Chemistry of 1-Alkoxy-1-glycosyl Radicals: Formation of β-Mannopyranosides by Radical Decarboxylation and Decarbonylation of *manno*-Heptulosonic Acid Glycoside Derivatives

David Crich,* Jae-Taeg Hwang, and Hongwei Yuan

Department of Chemistry, University of Illinois at Chicago, 845 West Taylor Street, Chicago, Illinois 60607-7061

Received May 1, 1996[⊗]

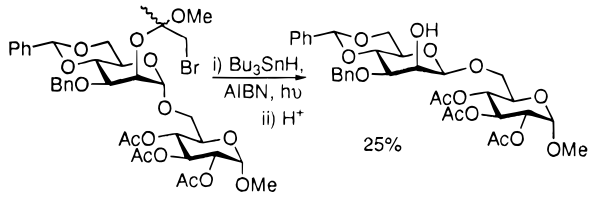
A method for the preparation of highly enriched β-mannopyranosides is described. A glycosyl donor **28** is prepared from tetraallyl mannonolactone by standard means and coupled to a number of primary carbohydrate alcohols, resulting in the isolation in excellent yields of axial disaccharides. Following exchange of the allyl groups for acetyl esters, the furan is oxidatively cleaved with catalytic RuO_2 and $NaIO_4$ and the resulting acid subjected to the Barton decarboxylation. Coupling of **28** to a secondary alcohol, methyl 2,3-isopropylidene-α-L-rhamnopyranoside, resulted in an apparent inversion of anomeric stereochemistry and isolation of an equatorial disaccharide.

Introduction

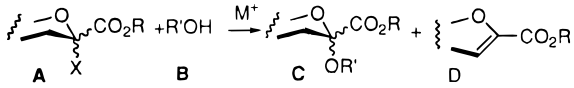
The problems inherent in the chemical synthesis of the β-mannopyranoside linkage continue to challenge and inspire the synthetic organic chemist.[1] In this laboratory we have investigated a method involving radical anomeric inversion of the more readily available α-mannosides (Scheme 1),[2] and a closely related protocol has been described by the Curran group.[3] Unfortunately, while it was possible to demonstrate highly stereoselective quenching[4] of the sp^3-hybridized,[5] anomeric radicals in the desired sense, the slow intramolecular hydrogen atom abstraction step requires the use of unacceptably low concentrations of stannane which in turn results in poor chain propagation and, above room temperature, in a competing fragmentation of the anomeric radical with cleavage of the mannose C5−O5 bond.

Thus, we were prompted to explore alternative means of generation of the 1-alkoxy-1-mannopyranosyl radical and ultimately had recourse to the decarboxylation[6] of ulosonic acid glycosides which had served us well in the preparation of 2-deoxy-β-glycosides from 3-deoxyulosonic acid glycosides.[7,8] This in turn raised the question of the efficient synthesis of ulosonic acid glycosides, a well appreciated problem in the field of ulosonic and sialic acids.[9] Herein, we describe the development of a method for the synthesis of mannoulosonic acid glycosides and

Scheme 1



Scheme 2



for their radical decarboxylation to highly stereochemically enriched β-mannopyranosides.

Results and Discussion

The formation of glycosidic linkages by coupling of aglycons (**B**) to suitably protected ulosonic or sialic acid glycosyl donors (**A**) is plagued by steric hindrance about the anomeric center and instability of the incipient oxacarbenium ion such that, in addition to the desired glycoside (**C**), elimination to the (alkoxycarbonyl)glycal (**D**) is a serious problem (Scheme 2). Indeed, this was the main problem in our earlier synthesis of the C,D-disaccharide of olivomycin A.[7j]

It was apparent therefore that the use of glycosyl donors such as **E**, with the added steric congestion and inductive destabilization of the incipient anomeric cation over and above that already present in the 3-deoxy series

[⊗] Abstract published in *Advance ACS Abstracts,* August 15, 1996.

(1) (a) For a compilation of references to recent advances in this area, see footnote 2b. (b) Stork, G.; La Clair, J. J. *J. Am. Chem. Soc.* **1996**, *118*, 247.

(2) (a) Crich, D.; Brunckova, J.; Yao, Q. *Tetrahedron Lett.* **1994**, *35*, 6619. (b) Crich, D.; Sun, S.; Brunckova, J. *J. Org. Chem.* **1996**, *61*, 605. (c) Dan, A.; Ito, Y.; Ogawa, T. *J. Org. Chem.* **1995**, *60*, 4680.

(3) Yamazaki, N.; Eichenberger, E. Curran, D. P. *Tetrahedron Lett.* **1994**, *35*, 6623.

