$ [MNa$^+$] 453.1342; found 453.1335.

Methyl 2-*S*-Acetyl-3-*O*-benzyl-4,6-*O*-benzylidene-2-deoxy-2-thio-α-D-mannopyranoside (17): Triflate **11** (206 mg, 0.48 mmol), KSAc (93 mg, 0.82 mmol) in DMF (5 mL) at 90 °C, for 1 h 50 min gave, by the same procedure as described for **13** and column chromatography (pentane/EtOAc, 10:1 → 4:1), thioacetate **17** (148 mg, 88%) as a yellow oil. $[\alpha]_D^{23}$ = +16 (c = 1.0, in $CHCl_3$); δ_H (500 MHz, $CDCl_3$): δ = 7.49–7.47 (m, 2 H, Ar-H), 7.39–7.23 (m, 8 H, Ar-H), 5.58 (s, 1 H, CHPh), 4.72 (s, 1 H, H-1), 4.68, 4.63 (2 d, J = 12.2 Hz, 2 H, PhCH_2), 4.38 (d, $J_{2,3}$ = 4.9 Hz, 1 H, H-2), 4.28 (dd, $J_{2,3}$ = 4.9 Hz, $J_{3,4}$ = 9.8 Hz, 1 H, H-3), 4.23 (dd, $J_{5,6'}$ = 4.4 Hz, $J_{6,6'}$ = 9.9 Hz, 1 H, H-6′), 3.87–3.76 (m, 2 H, H-5, H-6), 3.69 (at, J = 9.5 Hz, 1 H, H-4), 3.35 (s, 3 H, OCH_3), 2.39 [s, 3 H, C(O)CH_3]; δ_C (125 MHz, $CDCl_3$): δ = 194.2 (s, C=O), 138.0, 137.5 (2 s, 2 Ar-C), 129.0, 128.4, 128.3, 127.7, 127.7, 126.2 (6 d, Ar-CH), 102.5 (d, C-1), 101.7 (d, CHPh), 80.6 (d, C-4), 72.9 (d, C-3), 72.1 (t, PhCH_2), 68.9 (t, C-6), 63.9 (d, C-5), 55.3 (q, OCH_3), 48.2 (d, C-2), 30.8 [q, C(O)CH_3]. IR (film): $\tilde{\nu}$ = 1694 (C=O) cm^{-1}. MS (ES$^+$): m/z (%) = 469 (2) [M + K$^+$] 453 (100) [M + Na$^+$]. HRMS: calcd. for $C_{23}H_{26}O_6SNa$ [MNa$^+$] 453.1342; found 453.1322.

Methyl 4-*S*-Acetyl-2,3,6-tri-*O*-benzoyl-4-deoxy-4-thio-β-D-glucopyranoside (18): Triflate **12** (288 mg, 0.45 mmol), KSAc (103 mg, 0.90 mmol) in DMF (3 mL) at 90 °C for 50 min gave, by the same

procedure as described for **13** and chromatography (pentane/EtOAc, 3:1) the thioacetate **18** (147 mg, 58%) as a white solid, which was recrystallised: colourless crystals, m.p. 154–157 °C (EtOAc/pentane). $[\alpha]_D^{23}$ = +114 (*c* = 1.0, in $CHCl_3$). ^1H NMR (300 MHz, $CDCl_3$): δ = 8.13–8.11 (m, 2 H, Ar-H), 7.95–7.89 (m, 4 H, Ar-H), 7.61–7.31 (m, 9 H, Ar-H), 5.75 (at, *J* = 10.1 Hz, 1 H, 3-H), 5.44 (at, *J* = 8.7 Hz, 1 H, 2-H), 4.74–4.67 (m, 2 H, 1-H, 6′-H), 4.58 (dd, $J_{5,6}$ = 4.6, $J_{6,6'}$ = 12.0 Hz, 1 H, 6-H), 4.13–4.03 (m, 2 H, 4-H, 5-H), 3.51 (s, 3 H, OCH_3), 2.19 [s, 3 H, $SC(O)CH_3$] ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 192.7 (s, SC=O), 166.3, 165.8, 165.3 (3 s, 3 OC=O), 133.4, 133.3, 133.2 (3 s, 3 Ar-C), 130.2, 129.9, 129.9, 129.9, 129.4, 129.0, 128.5, 128.4, 128.4 (9 d, Ar-CH), 101.9 (d, C-1), 73.1, 73.0 (2 d, C-2, C-5), 71.9 (d, C-3), 64.0 (t, C-6), 57.0 (q, OCH_3), 44.7 (d, C-4), 30.8 [q, $SC(O)CH_3$] ppm. IR (film): $\tilde{\nu}$ = 1727 (C=O) cm^{-1}. MS (ES^+): *m*/*z* = 582 [M + NH_4^+]. HRMS: calcd. for $C_{30}H_{32}O_9NS$ (MNH_4^+) 582.1792; found 582.1800.

The elimination product was also isolated: 41 mg (19%) of a yellow oil; NMR spectroscopic data were identical to those described for methyl 2,3,6-tri-*O*-benzoyl-4-deoxy-α-L-*threo*-hex-4-enopyranoside.[44]

General Procedure I: Thioether Pseudodisaccharide Formation from Thioacetates: (Table 1). The thioacetate (0.12–0.35 mmol) was dissolved in MeOH (1–3 mL). A solution of sodium (1.5–2 equiv.) in MeOH (1 mL) was added, and the solution immediately degassed and stirred at room temp. under N_2. After TLC indicated complete conversion of the starting material to a major product (typically 20–40 min), the reaction mixture was added to NH_4Cl (satd. aq., 25 mL), and extracted with CH_2Cl_2 (25 mL). The organic phase was dried (Na_2SO_4), filtered, and concentrated in vacuo.

The residue was dissolved in DMF, and sulfonate (usually 1.5 equiv.) was added either as a solution in DMF (total 2–3 mL) or as a solid. The mixture was degassed under N_2. Sodium hydride (60% in oil, 2 equiv.) was added, and the mixture was stirred at 50 °C. After TLC indicated complete consumption of thiol or sulfonate (ca. 30 min), NH_4Cl (satd. aq., 25 mL) was added, and the mixture extracted with Et_2O (2 × 25 mL). The organic phase was dried (Na_2SO_4), filtered, and concentrated in vacuo. The residue was purified by flash column chromatography to give the thioether pseudodisaccharide.

General Procedure II: Pseudodisaccharide Formation by Triflate Dimerisation with Sodium Sulfide: See Table 2; sodium sulfide nonahydrate (2–4 equiv.) was dried by heating with a heat gun in air. The crystals first melted to give a liquid, which upon further heating lost water to give a solid pale yellow residue. Note: excessive heating of this solid leads to discolouration and is avoided. The residue was cooled to room temp. under vacuum (water aspirator) before use. Molecular sieves (powdered, 4 Å) were added. The triflate (0.18–1.9 mmol) was dissolved in acetonitrile (2–6 mL) and added. The mixture was stirred at 50 °C under N_2 until TLC showed complete consumption of triflate. Efficient stirring is necessary here as the reaction mixture is heterogeneous. The mixture was then cooled to room temp. then filtered through Celite and rinsed through with CH_2Cl_2 (50 mL). The solution was washed with HCl (1 M, 50 mL) and the aqueous phase re-extracted with CH_2Cl_2. The combined organic extracts were dried (Na_2SO_4), filtered, and concentrated in vacuo. The residue was purified by flash column chromatography to give the thioether.

Bis(methyl 2,3,4-tri-*O*-benzyl-6-deoxy-α-D-mannopyranosid-6-yl)-sulfane (20) and Bis(methyl 2,3,4-Tri-*O*-benzyl-6-deoxy-α-D-mannopyranosid-6-yl)disulfane (33): According to general procedure I, thioacetate **13** (149 mg, 0.29 mmol) and mesylate **7** (232 mg, 0.43 mmol) gave, after purification by flash chromatography (pentane/EtOAc, 5:1 → 4:1), the thioether **20** (142 mg, 47%) as a colourless oil. $[\alpha]_D^{21}$ = +44.6 (*c* = 1.0, in $CHCl_3$). ^1H NMR (400 MHz, $CDCl_3$): δ = 7.39–7.23 (m, 30 H, Ar-H), 4.94, 4.63 (2 d, *J* = 11.1 Hz, 4 H, PhCH_2), 4.73, 4.69 (2 d, *J* = 12.4 Hz, 4 H, PhCH_2), 4.66 (d, $J_{1,2}$ = 1.6 Hz, 2 H, 1-H), 4.60 (s, 4 H, PhCH_2), 3.85 (dd, $J_{2,3}$ = 3.1, $J_{3,4}$ = 9.0 Hz, 2 H, 3-H), 3.81–3.74 (m, 4 H, 2-H, 4-H), 3.71 (atd, J_{at} = 9.0, $J_{5,6'}$ = 1.9 Hz, 2 H, 5-H), 3.29 (s, 6 H, OCH_3), 3.12 (dd, $J_{5,6'}$ = 1.9, $J_{6,6'}$ = 13.4 Hz, 2 H, 6′-H), 2.78 (dd, $J_{5,6}$ = 8.8, $J_{6,6'}$ = 13.4 Hz, 2 H, 6-H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 138.7, 138.6, 138.5 (3 s, 6 Ar-C), 128.5, 128.0, 128.0, 127.9, 127.8, 127.7, 127.7 (7 d, Ar-CH), 98.9 (d, C-1), 80.4 (d, C-3), 78.0 (d, C-4), 75.2, 72.8, 72.2 (3 t, 6 Ph*C*H_2), 74.8 (d, C-2), 72.7 (d, C-5), 54.8 (q, OCH_3), 35.0 (t, C-6) ppm. MS (ES^+): *m*/*z* (%) = 949 (85) [M + Na^+], 944 (100) [M + NH_4^+]. HRMS: calcd. for $C_{56}H_{62}O_{10}SNa$ [MNa^+] 949.3956; found 949.3940.

The disulfide **33** (20 mg, 15%) was isolated as a colourless oil. $[\alpha]_D^{24}$ = +137 (*c* = 1.0, in $CHCl_3$). ^1H NMR (400 MHz, $CDCl_3$): δ = 7.37–7.21 (m, 30 H, Ar-H), 4.92, 4.57 (2 d, *J* = 11.2 Hz, 4 H, PhCH_2), 4.73, 4.68 (2 d, *J* = 12.4 Hz, 4 H, PhCH_2), 4.68 (d, $J_{1,2}$ = 1.5 Hz, 2 H, 1-H), 4.59 (s, 4 H, PhCH_2), 3.88–3.80 (m, 4 H, 3-H, 5-H), 3.77 (at, *J* = 2.3 Hz, 2 H, 2-H), 3.73 (at, *J* = 9.2 Hz, 2 H, 4-H), 3.31 (s, 6 H, OCH_3), 3.17 (dd, $J_{5,6'}$ = 2.0, $J_{6,6'}$ = 13.4 Hz, 2 H, 6′-H), 2.86 (dd, $J_{5,6}$ = 9.1, $J_{6,6'}$ = 13.4 Hz, 2 H, 6-H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 41.6 (t, C-6), 55.0 (q, OCH_3), 70.5 (d, C-5), 72.3, 72.9, 75.1 (3 t, 6 Ph*C*H_2), 74.8 (d, C-2), 77.9 (d, C-4), 80.4 (d, C-3), 99.0 (d, C-1), 127.7, 127.8, 127.8, 128.0, 128.5 (5 d, Ar-CH), 138.4, 138.5, 138.6 (3 s, 6 Ar-C) ppm. MS (MALDI): *m*/*z* = 998 [M + K^+], 982 [M + Na^+]. HRMS: calcd. for $C_{56}H_{66}O_{10}NS_2$ (MNH_4^+) 976.4123; found 976.4094.

(1,2:5,6-Di-*O*-isopropylidene-3-deoxy-α-D-glucofuranos-3-yl)(methyl 2,3,4-tri-*O*-benzyl-6-deoxy-α-D-mannopyranosid-6-yl)sulfane (21): According to general procedure I, thioacetate **13** (160 mg, 0.31 mmol) and triflate **8** (82 mg, 0.20 mmol) gave, after purification by flash chromatography (pentane/EtOAc, 5:1), the thioether **21** (123 mg, 81%) as a colourless oil. $[\alpha]_D^{24}$ = +19.3 (*c* = 1.0, in $CHCl_3$). ^1H NMR (400 MHz, $CDCl_3$): δ = 7.39–7.26 (m, 15 H, Ar-H), 5.79 (d, $J_{1,2}$ = 3.5 Hz, 1 H, 1^{II}-H), 4.96, 4.64 (2 d, *J* = 10.8 Hz, 2 H, PhCH_2), 4.79 (d, $J_{1,2}$ = 3.5 Hz, 1 H, 2^{II}-H), 4.76 (d, *J* = 12.4 Hz, 1 H, PhCH*H*′), 4.72–4.69 (m, 2 H, 1^{I}-H, PhC*H*H′), 4.60 (s, 2 H, PhCH_2), 4.37 (dat, $J_{4,5}$ = 8.6, J_{at} = 5.6 Hz, 1 H, 5^{II}-H), 4.20 (dd, $J_{3,4}$ = 3.7, $J_{4,5}$ = 8.6 Hz, 1 H, 4^{II}-H), 4.10 (dd, $J_{5,6'}$ = 6.2, $J_{6,6'}$ = 8.6 Hz, 1 H, $6'^{II}$-H), 3.97 (dd, $J_{5,6}$ = 5.2, $J_{6,6'}$ = 8.6 Hz, 1 H, 6^{II}-H), 3.91 (at, *J* = 9.0 Hz, 1 H, 4^{I}-H), 3.86 (dd, $J_{2,3}$ = 2.8, $J_{3,4}$ = 9.0 Hz, 1 H, 3^{I}-H), 3.80–3.75 (m, 2 H, 2^{I}-H, 5^{I}-H), 3.59 (d, $J_{3,4}$ = 3.7 Hz, 1 H, 3^{II}-H), 3.34 (s, 3 H, OCH_3), 3.05 (dd, $J_{5,6'}$ = 2.4, $J_{6,6'}$ = 13.7 Hz, 1 H, $6'^{I}$-H), 2.91 (dd, $J_{5,6}$ = 7.4, $J_{6,6'}$ = 13.7 Hz, 1 H, 6^{I}-H), 1.51, 1.35, 1.29, 1.27 [4 s, 12 H, 2 $C(CH_3)_2$] ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 138.6, 138.4 (2 s, Ar-C), 128.6, 128.5, 128.1, 128.0, 127.9, 127.8 (6 d, Ar-CH), 111.9, 109.4 [2 s, 2 *C*$(CH_3)_2$], 105.0 (d, C-1^{II}), 99.1 (d, C-1^{I}), 86.2 (d, C-2^{II}), 80.6, 80.3 (2 d, C-3^{I}, C-4^{II}), 77.4 (d, C-4^{I}), 75.4, 72.9, 72.3 (3 t, 3 Ph*C*H_2), 74.7, 73.0 (2 d, C-2^{I}, C-5^{I}), 74.2 (d, C-5^{II}), 67.9 (t, C-6^{II}), 55.0 (q, OCH_3), 53.2 (d, C-3^{II}), 34.0 (t, C-6^{I}), 27.0, 26.9, 26.5, 25.5 (4 q, 4 CH_3) ppm. MS (ES^+): *m*/*z* (%) = 1467 (5) [2M + Na^+], 745 (100) [M + Na^+]. HRMS: calcd. for $C_{40}H_{50}O_{10}SNa$ [MNa^+] 745.3017; found 745.2999.

(Methyl 3-*O*-benzyl-4,6-*O*-benzylidene-2-deoxy-β-D-mannopyranosid-2-yl)(methyl 2,3,4-tri-*O*-benzyl-6-deoxy-α-D-mannopyranosid-6-yl)-sulfane (22): According to general procedure I, thioacetate **15** (58 mg, 0.14 mmol) and mesylate **7** (110 mg, 0.20 mmol) gave, after purification by flash chromatography (pentane/EtOAc, 4:1), the

thioether **22** (52 mg, 47%) as a colourless oil. $[a]_D^{23}$ = –2.0 (*c* = 0.5, in $CHCl_3$). ^1H NMR (400 MHz, $CDCl_3$): δ = 7.48–7.21 (m, 25 H, Ar-H), 5.58 (s, 1 H, PhC*H*), 4.93, 4.60 (2 d, *J* = 11.1 Hz, 2 H, PhCH_2), 4.80–4.69 (m, 5 H, 1^{II}-H, 2 PhCH_2), 4.60 (s, 2 H, PhCH_2), 4.48 (d, 1 H, 1^{I}-H), 4.28 (dd, $J_{5,6'}$ = 4.8, $J_{6,6'}$ = 10.4 Hz, 1 H, $6'^{I}$-H), 4.07 (at, *J* = 9.4 Hz, 1 H, 4^{I}-H), 3.88–3.76 (m, 6 H, 2^{II}-H, 3^{II}-H, 4^{II}-H, 5^{II}-H, 3^{I}-H, 6^{I}-H), 3.55 (dd, $J_{1,2}$ = 1.5, $J_{2,3}$ = 4.4 Hz, 1 H, 2^{I}-H), 3.47, 3.34 (2 s, 6 H, 2 OCH_3), 3.32–3.27 (m, 2 H, 5^{I}-H, $6'^{II}$-H), 2.98 (m, 1 H, 6^{II}-H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 138.8, 138.7, 138.5, 138.5, 137.7 (5 s, 5 Ar-C), 129.0, 128.5, 128.4, 128.3, 128.0, 127.9, 127.8, 127.7, 127.7, 126.2 (10 d, Ar-CH), 103.2 (d, C-1^{I}), 101.6 (d, Ph*C*H), 99.0 (d, C-1^{II}), 80.5, 78.1, 77.2, 75.0, 72.5 (5 d, C-2^{II}, C-3^{II}, C-4^{II}, C-5^{II}, C-3^{I}), 80.0 (d, C-4^{I}), 75.2, 73.0, 72.4, 72.2 (4 t, 4 PhCH_2), 68.8 (t, C-6^{I}), 67.9 (d, C-5^{I}), 57.2, 55.0 (2 q, 2 OCH_3), 53.0 (d, C-2^{I}), 36.1 (t, C-6^{II}) ppm. *m*/*z* (MALDI) 874 (M + K^+), 858 [M + Na^+]. MS (ES^+): *m*/*z* (%) = 852 (80) [M + NH_4^+]. HRMS: calcd. for $C_{49}H_{58}O_{10}NS$ (MNH_4^+) 852.3776; found 852.3746.

According to general procedure I, thioacetate **13** (70 mg, 0.13 mmol) and triflate **9** (101 mg, 0.20 mmol) gave, after purification by flash chromatography (pentane/EtOAc, 3:1), the thioether **22** (47 mg, 42%) identical to that described above.