(4) Axial quenching of 1-alkoxy-1-glycosyl radicals was initially predictable in so far as it is effectively the microscopic reverse of hydrogen atom abstraction from alkoxytetrahydropyrans by electrophilic radicals wherein the axial hydrogen is abstracted up to eight times as rapidly as the equatorial one: (a) Hayday, K.; McKelvey, R. D. *J. Org. Chem.* **1976**, *41*, 2222. (b) Beckwith, A. L. J.; Easton, C. J. *J. Am. Chem. Soc.* **1981**, *103*, 615. (c) Beckwith, A. L. J.; Brumby, S. *J. Chem. Soc., Perkin Trans. 2* **1987**, 1801.

(5) (a) Malatesta, V.; McKelvey, R. D.; Babcock, B. W.; Ingold, K. U. *J. Org. Chem.*, **1979**, *44*, 1872. (b) Malatesta, V. Ingold, K. U. *J. Am. Chem. Soc.* **1981**, *103*, 609. (c) Gregory, A. R.; Malatesta, V. *J. Org. Chem.* **1980**, *45*, 122.

(6) Barton, D. H. R.; Crich, D.; Motherwell, W. B. *Tetrahedron* **1985**, *41*, 3901.

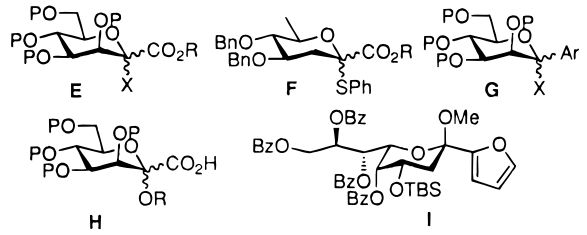
(7) (a) Crich, D.; Ritchie, T. J. *Tetrahedron* **1988**, *44*, 2319. (b) Crich, D.; Ritchie, T. J. *J. Chem. Soc., Chem. Commun.* **1988**, 986. (c) Crich, D.; Ritchie, T. J. *J. Chem. Soc., Chem. Commun.* **1988**, 1461. (d) Crich, D.; Ritchie, T. J. *Carbohydr. Res.* **1989**, *190*, c3. (e) Crich, D.; Ritchie, T. J. *J. Chem. Soc., Perkin Trans. 1* **1990**, 945. (f) Crich, D.; Lim, L. B. L. *Tetrahedron Lett.* **1990**, *31*, 1897. (g) Crich, D.; Lim, L. B. L. *Tetrahedron Lett.* **1991**, *32*, 2565. (h) Crich, D.; Lim, L. B. L. *J. Chem. Soc., Perkin Trans. 1* **1991**, 2205. (i) Crich, D.; Lim, L. B. L. *J. Chem. Soc., Perkin Trans. 1* **1991**, 2209. (j) Crich, D.; Hermann, F. *Tetrahedron Lett.* **1993**, *34*, 3385.

(8) Also see: (a) Kahne, D.; Yang, D.; Lim, J. J.; Miller, R.; Paguaga, E. *J. Am. Chem. Soc.* **1988**, *110*, 8716. (b) Sugai, T.; Shen, G.-J.; Ichikawa, Y.; Wong, C.-H. *J. Am. Chem. Soc.* **1993**, *115*, 413.

(9) (a) Okamoto, K.; Goto, T. *Tetrahedron* **1990**, *46*, 5835. (b) DeNinno, M. P. *Synthesis* **1991**, 583. (c) However, for recent advances, see: Martichonok, V.; Whitesides, G. M. *J. Org. Chem.* **1996**, *61*, 1702.

S0022-3263(96)00799-2 CCC: $12.00

(**F**), would not result in synthetically useful yields of glycoside. We reasoned that the problem might be best approached through use of a C-aryl, or heteroaryl, glycosyl donor (**G**) in which the electron rich aryl group would stabilize any anomeric cation and so promote glycosylation, and subsequently be readily cleaved oxidatively to the acid (**H**) required for the stereodefining radical decarboxylation step. The 2-furyl moiety was selected for use as the latent carboxylic acid on the grounds that (i) Danishefsky, as a corollary to his synthesis of *N*-acetylneuraminic acid, had demonstrated the ability of **I** to undergo *trans*-glycosylation reactions in good yield;[10] (ii) the Danishefsky group had subsequently cleanly oxidized the furan to the acid using the Sharpless protocol;[11] and (iii) Dondoni had described the clean high yield addition of 2-furyllithium to tetrabenzylglucopyranose, followed by ozonolytic cleavage,[12] pointing the way to a rapid entry into **G**. The use of a 2-thiazolyl group as latent carboxylic acid, as advanced by Dondoni,[13] was eschewed because of the complex two step cleavage it requires.



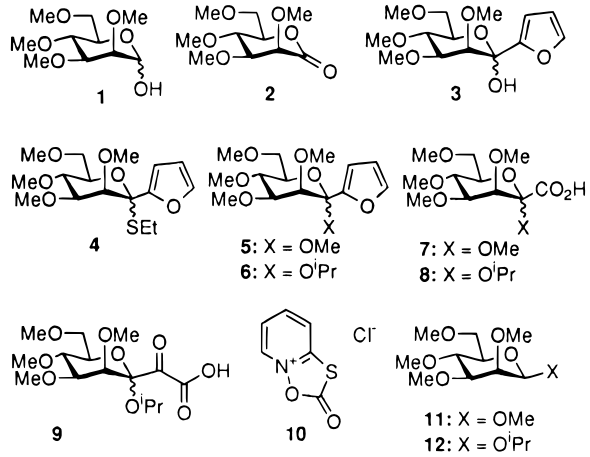
We began with a feasibility study in which 2,3,4,6-tetra-*O*-methylmannopyranose (**1**)[14] was conveniently converted to the known 1,5-mannonolactone (**2**)[15] by oxidation with catalytic tetrapropylammonium perruthenate (TPAP)[16] and *N*-methylmorpholine *N*-oxide (NMNO) as stoichiometric oxidant in 93% yield. The same conversion could also be affected by the Swern protocol[17] in excellent yield. Treatment of **2** with 2-furyllithium in THF at −78 °C followed, after workup, by ethanethiol and $BF_3{\cdot}OEt_2$ in CH_2Cl_2 from −78 to 0 °C provided the glycosyl donor **4** in 83% overall yield for the two steps. Purification of the intermediate **3** was not necessary for the success of this operation. Treatment of **4** in CH_2Cl_2 with MeOH and 2-propanol in the presence of pyridine as base and silver triflate as activator enabled the isolation of the glycosides **5** and **6**, respectively, both in quantitative yield (Table 1, entries 1 and 2).

Oxidation of **5** according to the Sharpless protocol provided the acid **7** in 77% yield. This was then subjected to the Barton reductive decarboxylation protocol[6] involving stirring with the heterocycle **10** and Et_3N in CH_2Cl_2,

Table 1. Glycosylation Reactions

entry	donor	acceptor equiv	promoter	solvent	base	glycoside (% yield)
1	**4**	MeOH (1.9)	AgOTf	CH_2Cl_2	py	**5** (100)
2	**4**	iPrOH (1.8)	AgOTf	CH_2Cl_2	py	**6** (100)
3	**15**	MeOH (1.1)	AgOTf	CH_2Cl_2	py	**16** (97)
4	**28**	MeOH (1.1)	AgOTf	CH_2Cl_2	py	**32** (94)
5	**28**	**29** (1.1)	AgOTf	CH_2Cl_2	py	**35** (89)
6	**28**	**30** (1.1)	AgOTF	THF	DBMP	**38** (86)
7	**28**	**31** (1.2)	AgOTf	CH_2Cl_2	py	**41** (10)
8	**28**	**31** (4)	AgOTf	CH_2Cl_2	py	**41** (65)
9	**28**	**31** (1.5)	AgOTf	THF	DBMP	**41** (75)

to form the derived *O*-acyl thiohydroxamate, followed by addition of t-BuSH and white light photolysis. In this manner the β-mannoside **11** was isolated in 75% yield. Examination of the crude reaction, with the aid of an authentic sample of the α-mannoside,[18] revealed the clean formation of the β-anomer (Table 2, entry 1). Oxidative cleavage of the more hindered glycoside **6** proved to be somewhat less efficient than that of **5** such that, even after 2 days at room temperature, **8** was isolated in admixture (2:1) with a further compound of closely similar polarity presumed to be the α-keto acid **9**. This assignment was made on the grounds of mass spectrometry of the mixture which, in addition to a peak at $m/z = 321$ representing $[M - H]^{+\bullet}$ for **8**, revealed a further peak at $m/z = 349$ corresponding to $[\mathbf{8} + CO - H]^+$, or $[\mathbf{9} - H]^+$. ^{13}C-NMR spectroscopy of the mixture, with three carbonyl carbons at 169.3, 163.0, and 194.2 representing the two carboxyl carbons of **8** and **9** and the carbonyl of the latter, respectively, also supported this assignment.[19] This recalcitrant mixture was subjected to the decarboxylation procedure, resulting in the isolation of **12** in 48% yield (Table 2, entry 2).



With the fundamental method established, attention was turned to the use of a more apposite protecting group than the methyl ether. The ideal blocking group for the 2,3,4,6-hydroxy groups of the mannopyranose framework would meet several criteria aside from the usual considerations of clean introduction and removal. Thus, it should be compatible with the use of furyllithium and with the use of oxidizing conditions for the cleavage of

(10) (a) Danishefsky, S. J.; Pearson, W. H.; Segmuller, B. E. *J. Am. Chem. Soc.* **1985**, *107*, 1280. (b) DeNinno, M. P.; Danishefsky, S. J.; Schulte, G. *J. Am. Chem. Soc.* **1988**, *110*, 3925. (c) Danishefsky, S. J.; DeNinno, M. P.; Chen, S.-H. *J. Am. Chem. Soc.* **1988**, *110*, 3929.