Bis(1,2:5,6-di-*O*-isopropylidene-3-deoxy-α-D-glucofuranos-3-yl)sulfane (23) and Bis(1,2:5,6-di-*O*-isopropylidene-3-deoxy-α-D-glucofuranos-3-yl)disulfane (34): According to general procedure I, thioacetate **14** (41 mg, 0.12 mmol) and triflate **8** (72 mg, 0.18 mmol) gave, after purification by flash chromatography (pentane/EtOAc, 4:1), the thioether **23** (43 mg, 68%) as a colourless oil. $[a]_D^{23}$ = –40.9 (*c* = 1.0, in $CHCl_3$). ^1H NMR (400 MHz, $CDCl_3$): δ = 5.81 (d, $J_{1,2}$ = 3.5 Hz, 2 H, 1-H), 4.82 (d, $J_{1,2}$ = 3.5 Hz, 2 H, 2-H), 4.31 (dat, $J_{4,5}$ = 8.8, J_{at} = 5.6 Hz, 2 H, 5-H), 4.19 (dd, $J_{3,4}$ = 3.7, $J_{4,5}$ = 8.8 Hz, 2 H, 4-H), 4.12 (dd, $J_{5,6'}$ = 6.0, $J_{6,6'}$ = 8.6 Hz, 2 H, 6′-H), 3.96 (dd, $J_{5,6}$ = 5.3, $J_{6,6'}$ = 8.6 Hz, 2 H, 6-H), 3.51 (d, $J_{3,4}$ = 3.7 Hz, 2 H, 3-H), 1.50, 1.42, 1.35, 1.31 (4 s, 24 H, 8 CH_3) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 109.5, 112.1 [2 s, 4 $C(CH_3)_2$], 105.0 (d, C-1), 86.2 (d, C-2), 80.3 (d, C-4), 74.1 (d, C-5), 68.0 (t, C-6), 52.8 (d, C-3), 27.0, 26.8, 26.4, 25.4 (4 q, 8 CH_3) ppm. MS (MALDI): *m*/*z* = 541 [M + Na^+]. HRMS: calcd. for $C_{24}H_{38}O_{10}SNa$ [MNa^+] 541.2078; found 541.2079.

The disulfide **34** was isolated (5 mg, 7%)[45] as a colourless oil. ^1H NMR (400 MHz, $CDCl_3$): δ = 5.92 (d, $J_{1,2}$ = 3.5 Hz, 2 H, 1-H), 4.90 (d, $J_{1,2}$ = 3.5 Hz, 2 H, 2-H), 4.30 (ddd, $J_{4,5}$ = 8.8, $J_{5,6}$ = 4.8, $J_{5,6'}$ = 6.0 Hz, 2 H, 5-H), 4.19 (dd, $J_{3,4}$ = 3.8, $J_{4,5}$ = 8.8 Hz, 2 H, 4-H), 4.13 (dd, $J_{5,6'}$ = 6.0, $J_{6,6'}$ = 8.6 Hz, 2 H, 6′-H), 3.96 (dd, $J_{5,6}$ = 4.8, $J_{6,6'}$ = 8.6 Hz, 2 H, 6-H), 3.64 (d, $J_{3,4}$ = 3.8 Hz, 2 H, 3-H), 1.52, 1.43, 1.37, 1.34 (4 s, 24 H, 8 CH_3) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 112.1, 109.8, [2 s, 4 $C(CH_3)_2$], 105.2 (d, C-1), 85.7 (d, C-2), 80.4 (d, C-4), 73.8 (d, C-5), 68.1 (t, C-6), 57.9 (d, C-3), 27.0, 26.8, 26.4, 25.2 (4 q, 8 CH_3) ppm.

According to general procedure II, triflate **8** (660 mg, 1.7 mmol), sodium sulfide (811 mg, 3.4 mmol), molecular sieves (50 mg) and MeCN (6 mL) gave, after purification by flash chromatography (pentane/EtOAc, 5:1, 1% Et_3N), the thioether **23** (375 mg, 86%) identical to that described above.

(Methyl 3-*O*-benzyl-4,6-*O*-benzylidene-2-deoxy-β-D-mannopyranosid-2-yl)(1,2:5,6-di-*O*-isopropylidene-3-deoxy-α-D-glucofuranos-3-yl)sulfane (24): According to general procedure I, thioacetate **14** (123 mg, 0.34 mmol) and triflate **9** (297 mg, 0.59 mmol) gave, after purification by flash chromatography (pentane/EtOAc, 4:1 → 3:1), the thioether **24** (174 mg, 75%) as a colourless oil. $[a]_D^{20}$ = –28.8 (*c* = 1.0, in $CHCl_3$). ^1H NMR (400 MHz, $CDCl_3$): δ = 7.50–7.26 (m, 10 H, Ar-H), 5.78 (d, $J_{1,2}$ = 3.5 Hz, 1 H, 1^{II}-H), 5.61 (s, 1 H, PhC*H*), 4.92 (d, *J* = 12.4 Hz, 1 H, PhCH*H*′), 4.82–4.78 (m, 2 H, 2^{II}-H, PhCHH′), 4.66 (dat, $J_{5,6}$ = 6.0, J_{at} = 7.8 Hz, 1 H, 5^{II}-H), 4.52 (d, $J_{1,2}$ = 1.6 Hz, 1 H, 1^{I}-H), 4.29 (dd, $J_{5,6'}$ = 4.8, $J_{6,6'}$ = 10.4 Hz, 1 H, $6'^{I}$-H), 4.24 (dd, $J_{3,4}$ = 3.5, $J_{4,5}$ = 7.9 Hz, 1 H, 4^{II}-H), 4.17–4.09 (m, 2 H, 4^{I}-H, $6'^{II}$-H), 3.98 (dd, $J_{5,6}$ = 6.0, $J_{6,6'}$ = 8.4 Hz, 1 H, 6^{II}-H), 3.87–3.80 (m, 4 H, 2^{I}-H, 3^{I}-H, 6^{I}-H, 3^{II}-H), 3.51 (s, 3 H, OCH_3), 3.33 (atd, J_{at} = 9.7, $J_{5,6'}$ = 4.8 Hz, 1 H, 5^{I}-H), 1.49, 1.44, 1.34, 1.24 [4 s, 12 H, 2 $C(CH_3)_2$] ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 138.2, 137.5 (2 s, Ar-C), 129.0, 128.5, 128.3, 127.8, 127.6, 126.1 (6 d, Ar-CH), 111.7, 109.1 [2 s, 2 $C(CH_3)_2$], 104.7 (d, C-1^{II}), 102.6 (d, C-1^{I}), 101.6 (d, Ph*C*H), 86.1 (d, C-2^{II}), 80.9 (d, C-4^{II}), 80.2 (d, C-4^{I}), 77.2 (d, C-3^{I}), 73.8 (d, C-5^{II}), 73.0 (t, PhCH_2), 68.6 (t, C-6^{I}), 67.9 (d, C-5^{I}), 67.6 (t, C-6^{II}), 57.2 (q, OCH_3), 53.3, 52.4 (2 d, C-2^{I}, C-3^{II}), 26.9, 26.7, 26.3, 25.4 (4 q, 4 CH_3) ppm. MS (MALDI): *m*/*z* = 669 [M + K^+], 653 [M + Na^+]. HRMS: calcd. for $C_{33}H_{42}O_{10}SNa$ [MNa^+] 653.2391; found 653.2403.

Recovered triflate was also isolated (112 mg).

According to general procedure I, thioacetate **15** (133 mg, 0.31 mmol) and triflate **8** (82 mg, 0.20 mmol) gave, after purification by flash chromatography (pentane/EtOAc, 7:2), the thioether **24** (92 mg, 70%) identical to that described above.

Bis(methyl 3-*O*-benzyl-4,6-*O*-benzylidene-2-deoxy-β-D-mannopyranosid-2-yl)sulfane (25): According to general procedure I, thioacetate **15** (231 mg, 0.54 mmol) and triflate **9** (135 mg, 0.27 mmol) gave, after purification by flash chromatography (pentane/EtOAc, 3:1), the thioether **25** (146 mg, 73%) as a colourless oil. $[a]_D^{21}$ = –131 (*c* = 1.0, in $CHCl_3$). ^1H NMR (400 MHz, $CDCl_3$): δ = 7.52–7.26 (m, 20 H, Ar-H), 5.57 (s, 2 H, PhC*H*), 4.96, 4.69 (2 d, *J* = 12.1 Hz, 4 H, PhCH_2), 4.58 (d, $J_{1,2}$ = 1.1 Hz, 2 H, 1-H), 4.35 [br. s (obsd.), 2 H, 2-H], 4.34 (dd, $J_{5,6'}$ = 4.8, $J_{6,6'}$ = 10.2 Hz, 2 H, 6′-H), 4.05 (at, *J* = 9.5 Hz, 2 H, 4-H), 3.92 (at, *J* = 10.2 Hz, 2 H, 6-H), 3.88 (dd, $J_{2,3}$ = 4.8, $J_{3,4}$ = 9.7 Hz, 2 H, 3-H), 3.53 (s, 6 H, OCH_3), 3.37 (atd, J_{at} = 9.6, $J_{5,6'}$ = 4.8 Hz, 2 H, 5-H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 138.5, 137.7 (2 s, Ar-C), 128.9, 128.3, 128.3, 128.1, 127.5, 126.2 (6 d, Ar-CH), 104.0 (d, C-1), 101.5 (d, Ph*C*H), 78.7 (d, C-4), 76.8 (d, C-3), 70.8 (t, PhCH_2), 68.8 (t, C-6), 68.2 (d, C-5), 57.0 (q, OCH_3), 49.9 (d, C-2) ppm. MS (MALDI): *m*/*z* = 781 [M + K^+], 765 [M + Na^+]. HRMS: calcd. for $C_{42}H_{46}O_{10}SNa$ [MNa^+] 765.2704; found 765.2674.

According to general procedure II, triflate **9** (500 mg, 1.0 mmol), sodium sulfide (475 mg, 2.0 mmol), molecular sieves (500 mg) and MeCN (6 mL) gave, after purification by flash chromatography (pentane/EtOAc, 3:1, 1% Et_3N), the thioether **25** (316 mg, 86%) identical to that described above.

(Methyl 2-*O*-benzyl-4,6-*O*-benzylidene-3-deoxy-β-D-allopyranosid-3-yl)(methyl 2,3,4-tri-*O*-benzyl-6-deoxy-α-D-mannopyranosid-6-yl)sulfane (26): According to general procedure I, thiol **13-SH** (isolated thiol derived from deprotection of thioacetate **13**, 78 mg, 0.16 mmol) and triflate **10** (55 mg, 0.11 mmol) gave, after purification by flash chromatography (pentane/EtOAc, 5:1), the thioether **26** (77 mg, 85%) as a colourless oil. $[a]_D^{22}$ = +20.5 (*c* = 2.2, in $CHCl_3$). ^1H NMR (500 MHz, $CDCl_3$): δ = 7.50–7.18 (m, 25 H, Ar-H), 5.43 (s, 1 H, PhC*H*), 4.84, 4.52 (2 d, *J* = 11.1 Hz, 2 H, PhCH_2), 4.80, 4.74 (2 d, *J* = 12.4 Hz, 2 H, PhCH_2), 4.75 (d, $J_{1,2}$ = 7.9 Hz, 1 H, 1^{II}-H), 4.73, 4.68 (2 d, *J* = 12.4 Hz, 2 H, PhCH_2), 4.70 (d, $J_{1,2}$ = 1.5 Hz, 1 H, 1^{I}-H), 4.59, 4.56 (2 d, *J* = 11.9 Hz, 2 H, PhCH_2), 4.33 (dd, $J_{5,6'}$ = 5.2, $J_{6,6'}$ = 10.5 Hz, 1 H, $6'^{II}$-H), 4.01 (atd, J_{at} = 9.7, $J_{5,6'}$ = 5.2 Hz, 1 H, 5^{II}-H), 3.86 (at, *J* = 4.0 Hz, 1 H, 3^{II}-H), 3.81–3.78 (m, 2 H, 3^{I}-H, 4^{I}-H), 3.78–3.73 (m, 2 H, 2^{I}-H, 5^{I}-H), 3.68 (at, *J* = 10.0 Hz, 1 H, 6^{II}-H), 3.63 (dd, $J_{3,4}$ = 3.8, $J_{4,5}$ = 9.3 Hz, 1 H, 4^{II}-H), 3.56 (s, 3 H, OCH_3), 3.52 (dd, $J_{1,2}$ = 7.9, $J_{2,3}$ = 4.4 Hz,

1 H, 2^{II}-H), 3.29 (dd, $J_{5,6'}$ = 1.8, $J_{6,6'}$ = 13.8 Hz, 1 H, $6'^{I}$-H), 3.19 (s, 3 H, OCH_3), 3.01 (dd, $J_{5,6}$ = 8.9, $J_{6,6'}$ = 13.8 Hz, 1 H, 6^{I}-H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 137.5, 138.3, 138.5, 138.6, 138.8 (5 s, 5 Ar-C), 129.0, 128.4, 128.4, 128.3, 128.2, 127.9, 127.8, 127.8, 127.7, 127.7, 127.6, 127.5, 126.4 (13 d, Ar-CH), 102.7 (d, C-1^{II}), 101.6 (d, Ph*C*H), 98.9 (d, C-1^{I}), 80.4, 78.0 (2 d, C-3^{I}, C-4^{I}), 79.2 (d, C-4^{II}), 77.5 (d, C-2^{II}), 75.1, 72.9, 72.2, 72.2 (4 t, 4 Ph*C*H_2), 74.9 (d, C-2^{I}), 72.3 (d, C-5^{I}), 69.3 (t, C-6^{II}), 64.5 (d, C-5^{II}), 57.4, 54.7 (2 q, 2 OCH_3), 50.1 (d, C-3^{II}), 35.9 (t, C-6^{I}) ppm. MS (ES^+): *m*/*z* (%) = 873 (21) [M + K^+], 857 (92) [M + Na^+] 852 (100) [M + NH_4^+]. HRMS: calcd. for $C_{49}H_{58}O_{10}SN$ (MNH_4^+) 852.3776; found 852.3764.

(Methyl 2-*O*-benzyl-4,6-*O*-benzylidene-3-deoxy-β-D-allopyranosid-3-yl)(methyl 3-*O*-benzyl-4,6-*O*-benzylidene-2-deoxy-β-D-mannopyranosid-2-yl)sulfane (27): According to general procedure I, thioacetate **16** (150 mg, 0.35 mmol) and triflate **9** (264 mg, 0.52 mmol) gave, after purification by flash chromatography (pentane/EtOAc, 4:1), the thioether **27** (150 mg, 60%) as a colourless oil. $[\alpha]_D^{23}$ = –118 (*c* = 1.0, in $CHCl_3$). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.55–7.05 (m, 20 H, Ar-H), 5.57, 5.54 (2 s, 2 H, 2 PhC*H*), 4.96, 4.67 (2 d, *J* = 11.5 Hz, 2 H, PhCH_2), 4.75–4.71 (m, 3 H, 1^{II}-H, 3^{II}-H, PhCH*H*′), 4.58 (d, $J_{1,2}$ = 0.9 Hz, 1 H, 1^{I}-H), 4.52–4.42 (m, 2 H, 5^{II}-H, $6'^{II}$-H), 4.38 (br. d, $J_{2,3}$ = 4.9 Hz, 1 H, 2^{I}-H), 4.32 (dd, $J_{5,6'}$ = 4.8, $J_{6,6'}$ = 10.3 Hz, 1 H, $6'^{I}$-H), 4.19 (d, *J* = 13.0 Hz, 1 H, PhC*H*H′), 3.94 (at, *J* = 9.5 Hz, 1 H, 4^{I}-H), 3.90 (at, *J* = 10.2 Hz, 1 H, 6^{I}-H), 3.81 (dd, $J_{3,4}$ = 3.1, $J_{4,5}$ = 8.8 Hz, 1 H, 4^{II}-H), 3.77 (at, *J* = 9.8 Hz, 1 H, 6^{II}-H), 3.72 (dd, $J_{2,3}$ = 4.9, $J_{3,4}$ = 9.9 Hz, 1 H, 3^{I}-H), 3.59 (dd, $J_{1,2}$ = 8.1, $J_{2,3}$ = 4.8 Hz, 1 H, 2^{II}-H), 3.54, 3.56 (2 s, 6 H, 2 OCH_3), 3.29 (atd, J_{at} = 9.7, $J_{5,6'}$ = 4.8 Hz, 1 H, 5^{I}-H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 138.2, 138.1, 137.7, 137.6 (4 s, 4 Ar-C), 128.9, 128.5, 128.4, 128.4, 128.2, 128.0, 127.7, 127.5, 127.2, 126.2, 126.1 (11 d, Ar-CH), 104.1 (d, C-1^{I}), 101.5, 101.4, 101.4 (3 d, 2 Ph*C*H, C-1^{II}), 81.2 (d, C-4^{II}), 78.2 (d, C-4^{I}), 76.7 (d, C-2^{II}), 76.3 (d, C-3^{I}), 70.3 (t, 2 PhCH_2), 69.2 (t, C-6^{II}), 68.7 (t, C-6^{I}), 68.1 (d, C-5^{I}), 63.5 (d, C-5^{II}), 57.4, 57.0 (2 q, 2 OCH_3), 49.0 (d, C-2^{I}), 46.5 (d, C-3^{II}) ppm. MS (ES^+): *m*/*z* (%) = 1507 (10) [2M + Na^+], 765 (100) [M + Na^+]. HRMS: calcd. for $C_{42}H_{46}O_{10}SNa$ [MNa^+] 765.2704; found 765.2687.