(11) Carlsen, P. H. J.; Katsuki, T.; Martin, V. S.; Sharpless, K. B. *J. Org. Chem.* **1981**, *46*, 3986.

(12) Dondoni, A.; Marra, A.; Scherrmann, M.-C. *Tetrahedron Lett.* **1993**, *34*, 7323.

(13) Dondoni, A.; Marra, A.; Merino, P. *J. Am. Chem. Soc.* **1994**, *116*, 3324.

(14) Drew, H. D. K.; Goodyear, E. H.; Haworth, W. N. *J. Chem. Soc.* **1927**, 1237

(15) Haworth, W. N.; Hirst, E. L.; Smith, J. A. B. *J. Chem. Soc.* **1930**, 2659

(16) Ley, S. V.; Norman, J.; Griffith, W. P.; Marsden, S. P. *Synthesis* **1994**, 639.

(17) Mancuso, A. J.; Huang, S.-L.; Swern, D. *J. Org. Chem.* **1978**, *43*, 2480.

(18) $[\alpha]^{23}_D$ +47.4° (*c* 1); ^{1}H-NMR δ 3.35 (s, 3H), 3.39 (s, 3H), 3.45 (s, 3H), 3.42−3.45 (m, 4H), 3.50 (s, 3H), 3.51−3.55 (m, 2H), 3.57 (m, 3H), 4.78 (d, J = 1.7 Hz, 1H); ^{13}C NMR δ 54.8, 57.5, 58.8, 59.1, 60.5, 71.0, 71.6, 76.3, 76.9, 81.0, 97.8. Bott, H. G.; Haworth, W. N.; Hirst, E. L. *J. Chem. Soc.* **1930**, 2653 ($[\alpha]^{20}_D$ +57°, $CHCl_3$).

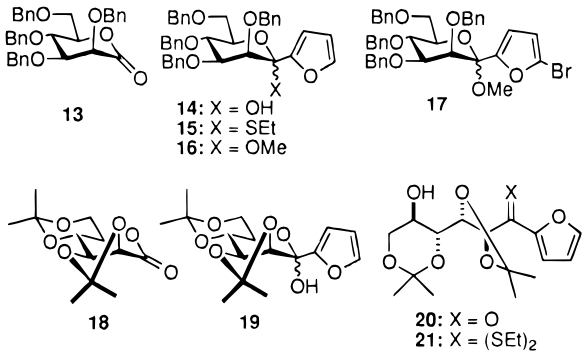
(19) For previous examples of the oxidation of substituted furans to 1,2-dicarbonyl compounds, see: (a) White, H. M.; Colomb, H. O.; Bailey, P. S. *J. Org. Chem.* **1965**, *30*, 481. (b) Bailey, P. S.; White, H. M.; Colomb, H. O. *J. Org. Chem.* **1965**, *30*, 487.

Table 2. Furan Cleavage and Decarboxylation

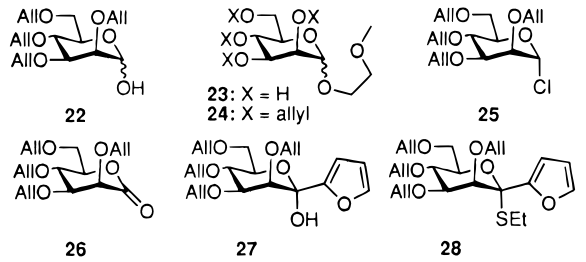
entry	furan	acid (% yield)	method[a]	mannoside (% yield)	β:α
1	**5**	**7** (74)	A	**11** (75)	>25:1
2	**6**	**8** + **9** (2:1, 90)	A	**12** (48)	>25:1
3	**33**	**34** (~100)	A	**46** (80)	>10:1
4	**36**	**37** (~100)	A	**47** (35)	>25:1
5	**36**	**37** (~100)	B	**47** (56)	>25:1
6	**39**	**40** (~100)	B	**48** (67)	>25:1
7	**42**	**43** + **44** (4:1, 100)	B	**49** (0)	
8	**6**	**8** + **9** (2:1, 90)	C	**12** (68)	>25:1

[a] A = Barton decarboxylation with **10**; B = Barton decarboxylation with **45**; C = decarbonylation of thiol ester.

the furan ring. On the basis of the premise that the furan ring could be oxidatively degraded selectively in the presence of benzyl ethers, we initially investigated this common carbohydrate protecting group. Tetra-*O*-benzylmannonolactone (**13**) smoothly furnished the adduct **14** as a mixture of anomers essentially quantitatively, and this was converted immediately to the anomerically pure glycosyl donor **15** in 94% yield by treatment with ethanethiol and $BF_3{\cdot}OEt_2$. The coupling of **15** with 1.1 equiv of MeOH in CH_2Cl_2 was instantaneous with silver triflate as activator and pyridine as acid scavenger, enabling the isolation of the glycoside **16** in 97% yield as a single anomer. Attempted oxidation of **16** with catalytic RuO_2 and sodium, potassium, or tetrabutylammonium periodate in biphasic mixtures of acetontrile, CCl_4, and water over a range a pH values unfortunately all resulted in failure owing to the competing oxidation of the the benzyl ethers and the liberation of benzoic acid. Various other approaches to the degradation of the furan ring were also unsatisfactory. Oxidation with mCPBA[20] resulted in cleavage of the glycosidic bond, and treatment with bromine in water[21] led to the isolation of **17**, suggesting that attack on the intermediate arenium ion was sterically hindered. Carefully controlled ozonolysis experiments suggested that the furan C4′−C5′ was readily and rapidly attacked, but that of the more hindered C2′−C3′ bond could not compete with oxidation of the benzyl ether functions. Singlet oxygenation[22] of **16** also resulted in failure with the recovery of substrate, presumably for steric reasons. This series of experiments, apart from ruling out the use of benzyl ethers, served to reveal the somewhat sterically hindered nature of the furan 2′−3′ bond in this type of system. The obvious use of acetonide protecting groups was thwarted when reaction of furyllithium with 2,3:4,6-diisopropylidene-1,5-mannonolactone[23] (**18**) resulted in the isolation of the furyl ketone **20** rather than of the anticipated pyranose form (**19**), as signaled by the presence of signals δ 185.5 and 1655 cm^{-1}, in the ^{13}C-NMR and IR spectra, respectively, indicative of a furyl ketone and of the clear presence of an hydroxy group (IR). Treatment of **20** with ethanethiol and $BF_3{\cdot}OEt_2$ or $ZnCl_2$ did not lead to the ethyl thioglycoside analogous to **4** or **15** but rather the dithioacetal **21**. Evidently, the pyranose **19** is strained and rapidly opens to **20**, which then resists closure.[24]



In light of the above, we were constrained to adopt a strategy in which an initial set of 2,3,4,6-blocking groups were exchanged for acetates prior to oxidative cleavage of the furan ring. The allyl ether hydroxy protecting group was selected for this purpose.[25] On a large scale, tetra-*O*-allylmannopyranose **22** was best prepared by Fischer glycosylation of *d*-mannose with methoxyethanol to give the glycoside **23**, followed by perallylation with NaH and allyl bromide in DMF to give **24** in essentially quantitative yield for the two steps. Treatment of **24** with $TiCl_4$ in dichloromethane gave 97% of the chloride **25**, which could then be readily hydrolyzed to **22**. Subsequent Swern oxidation (92%) gave lactone **26**, allowing for an overall yield of 85% from *d*-mannose. Attempted direct oxidation of **25** to **26** by the Kornblum protocol[26] (DMSO, $AgBF_4$) was unsuccessful. In passing we note the very clean conversion of **24** to the glycosyl chloride **25** with $TiCl_4$ and suggest that methoxyethyl glycosides might generally function as a substantially more economical variant of the 2-(trimethylsilyl)ethyl glycosides.[27] Treatment of **26** with furyllithium cleanly gave **27**, devoid of any open chain tautomer, and subsequent reaction with ethanethiol and $BF_3{\cdot}OEt_2$ gave the glycosyl donor **28** as a single anomer, and in 92% yield for the two steps.



Glycosidation of **28** with 1.1 equiv of MeOH in CH_2Cl_2 in the presence of pyridine and silver triflate gave 94% of the glycoside **32** (Table 1, entry 4). Reaction of **28** with

(20) (a) Williams, P. D.; LeGoff, E. *J. Org. Chem.* **1981**, *46*, 4143.

(21) (a) Jurczak, J.; Pikul, S. *Tetrahedron Lett.* **1985**, *26*, 3039. (b) Fitzpatrick, J. E.; Milner, D. J.; White, P. *Synth. Commun.* **1982**, *12*, 489.

(22) (a) Tsai, T. Y. R.; Wiesner, K. *Can. J. Chem.* **1982**, *60*, 2161. (b) Atwal, K. S.; Sahoo, S. P.; Tsai, T. Y. R.; Wiesner, K. *Heterocycles* **1982**, *19*, 641. (c) Reveiw: Feringa, B. L. *Rec. Trav. Chim. Pays-Bas* **1987**, *106*, 469.

(23) Bandzouzi, A.; Lakhrissi, M.; Chapleur, Y. *J. Chem. Soc., Perkin Trans. 1* **1992**, 147.