(Methyl 3-*O*-benzyl-4,6-*O*-benzylidene-2-deoxy-α-D-mannopyranosid-2-yl)(3-deoxy-1,2:5,6-di-*O*-isopropylidene-α-D-glucofuranos-3-yl)sulfane (28): According to general procedure I, thioacetate **17** (217 mg, 0.50 mmol) and triflate **8** (284 mg, 0.72 mmol) gave, after purification by flash chromatography (pentane/EtOAc, 8:1 → 5:1), the thioether **28** (300 mg, 94%) as a colourless oil. $[\alpha]_D^{23}$ = +13.2 (*c* = 1.0, in $CHCl_3$); δ_H (400 MHz, $CDCl_3$): δ = 7.50–7.48 (m, 2 H, Ar-H), 7.40–7.24 (m, 8 H, Ar-H), 5.73 (d, $J_{1,2}$ = 3.5 Hz, 1 H, H-1^{II}), 5.62 (s, 1 H, C*H*Ph), 4.96 (d, $J_{1,2}$ = 1.1 Hz, 1 H, H-1^{I}), 4.92, 4.75 (2 d, *J* = 12.1 Hz, 2 H, PhCH_2), 4.87 (d, $J_{1,2}$ = 3.5 Hz, 1 H, H-2^{II}), 4.41 (dat, J_{at} = 5.9 Hz, *J* = 8.7 Hz, 1 H, H-5^{II}), 4.24–4.14 (m, 4 H, H-$6'^{II}$, H-3^{II} or H-4^{II}, H-5^{I}, H-$6'^{I}$), 4.07 (at, *J* = 8.9 Hz, 1 H, H-4^{I}), 3.96 (dd, $J_{5,6}$ = 5.7 Hz, $J_{6,6'}$ = 8.6 Hz, 1 H, H-6^{II}), 3.84–3.78 (m, 2 H, H-3^{I}, H-6^{I}), 3.59–3.56 (m, 2 H, H-2^{I}, H-3^{II} or H-4^{II}), 3.34 (s, 3 H, OCH_3), 1.48, 1.43, 1.35, 1.18 [4 s, 12 H, 2 C(CH_3)$_2$]; δ_C (125 MHz, $CDCl_3$): δ = 138.6, 137.6 (2 s, 2 Ar-C), 129.0, 128.5, 128.3, 127.7, 127.7, 126.2 (6 d, 6 Ar-CH), 111.9, 109.4 [2 s, 2 *C*(CH_3)$_2$], 104.9 (d, C-1^{II}), 103.2 (d, C-1^{I}), 101.7 (d, *C*HPh), 86.2 (d, C-2^{II}), 80.7 (d, C-4^{I}), 80.6, 74.8 (2 d, C-4^{II}, C-5^{I}), 74.3 (d, C-5^{II}), 73.5 (t, PhCH_2), 69.0 (t, C-6^{I}), 68.2 (t, C-6^{II}), 64.2 (d, C-3^{I}), 55.3, 53.0 (2 d, C-2^{I}, C-3^{II}), 55.0 (q, OCH_3), 27.0, 26.8, 26.3, 25.5 [4 q, 2 C(*C*H_3)$_2$]. MS (ES^+): *m*/*z* (%) = 669 (13) [M + K^+], 653 (100) [M + Na^+]. HRMS: calcd. for $C_{33}H_{42}O_{10}SNa$ [MNa^+] 653.2391; found 653.2386.

(Methyl 2-*O*-benzyl-4,6-*O*-benzylidene-3-deoxy-α-D-mannopyranosid-3-yl)(3-deoxy-1,2:5,6-di-*O*-isopropylidene-α-D-glucofuranos-3-yl)sulfane (29): According to general procedure I, thioacetate **19** (75 mg, 0.17 mmol) and triflate **8** (105 mg, 0.27 mmol) gave, after purification by flash chromatography (toluene → toluene/EtOAc, 12:1), the thioether **29** (89 mg, 81%) as a colourless oil. $[\alpha]_D^{21}$ = –10.9 (*c* = 1.0, in $CHCl_3$); δ_H (500 MHz, $CDCl_3$): δ = 7.56–7.53 (m, 2 H, Ar-H), 7.41–7.31 (m, 8 H, Ar-H), 5.72 (d, $J_{1,2}$ = 3.5 Hz, 1 H, H-1^{II}), 5.64 (s, 1 H, C*H*Ph), 4.87 (d, $J_{1,2}$ = 3.5 Hz, 1 H, H-2^{II}), 4.70 (s, 2 H, PhCH_2), 4.65 (s, 1 H, H-1^{I}), 4.40 (dat, *J* = 6.3 Hz, J_{at} = 8.5 Hz, 1 H, H-5^{II}), 4.25 (m, 1 H, H-$6'^{I}$), 4.19–4.12 (m, 2 H, H-4^{II}, H-$6'^{II}$), 3.97 (dd, $J_{3,4}$ = 11.0 Hz, $J_{4,5}$ = 8.3 Hz, 1 H, H-4^{I}), 3.92 (dd, $J_{5,6}$ = 6.3 Hz, $J_{6,6'}$ = 8.3 Hz, 1 H, H-6^{II}), 3.85–3.79 (m, 3 H, H-2^{I}, H-5^{I}, H-6^{I}), 3.65 (d, $J_{3,4}$ = 3.5 Hz, 1 H, H-3^{II}), 3.50 (dd, $J_{2,3}$ = 3.0 Hz, $J_{3,4}$ = 11.0 Hz, 1 H, H-3^{I}), 3.36 (s, 3 H, OCH_3), 1.46, 1.40, 1.33, 1.11 [4 s, 12 H, 2 C(CH_3)$_2$]; δ_C (125 MHz, $CDCl_3$): δ = 137.7, 137.6 (2 s, Ar-C), 128.9, 128.5, 128.3, 128.2, 128.1, 126.2 (6 d, Ar-CH), 111.8, 109.3 [2 s, 2 *C*(CH_3)$_2$], 104.9 (d, C-1^{II}), 101.9 (d, *C*HPh), 98.5 (d, C-1^{I}), 86.5 (d, C-2^{II}), 80.8 (d, C-4^{II}), 79.9 (d, C-2^{I}), 79.7 (d, C-4^{I}), 74.3 (d, C-5^{II}), 74.1 (t, PhCH_2), 69.0 (t, C-6^{I}), 68.2 (t, C-6^{II}), 65.7 (d, C-5^{I}), 54.9 (q, OCH_3), 53.9 (d, C-3^{II}), 49.0 (d, C-3^{I}), 26.8, 26.2, 25.3 [3 q, 2 C(*C*H_3)$_2$]. MS (ES^+): *m*/*z* (%) = 669 (6) [M + K^+] 653 (100) [M + Na^+]. HRMS: calcd. for $C_{33}H_{42}O_{10}SNa$ [MNa^+] 653.2391; found 653.2385.

Bis(methyl 2-*O*-benzyl-4,6-*O*-benzylidene-3-deoxy-β-D-allopyranosid-3-yl)sulfane (30): According to general procedure II, triflate **10** (500 mg, 1.0 mmol), sodium sulfide (475 mg, 2.0 mmol), molecular sieves (500 mg) and MeCN (6 mL) gave, after purification by flash chromatography (pentane/EtOAc, 3:1, 1% Et_3N), the thioether **30** (331 mg, 90%) as a colourless oil. $[\alpha]_D^{21}$ = –112 (*c* = 1.0, in $CHCl_3$). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.52–7.12 (m, 20 H, Ar-H), 5.57 (s, 2 H, PhC*H*), 4.76, 4.24 (2 d, *J* = 12.2 Hz, 4 H, PhCH_2), 4.72 (at, *J* = 4.0 Hz, 2 H, 3-H), 4.67 (d, $J_{1,2}$ = 8.1 Hz, 2 H, 1-H), 4.49 (atd, J_{at} = 9.6, $J_{5,6'}$ = 5.4 Hz, 2 H, 5-H), 4.41 (dd, $J_{5,6'}$ = 5.4, $J_{6,6'}$ = 10.4 Hz, 2 H, 6′-H), 3.79 (dd, $J_{3,4}$ = 3.3, $J_{4,5}$ = 9.1 Hz, 2 H, 4-H), 3.75 (at, *J* = 10.3 Hz, 2 H, 6-H), 3.51 (s, 6 H, OCH_3), 3.45 (dd, $J_{1,2}$ = 8.1, $J_{2,3}$ = 4.8 Hz, 2 H, 2-H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 137.8, 137.7 (2 s, 4 Ar-C), 129.0, 128.4, 128.2, 127.8, 127.4, 126.1 (6 d, Ar-CH), 101.7 (d, Ph*C*H), 101.3 (d, C-1), 81.3 (d, C-4), 76.7 (d, C-2), 70.2 (t, PhCH_2), 69.2 (t, C-6), 63.5 (d, C-5), 57.5 (q, OCH_3), 46.0 (d, C-3) ppm. MS (MALDI): *m*/*z* = 781 [M + K^+], 765 [M + Na^+]. HRMS: calcd. for $C_{42}H_{50}O_{10}SN$ (MNH_4^+) 760.3150; found 760.3142.

Bis(methyl 3-*O*-benzyl-4,6-*O*-benzylidene-2-deoxy-α-D-mannopyranosid-2-yl)sulfane (31): According to general procedure II, purified triflate **11** (141 mg, 0.28 mmol), sodium sulfide (210 mg, 0.88 mmol), molecular sieves (300 mg) and MeCN (3 mL) gave, after purification by flash chromatography (pentane/EtOAc, 10:1 → 7:1 → 5:1, 1% Et_3N), the thioether **31** (66 mg, 64%) as a colourless oil. $[\alpha]_D^{22}$ = +26.1 (*c* = 1.0, in $CHCl_3$); δ_H (500 MHz, $CDCl_3$): δ = 7.53–7.51 (m, 4 H, Ar-H), 7.42–7.28 (m, 16 H, Ar-H), 5.65 (s, 2 H, PhC*H*), 5.04 (d, $J_{1,2}$ = 1.0 Hz, 2 H, H-1), 4.92, 4.67 (2 d, *J* = 11.8 Hz, 4 H, PhCH_2), 4.27–4.16 (m, 6 H, H-3, H-4 or H-5, H-6′), 3.85–3.79 (m, 4 H, H-4 or H-5, H-6), 3.53 (dd, $J_{1,2}$ = 1.0 Hz, $J_{2,3}$ = 4.1 Hz, 2 H, H-2), 3.19 (s, 6 H, OCH_3); δ_C (125 MHz, $CDCl_3$): δ = 138.8, 137.7 (2 s, Ar-C), 129.0, 128.4, 128.3, 127.7, 127.7, 126.1 (6 d, Ar-CH), 103.1 (d, C-1), 101.6 (d, Ph*C*H), 80.7, 75.6, 64.1 (3 d, C-3, C-4, C-5), 73.6 (t, PhCH_2), 69.0 (t, C-6), 54.8 (q, OCH_3), 54.2 (d, C-2). MS (ES^+): *m*/*z* (%) = 781 (6) [M + K^+], 765 (100) [M + Na^+]. HRMS: calcd. for $C_{42}H_{46}O_{10}SNa$ [MNa^+] 765.2704; found 765.2693.

Bis(methyl 2,3,6-tri-*O*-benzoyl-4-deoxy-β-D-glucopyranosid-4-yl)sulfane (32) and Bis(methyl 2,3,6-tri-*O*-benzoyl-4-deoxy-β-D-glucopyr-

anosid-4-yl)disulfane (35): According to general procedure II, triflate **12** (206 mg, 0.32 mmol), sodium sulfide (156 mg, 0.65 mmol), molecular sieves (200 mg) and MeCN (4 mL) gave, after purification by flash chromatography (two columns, pentane/EtOAc, 3:1, 1% Et_3N; then CH_2Cl_2/Et_2O, 30:1), the thioether **32** (75 mg, 46%) as white crystals, m.p. 248–249 °C (*i*PrOH/CH_2Cl_2). $[\alpha]_D^{22}$ = +82.4 (c = 1.0, in $CHCl_3$). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.01 (d, J = 7.1 Hz, 4 H, Ar-H), 7.95 (d, J = 7.1 Hz, 4 H, Ar-H), 7.86 (d, J = 7.1 Hz, 4 H, Ar-H), 7.58 (at, J = 7.4 Hz, 2 H, Ar-H), 7.48–7.20 (m, 16 H, Ar-H), 5.59 (dd, $J_{2,3}$ = 9.3, $J_{3,4}$ = 11.0 Hz, 2 H, 3-H), 5.28 (dd, $J_{1,2}$ = 7.6, $J_{2,3}$ = 9.3 Hz, 2 H, 2-H), 4.78 (dd, $J_{5,6'}$ = 1.9, $J_{6,6'}$ = 11.7 Hz, 2 H, 6′-H), 4.60 (dd, $J_{5,6}$ = 6.0, $J_{6,6'}$ = 11.7 Hz, 2 H, 6-H), 4.54 (d, $J_{1,2}$ = 7.6 Hz, 2 H, 1-H), 3.85 (ddd, $J_{4,5}$ = 10.2, $J_{5,6}$ = 6.0, $J_{5,6'}$ = 1.9 Hz, 2 H, 5-H), 3.33 (s, 6 H, OCH_3), 3.30 (at, J = 10.6 Hz, 2 H, 4-H) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 166.0, 165.6, 165.2 (3 s, 3 C=O), 133.4, 133.4, 133.2 (3 d, Ar-CH), 129.9, 129.9, 129.8, 129.3, 128.7, 128.3 (6 s, d, Ar-C, CH), 101.6 (d, C-1), 76.0 (d, C-5), 73.0 (d, C-2), 72.5 (d, C-3), 63.8 (t, C-6), 56.7 (q, OCH_3), 47.9 (d, C-4) ppm. MS (ES^+): m/z (%) = 1033 (100) [M + Na^+]. HRMS: calcd. for $C_{56}H_{50}O_{16}SNa$ [MNa^+] 1033.2712; found 1033.2712.

An elimination product was also isolated (28 mg, 18%) identical to that obtained in the preparation of **18**.[44]

Disulfide **35** was obtained as a colourless oil (10 mg, 6%). $[\alpha]_D^{22}$ = –70.6 (c = 0.5, in $CHCl_3$). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.16–7.18 (m, 30 H, Ar-H), 5.65 (at, J = 10.1 Hz, 2 H, 3-H), 5.42 (at, J = 8.7 Hz, 2 H, 2-H), 4.92 (dd, $J_{5,6'}$ = 2.2, $J_{6,6'}$ = 12.0 Hz, 2 H, 6′-H), 4.38 (dd, $J_{5,6}$ = 5.9, $J_{6,6'}$ = 12.0 Hz, 2 H, 6-H), 4.14 (br. s, 2 H, 1-H), 3.95 (ddd, $J_{4,5}$ = 10.4, $J_{5,6}$ = 5.9, $J_{5,6'}$ = 2.2 Hz, 2 H, 5-H), 3.30 [br. m (obsd.), 2 H, 4-H], 3.29 (s, 6 H, OCH_3) ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 166.2, 165.6, 165.3 (3 s, 3 C=O), 133.6, 133.4, 133.2 (3 d, Ar-CH), 130.1, 130.0, 129.8, 129.5, 129.2, 128.7, 128.6, 128.4 (8 s, d, Ar-C, CH), 101.3 (d, C-1), 73.5 (d, C-5), 73.0 (d, C-2), 72.0 (d, C-3), 64.2 (t, C-6), 56.8 (q, OCH_3), 52.4 (br. d, C-4) ppm. MS (ES^+): m/z (%) = 1065 (100) [M + Na^+]. HRMS: calcd. for $C_{56}H_{50}O_{16}S_2Na$ [MNa^+] 1065.2432; found 1065.2394.

General Procedure III: Deprotection by Dissolving-Metal Reduction, Followed by Acetylation: Ammonia was condensed into a flask cooled to –78 °C and sodium was added. The metal quickly dissolved to give a dark blue solution. The protected pseudodisaccharide was dissolved in THF and added by cannula to the vigorously stirred reducing solution. MeOH was added in some cases. The mixture was stirred at –78 °C for a short time (typically 2–10 min), after which time ammonium chloride (solid) was added to quench the reaction mixture and destroy the blue colour. The cooling bath was removed and the ammonia was allowed to evaporate and then the residue left under vacuum.

The residue was dissolved in pyridine, and Ac_2O was added. The mixture was stirred overnight, after which time, TLC (pentane/EtOAc, 1:1) showed the presence of a major carbohydrate component. The reaction was worked up and the residue purified by flash column chromatography (pentane/EtOAc, 1:1, 1% Et_3N) to give the peracetate.

Alternatively, the THF solution of protected pseudodisaccharide was cooled to –78 °C and ammonia was condensed into the flask. Sodium was added to the vigorously stirred solution and slowly dissolved to give a blue colour. MeOH was added (see Table 3). The mixture was stirred at –78 °C for a short time. Further sodium was added if necessary to maintain the blue colour. Then ammonium chloride was added to quench and the reaction mixture was processed as described above. This procedure could give lower product yields than the reverse addition procedure described above and recovery of unreacted starting material, presumably due to the low solubility of the protected pseudodisaccharides in the NH_3/THF mixture.

Bis(methyl 6-deoxy-α-D-mannopyranosid-6-yl)sulfane (46): Following general procedure III, benzylated pseudodisaccharide **20** (46 mg, 0.05 mmol) gave, with THF (2 mL), ammonia (ca. 10 mL), sodium (ca. 80 mg); then acetylation and chromatography, hexaacetate **36** (23 mg, 73%) as a colourless oil.

Hexaacetate **36** (23 mg, 0.036 mmol) was dissolved in MeOH (1.5 mL). Sodium (2 mg, 0.09 mmol) was dissolved in MeOH and the resulting solution added to the solution of pseudodisaccharide. The mixture was stirred at room temp. for 2 h, after which time, TLC (EtOAc/MeOH, 9:1) showed the presence of a single component (R_f = 0.1). Dowex resin (H^+) was added, then the mixture filtered and concentrated in vacuo. The residue was purified by flash column chromatography (EtOAc/MeOH, 4:1) to give the unprotected pseudodisaccharide **46** (10 mg, 72%) as a white solid. $[\alpha]_D^{23}$ = +94.4 (c = 0.5, in MeOH). ^{1}H NMR (400 MHz, CD_3OD): δ = 4.59 (d, $J_{1,2}$ = 1.6 Hz, 2 H, 1-H), 3.77 (dd, $J_{1,2}$ = 1.6, $J_{2,3}$ = 3.3 Hz, 2 H, 2-H), 3.61 (dd, $J_{3,4}$ = 9.2, $J_{2,3}$ = 3.3 Hz, 2 H, 3-H), 3.59 (atd, $J_{5,6'}$ = 2.0, J_{at} = 8.7 Hz, 2 H, 5-H), 3.53 (at, J = 9.2 Hz, 2 H, 4-H), 3.40 (s, 6 H, OCH_3), 3.11 (dd, $J_{5,6'}$ = 2.0, $J_{6,6'}$ = 13.7 Hz, 2 H, 6′-H), 2.79 (dd, $J_{5,6}$ = 8.4, $J_{6,6'}$ = 13.7 Hz, 2 H, 6-H) ppm. ^{13}C NMR (100 MHz, CD_3OD): δ = 102.6 (d, C-1), 74.8 (d, C-5), 72.6 (d, C-3), 72.1 (d, C-2), 71.6 (d, C-4), 55.2 (q, OCH_3), 35.8 (t, C-6) ppm. MS (ES^+): m/z (%) = 409 (100) [M + Na^+]. HRMS: calcd. for $C_{14}H_{26}O_{10}S$ [MNa^+] 409.1139; found 409.1140.

(Methyl 6-deoxy-α-D-mannopyranosid-6-yl)(3-deoxy-D-glucopyranos-3-yl)sulfane (47): Pseudodisaccharide **21** (123 mg, 0.170 mmol) was dissolved in THF (1.5 mL) and cooled to –78 °C under N_2. NH_3 (ca. 20 mL) was condensed into the flask and Na (ca. 125 mg, 5.4 mmol) was added. The mixture turned deep blue. After 2 min, MeOH (150 μL) was added. After a further 2 min, the reaction was quenched by the addition of $NH_4Cl_{(s)}$, and the mixture warmed to room temp. The mixture was partitioned between water (40 mL) and EtOAc (3 × 30 mL). The combined organic extracts were dried (Na_2SO_4), filtered, and concentrated in vacuo. TLC (EtOAc) showed the presence of a major component (R_f = 0.2). The residue was purified by flash column chromatography (EtOAc).