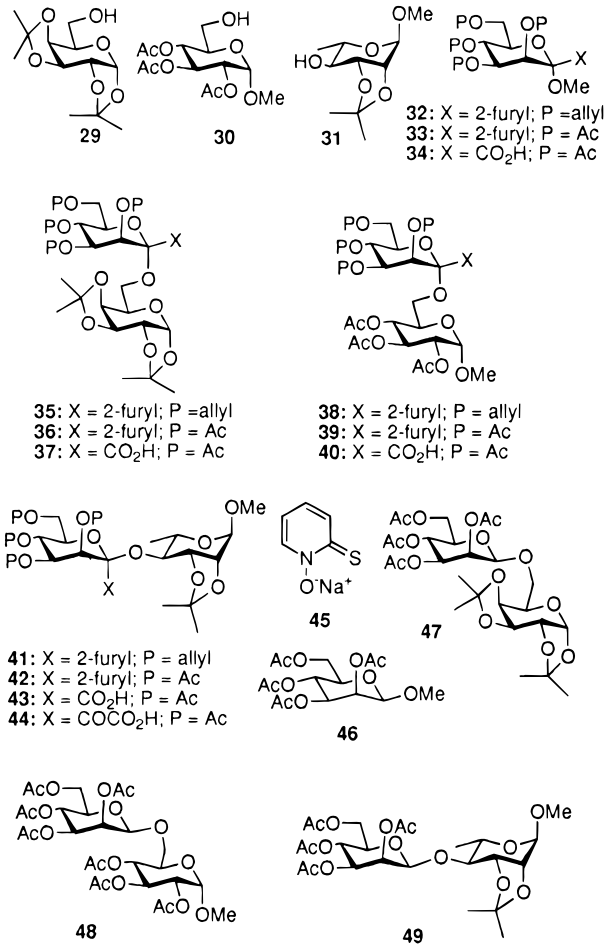
(24) Interestingly, this strain is mainly due to the 4,6-, rather than the 2,3-acetonide, as subsequent experiments with 4,6-*O*-isopropylidene-2,3-di-*O*-[[2-(trimethylsilyl)ethoxy]methyl]mannonolactone gave exactly analogous results.

(25) Reviews: (a) Greene, T. W.; Wuts, P. G. M. *Protective Groups in Organic Synthesis*; 2nd ed.; Wiley, New York, 1991. (b) Kocienski, P. J. *Protecting Groups*; Georg Thieme Verlag: Stuttgart, 1994.

(26) Ganem, B.; Boeckman, R. K. *Tetrahedron Lett.* **1974**, 917.

(27) (a) Lipshutz, B. H.; Pegram, J. J.; Morey, M. C. *Tetrahedron Lett.* **1981**, *22*, 4603. (b) Jansson, K.; Ahlfors, S.; Frejd, T.; Kihlberg, J.; Magnusson, G. *J. Org. Chem.* **1988**, *53*, 5629. (c) Jannson, K.; Magnusson, G. *Tetrahedron* **1990**, *46*, 59. (d) Pozsgay, V. *Tetrahedron Lett.* **1993**, *34*, 7175.

1.1 equiv of 1,2:3,4-di-*O*-isopropylidenegalactose (**29**)[28] in CH_2Cl_2 in the presence of silver triflate and pyridine as acid scavenger resulted in the isolation of the glycoside **35** in 89% yield (Table 1, entry 5). A comparable protocol with methyl 2,3,4-tri-*O*-acetylglucopyranose (**30**)[29] using 2,6-di-*tert*-butyl-4-methylpyridine (DBMP) as base in THF as solvent gave 86% of **38** (Table 1, entry 6). With 1.2 equiv of the more hindered rhamnose-derived secondary alcohol **31**[30] using pyridine as base in CH_2Cl_2, a disappointing yield of only 10% of glycoside **41** was obtained (Table 1, entry 7). This yield could be substantially improved by use of 4 equiv of **31** (Table 1, entry 8), but a more satisfactory protocol involved switching to the more polar solvent THF and use of non-nucleophilic DBMP as the acid scavenger; a 75% yield of **41** could be obtained with only a 50% excess of **31** (Table 1, entry 9).



With the exception of **4**, both thioglycosides (**15**, and **28**) and each of the glycosides (**7**, **8**, **16**, **32**, **35**, **38**, and **41**) were obtained as anomerically pure compounds, and with the single exception of **41**, each is assigned the axial configuration shown. This assignment is based on the assumption that each is formed by preferential axial attack of the alcohol or thiol on a delocalized, cation-like precursor. Numerous attempts at the observation of nuclear Overhauser effects between H-3/5 of the mannosyl fragment and the coupled alcohol were either unsuccessful or ambiguous due to insufficient spectral resolution. However, it was clear from the close similarities in the ^{1}H-NMR spectra and molecular rotations that, with the exception of **41**, all compounds had both the same conformation of the mannose ring and anomeric configuration. A subsequent NOE (*vide infra*) served to confirm this assignment. The spectroscopic characteristics (^{1}H-, ^{13}C-NMR) of **41** indicate that it is clearly different from the other glycosides in terms of either anomeric configuration or conformation of the mannopyranosyl ring or both. Subsequent studies soon revealed its chemistry to be equally different.

Efficient replacement of the allyl protecting groups by acetate esters in the presence of the acid labile glycosidic linkages was the next problem to be addressed. For the methyl glycoside **32** this was achieved by isomerization to the enol ethers either with Wilkinson's catalyst [$(Ph_3P)_3RhCl$] in refluxing 90% aqueous ethanol[31,32] or, preferably, with an iridium(I) [$(Ph_2MeP)_2(COD)Ir^+PF_6^-$] complex developed by Felkin[33] which affected the conversion in THF at room temperature. Without purification, the enol ethers were cleaved with catalytic OsO_4 and NMNO,[34] and the resulting tetraol was acetylated in the usual manner to give **33**. With Wilkinson's catalyst the conversion was achieved in 72% overall yield, as opposed to 77% with the iridium catalyst. We note that, although this protecting group exchange is necessarily a three-step process, it was achieved cleanly and in high yield without isolation and purification of any of the various intermediates.[35] Double irradiation of the methyl protons in **33** resulted in a strong enhancement of the now well-resolved resonance attributed to H-5, confirming its assignment and, by extrapolation, those of **4**, **7**, **8**, **15**, **16**, **28**, **32**, **35**, and **38** as α-glycosides. Application of the same three-step protecting group exchange to **35** provided **36** in 65 and 75% overall yields with Wilkinson's and the iridium catalyst, respectively. Likewise, the allyl groups of **38** were converted to the esters of **39** in 71% overall yield using the Felkin complex as isomerizing catalyst. Application of the same protocol to **41** was problematic. We suspected that a minor, comigrating, sulfur-based impurity carried over from the glycosylation was at the root of this problem, and indeed, when a highly purified sample was obtained by repeated preparative TLC, the isomerization was fast and clean. However, on a preparative scale, the isomerization could be readily achieved with t-BuO^-K^+ in DMSO.[36] Subsequent treatment with OsO_4/NMNO followed by acetylation provided **42** in 65% overall yield. Inspection of the coupling constants around the mannosyl ring of **42** revealed it to be a $^4C_1$ chair, as were **33**, **36**, and **39**, but the slightly downfield shift of the H-2 and H-4 signals with respect to those in **33**, **36**, and **39** and the comparatively upfield shift of the H-3 resonance suggested that it differs in anomeric configuration. In addition, NOESY spectroscopy revealed cross

(28) Raymon, D. A. L.; Schroeder, E. F. *J. Am. Chem. Soc.* **1948**, *70*, 2785.

(29) Whistler, R. L.; Doner, L. W.; Kosik, M. *Methods in Carbohydrate Chemistry*; Whistler, R. L., BeMiller, J. N., Eds.; Academic Press: New York, 1972; Vol. 6, p 411.

(30) (a) Levene, P. A.; Muskat, I. E. *J. Biol. Chem.* **1934**, *105*, 431. (b) Bebault, G. M.; Dutton, G. G. S. *Can. J. Chem.* **1972**, *50*, 3373.

(31) (a) Corey, E. J.; Suggs, J. W. *J. Org. Chem.* **1973**, *38*, 3224. (b) Gent, P. A.; Gigg, R. *J. Chem. Soc., Chem. Commun.* **1974**, 277.

(32) For recent improvements with a $(Ph_3P)_3RhCl$/BuLi couple, see: Boons, G.-J.; Burton, A.; Isles, S. *J. Chem. Soc., Chem. Commun.* **1996**, 141.

(33) (a) Baudry, D.; Ephritikhine, M.; Felkin, H. *J. Chem. Soc., Chem. Commun.* **1978**, 694. (b) Oltvoort, J. J.; van Boeckel, C. A. A.; de Konig, J. H.; van Boom, J. H. *Synthesis* **1981**, 305.

(34) For an earlier example of this process see: Lamberth, C.; Bednarski, M. D. *Tetrahedron Lett.* **1991**, *32*, 7369.

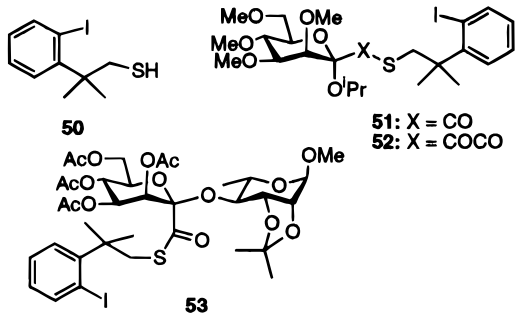
(35) Attempted application of this exchange process to the glycosyl donor **28** failed, probably due to poisoning of the catalysts by the thiol ether moiety: Yin, H.; Franck. R. W.; Cheng, S.-L.; Quigley, G. J.; Todaro, L. *J. Org. Chem.* **1992**, *57*, 644.