The major component was dissolved in TFA (90%, 1 mL) and stired at room temp. After 1 h, water (2 mL) was added, and the mixture concentrated in vacuo. The residue was purified by flash column chromatography (EtOAc/MeOH, 4:1), to give the unprotected pseudodisaccharide **47** (12 mg, 19%) as a colourless oil (glucose: α/β, 1:1). The $_\alpha$ and $_\beta$ descriptors refer to the two pseudodisaccharides containing α- and β-glucose residues, respectively.

Selected data: ^{1}H NMR (500 MHz, D_2O): δ = 5.23 (d, $J_{1,2}$ = 3.5 Hz, 1 H, $1^{II}{}_\alpha$-H), 4.73 (s, 2 H, $1^{I}{}_\alpha$-H, $1^{I}{}_\beta$-H), 4.65 (d, $J_{1,2}$ = 7.7 Hz, 1 H, $1^{II}{}_\beta$-H), 3.93–3.47 (m), 3.44 (s, 6 H, 2 OCH_3), 3.26 (dd, $J_{1,2}$ = 7.7, $J_{2,3}$ = 10.8 Hz, 1 H, $2^{II}{}_\beta$-H), 3.20–3.17 (m, 2 H, 6′^{I}-H), 2.97–2.89 (m, 3 H, $3^{II}{}_\alpha$-H, 6^{I}-H), 2.71 (at, J = 10.2 Hz, 1 H, $3^{II}{}_\beta$-H) ppm. ^{13}C NMR (data from HSQC, 500 MHz, D_2O): δ = 101.6 (C-1^{I}), 97.9 (C-$1^{II}{}_\beta$), 92.2 (C-$1^{II}{}_\alpha$), 61.5, 61.7 (C-$6^{II}{}_\alpha$, C-$6^{II}{}_\beta$), 56.0 (C-$3^{II}{}_\beta$), 55.7 (OCH_3), 52.5 (C-$3^{II}{}_\alpha$), 32.4 (C-6^{I}) ppm. MS (ES^+): m/z (%) = 395 (100) [M + Na^+]. HRMS: calcd. for $C_{13}H_{24}O_{10}S$ [MNa^+] 395.0982; found 395.0976.

(Methyl 2-deoxy-β-D-mannopyranosid-2-yl)(methyl 6-deoxy-α-D-mannopyranosid-6-yl)sulfane (48): Following general procedure III, benzylated pseudodisaccharide **22** (46 mg, 0.05 mmol) gave, with THF (2 mL), ammonia (ca. 10 mL), sodium (ca. 120 mg); then

acetylation and chromatography, hexaacetate **37** (23 mg, 64%) as a colourless oil.

Hexaacetate **37** (18 mg, 0.028 mmol) was deprotected as described for **46** to give the unprotected pseudodisaccharide **48** (10 mg, 92%) as a white solid. $[\alpha]_D^{23}$ = –2.8 (*c* = 0.5, in MeOH). ^{1}H NMR (400 MHz, CD_3OD): δ = 4.59 (d, $J_{1,2}$ = 1.6 Hz, 1 H, 1^{II}-H), 4.58 (d, $J_{1,2}$ = 1.5 Hz, 1 H, 1^{I}-H), 3.84 (dd, $J_{5,6'}$ = 2.4, $J_{6,6'}$ = 11.9 Hz, 1 H, $6'^{I}$-H), 3.76 (dd, $J_{1,2}$ = 1.6, $J_{2,3}$ = 3.2 Hz, 1 H, 2^{II}-H), 3.72 (dd, $J_{2,3}$ = 4.4, $J_{3,4}$ = 9.3 Hz, 1 H, 3^{I}-H), 3.65–3.53 (m, 4 H, 3^{II}-H, 4^{II}-H, 5^{II}-H, 6^{I}-H), 3.51, 3.42 (2 s, 6 H, 2 OCH_3), 3.40 [dd (obsd.), $J_{1,2}$ = 1.5, $J_{2,3}$ = 4.4 Hz, 1 H, 2^{I}-H], 3.37 (at, *J* = 9.3 Hz, 1 H, 4^{I}-H), 3.18 (ddd, $J_{4,5}$ = 9.3, $J_{5,6}$ = 6.2, $J_{5,6'}$ = 2.4 Hz, 1 H, 5^{I}-H), 3.15 (dd, $J_{5,6'}$ = 1.8 Hz, 1 H, $6'^{II}$-H), 2.81 (dd, $J_{5,6}$ = 8.3, $J_{6,6'}$ = 14.0 Hz, 1 H, 6^{II}-H) ppm. ^{13}C NMR (100 MHz, CD_3OD): δ = 103.4 (d, C-1^{I}), 102.7 (d, C-1^{II}), 78.9 (d, C-5^{I}), 75.1 (d, C-3^{I}), 74.4 (d, C-5^{II}), 72.4 (d, C-3^{II}), 72.1 (d, C-2^{II}), 71.4 (d, C-4^{II}), 69.8 (d, C-4^{I}), 63.0 (t, C-6^{I}), 57.0, 55.5 (2 q, 2 OCH_3), 57.0 (d, C-2^{I}), 37.1 (t, C-6^{II}) ppm. MS (ES^+): *m*/*z* (%) = 795 (20) [2M + Na^+], 409 (100) [M + Na^+]. HRMS: calcd. for $C_{14}H_{26}O_{10}S$ [MNa^+] 409.1139; found 409.1144.

Bis(3-deoxy-D-glucopyranos-3-yl)sulfane (49): Protected pseudodisaccharide **23** (42 mg, 0.08 mmol) was dissolved in a mixture of TFA (1.8 mL) and water (0.2 mL). After 1 h, water was added, and the mixture concentrated in vacuo.

The residue was dissolved in Ac_2O (2 mL), and sodium acetate (3 mg) was added. The mixture was heated at 150 °C for 40 min, then allowed to cool to room temp. The mixture was diluted with EtOAc (25 mL), and washed with water (25 mL). The organic phase was dried (Na_2SO_4), filtered, and concentrated in vacuo. The residue was purified by flash column chromatography (EtOAc/pentane, 1:1 → EtOAc) to give the octaacetate **38** (52 mg, 92%) as a colourless oil.

Octaacetate **38** (47 mg, 0.068 mmol) was deprotected as described for **46** to give the unprotected pseudodisaccharide **49** (19 mg, 78%) as a white solid (α,α/α,β/β,β, 1:2:1). The $_\alpha$ and $_\beta$ descriptors refer to signals from α- and β-configured glucose residues, respectively. ^{1}H NMR (400 MHz, CD_3OD): δ = 5.16 (d, $J_{1,2}$ = 3.3 Hz, 2 H, 1_α-H, 1_α-H), 4.52 (d, $J_{1,2}$ = 7.5 Hz, 2 H, 1_β-H, 1_β-H), 3.86–3.65 (m, 10 H, 5-H, 5-H, 6_α-H, 6_α-H, 6_β-H, 6_β-H, $6'_\alpha$-H, $6'_\alpha$-H, $6'_\beta$-H, $6'_\beta$-H), 3.46 (dd, $J_{1,2}$ = 3.5, $J_{2,3}$ = 11.0 Hz, 1 H, 2_α-H), 3.44 (dd, $J_{1,2}$ = 3.5, $J_{2,3}$ = 11.0 Hz, 1 H, 2_α-H), 3.40–3.27 [m (obsd.), 6 H, 5-H, 5-H, 4_α-H, 4_α-H, 4_β-H, 4_β-H], 3.15 (dd, $J_{1,2}$ = 7.5, $J_{2,3}$ = 10.8 Hz, 1 H, 2_β-H), 3.14 (dd, $J_{1,2}$ = 7.5, $J_{2,3}$ = 10.8 Hz, 1 H, 2_β-H), 3.02 (at, 10.7 Hz, 1 H, 3_α-H), 3.01 (at, *J* = 10.7 Hz, 1 H, 3_α-H), 2.67 (at, *J* = 10.5 Hz, 1 H, 3_β-H), 2.65 (at, *J* = 10.6 Hz, 1 H, 3_β-H) ppm. ^{13}C NMR (100 MHz, CD_3OD): δ = 99.3 (d, C-1_β, C-1_β), 93.2 (d, C-1_α, C-1_α), 80.4, 80.3 (2 d, C-5, C-5), 75.2, 74.9 (2 d, C-2_β, C-2_β), 73.9 (d, C-5, C-5), 72.0, 72.3 (2 d, C-2_α, C-2_α), 70.8, 70.6, 70.1, 69.9 (4 d, C-4_α, C-4_α, C-4_β, C-4_β), 63.0 (t, C-6_α, C-6_α, C-6_β, C-6_β), 58.8, 57.1 (2 d, C-3_β, C-3_β), 54.8, 53.3 (2 d, C-3_α, C-3_α) ppm. MS (ES^+): *m*/*z* (%) = 1097 (5) [3M + Na^+], 739 (30) [2M + Na^+], 381 (100) [M + Na^+]. HRMS: calcd. for $C_{12}H_{22}O_{10}S$ [MNa^+] 381.0826; found 381.0819.

(Methyl 2-deoxy-β-D-mannopyranosid-2-yl)(3-deoxy-D-glucopyranos-3-yl)sulfane (50): Pseudodisaccharide **24** (49 mg, 0.077 mmol) was dissolved in THF (2 mL) and cooled to –78 °C under N_2. NH_3 (ca. 10 mL) was condensed into the flask and Na (ca. 75 mg, 3.2 mmol) was added. The mixture turned deep blue. After 1 h 20 min, the reaction was quenched by the addition of $NH_4Cl_{(s)}$, and the mixture warmed to room temp. The mixture was partitioned between water (50 mL) and EtOAc (5 × 25 mL). The combined organic extracts were dried (Na_2SO_4), filtered, and concentrated in vacuo. TLC (EtOAc) showed the presence of a major component (R_f = 0.2). The residue was purified by flash column chromatography (EtOAc → EtOAc/MeOH, 10:1).

The major component was dissolved in TFA (90%, 2 mL) and stirred at room temp. After 1 h, water (2 mL) was added, and the mixture concentrated in vacuo. The residue was purified on a Waters Sep-pak cartridge eluting with water, to give the unprotected pseudodisaccharide **50** (11 mg, 38%) as a colourless oil (glucose: α/β, 1:1). The $_\alpha$ and $_\beta$ descriptors refer to the two pseudodisaccharides containing α- and β-glucose residues, respectively. ^{1}H NMR (400 MHz, CD_3OD): δ = 5.18 (d, $J_{1,2}$ = 3.5 Hz, 1 H, $1^{II}{}_\alpha$-H), 4.64 (m, 2 H, $1^{I}{}_\alpha$-H, $1^{I}{}_\beta$-H), 4.52 (d, $J_{1,2}$ = 7.5 Hz, 1 H, $1^{II}{}_\beta$-H), 3.58, 3.58 (2 s, 6 H, $OCH_3{}^{I}{}_\alpha$, $OCH_3{}^{I}{}_\beta$), 3.53–3.87 (m, 11 H, $6^{II}{}_\alpha$-H, $6'^{II}{}_\alpha$-H, $6^{II}{}_\beta$-H, $6'^{II}{}_\beta$-H, $6^{I}{}_\alpha$-H, $6'^{I}{}_\alpha$-H, $6^{I}{}_\beta$-H, $6'^{I}{}_\beta$-H), 3.27–3.44 [m (obsd.), 8 H, $2^{I}{}_\alpha$-H, $2^{I}{}_\beta$-H], 3.18–3.22 (m, 2 H), 3.12 (dd, $J_{1,2}$ = 7.5, $J_{2,3}$ = 10.8 Hz, 1 H, $2^{II}{}_\beta$-H), 2.91 (at, *J* = 10.7 Hz, 1 H, $3^{II}{}_\alpha$-H), 2.54 (at, *J* = 10.4 Hz, 1 H, $3^{II}{}_\beta$-H) ppm. ^{13}C NMR (100 MHz, CD_3OD): δ = 102.6, 102.6 (2 d, C-$1^{I}{}_\alpha$, C-$1^{I}{}_\beta$), 99.3 (d, C-$1^{II}{}_\beta$), 93.1 (d, C-$1^{II}{}_\alpha$), 80.3, 78.8, 78.8, 74.5, 74.3, 74.2, 73.9, 71.5, 70.0, 69.9, 69.3 (11 d, C-$2^{II}{}_\alpha$, C-$2^{II}{}_\beta$, C-$4^{II}{}_\alpha$, C-$4^{II}{}_\beta$, C-$5^{II}{}_\alpha$, C-$5^{II}{}_\beta$, C-$3^{I}{}_\alpha$, C-$3^{I}{}_\beta$, C-$4^{I}{}_\alpha$, C-$4^{I}{}_\beta$, C-$5^{I}{}_\alpha$, C-$5^{I}{}_\beta$), 63.0, 62.9, 62.8 (3 t, C-$6^{II}{}_\alpha$,C-$6^{II}{}_\beta$, C-$6^{I}{}_\alpha$, C-$6^{I}{}_\beta$), 60.3 (d, C-$3^{II}{}_\beta$), 57.1 (q, $OCH_3{}^{I}{}_\alpha$, $OCH_3{}^{I}{}_\beta$), 56.0 (d, C-$3^{II}{}_\alpha$), 55.3, 53.9 (2 d, C-$2^{I}{}_\alpha$, C-$2^{I}{}_\beta$) ppm. MS (ES^+): *m*/*z* (%) = 1139 (5) [3M + Na^+], 767 (25) [2M + Na^+], 395 (100) [M + Na^+]. HRMS: calcd. for $C_{13}H_{24}O_{10}S$ [MNa^+] 395.0982; found 395.0984.

Bis(methyl 2-deoxy-β-D-mannopyranosid-2-yl)sulfane (51): Following general procedure III, benzylated pseudodisaccharide **25** (316 mg, 0.43 mmol) gave, with THF (3 mL), ammonia (ca. 20 mL), sodium (ca. 280 mg) and MeOH (40 μL); then acetylation and chromatography, hexaacetate **39** (167 mg, 61%) as a colourless oil. Also starting material **25** was recovered after the reduction step by partitioning the residue between toluene and water. Chromatography (pentane/EtOAc, 2:1) on the organic phase gave starting material **25** (70 mg, 22%).

Hexaacetate **39** (167 mg, 0.26 mmol) was deprotected as described for **46** to give the unprotected pseudodisaccharide **51** (98 mg, 97%) as a white solid. $[\alpha]_D^{21}$ = –136 (*c* = 1.0, in MeOH). ^{1}H NMR (500 MHz, D_2O): δ = 4.76 (d, $J_{1,2}$ = 1.3 Hz, 2 H, 1-H), 3.89 (dd, $J_{5,6'}$ = 2.2, $J_{6,6'}$ = 12.4 Hz, 2 H, 6′-H), 3.82 (dd, $J_{2,3}$ = 4.4, $J_{3,4}$ = 9.4 Hz, 2 H, 3-H), 3.68 (dd, $J_{5,6}$ = 6.4, $J_{6,6'}$ = 12.4 Hz, 2 H, 6-H), 3.57 (s, 6 H, OCH_3), 3.49 (dd, $J_{1,2}$ = 1.3, $J_{2,3}$ = 4.4 Hz, 2 H, 2-H), 3.43 (at, *J* = 9.6 Hz, 2 H, 4-H), 3.35 (ddd, $J_{4,5}$ = 9.6, $J_{5,6}$ = 6.4, $J_{5,6'}$ = 2.2 Hz, 2 H, 5-H) ppm. ^{13}C NMR (125 MHz, D_2O): δ = 101.8 (d, C-1), 77.2 (d, C-5), 73.5 (d, C-3), 68.7 (d, C-4), 61.5 (t, C-6), 57.7 (d, C-2), 57.4 (q, OCH_3) ppm. MS (ES^+): *m*/*z* (%) = 795 (92) [2M + Na^+], 409 (100) [M + Na^+]. HRMS: calcd. for $C_{28}H_{52}O_{20}S_2Na$ (2MNa^+) 795.2386; found 795.2377.

(Methyl 3-deoxy-β-D-allopyranosid-3-yl)(methyl 6-deoxy-α-D-mannopyranosid-6-yl)sulfane (52): Following general procedure III, benzylated pseudodisaccharide **26** (134 mg, 0.16 mmol) gave, with THF (2 mL), ammonia (ca. 10 mL), sodium (ca. 140 mg), MeOH (40 μL); then acetylation and chromatography, hexaacetate **40** (59 mg, 58%) as a colourless oil.

Hexaacetate **40** (59 mg, 0.092 mmol) was deprotected as described for **46** to give the unprotected pseudodisaccharide **52** (33 mg, 92%) as a white solid. $[\alpha]_D^{23}$ = +42.2 (*c* = 1.0, in MeOH). ^{1}H NMR (500 MHz, D_2O): δ = 4.73 (d, 1 H, 1^{I}-H), 4.50 (d, $J_{1,2}$ = 8.0 Hz, 1 H, 1^{II}-H), 3.93 (dd, $J_{1,2}$ = 1.5, $J_{2,3}$ = 3.2 Hz, 1 H, 2^{I}-H), 3.90–3.86 (m, 2 H, $6'^{II}$-H), 3.76–3.60 (m, 7 H, 2^{II}-H, 3^{II}-H, 6^{II}-H, 3^{I}-H, 5^{I}-H), 3.53, 3.44 (2 s, 6 H, 2 OCH_3), 3.18 (dd, $J_{5,6'}$ = 2.2, $J_{6,6'}$ = 13.8 Hz, 1 H, $6'^{I}$-H), 2.94 (dd, $J_{5,6}$ = 8.1, $J_{6,6'}$ = 13.8 Hz, 1 H, 6^{I}-

H) ppm. ^{13}C NMR (125 MHz, D_2O): δ = 102.4 (d, C-1^{II}), 101.6 (d, C-1^{I}), 76.1, 72.7, 70.9, 70.8, 70.5, 70.0, 67.4 (7 d, C-2^{II}, C-4^{II}, C-5^{II}, C-2^{I}, C-3^{I}, C-4^{I}, C-5^{I}), 61.6 (t, C-6^{II}), 57.6, 55.6 (2 q, 2 OCH_3), 56.8 (d, C-3^{II}), 36.8 (t, C-6^{I}) ppm. MS (ES^+): *m/z* (%) = 795 (10) [2M + Na^+], 409 (100) [M + Na^+]. HRMS: calcd. for $C_{28}H_{52}O_{20}S_2Na$ (2MNa^+) 795.2386; found 795.2386; calcd. for $C_{14}H_{26}O_{10}SNa$ [MNa^+] 409.1128; found 409.1139.

(Methyl 3-deoxy-β-D-allopyranosid-3-yl)(methyl 2-deoxy-β-D-mannopyranosid-2-yl)sulfane (53): Following general procedure III, benzylated pseudodisaccharide **27** (118 mg, 0.16 mmol) gave, with THF (2 mL), ammonia (ca. 10 mL), sodium (ca. 120 mg), MeOH (40 μL); then acetylation and chromatography, hexaacetate **41** (77 mg, 76%) as a colourless oil.

Hexaacetate **41** (77 mg, 0.12 mmol) was deprotected as described for **46** to give the unprotected pseudodisaccharide **53** (36 mg, 77%) as a white solid. $[\alpha]_D^{23}$ = –86.6 (*c* = 1.0, in MeOH). ^{1}H NMR (500 MHz, D_2O): δ = 4.77 [m (obsd.), 1 H, 1^{I}-H], 4.46 (d, $J_{1,2}$ = 7.9 Hz, 1 H, 1^{II}-H), 3.92–3.86 (m, 4 H, 6′^{II}-H, 6′^{I}-H), 3.72–3.62 (m, 5 H, 2^{II}-H, 3^{II}-H, 6^{II}-H, 6^{I}-H), 3.58, 3.53 (2 s, 6 H, 2 OCH_3), 3.50–3.46 (m, 2 H, 4-H, 2^{I}-H), 3.37 (ddd, *J* = 2.3, *J* = 6.4, *J* = 9.6 Hz, 1 H, 5-H) ppm. ^{13}C NMR (125 MHz, D_2O): δ = 102.5 (d, C-1^{II}), 101.7 (d, C-1^{I}), 77.3, 76.2, 73.3, 70.8, 68.6, 67.5, 68.6 (6 d, C-2^{II}, C-4^{II}, C-5^{II}, C-3^{I}, C-4^{I}, C-5^{I}), 61.5, 61.5 (2 t, C-6^{II}, C-6^{I}), 59.0 (d, C-3^{II}), 58.5 (d, C-2^{I}), 57.5, 57.4 (2 q, 2 OCH_3) ppm. MS (ES^+): *m/z* (%) = 795 (35) [2M + Na^+], 409 (100) [M + Na^+]. HRMS: calcd. for $C_{14}H_{26}O_{10}SNa$ [MNa^+] 409.1128; found 409.1143.

(Methyl 2-deoxy-α-D-mannopyranosid-2-yl)(3-deoxy-D-glucopyranos-3-yl)sulfane (54): Thioether **28** (134 mg, 0.21 mmol) was dissolved in THF (3 mL) under Ar and cooled to –78 °C. Ammonia (ca. 20 mL) was condensed into the reaction flask and MeOH (70 μL, 1.70 mmol) and sodium (67 mg, 2.9 mmol) were added. After a few minutes, the reaction mixture turned dark blue. After 2 min, the reaction was quenched by addition of NH_4Cl (160 mg, 3 mmol) and left to warm to room temp. for the ammonia to evaporate. The crude residue was purified by column chromatography (EtOAc), to give the triol as a colourless oil (82 mg, 85%).

A mixture of TFA (2 mL) and water (0.23 mL) was added to the triol (36 mg, 0.08 mmol). After 4 min, the reaction mixture was diluted with H_2O (10 mL) and concentrated in vacuo. TLC (EtOAc/MeOH, 10:1) indicated the complete consumption of starting material (R_f = 0.5) and the formation of at least two major products (R_f = 0.2 and 0). The remaining water was removed by repeated co-evaporation with toluene and the residue was dried under high vacuum for 45 min.

The residue was dissolved in pyridine (3 mL) and Ac_2O (1.5 mL), and after 13 h, TLC (toluene/EtOAc, 2:1) indicated the formation of two major products (R_f = 0.4 and 0.3). The reaction mixture was diluted with EtOAc (20 mL) and washed with HCl (1 M, 3 × 20 mL). The combined aqueous phases were extracted with EtOAc (2 × 20 mL). The combined organic phases were then washed with $NaHCO_3$ (satd. aqueous, 3 × 20 mL). The combined aqueous phases were extracted with EtOAc (2 × 20 mL). The combined organic phases were then dried (Na_2SO_4), filtered, and concentrated in vacuo. The residue was purified by column chromatography (pentane/EtOAc, 2:1 → 1:1) to give heptaacetate **42** (25 mg, α/β 1:1; 47%) as a colourless oil.

Heptaacetate **42** (19 mg, 0.03 mmol) was deprotected as described for **46** and the crude product purified by column chromatography (EtOAc/MeOH, 4:1) to give the unprotected pseudodisaccharide **54** (9 mg; α/β, 1:1; 83%) as a white solid; The $_\alpha$ and $_\beta$ descriptors refer to the two pseudodisaccharides containing α- and β-glucose residues, respectively: ^{1}H NMR (400 MHz, D_2O): δ = 5.21 (d, $J_{1,2}$ = 3.5 Hz, 1 H, 1$^{II}_\alpha$-H), 5.09–5.08 (m, 2 H, 1$^{I}_\alpha$-H, 1$^{I}_\beta$-H), 4.64 (d, $J_{1,2}$ = 7.7 Hz, 1 H, 1$^{II}_\beta$-H), 4.10–4.07 (m, 2 H), 3.89–3.68 (m, 9 H, 6$^{I}_\alpha$-H, 6$^{II}_\alpha$-H, 6$^{I}_\beta$-H, 6$^{II}_\beta$-H, 6′$^{I}_\alpha$-H, 6′$^{II}_\alpha$-H, 6′$^{I}_\beta$-H, 6′$^{II}_\beta$-H), 3.62–3.48 (m, 6 H, 2$^{II}_\alpha$-H), 3.44–3.36 (m, 7 H, 2$^{I}_\alpha$-H, 2$^{I}_\beta$-H, 4$^{II}_\alpha$-H, 4$^{II}_\beta$-H, OCH_3), 3.33 (s, 3 H, OCH_3), 3.25 (dd, $J_{1,2}$ = 7.7, $J_{2,3}$ = 10.8 Hz, 1 H, 2$^{II}_\beta$-H), 2.97 (at, *J* = 10.9 Hz, 1 H, 3$^{II}_\alpha$-H), 2.75 (at, *J* = 10.5 Hz, 1 H, 3$^{II}_\beta$-H) ppm. ^{13}C NMR (125 MHz, D_2O): δ = 102.1, 102.0 (2 d, C-1$^{I}_\alpha$, C-1$^{I}_\beta$), 97.1 (d, C-1$^{II}_\beta$), 91.4 (d, C-1$^{II}_\alpha$), 78.3, 72.3, 70.5, 69.8, 69.7 (5 d), 73.0 (d, C-2$^{II}_\beta$), 72.8 (d, C-2$^{II}_\alpha$), 68.7, 68.4 (2 d, C-4$^{II}_\alpha$, C-4$^{II}_\beta$), 67.8 (d), 61.0, 60.8, 60.7 (3 t, C-6$^{I}_\alpha$, C-6$^{II}_\alpha$, C-6$^{I}_\beta$, C-6$^{II}_\beta$), 57.3 (d, C-3$^{II}_\beta$), 54.8 (q, 2 OCH_3), 54.0 (C-3$^{II}_\alpha$), 52.3, 52.4 (2 d, C-2$^{I}_\alpha$, C-2$^{I}_\beta$) ppm. MS (ES^+): *m/z* (%) = 395 (100) [M + Na^+]. HRMS: calcd. for $C_{13}H_{24}O_{10}SNa$ [M + Na^+] 395.0982; found 395.0970.

(Methyl 3-deoxy-α-D-mannopyranosid-3-yl)(3-deoxy-D-glucopyranos-3-yl)sulfane (55): Thioether **29** (52 mg, 0.08 mmol) was dissolved in THF (3 mL) under Ar and cooled to –78 °C. Ammonia (ca. 15 mL) was condensed into the reaction flask and MeOH (30 μL, 1.7 mmol) and sodium (42 mg, 1.8 mmol) were added. After approximately 10 s, the reaction mixture turned dark blue. After a further 2 min, the reaction was quenched by the addition of NH_4Cl (105 mg, 3 mmol) and left to warm to room temp. The crude residue was purified by column chromatography (EtOAc), yielding the triol as a colourless oil (28 mg, 75%).

A solution of 90% aqueous trifluoroacetic acid (1.5 mL TFA and 0.16 mL H_2O) was added to the triol (17 mg, 0.04 mmol). After 25 min, the reaction mixture was diluted with H_2O (5 mL) and concentrated in vacuo in order to remove the TFA. TLC (EtOAc/MeOH, 10:1) indicated the complete consumption of starting material (R_f = 0.5) and the formation of two major products (R_f = 0.2 and 0.1). The remaining water was removed by repeated co-evaporation with toluene and the resulting residue was dried under high vacuum for 1 h.

The residue was dissolved in pyridine (1 mL) and Ac_2O (1 mL), and after 16 h, TLC (pentane/EtOAc, 1:2) indicated the formation of a major product (R_f = 0.3). The reaction mixture was diluted with EtOAc (20 mL) and washed with 1 M HCl (3 × 20 mL). The combined aqueous phases were extracted with EtOAc (2 × 20 mL). The combined organic phases were then washed with $NaHCO_3$ (satd. aq., 3 × 20 mL). The combined aqueous phases were extracted with EtOAc (2 × 20 mL). The combined organic phases were dried (Na_2SO_4), filtered, and concentrated in vacuo. The residue was purified by column chromatography (pentane/EtOAc, 1:1 → 1:2) to give heptaacetate **43** (23 mg; α/β, 1:1; 91%) as a colourless oil.

Heptaacetate **43** (23 mg, 0.03 mmol) was deprotected as described for **46** and the crude product purified by column chromatography (EtOAc/MeOH, 5:1) to give the unprotected pseudodisaccharide **55** (10 mg; α/β, 1:1.4, 75%) as a white solid; The $_\alpha$ and $_\beta$ descriptors refer to the two pseudodisaccharides containing α- and β-glucose residues, respectively. ^{1}H NMR (400 MHz, D_2O): δ = 5.21 (d, $J_{1,2}$ = 3.5 Hz, 1 H, 1$^{II}_\alpha$-H), 4.71 (m, 2 H, 1$^{I}_\alpha$-H, 1$^{I}_\beta$-H), 4.64 (d, $J_{1,2}$ = 7.6 Hz, 1 H, 1$^{II}_\beta$-H), 4.03–4.02 (m, 2 H, 2$^{I}_\alpha$-H, 2$^{I}_\beta$-H), 3.89–3.57 (m, 14 H, 2$^{II}_\alpha$-H, 4$^{I}_\alpha$-H, 4$^{I}_\beta$-H, 5$^{I}_\alpha$-H, 5$^{I}_\beta$-H, 5$^{II}_\alpha$-H or 5$^{II}_\beta$-H, 6$^{I}_\alpha$-H, 6$^{II}_\alpha$-H, 6$^{I}_\beta$-H, 6$^{II}_\beta$-H, 6′$^{I}_\alpha$-H, 6′$^{II}_\alpha$-H, 6′$^{I}_\beta$-H, 6′$^{II}_\beta$-H), 3.50 (m, 1 H, 5$^{II}_\alpha$-H or 5$^{II}_\beta$-H), 3.41–3.33 (m, 8 H, 2 OCH_3, 4$^{II}_\alpha$-H, 4$^{II}_\beta$-H), 3.26 (dd, $J_{1,2}$ = 7.6, $J_{2,3}$ = 10.8 Hz, 1 H, 2$^{II}_\beta$-H), 3.21–3.17 (m, 2 H, 3$^{I}_\alpha$-H, 3$^{I}_\beta$-H), 3.04 (at, *J* = 10.6 Hz, 1 H, 3$^{II}_\alpha$-H), 2.81 (at, *J* = 10.6 Hz, 1 H, 3$^{II}_\beta$-H) ppm. ^{13}C NMR (125 MHz, D_2O): δ = 99.9 (d, C-1$^{I}_\alpha$, C-1$^{I}_\beta$), 97.1 (d, C-1$^{II}_\beta$), 91.4 (d, C-1$^{II}_\alpha$), 78.4 (d, C-5$^{II}_\alpha$ or

C-5$^{II}_{\beta}$), 73.6, 72.3, 70.7, 66.5, 66.4 (5 d), 73.2 (d, C-2$^{II}_{\beta}$), 71.0, 70.9 (2 d, C-2$^{I}_{\alpha}$, C-2$^{I}_{\beta}$), 68.9, 68.5 (2 d, C-4$^{II}_{\alpha}$, C-4$^{II}_{\beta}$), 61.2, 61.0, 60.9 (3 t, C-6$^{I}_{\alpha}$, C-6$^{II}_{\alpha}$, C-6$^{I}_{\beta}$, C-6$^{II}_{\beta}$), 55.8 (d, C-3$^{II}_{\beta}$), 54.6 (q, 2 OCH_3), 52.2 (d, C-3$^{II}_{\alpha}$), 50.9, 50.6 (2 d, C-3$^{I}_{\alpha}$, C-3$^{I}_{\beta}$) ppm. MS (ES^+): *m*/*z* (%) = 395 (100) [M + Na^+]. HRMS: calcd. for $C_{13}H_{24}O_{10}SNa$ [M + Na^+] 395.0982; found 395.0974.

Bis(methyl 3-deoxy-β-D-allopyranosid-3-yl)sulfane (56): Following general procedure III, benzylated pseudodisaccharide **30** (692 mg, 0.93 mmol) gave, with THF (6 mL), ammonia (ca. 30 mL), sodium (ca. 280 mg), MeOH (72 μL); then acetylation and chromatography, hexaacetate **44** (337 mg, 57%) as colourless crystals.

Hexaacetate **44** (337 mg, 0.53 mmol) was deprotected as described for **46** to give the unprotected pseudodisaccharide **56** (192 mg, 94%) as a white solid. $[\alpha]_D^{23}$ = –28.1 (*c* = 1.0, in MeOH). ^{1}H NMR (500 MHz, D_2O): δ = 4.40 (d, $J_{1,2}$ = 8.1 Hz, 2 H, 1-H), 3.82–3.77 (m, 4 H, 4-H, 6′-H), 3.64–3.60 (m, 6 H, 2-H, 5-H, 6-H), 3.56 (at, *J* = 4.3 Hz, 2 H, 3-H), 3.46 (s, 6 H, OCH_3) ppm. ^{13}C NMR (125 MHz, D_2O): δ = 101.9 (d, C-1), 75.6 (d, C-5), 70.2 (d, C-2), 66.9 (d, C-4), 60.8 (t, C-6), 59.4 (d, C-3), 57.0 (q, OCH_3) ppm. MS (ES^+): *m*/*z* (%) = 1181 (4) [3M + Na^+], 795 (23) [2M + Na^+], 409 (100) [M + Na^+]. HRMS: calcd. for $C_{14}H_{26}O_{10}SNa$ [MNa^+] 409.1139; found 409.1150.

Bis(methyl 2-deoxy-α-D-mannopyranosid-2-yl)sulfane (57): Following general procedure III, benzylated pseudodisaccharide **31** (77 mg, 0.10 mmol) gave, with THF (2.5 mL), ammonia (ca. 35 mL), sodium (52 mg), MeOH (35 μL); then acetylation and chromatography, column chromatography (pentane/EtOAc, 2:1 → 1:1, 1% Et_3N), hexaacetate **45** (53 mg, 80%) as an off-white solid.

Hexaacetate **45** (31 mg, 0.05 mmol) was deprotected as described for **46** and purified by column chromatography (EtOAc/MeOH, 5:1) to yield the unprotected pseudodisaccharide **57** (14 mg, 76%) as a white solid. $[\alpha]_D^{21}$ = +49.8 (*c* = 1.0, in MeOH). ^{1}H NMR (500 MHz, D_2O): δ = 5.08 (br. s, 2 H, 1-H), 4.10 (dd, $J_{2,3}$ = 4.8, $J_{3,4}$ = 9.4 Hz, 2 H, 3-H), 3.85 (dd, $J_{5,6'}$ = 2.2, $J_{6,6'}$ = 12.3 Hz, 2 H, 6′-H), 3.74 (dd, $J_{5,6}$ = 5.5, $J_{6,6'}$ = 12.3 Hz, 2 H, 6-H), 3.62–3.52 (m, 4 H, 4-H, 5-H), 3.39 (s, 6 H, OCH_3), 3.34 (dd, $J_{1,2}$ = 1.1, $J_{2,3}$ = 4.8 Hz, 2 H, 2-H) ppm. ^{13}C NMR (125 MHz, D_2O): δ = 101.5 (d, C-1), 72.9 (d, C-5), 69.5 (d, C-3), 67.5 (d, C-4), 60.7 (t, C-6), 54.8 (q, OCH_3), 54.2 (d, C-2) ppm. MS (ES^+): *m*/*z* (%) = 795 (48) [2M + Na^+], 409 (100) [M + Na^+]. HRMS: calcd. for $C_{28}H_{52}O_{20}S_2Na$ (2MNa^+) 795.2386; found 795.2382; calcd. for $C_{14}H_{26}O_{10}SNa$ [MNa^+] 409.1139; found 409.1122.

Bis(methyl 4-deoxy-β-D-glucopyranosid-4-yl)sulfane (58): Sodium (6 mg, 0.23 mmol) was dissolved in MeOH (3 mL). This solution was added to a suspension of hexabenzoate **32** (40 mg, 0.04 mmol) in MeOH (3 mL) and BuOH (1.5 mL). The mixture was heated at 50 °C for 22 h, after which time, Dowex resin (H^+) was added, the mixture was filtered, and the filtrate concentrated in vacuo. The residue was purified by flash column chromatography ($CHCl_3$/MeOH, 3:1) followed by purification on Sep-Pak eluting with water → water/MeOH, 8:2 to give the unprotected pseudodisaccharide **58** (12 mg, 78%) as a white solid. ^{1}H NMR (500 MHz, D_2O): δ = 4.33 (d, $J_{1,2}$ = 8.2 Hz, 2 H, 1-H), 4.14 (dd, $J_{5,6'}$ = 2.0, $J_{6,6'}$ = 12.3 Hz, 2 H, 6′-H), 3.95 (dd, $J_{5,6}$ = 5.4, $J_{6,6'}$ = 12.3 Hz, 2 H, 6-H), 3.56 [m (obsd.), 2 H, 5-H], 3.55 (s, 6 H, OCH_3), 3.50 (dd, $J_{2,3}$ = 9.0, $J_{3,4}$ = 10.4 Hz, 2 H, 3-H), 3.27 (dd, $J_{1,2}$ = 8.2, $J_{2,3}$ = 9.0 Hz, 2 H, 2-H), 2.84 (at, *J* = 10.7 Hz, 2 H, 4-H) ppm. ^{13}C NMR (125 MHz, D_2O): δ = 103.6 (d, C-1), 77.2 (d, C-5), 75.9 (d, C-3), 74.7 (d, C-2), 62.2 (t, C-6), 57.7 (q, OCH_3), 48.7 (d, C-4) ppm. MS (ES^+): *m*/*z* (%) = 1181 (40) [3M + Na^+], 795 (100) [2M + Na^+], 409 (90) [M + Na^+]. HRMS: calcd. for $C_{14}H_{26}O_{10}S$ [MNa^+] 409.1139; found 409.1151.

Bis(methyl 2-deoxy-β-D-mannopyranosid-2-yl) Sulfoxide (59): The thioether **51** (25 mg, 0.064 mmol) was dissolved in a mixture of CH_2Cl_2 (0.5 mL) and MeOH (2 mL) and cooled to 0 °C. *m*CPBA (70%, 32 mg, 0.13 mmol) was added, and it dissolved slowly. The mixture was stirred at 0 °C for 45 min, after which time TLC (CMAW) showed complete conversion of the starting material (R_f = 0.3) into a single product (R_f = 0.2). Ethanethiol (10 mL) was added, then the mixture was concentrated in vacuo. The residue was purified by flash column chromatography (CMAW) to give the sulfoxide **59** (26 mg, 99%) as a colourless oil. $[\alpha]_D^{23}$ = –96.9 (*c* = 1.0, in MeOH). ^{1}H NMR (500 MHz, D_2O): δ = 5.08 (d, $J_{1,2}$ = 2.8 Hz, 1 H, 1^{II}-H), 4.91 (d, $J_{1,2}$ = 2.2 Hz, 1 H, 1^{I}-H), 4.49 (dd, $J_{1,2}$ = 2.2, $J_{2,3}$ = 4.8 Hz, 1 H, 2^{I}-H), 4.22 (dd, $J_{2,3}$ = 4.8, $J_{3,4}$ = 8.8 Hz, 1 H, 3^{I}-H), 4.16 (dd, $J_{2,3}$ = 5.5, $J_{3,4}$ = 8.0 Hz, 1 H, 3^{II}-H), 4.09 [m (obsd.), 1 H, 2^{II}-H], 4.07 (at, *J* = 8.6 Hz, 1 H, 4^{I}-H), 3.98 (dd, $J_{5,6'}$ = 2.8, $J_{6,6'}$ = 12.1 Hz, 1 H, 6′^{I}-H), 3.96 (dd, $J_{5,6'}$ = 3.3, $J_{6,6'}$ = 12.0 Hz, 1 H, 6′^{II}-H), 3.87 (at, *J* = 7.8 Hz, 1 H, 4^{II}-H), 3.82–3.86 (m, 2 H, 6^{I}-H, 6^{II}-H), 3.66 (ddd, $J_{4,5}$ = 7.7, $J_{5,6}$ = 6.9, $J_{5,6'}$ = 3.3 Hz, 1 H, 5^{II}-H), 3.58 (s, 3 H, OCH_3), 3.57 (m, 1 H, 5^{I}-H), 3.52 (s, 3 H, OCH_3) ppm. ^{13}C NMR (125 MHz, D_2O): δ = 100.2 (d, C-1^{II}), 99.8 (d, C-1^{I}), 77.2 (d, C-5^{I}), 76.8 (d, C-5^{II}), 73.2 (d, C-3^{I}), 69.7 (d, C-3^{II}), 68.1 (d, C-4^{II}), 67.3 (d, C-4^{I}), 61.4, 61.2 (2 t, C-6^{I}, C-6^{II}), 61.0 (d, C-2^{II}), 59.5 (d, C-2^{I}), 56.9, 56.8 (2 q, 2 OCH_3) ppm. MS (ES^+): *m*/*z* (%) = 827 (8) [2M + Na^+], 425 (100) [M + Na^+]. HRMS: calcd. for $C_{14}H_{26}O_{11}SNa$ [MNa^+] 425.1088; found 425.1090.

Bis(methyl 2-deoxy-β-D-mannopyranosid-2-yl) Sulfone (60): The thioether **51** (18 mg, 0.042 mmol) was dissolved in a mixture of CH_2Cl_2 (0.5 mL) and MeOH (2 mL) and cooled to 0 °C. *m*CPBA (70%, 46 mg, 0.19 mmol) was added. The mixture was then stirred at room temp. for 6 h, after which time TLC (CMAW) showed complete conversion of the starting material (R_f = 0.3) into a single product (R_f = 0.2). The mixture was concentrated in vacuo and the residue was purified by flash column chromatography (EtOAc/MeOH, 10:1) to give the sulfone **60** (15 mg, 77%) as a white solid. $[\alpha]_D^{23}$ = –33.2 (*c* = 0.5, in MeOH). ^{1}H NMR (500 MHz, D_2O): δ = 5.04 (d, $J_{1,2}$ = 2.4 Hz, 2 H, 1-H), 4.58 (dd, $J_{1,2}$ = 2.4, $J_{2,3}$ = 4.6 Hz, 2 H, 2-H), 4.24 (dd, $J_{2,3}$ = 4.6, $J_{3,4}$ = 8.2 Hz, 2 H, 3-H), 4.09 (at, *J* = 7.9 Hz, 2 H, 4-H), 3.99 (dd, $J_{5,6'}$ = 3.2, $J_{6,6'}$ = 12.2 Hz, 2 H, 6′-H), 3.90 (dd, $J_{5,6}$ = 6.9, $J_{6,6'}$ = 12.2 Hz, 2 H, 6-H), 3.65 (atd, $J_{5,6'}$ = 3.2, J_{at} = 7.2 Hz, 2 H, 5-H), 3.60 (s, 6 H, OCH_3) ppm. ^{13}C NMR (125 MHz, D_2O): δ = 99.1 (d, C-1), 77.2 (d, C-5), 70.4 (d, C-3), 66.8 (d, C-4), 65.1 (d, C-2), 60.9 (t, C-6), 56.7 (q, OCH_3) ppm. MS (ES^+): *m*/*z* (%) = 859 (12) [2M + Na^+], 441 (100) [M + Na^+]. HRMS: calcd. for $C_{14}H_{26}O_{12}SNa$ [MNa^+] 441.1037; found 441.1050.

Bis(methyl 3-deoxy-β-D-allopyranosid-3-yl) Sulfoxide (61): The thioether **56** (28 mg, 0.073 mmol) was dissolved in a mixture of CH_2Cl_2 (0.5 mL) and MeOH (2 mL) and cooled to 0 °C. *m*CPBA (70%, 36 mg, 0.15 mmol) was added, and it dissolved slowly. The mixture was stirred at 0 °C for 45 min, after which time TLC (CMAW) showed complete conversion of the starting material (R_f = 0.8) into a single product (R_f = 0.7). Ethanethiol (20 mL) was added, then the mixture was concentrated in vacuo. The residue was purified by flash column chromatography (CMAW) to give the sulfoxide **61** (26 mg, 89%) as a colourless oil. $[\alpha]_D^{23}$ = –50.5 (*c* = 1.0, in MeOH). ^{1}H NMR (500 MHz, D_2O): δ = 5.04 (d, $J_{1,2}$ = 5.6 Hz, 1 H, 1^{II}-H), 4.80 (d, $J_{1,2}$ = 4.9 Hz, 1 H, 1^{I}-H), 4.25 (at, *J* = 4.2 Hz, 1 H, 4^{I}-H), 4.20 (aq, *J* = 5.4 Hz, 1 H, 5^{I}-H), 4.11–4.03 (m, 3 H, 3^{I}-H, 2^{II}-H, 4^{II}-H), 3.98–3.94 (m, 2 H, 3^{II}-H, 5^{II}-H), 3.90 (at, *J* = 4.4 Hz, 1 H, 2^{I}-H), 3.78 (dd, $J_{5,6'}$ = 4.7, $J_{6,6'}$ = 12.1 Hz, 1 H, 6′^{II}-H), 3.73 (dd, $J_{5,6'}$ = 5.3, $J_{6,6'}$ = 12.0 Hz, 1 H, 6′^{I}-H), 3.69–3.64 (m, 2 H, 6^{I}-H, 6^{II}-H), 3.46, 3.45 (2 s, 6 H, 2 OCH_3) ppm. ^{13}C NMR (125 MHz, D_2O): δ = 102.4 (d, C-1^{I}), 102.1 (d, C-1^{II}), 79.4 (d, C-5^{I}), 78.1 (d,

C-5^{II}), 69.3 (d, C-2^{II}), 67.9 (d, C-2^{I}), 65.9 (d, C-4^{I}), 65.7 (d, C-4^{II}), 62.0, 61.9 (2 t, C-6^{I}, C-6^{II}), 59.2 (d, C-3^{II}), 58.0 (d, C-3^{I}), 57.3, 57.2 (2 q, 2 OCH_3) ppm. MS (ES^+): *m*/*z* (%) = 425 (100) [M + Na^+]. HRMS: calcd. for $C_{14}H_{26}O_{11}SNa$ [MNa^+] 425.1088; found 425.1079.

Bis(methyl 3-deoxy-β-D-allopyranosid-3-yl) Sulfone (62): The thioether **56** (20 mg, 0.052 mmol) was dissolved in a mixture of CH_2Cl_2 (0.5 mL) and MeOH (2 mL) and cooled to 0 °C. *m*CPBA (70%, 50 mg, 0.20 mmol) was added. The mixture was then stirred at room temp. for 4 h, after which time TLC (CMAW) showed complete conversion of the starting material (R_f = 0.8) into a single product (R_f = 0.9). The mixture was concentrated in vacuo and the residue was purified by flash column chromatography (EtOAc/MeOH, 10:1) to give the sulfone **62** (22 mg, 99%) as a white solid. $[\alpha]_D^{23}$ = –68.3 (*c* = 1.0, in MeOH). ^{1}H NMR (500 MHz, D_2O): δ = 4.85 (d, $J_{1,2}$ = 2.7 Hz, 2 H, 1-H), 4.54 (atd, $J_{2,4}$ = 1.4, J_{at} = 2.5 Hz, 2 H, 4-H), 4.33 (atd, $J_{2,4}$ = 1.4, J_{at} = 2.7 Hz, 2 H, 2-H), 4.13 (at, *J* = 2.7 Hz, 2 H, 3-H), 4.09 (dat, $J_{4,5}$ = 2.3, J_{at} = 6.7 Hz, 2 H, 5-H), 3.76 (dd, $J_{5,6'}$ = 6.3, $J_{6,6'}$ = 11.7 Hz, 2 H, 6′-H), 3.73 (dd, $J_{5,6}$ = 7.1, $J_{6,6'}$ = 11.7 Hz, 2 H, 6-H), 3.48 (s, 6 H, OCH_3) ppm. ^{13}C NMR (125 MHz, D_2O): δ = 102.9 (d, C-1), 81.1 (d, C-5), 67.2 (d, C-2), 65.4 (d, C-4), 62.2 (t, C-6), 61.3 (d, C-3), 56.8 (q, OCH_3) ppm. MS (ES^+): *m*/*z* (%) = 441 (100) [M + Na^+]. HRMS: calcd. for $C_{14}H_{26}O_{12}SNa$ [MNa^+] 441.1037; found 441.1053.

($J_{2,4}$ value obtained from a sine-bell window function.)

Bis(methyl 2-deoxy-α-D-mannopyranosid-2-yl) Sulfoxide (63): Thioether **57** (14 mg, 0.04 mmol) was dissolved in MeOH (1.5 mL) and CH_2Cl_2 (0.5 mL) and cooled to 0 °C. *m*CPBA (70%, 10 mg, 0.04 mmol) was added and after 1 h, TLC (EtOAc/MeOH, 3:1) indicated the complete consumption of starting material (R_f = 0.3) and the formation of a major product (R_f = 0.2). The reaction was quenched by addition of ethanethiol (10 μL) and the reaction mixture concentrated concentrated in vacuo. The resulting crude residue was purified twice by column chromatography; first ($CHCl_3$/MeOH/AcOH/H_2O, 60:30:3:5) and then (EtOAc/MeOH, 5:1) to yield sulfoxide **63** (11 mg, 72%) as a white powder. $[\alpha]_D^{23}$ = +41.0 (*c* = 0.8, in MeOH). ^{1}H NMR (500 MHz, D_2O): δ = 5.18 (d, $J_{1,2}$ = 1.2 Hz, 1 H, 1^{I}-H), 5.15 (d, $J_{1,2}$ = 2.6 Hz, 1 H, 1^{II}-H), 4.40 (dd, $J_{2,3}$ = 5.2, $J_{3,4}$ = 7.8 Hz, 1 H, 3^{II}-H), 4.36 (dd, $J_{1,2}$ = 1.2, $J_{3,4}$ = 7.8 Hz, 1 H, 2^{I}-H), 4.28 (dd, $J_{3,4}$ = 7.8, $J_{3,4}$ = 9.3 Hz, 1 H, 3^{I}-H), 4.09 (dd, $J_{3,4}$ = 7.8, $J_{4,5}$ = 9.1 Hz, 1 H, 4^{II}-H), 3.90–3.93 (m, 2 H, 6′^{I}-H, 6′^{II}-H), 3.69–3.86 (m, 6 H, 5^{II}-H, 5^{I}-H, 6^{I}-H, 6^{II}-H, 2^{II}-H, 4^{I}-H), 3.46, 3.44 (2 s, 6 H, 2 OCH_3) ppm. ^{13}C NMR (125 MHz, D_2O): δ = 98.3 (d, C-1^{II}), 96.1 (d, C-1^{I}), 73.0, 72.5 (2 d, C-5^{I}, C-5^{II}), 71.0 (d, C-3^{II}), 69.2 (d, C-3^{I}), 67.6 (d, C-4^{II}), 67.5 (d, C-4^{I}), 63.6 (d, C-2^{II}), 62.0 (d, C-2^{I}), 61.4, 60.8 (2 t, C-6^{I}, C-6^{II}), 55.2, 55.1 (2 q, 2 OCH_3) ppm. MS (ES^+): *m*/*z* (%) = 425 (100) [M + Na^+]. HRMS: calcd. for $C_{14}H_{26}O_{11}SNa$ [MNa^+] 425.1088; found 425.1097.

Bis(methyl 2-deoxy-α-D-mannopyranosid-2-yl) Sulfone (64): Thioether **57** (13 mg, 0.03 mmol) was dissolved in MeOH (1.5 mL) and CH_2Cl_2 (1 mL) and *m*CPBA (70%, 25 mg, 0.10 mmol) was added. After 6 h 30 min, TLC (EtOAc/MeOH, 3:1) indicated the complete consumption of starting material (R_f = 0.3) and the formation of a major product (R_f = 0.4). The reaction mixture was concentrated in vacuo and the resulting residue was purified twice by column chromatography; first (EtOAc/MeOH, 5:1) and then (CMAW) to yield sulfone **64** (9 mg, 63%) as a white powder. $[\alpha]_D^{23}$ = +32.0 (*c* = 0.8, in MeOH). ^{1}H NMR (500 MHz, D_2O): δ = 5.45 (d, $J_{1,2}$ = 1.3 Hz, 2 H, 1-H), 4.43 (dd, $J_{1,2}$ = 1.3, $J_{2,3}$ = 5.7 Hz, 2 H, 2-H), 4.29 (dd, $J_{2,3}$ = 5.7, $J_{3,4}$ = 9.0 Hz, 2 H, 3-H), 4.10 (at, *J* = 9.2 Hz, 2 H, 4-H), 3.89 (dd, $J_{5,6'}$ = 2.0, $J_{6,6'}$ = 12.2 Hz, 2 H, 6′-H), 3.76 (dd, $J_{5,6}$ = 6.5, $J_{6,6'}$ = 12.2 Hz, 2 H, 6-H), 3.69 (ddd, $J_{4,5}$ = 9.3, $J_{5,6}$ = 6.5, $J_{5,6'}$ = 2.0 Hz, 2 H, 5-H), 3.43 (s, 6 H, OCH_3) ppm. ^{13}C NMR (125 MHz, D_2O): δ = 95.0 (d, C-1), 73.1 (d, C-5), 68.9 (d, C-3), 68.2 (d, C-2), 66.6 (d, C-4), 61.0 (t, C-6), 55.3 (q, OCH_3) ppm. MS (ES^+): *m*/*z* (%) = 441 (100) [M + Na^+]. HRMS: calcd. for $C_{14}H_{26}O_{12}SNa$ [MNa^+] 441.1037; found 441.1053.

Bis(methyl 3-deoxy-α-D-glucopyranosid-3-yl)sulfane (67): MeOH (5 mL) was cooled to 0 °C and AcCl (75 μL) was added. This solution was added to the pseudodisaccharide **49** (190 mg, 0.53 mmol), and the mixture heated at 65 °C. After 3 d, Et_3N (1.5 mL) was added, and the solvents removed in vacuo.

The residue was dissolved in a mixture of pyridine (2 mL) and acetic anhydride (2 mL) and stirred at room temp. After 24 h, the mixture was concentrated in vacuo and the residue purified by flash column chromatography (EtOAc/pentane, 2:1) to give first the α,α diglycoside **65** (27 mg, 8%) as a colourless oil; then a mixture of the α,β diglycoside and β,β diglycoside **66a**,**b** (34 mg, 10%) as a colourless oil (α,β/β,β ≈ 10:1).

The hexaacetate **65** (27 mg, 0.042 mmol) was dissolved in MeOH (1.5 mL). Sodium (3 mg, 0.13 mmol) was dissolved in MeOH (1.5 mL), and the resulting solution added to the solution of carbohydrate. The mixture was stirred at room temp. and after 2 h, TLC (EtOAc/MeOH, 5:1) showed the presence of a single component (R_f = 0.2). Silica was added to the reaction mixture, then the solvent was removed in vacuo and the residue purified by flash column chromatography (EtOAc/MeOH, 5:1) to give the unprotected pseudodisaccharide **67** (15 mg, 92%) as a white solid. $[\alpha]_D^{23}$ = +174 (*c* = 0.5, in MeOH). ^{1}H NMR (500 MHz, D_2O): δ = 4.84 (d, $J_{1,2}$ = 3.6 Hz, 2 H, 1-H), 3.86 (dd, $J_{5,6'}$ = 2.3, $J_{6,6'}$ = 12.2 Hz, 2 H, 6′-H), 3.76 (dd, $J_{5,6}$ = 5.4, $J_{6,6'}$ = 12.2 Hz, 2 H, 6-H), 3.69 (ddd, $J_{4,5}$ = 9.6, $J_{5,6}$ = 5.4, $J_{5,6'}$ = 2.3 Hz, 2 H, 5-H), 3.63 (dd, $J_{1,2}$ = 3.6, $J_{2,3}$ = 11.1 Hz, 2 H, 2-H), 3.42 (s, 6 H, OCH_3), 3.42 [m (obsd.), 2 H, 4-H], 3.01 (at, *J* = 10.8 Hz, 2 H, 3-H) ppm. ^{13}C NMR (125 MHz, D_2O): δ = 99.1 (d, C-1), 73.0 (d, C-5), 70.5 (d, C-2), 68.7 (d, C-4), 61.4 (t, C-6), 55.4 (q, OCH_3), 52.2 (d, C-3) ppm. MS (ES^+): *m*/*z* (%) = 795 (10) [2M + Na^+], 409 (100) [M + Na^+]. HRMS: calcd. for $C_{14}H_{26}O_{10}SNa$ [MNa^+] 409.1139; found 409.1140.

(Methyl 3-deoxy-α-D-glucopyranosid-3-yl)(methyl 3-deoxy-β-D-glucopyranosid-3-yl)sulfane and Bis(methyl 3-deoxy-β-D-glucopyranosid-3-yl)sulfane (68a,b): The hexaacetates **66a**,**b** (30 mg, 0.047 mmol) were deprotected as described for **67**, to give the unprotected pseudodisaccharides **68a**,**b** (18 mg, 99%) as a white solid (α,β/β,β ca. 10:1). Selected data for α,β compound: The $_\alpha$ and $_\beta$ descriptors refer to signals from α- and β-configured glucose residues, respectively. ^{1}H NMR (500 MHz, D_2O): δ = 4.84 (d, $J_{1,2}$ = 3.6 Hz, 1 H, 1_α-H), 4.42 (d, $J_{1,2}$ = 7.8 Hz, 1 H, 1_β-H), 3.92 (dd, $J_{5,6'}$ = 2.3, $J_{6,6'}$ = 12.3 Hz, 1 H, $6'_\beta$-H), 3.86 (dd, $J_{5,6'}$ = 2.3, $J_{6,6'}$ = 12.3 Hz, 1 H, $6'_\alpha$-H), 3.71–3.78 (m, 2 H, 6_α-H, 6_β-H), 3.69 (m, 1 H, 5_α-H), 3.63 (dd, $J_{1,2}$ = 3.6, $J_{2,3}$ = 11.2 Hz, 1 H, 2_α-H), 3.57 (s, 3 H, OCH_3), 3.54 (m, 1 H, 5_β-H), 3.44 (s, 3 H, OCH_3), 3.40–3.47 (m, 2 H, 4_α-H, 4_β-H), 3.30 (dd, $J_{1,2}$ = 7.8, $J_{2,3}$ = 10.8 Hz, 1 H, 2_β-H), 3.02 (at, *J* = 10.8 Hz, 1 H, 3_α-H), 2.83 (at, *J* = 10.6 Hz, 1 H, 3_β-H) ppm. ^{13}C NMR (125 MHz, D_2O): δ = 104.8 (d, C-1_β), 99.1 (d, C-1_α), 78.8 (d, C-5_β), 73.0 (d, C-5_α), 72.5 (d, C-2_β), 70.4 (d, C-2_α), 68.8, 69.2 (2 d, C-4_α, C-4_β), 61.6 (t, C-6_β), 61.4 (t, C-6_α), 57.7 (q, OCH_3), 55.4, 55.4 (d, q, C-3_β, OCH_3), 52.9 (d, C-3_α) ppm. Selected data for the β,β compound: ^{1}H NMR (500 MHz, D_2O): δ = 4.43 (d, $J_{1,2}$ = 7.8 Hz, 1 H, 1-H), 2.84 (at, *J* = 10.6 Hz, 1 H, 3-H) ppm. ^{13}C NMR (125 MHz, D_2O): δ = 55.8 (d, C-3) ppm. MS (ES^+): *m*/*z* (%) = 795 (25) [2M + Na^+], 409 (100) [M + Na^+]. HRMS: calcd. for $C_{14}H_{26}O_{10}SNa$ [MNa^+] 409.1139; found 409.1138.

Methyl 3-*O*-(1,2:5,6-Di-*O*-isopropylidene-3-deoxy-α-D-glucofuranos-3-yl)-4,6-*O*-benzylidene-2-*O*-benzyl-α-D-glucopyranoside (74): Alcohol **84** (113 mg, 0.30 mmol) and triflate **8** (180 mg, 0.46 mmol) were dissolved in DMF (3 mL). Sodium hydride (60% in oil, 24 mg, 0.60 mmol) was added, and the mixture was stirred under N_2. After 30 min, TLC (pentane/EtOAc, 2:1) showed complete consumption of triflate (R_f = 0.8), some alcohol remaining (R_f = 0.5) and the formation of product (R_f = 0.7) as well as more polar compounds. The reaction mixture was added to brine (50 mL) and extracted with Et_2O (2 × 50 mL). The organic phase was dried (Na_2SO_4), filtered, and concentrated in vacuo. The residue was purified by flash column chromatography (pentane/EtOAc, 3:1) to give the pseudodisaccharide **74** (36 mg, 19%) as a colourless oil. $[\alpha]_D^{21}$ = –9.2 (*c* = 1.0, in $CHCl_3$). ^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.48–7.29 (m, 10 H, Ar-H), 5.61 (d, $J_{1,2}$ = 3.7 Hz, 1 H, 1^{II}-H), 5.50 (s, 1 H, PhC*H*), 4.88, 4.59 (2 d, *J* = 12.1 Hz, 2 H, PhCH_2), 4.77 (d, $J_{1,2}$ = 3.7 Hz, 1 H, 2^{II}-H), 4.47 (d, $J_{1,2}$ = 3.7 Hz, 1 H, 1^{I}-H), 4.43 (m, 1 H, 5^{II}-H), 4.38 (d, $J_{3,4}$ = 2.8 Hz, 1 H, 3^{II}-H), 4.24 (dd, $J_{5,6'}$ = 4.8, $J_{6,6'}$ = 10.2 Hz, 1 H, 6′^{I}-H), 4.11 (dd, $J_{3,4}$ = 2.8, $J_{4,5}$ = 7.6 Hz, 1 H, 4^{II}-H), 4.06 (dd, $J_{5,6'}$ = 6.3, $J_{6,6'}$ = 8.6 Hz, 1 H, 6′^{II}-H), 4.02–3.98 (m, 2 H, 3^{I}-H, 6^{II}-H), 3.81 (atd, J_{at} = 10.0, $J_{5,6'}$ = 4.8 Hz, 1 H, 5^{I}-H), 3.68 (at, *J* = 10.3 Hz, 1 H, 6^{I}-H), 3.48 (dd, $J_{1,2}$ = 3.7, $J_{2,3}$ = 9.2 Hz, 1 H, 2^{I}-H), 3.43 (at, *J* = 9.5 Hz, 1 H, 4^{I}-H), 3.34 (s, 3 H, OCH_3), 1.44, 1.34, 1.29, 1.12 [4 s, 12 H, 2 C(CH_3)$_2$] ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 138.5, 137.3 (2 s, 2 Ar-C), 129.3, 128.6, 128.4, 128.2, 128.1, 126.0 (6 d, Ar-CH), 111.5, 109.1 [2 s, 2 *C*(CH_3)$_2$], 105.1 (d, C-1^{II}), 101.7 (d, Ph*C*H), 99.1 (d, C-1^{I}), 83.0 (d, C-3^{II}), 82.5 (d, C-2^{II}), 81.2 (d, C-4^{II}), 80.5 (d, C-2^{I}), 80.1 (d, C-4^{I}), 76.6 (d, C-3^{I}), 74.1 (t, PhCH_2), 72.3 (d, C-5^{II}), 69.1 (t, C-6^{I}), 67.4 (t, C-6^{II}), 62.5 (d, C-5^{I}), 55.5 (q, OCH_3), 26.8, 26.8, 25.9, 25.7 [4 q, 2 C(*C*H_3)$_2$] ppm. MS (ES$^+$): *m*/*z* (%) = 1251 (10) [2M + Na$^+$], 637 (100) [M + Na$^+$]. HRMS: calcd. for $C_{33}H_{42}O_{11}Na$ [MNa$^+$] 637.2619; found 637.2593.

Methyl 3-*O*-(1,2:5,6-Di-*O*-isopropylidene-3-deoxy-α-D-glucofuranos-3-yl)-4,6-*O*-benzylidene-2-*O*-benzyl-β-D-glucopyranoside (75): Alcohol **4** (63 mg, 0.17 mmol) and triflate **8** (100 mg, 0.26 mmol) were dissolved in DMF (2 mL). Sodium hydride (60% in oil, 14 mg, 0.34 mmol) was added, and the mixture was stirred under N_2. After 1 h, TLC (pentane/EtOAc, 3:1) showed complete consumption of triflate (R_f = 0.7), some alcohol remaining (R_f = 0.5) and the formation of product (R_f = 0.6) as well as more polar compounds. Further triflate **8** (45 mg, 0.11 mmol) was added, along with further NaH (14 mg, 0.34 mmol). After a further 1 h, the reaction mixture was added to brine (50 mL) and extracted with Et_2O (2 × 50 mL). The organic phase was dried (Na_2SO_4), filtered, and concentrated in vacuo. The residue was purified by flash column chromatography (pentane/EtOAc, 4:1) to give the pseudodisaccharide **75** (47 mg, 45%) as a colourless oil. $[\alpha]_D^{22}$ = –20.7 (*c* = 1.0, in $CHCl_3$). ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.50–7.28 (m, 10 H, Ar-H), 5.65 (d, $J_{1,2}$ = 3.6 Hz, 1 H, 1^{II}-H), 5.53 (s, 1 H, PhC*H*), 4.88, 4.84 (2 d, *J* = 10.5 Hz, 2 H, PhCH_2), 4.79 (d, $J_{1,2}$ = 3.6 Hz, 1 H, 2^{II}-H), 4.42–4.35 (m, 4 H, 1^{I}-H, 6′^{I}-H, 3^{II}-H, 5^{II}-H), 4.07 (dd, *J* = 2.9, *J* = 8.1 Hz, 1 H, 4^{II}-H), 4.04 (dd, $J_{5,6'}$ = 6.3, $J_{6,6'}$ = 8.6 Hz, 1 H, 6′^{II}-H), 3.96 (dd, $J_{5,6}$ = 6.0, $J_{6,6'}$ = 8.6 Hz, 1 H, 6^{II}-H), 3.76 (at, *J* = 10.2 Hz, 1 H, 6^{I}-H), 3.74 (at, *J* = 9.0 Hz, 1 H, 3^{I}-H or 4^{I}-H), 3.56 (s, 3 H, OCH_3), 3.52 (at, *J* = 9.4 Hz, 1 H, 3^{I}-H or 4^{I}-H), 3.44–3.38 (m, 2 H, 2^{I}-H, 5^{I}-H), 1.46, 1.25, 1.21, 1.12 [4 s, 12 H, 2 C(CH_3)$_2$] ppm. ^{13}C NMR (100 MHz, $CDCl_3$): δ = 138.8, 137.2 (2 s, 2 Ar-C), 129.3, 128.4, 128.4, 127.9, 127.7, 126.0 (6 d, Ar-CH), 111.6, 109.1 [2 s, 2 *C*(CH_3)$_2$], 105.7 (d, C-1^{I}), 105.1 (d, C-1^{II}), 101.5 (d, Ph*C*H), 83.1, 82.8, 82.6 (3 d, C-2^{I}, C-2^{II}, C-3^{II}), 81.3 (d, C-4^{II}), 79.5, 79.5 (2 d, C-3^{I}, C-4^{I}), 74.9 (t, PhCH_2), 72.0 (d, C-5^{II}), 68.8 (t, C-6^{I}), 67.5 (t, C-6^{II}), 66.2 (d, C-5^{I}), 57.6 (q, OCH_3), 26.8, 26.8, 25.9, 25.5 [4 q, 2 C(*C*H_3)$_2$] ppm. MS (ES$^+$): *m*/*z* (%) = 1251 (15) [2M + Na$^+$], 637 (100) [M + Na$^+$]. HRMS: calcd. for $C_{33}H_{42}O_{11}Na$ [MNa$^+$] 637.2619; found 637.2590.

Bis(3-deoxy-D-glucopyranos-3-yl) Ether (76): The protected pseudodisaccharide **69** (223 mg, 0.44 mmol) was dissolved in a mixture of TFA (3 mL) and water (0.3 mL) and stirred at room temp. After 2 h, water (3 mL) was added, and the mixture concentrated in vacuo. The residue was purified by flash column chromatography ($CHCl_3$/MeOH, 4:1) to give the deprotected compounds **76** (126 mg, 83%) as a white solid. Mixture of three compounds: α,α; α,β; β,β. The $_\alpha$ and $_\beta$ descriptors refer to signals from α- and β-configured glucose residues, respectively. Partial data ^{1}H NMR (500 MHz, D_2O): δ = 5.25 (d, $J_{1,2}$ = 3.7 Hz, 1 H, 1_α-H), 4.69 (d, $J_{1,2}$ = 7.9 Hz, 1 H, 1_β-H), 4.68 (d, $J_{1,2}$ = 7.9 Hz, 1 H, 1_β-H) ppm. ^{13}C NMR (125 MHz, D_2O): δ = 96.5, 96.5 (2 d, 2 C-1_β), 92.6, 92.6 (2 d, 2 C-1_α), 88.4, 88.2 (2 d), 85.7, 85.6 (2 d), 61.2, 61.0 (2 t, C-6) ppm. MS (ES$^+$): *m*/*z* (%) = 1049 (5) [3M + Na$^+$], 707 (30) [2M + Na$^+$], 365 (100) [M + Na$^+$]. HRMS: calcd. for $C_{12}H_{22}O_{11}Na$ [MNa$^+$] 365.1054; found 365.1046.

3-*O*-(3-Deoxy-D-allopyranos-3-yl)-D-glucopyranose (77): Unsymmetrical pseudodisaccharide **70** (153 mg, 0.30 mmol) was deprotected with 90% TFA in an analogous manner to that described for **76** to give the deprotected compounds **77** (81 mg, 78%) as a colourless solid. Predominantly a mixture of two compounds: Glc*p*α,All*p*β and Glc*p*βAll*p*β, approx 1:1. Smaller trace amounts of other allose configurations could be seen in ^{1}H NMR spectrum. Partial data. The $_\alpha$ and $_\beta$ descriptors refer to signals from α- and β-configured monosaccharide residues, respectively. ^{1}H NMR (500 MHz, D_2O): δ = 5.25 (d, $J_{1,2}$ = 3.1 Hz, 1 H, 1$^{II}_\alpha$-H), 4.93 (d, $J_{1,2}$ = 8.2 Hz, 1 H, 1$^{I}_\beta$-H), 4.92 (d, $J_{1,2}$ = 8.3 Hz, 1 H, 1$^{I}_\beta$-H), 4.69 (d, $J_{1,2}$ = 7.9 Hz, 1 H, 1$^{II}_\beta$-H) ppm. ^{13}C NMR (125 MHz, D_2O): δ = 95.9 (d, C-1$^{II}_\beta$), 94.2, 94.2 (2 d, 2 C-1$^{I}_\beta$), 92.1 (d, C-1$^{II}_\alpha$), 87.6, 85.0 (2 d), 83.4, 83.2 (2 d), 61.2, 60.8, 60.7 (3 t, C-6) ppm. MS (ES$^+$): *m*/*z* (%) = 707 (20) [2M + Na$^+$], 365 (100) [M + Na$^+$]. HRMS: calcd. for $C_{12}H_{22}O_{11}Na$ [MNa$^+$] 365.1054; found 365.1046.

Methyl 2-*O*-(3-Deoxy-D-glucopyranos-3-yl)-α-D-mannopyranoside (78): The protected compound **71** (110 mg, 0.18 mmol) was dissolved in a mixture of TFA (1.4 mL) and water (0.15 mL), and the mixture was stirred at room temp. in air. After 20 min, water (5 mL) was added and the mixture was concentrated in vacuo. Toluene was then added and the mixture concentrated in vacuo.

The resulting residue was dissolved in a mixture of water (1.5 mL) and AcOH (0.1 mL), and Pd (10% on C, 10 mg) was added. The mixture was degassed and stirred under H_2. After 20 h, TLC (EtOAc/MeOH, 4:1) showed a single product (R_f = 0.1). The mixture was filtered through Celite and concentrated in vacuo.

The residue was dissolved in a mixture of acetic anhydride (1 mL) and pyridine (1 mL), and stirred at room temp. After 17 h, the mixture was added to HCl (1 M, 25 mL) and extracted with CH_2Cl_2 (25 mL). The organic phase was washed with $NaHCO_3$ (satd. aq. 25 mL), then dried (Na_2SO_4), filtered, and concentrated in vacuo. The residue was purified by flash column chromatography (pentane/EtOAc, 1:3) to give the heptaacetate (94 mg, 81%) as a colourless oil.

The heptaacetate was deacetylated with NaOMe in MeOH and purified by flash column chromatography (CMAW) to give the free pseudodisaccharide **78** (50 mg, 79%) as a colourless oil; mixture of two compounds (α/β, 1:1). The $_\alpha$ and $_\beta$ descriptors refer to signals from α- and β-configured glucose residues, respectively. Partial data ^{1}H NMR (500 MHz, D_2O): δ = 5.26 (d, $J_{1,2}$ = 3.5 Hz, 1 H, 1$^{II}_\alpha$-

H), 5.01 (d, $J_{1,2}$ = 1.5 Hz, 1 H, 1^{I}-H), 5.00 (d, $J_{1,2}$ = 1.5 Hz, 1 H, 1^{I}-H), 4.68 (d, $J_{1,2}$ = 7.9 Hz, 1 H, 1^{II}_{β}-H), 3.44, 3.43 (2 s, 6 H, 2 OCH_3) ppm. ^{13}C NMR (125 MHz, D_2O): δ = 100.0, 99.8 (2 d, C-1^{I}), 95.9 (d, C-1^{II}_{β}), 91.9 (d, C-1^{II}_{α}), 60.9, 60.7, 60.5 (3 t, C-6), 54.9 (q, OCH_3) ppm. MS (ES^+): *m*/*z* (%) = 735 (15) [2M + Na^+], 379 (100) [M + Na^+]. HRMS: calcd. for $C_{13}H_{24}O_{11}Na$ [MNa^+] 379.1211; found 379.1200.

Methyl 3-*O*-(3-Deoxy-D-glucopyranos-3-yl)-α-D-altropyranoside (79): According to the method described for **78**, protected pseudodisaccharide **72** (60 mg, 0.098 mmol) was converted to its heptaacetate, and then deacetylated with NaOMe in MeOH and purified by flash column chromatography (CMAW) to give the free pseudodisaccharide **79** (25 mg, 72%); mixture of two compounds (α/β, 1:1). The $_{\alpha}$ and $_{\beta}$ descriptors refer to signals from α- and β-configured glucose residues, respectively. Partial data. ^1H NMR (400 MHz, D_2O): δ = 5.24 (d, $J_{1,2}$ = 3.6 Hz, 1 H, 1^{II}_{α}-H), 4.69 (br. s, 2 H, 1^{I}-H), 4.67 (d, $J_{1,2}$ = 8.0 Hz, 1 H, 1^{II}_{β}-H), 3.42 (s, 6 H, 2 OCH_3) ppm. ^{13}C NMR (100 MHz, D_2O): δ = 100.8 (d, C-1^{I}), 95.6 (d, C-1^{II}_{β}), 91.8 (d, C-1^{II}_{α}), 60.9, 60.5, 60.3 (3 t, C-6), 55.4 (q, OCH_3) ppm. MS (ES^+): *m*/*z* (%) = 1091 (5) [3M + Na^+], 735 (25) [2M + Na^+], 379 (100) [M + Na^+]. HRMS: calcd. for $C_{13}H_{24}O_{11}Na$ [MNa^+] 379.1211; found 379.1203.

Methyl 3-*O*-(3-Deoxy-D-glucopyranos-3-yl)-α-D-mannopyranoside (80): According to the method described for **78**, protected pseudodisaccharide **73** (289 mg, 0.47 mmol) was converted to its heptaacetate (238 mg, 78%); this was deacetylated with NaOMe in MeOH and purified by flash column chromatography (CMAW) to give the free pseudodisaccharide **80** (130 mg, 78%); mixture of two compounds (α/β, 1:1). The $_{\alpha}$ and $_{\beta}$ descriptors refer to signals from α- and β-configured glucose residues, respectively. Partial data. ^1H NMR (500 MHz, D_2O): δ = 5.24 (d, $J_{1,2}$ = 2.6 Hz, 1 H, 1^{II}_{α}-H), 4.80 [m (obsd.), 2 H, 1^{I}-H], 4.67 (d, $J_{1,2}$ = 7.9 Hz, 1 H, 1^{II}_{β}-H), 3.41, 3.41 (2 s, 6 H, 2 OCH_3) ppm. ^{13}C NMR (125 MHz, D_2O): δ = 101.3 (d, C-1^{I}), 96.1 (d, C-1^{II}_{β}), 92.3 (d, C-1^{II}_{α}), 61.3, 61.1, 61.0 (3 t, C-6), 55.2 (q, OCH_3) ppm. MS (ES^+): *m*/*z* (%) = 1091 (10) [3M + Na^+], 735 (80) [2M + Na^+], 379 (100) [M + Na^+]. HRMS: calcd. for $C_{13}H_{24}O_{11}Na$ [MNa^+] 379.1211; found 379.1194.

Methyl 3-*O*-(3-Deoxy-D-glucopyranos-3-yl)-α-D-glucopyranoside (81): Protected **74** (36 mg, 0.059 mmol) was converted into the heptaacetate (31 mg, 81%), a colourless oil, in an identical manner as described for **75** below (α/β, 1:1.4).

The heptaacetate (31 mg, 0.048 mmol) was converted into the deprotected compound **81** (14 mg, 81%) in an identical manner as described for **82**. The $_{\alpha}$ and $_{\beta}$ descriptors refer to signals from α- and β-configured glucose residues, respectively. Partial data. ^1H NMR (500 MHz, D_2O): δ = 5.24 (d, $J_{1,2}$ = 3.7 Hz, 1 H, 1^{II}_{α}-H), 4.83 (d, $J_{1,2}$ = 3.7 Hz, 2 H, 1^{I}-H), 4.68 (d, $J_{1,2}$ = 8.0 Hz, 1 H, 1^{II}_{β}-H), 3.55 (s, 6 H, 2 OCH_3) ppm. ^{13}C NMR (data from HSQC, 500 MHz, D_2O): δ = 100.0 (C-1^{I}), 96.6 (C-1^{II}_{β}), 92.7 (C-1^{II}_{α}) ppm. MS (ES^+): *m*/*z* (%) = 1091 (5) [3M + Na^+], 735 (30) [2M + Na^+], 379 (100) [M + Na^+]. HRMS: calcd. for $C_{13}H_{24}O_{11}Na$ [MNa^+] 379.1211; found 379.1225.

Methyl 3-*O*-(3-Deoxy-D-glucopyranos-3-yl)-β-D-glucopyranoside (82): The protected compound **75** (48 mg, 0.078 mmol) was dissolved in a mixture of TFA (1.4 mL) and water (0.15 mL), and the mixture was stirred at room temp. in air. After 30 min, water (5 mL) was added and the mixture was concentrated in vacuo. Toluene was then added and the mixture concentrated in vacuo.

The resulting residue was dissolved in a mixture of MeOH (1 mL), water (1 mL) and AcOH (0.1 mL), and Pd (10% on C, 10 mg) was added. The mixture was degassed and stirred under H_2. After 20 h, TLC (EtOAc/MeOH, 4:1) showed a single product (R_f = 0.2). The mixture was filtered through Celite and concentrated in vacuo.

The residue was dissolved in a mixture of acetic anhydride (1 mL) and pyridine (1 mL), and stirred at room temp. After 17 h, the mixture was added to HCl (1 M, 50 mL) and extracted with EtOAc (50 mL). The organic phase was washed with $NaHCO_3$ (satd. aq. 30 mL), then dried (Na_2SO_4), filtered, and concentrated in vacuo. The residue was purified by flash column chromatography (pentane/EtOAc, 2:1) to give the heptaacetate (44 mg, 87%) as a colourless oil, α:β, 1:1.2.

The heptaacetate (28 mg, 0.043 mmol) was dissolved in a mixture of MeOH (3 mL) and aqueous ammonia (1.5 mL) and stirred at room temp. After 90 min, the mixture was concentrated in vacuo. The residue was purified by Sep-Pak eluting with water, and freeze-dried to give the deprotected compound **82** (11 mg, 70%); The $_{\alpha}$ and $_{\beta}$ descriptors refer to signals from α- and β-configured glucose residues, respectively. Partial data. ^1H NMR (500 MHz, D_2O): δ = 5.24 (d, $J_{1,2}$ = 3.8 Hz, 1 H, 1^{II}_{α}-H), 4.67 (d, $J_{1,2}$ = 7.9 Hz, 1 H, 1^{II}_{β}-H), 4.43 (d, $J_{1,2}$ = 8.0 Hz, 1 H, 1^{I}-H), 4.42 (d, $J_{1,2}$ = 8.0 Hz, 1 H, 1^{I}-H), 3.41 (s, 6 H, 2 OCH_3) ppm. ^{13}C NMR (data from HSQC, 500 MHz, D_2O): δ = 104.0 (C-1^{I}), 96.6 (C-1^{II}_{β}), 92.8 (C-1^{II}_{α}) ppm. MS (ES^+): *m*/*z* (%) = 735 (10) [2M + Na^+], 379 (100) [M + Na^+]. HRMS: calcd. for $C_{13}H_{24}O_{11}Na$ [MNa^+] 379.1211; found 379.1208.

Lectin Binding Studies: Banana lectin was prepared from over-ripe bananas by previously published methods[34,46] or modifications thereof.[47] Concanavalin A was available from previous studies. Ligands other than the pseudodisaccharides described herein were available from previous studies, or were purchased from Sigma (St. Louis, MO) or from V-Labs, Inc. (Covington, LA). Lectins and ligands were dissolved in PBS (10 mM sodium phosphate buffer, pH 7.2, 150 mM in NaCl, 0.2 mM in $CaCl_2$, and 0.04% NaN_3). Binding was determined by isothermal titration calorimetry using a Micro-Cal VP-ITC calorimeter (Micro-Cal, Northampton, MA, USA) at 25 °C. Data were analysed using Origin ver. 7 software supplied with the instrument. The lectin in PBS, generally at approx. 0.2 mM in subunits, was titrated with ligand, usually at 20–30 mM in the same buffer. Concentrations and titration volumes were adjusted so that the titration proceeded to at least a 10-fold excess of ligand at the expected stoichiometry. Nevertheless, especially for BanLec, the relatively low binding constants ($K_a < 1000\ M^{-1}$) precluded obtaining full saturation or a definite sigmoidal titration curve from which a definitive stoichiometry can be obtained. In such cases, the stoichiometry (*n*) was fixed at 1 for curve-fitting to determine K_a; *n* values between about 0.5 and 2–3 had little effect on the K_a value obtained. However, other thermodynamic parameters, such as molar enthalpy and entropy of binding cannot be determined accurately, so no attempt was made to assess the effects of ligand structure on these parameters.

Supporting Information (see also the footnote on the first page of this article): Characterisation data for peracetylated derivatives and copies of the ^1H and ^{13}C spectra for new compounds.

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[1] a) J. Farkas, K. Sebesta, K. Horská, Z. Samek, L. Dolejs, F. Sorm, *Collect. Czech. Chem. Commun.* **1969**, *34*, 1118–1120; b) M. Prystas, F. Sorm, *Collect. Czech. Chem. Commun.* **1971**, *36*, 1448–1471.

[2] a) A. H. Haines, *Org. Biomol. Chem.* **2004**, *2*, 2352–2358; b) H. Takahashi, T. Fukuda, H. Mitsuzuka, R. Namme, H. Miyamoto, Y. Ohkura, S. Ikegami, *Angew. Chem. Int. Ed.* **2003**, *42*, 5069–5071.

[3] a) G. Hodosi, P. Kovac, *Carbohydr. Res.* **1998**, *308*, 63–75; b) R. L. Whistler, A. Frowein, *J. Org. Chem.* **1961**, *26*, 3946–3948; c) P. Y. Gouéth, G. Ronco, P. Villa, *J. Carbohydr. Chem.* **1994**, *13*, 679–696; d) P. Y. Gouéth, M. Fauvin, I. Chellé-Regnaut, G. Ronco, P. Villa, *J. Carbohydr. Chem.* **1994**, *13*, 697–713.

[4] T. Akhtar, L. Eriksson, I. Cumpstey, *Carbohydr. Res.* **2008**, *343*, 2094–2100.

[5] K. Nishiyama, T. Nakayama, H. Natsugari, H. Takahashi, *Synthesis* **2008**, 3761–3768.

[6] a) B. Coxon, *Carbohydr. Res.* **1979**, *73*, 47–57; b) B. Coxon, *Carbohydr. Res.* **2007**, *342*, 1044–1054; c) J. Kroutil, M. Budesinsky, *Carbohydr. Res.* **2007**, *342*, 147–153; d) J. Neumann, S. Weingarten, J. Thiem, *Eur. J. Org. Chem.* **2007**, 1130–1144; e) K. Neimert-Andersson, S. Sauer, O. Panknin, T. Borg, E. Söderlind, P. Somfai, *J. Org. Chem.* **2006**, *71*, 3623–3626.

[7] T. Akhtar, I. Cumpstey, *Tetrahedron Lett.* **2007**, *48*, 8673–8677.

[8] a) M. Dahlgard, *J. Org. Chem.* **1965**, *30*, 4352–4353; b) M. V. Jesudason, L. N. Owen, *J. Chem. Soc. Perkin Trans. 1* **1974**, 2019–2024; c) M. Kojima, M. Wanatabe, T. Taguchi, *Tetrahedron Lett.* **1968**, *7*, 839–842; d) S. Ishiguro, S. Tejima, *Chem. Pharm. Bull.* **1968**, 1567–1572; e) D. Trimnell, E. I. Stout, W. M. Doane, C. R. Russell, *J. Org. Chem.* **1975**, *40*, 1337–1339.

[9] For a preliminary report of the synthesis of thioether pseudodisaccharides as described in this paper, see: I. Cumpstey, *Synlett* **2006**, 1711–1714.

[10] a) M. L. Uhrig, L. Szilágyi, K. E. Kövér, O. Varela, *Carbohydr. Res.* **2007**, *342*, 1841–1849; b) A. Wadouachi, L. Lescureux, D. Lesur, D. Beaupère, *Carbohydr. Res.* **2007**, *342*, 1490–1495.

[11] a) T. G. Marron, T. J. Woltering, G. Weitz-Schmidt, C.-H. Wong, *Tetrahedron Lett.* **1996**, *37*, 9037–9040; b) J. Tejler, F. Skogman, H. Leffler, U. J. Nilsson, *Carbohydr. Res.* **2007**, *342*, 1537–1982.

[12] a) A. Kato, N. Kato, E. Kano, I. Adachi, K. Ikeda, L. Yu, T. Okamoto, Y. Banba, H. Ouchi, H. Takahata, N. Asano, *J. Med. Chem.* **2005**, *48*, 2036–2044; b) Y. Blériot, D. Gretzke, T. M. Krülle, T. D. Butters, R. A. Dwek, R. J. Nash, N. Asano, G. W. J. Fleet, *Carbohydr. Res.* **2005**, *340*, 2713–2718; c) C.-Y. Yu, N. Asano, K. Ikeda, M.-X. Wang, T. D. Butters, M. R. Wormald, R. A. Dwek, A. L. Winters, R. J. Nash, G. W. J. Fleet, *Chem. Commun.* **2004**, 1936–1937.

[13] V. L. Maxwell, E. L. Evinson, D. P. G. Emmerson, P. R. Jenkins, *Org. Biomol. Chem.* **2006**, *4*, 2724–2732.

[14] a) R. J. Pieters, *Med. Res. Rev.* **2007**, *27*, 796–816; b) E. E. Simanek, G. J. McGarvey, J. A. Jablonowski, C.-H. Wong, *Chem. Rev.* **1998**, *98*, 833–862; c) F.-T. Liu, G. A. Rabinovich, *Nat. Rev. Cancer* **2005**, *5*, 29–41.

[15] a) K. Pachamuthu, R. R. Schmidt, *Chem. Rev.* **2006**, *106*, 160–187; b) H. Driguez, *Chembiochem* **2001**, *2*, 311–318; c) J. K. Fairweather, H. Driguez, in: *Carbohydrates in Chemistry and Biology* (Eds.: B. Ernst, G. W. Hart, P. Sinaÿ), Wiley-VCH, Weinheim, **2000**, vol. 1, pp. 531–564.

[16] R. Ruiz Contreras, J. P. Kamerling, J. F. G. Vliegenthart, *Recl. Trav. Chim. Pays-Bas* **1991**, *110*, 85–88.

[17] J. D. Stevens, in: *Methods in Carbohydrate Chemistry* (Eds.: R. L. Whistler, J. N. BeMiller), Academic Press, **1972**, vol. 6, pp. 123–128.

[18] P. V. Murphy, J. L. O'Brien, L. J. Gorey-Feret, A. B. Smith III, *Tetrahedron* **2003**, *59*, 2259–2271.

[19] P. J. Garegg, T. Iversen, S. Oscarson, *Carbohydr. Res.* **1976**, *50*, C12–C14.

[20] A. M. P. van Steijn, M. Jetten, J. P. Kamerling, J. F. G. Vliegenthart, *Recl. Trav. Chim. Pays-Bas* **1989**, *108*, 374–383.

[21] P. J. Garegg, S. Oscarson, *Carbohydr. Res.* **1985**, *137*, 270–275.

[22] M. J. Kiefel, B. Beisner, S. Bennett, I. D. Holmes, M. von Itzstein, *J. Med. Chem.* **1996**, *39*, 1314–1320.

[23] T. Haradahira, M. Maeda, H. Omae, Y. Yano, M. Kojima, *Chem. Pharm. Bull.* **1984**, *32*, 4758–4766.

[24] C. Grandjean, G. Lukacs, *J. Carbohydr. Chem.* **1996**, *15*, 831–856.

[25] G. W. J. Fleet, M. J. Gough, T. K. M. Shing, *Tetrahedron Lett.* **1984**, *25*, 4029–4032.

[26] T.-H. Lin, P. Kovac, C. P. J. Glaudemans, *Carbohydr. Res.* **1989**, *188*, 228–238.

[27] Note that triethylamine was used for this transformation, not pyridine as stated in the preliminary communication (ref.[9]).

[28] S.-H. Kim, D. Augeri, D. Yang, D. Kahne, *J. Am. Chem. Soc.* **1994**, *116*, 1766–1775.

[29] a) J. C. McAuliffe, R. V. Stick, D. M. G. Tilbrook, A. G. Watts, *Aust. J. Chem.* **1998**, *51*, 91–95; b) R. V. Stick, D. M. G. Tilbrook, S. J. Williams, *Aust. J. Chem.* **1999**, *52*, 895–904; c) H. Dong, Z. Pei, O. Ramström, *J. Org. Chem.* **2006**, *71*, 3306–3309; d) Z. Pei, H. Dong, R. Caraballo, O. Ramström, *Eur. J. Org. Chem.* **2007**, 4927–4934.

[30] I. Cumpstey, D. S. Alonzi, T. D. Butters, *Carbohydr. Res.* **2009**, *344*, 454–459.

[31] I. Cumpstey, A. Sundin, H. Leffler, U. J. Nilsson, *Angew. Chem. Int. Ed.* **2005**, *44*, 5110–5112.

[32] I. Cumpstey, L. Eriksson, *Acta Crystallogr., Sect. E* **2007**, *63*, O4197.

[33] P. Kovac, H. J. C. Yeh, C. P. J. Glaudemans, *Carbohydr. Res.* **1987**, *169*, 23–34.

[34] V. L. Koshte, W. van Dijk, M. E. van der Stelt, R. C. Aalberse, *Biochem. J.* **1990**, *272*, 721–726.

[35] H. Mo, H. C. Winter, E. J. M. van Damme, W. J. Peumans, A. Misaki, I. J. Goldstein, *Eur. J. Biochem.* **2001**, *268*, 2609–2615.

[36] H. C. Winter, S. Oscarson, R. Slättegård, M. Tian, I. J. Goldstein, *Glycobiology* **2005**, *15*, 1043–1050.

[37] I. J. Goldstein, H. C. Winter, H. Mo, A. Misaki, E. J. M. van Damme, W. J. Peumans, *Eur. J. Biochem.* **2001**, *268*, 2616–2619.

[38] J. L. Meagher, H. C. Winter, P. Ezell, I. J. Goldstein, J. A. Stuckey, *Glycobiology* **2005**, *15*, 1033–1042.

[39] The synthesis of the selenoether-linked compound **83** will be described elsewhere.

[40] I. J. Goldstein, C. M. Reichert, A. Misaki, *Ann. NY Acad. Sci.* **1974**, *234*, 283–295.

[41] D. K. Mandal, N. Kishore, C. F. Brewer, *Biochemistry* **1994**, *33*, 1149–1156.

[42] D. N. Moothoo, B. Canan, R. A. Field, J. A. Naismith, *Glycobiology* **1999**, *9*, 539–545.

[43] P. A. Risbood, T. S. Phillips, L. Goodman, *Carbohydr. Res.* **1981**, *94*, 101–107.

[44] V. Moreau, J. C. Norrild, H. Driguez, *Carbohydr. Res.* **1997**, *300*, 271–277.

[45] a) J. M. Heap, L. N. Owen, *J. Chem. Soc. C* **1970**, 707–712; b) D. H. Ball, M. H. Halford, L. Long Jr., *J. Org. Chem.* **1971**, *36*, 3714–3717.

[46] W. J. Peumans, W. Zhang, A. Barre, C. Houles-Astoul, P. J. Balint-Kurti, P. Rovira, P. Rougé, G. D. May, F. van Leuven, P. Truffa-Bachi, E. J. M. van Damme, *Planta* **2000**, *211*, 546–554.

[47] H. C. Winter, K. A. Wearne, I. J. Goldstein, in preparation.

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