(36) Gigg, R.; Warren, C. D. *J. Chem. Soc., C* **1968**, 1903.

peaks between H-3 of the mannose ring and H-3 and H-5 of the furan moiety. Glycoside **42** and its immediate precursor **41** are therefore β-glycosides. This reversal of glycosylation stereochemistry with the more bulky secondary alcohol **31** can presumably be rationalized by preferential attack along the less hindered equatorial direction in the coupling with the cation derived from **28**.

Oxidative cleavage of **33**, **36**, and **39** was routinely achieved with KIO_4 and catalytic RuO_2 in a two-phase system of water, acetonitrile, and CCl_4 buffered with K_2CO_3 and gave the corresponding acids **34**, **37**, and **40**, respectively, in essentially quantitative yield (Table 2, entries 3−6). No advantage was gained by purification of these polar compounds and as such they were used in the subsequent step after a simple extractive workup. Stirring **34** with **10** and Et_3N in CH_2Cl_2 at room temperature followed by addition of t-BuSH and white light photolysis resulted in a very clean reaction mixture comprised of the β-mannoside **46** and its α-anomer in a ratio of at least 10:1. No significant improvement in ratio was achieved by conducting the photolysis at 0 °C. Brief purification by filtration on silica gel yielded 80% of anomerically pure **46** (Table 2, entry 3), whose physical characteristics (mp, $[\alpha]_D$) were in excellent accord with the literature values.[37] Application of the same decarboxylation protocol to acid **37** gave a disappointing yield of only 35% of the β-mannoside **47** (Table 2, entry 4). There was however no evidence for formation of the corresponding α-anomer in the crude ^{1}H-NMR spectrum, and therefore, we reasoned that the low yield was a function of increased steric hindrance about the carboxylic acid. We therefore converted **37** to the corresponding acyl chloride and allowed it to react at room temperature with sodium omadine (**45**) before addition of t-BuSH and exposure to the ambient laboratory light. In this manner we obtained an improved 56% yield of the β-mannoside **47** (Table 2, entry 5). Again it was noteworthy that no evidence for formation of the α-mannoside was found on inspection of the crude photolyzate. Application of the same protocol to **40** furnished the β-mannoside **48**, free of α-anomer, in 67% yield (Table 2, entry 6).

Oxidation of the furan **42**, similar to that of **6** (Table 2, entry 2), was slow, and although complete consumption of the substrate could be achieved, a pure sample of the desired acid **43** could not be obtained (Table 2, entry 7). As in the oxidation of **6**, **43** was always contaminated by a closely related product assigned the structure **44** on the basis of an additional resonance in the ^{13}C-NMR spectrum at δ 192.4 ppm. Unfortunately, attempted decarboxylation of this mixture, via the derived acyl chlorides, proved fruitless (Table 2, entry 7), with no evidence in the crude ^{1}H-NMR for the formation of the β-mannoside **49** or, indeed, of its α-anomer. It was unclear, on the small scale employed, whether it was the formation of the acid chloride, the formation of the *O*-acyl thiohydroxamate, or the radical decarboxylation step that lay at the root of the problem. We therefore resolved to employ an alternative method for generation of the anomeric radical which would allow, unlike the Barton protocol, isolation of the intermediate derivative. To this end thiol **50**[38] was condensed with the acyl chlorides derived from the mixture of **8** and **9**, resulting in an inseparable mixture of the two thiol esters **51** and **52** in 70% overall yield. This mixture of thiol esters was then heated to reflux in benzene and treated with Bu_3SnH and AIBN as initiator resulting, by a process involving aryl radical generation, cyclization and expulsion of the acyl radical, decarbonylation, and axial quenching, in the isolation of the β-mannoside **12** in 68% yield (Table 2, entry 8). Furan **42** was oxidized with catalytic RuO_2 and $NaIO_4$ in acetonitrile/CCl_4/water for 24 h at reflux when the acid **43** was isolated free of **44** but only in 79% yield. Clearly, the more forcing conditions enabled complete conversion of the furan to the acid but resulted in parallel degradation of the carbohydrate. Nevertheless, **43** was converted to the corresponding acyl chloride and then, with **50**, to the thiol ester **53**, which was isolated in 27% overall yield from **42**. Treatment of **53** with Bu_3SnH and AIBN in benzene at reflux, or alternatively with UV photolysis at room temperature, resulted in a complex reaction mixture containing at least four closely migrating disaccharides, none of which could be positively identified as **49**.



In conclusion, a method has been developed for the preparation of mannosides with excellent β:α ratios in which the anomeric configuration is determined by a diastereoselective radical reaction. The method functions well for primary but is not satisfactory for secondary glycosyl acceptors, when complications arise in the coupling and radical steps.

Experimental Section

General. For general experimental detail, see footnote 2b.

2,3,4,6-Tetra-*O*-methyl-D-mannono-1,5-lactone (2). TPAP (0.3 g, 5 mol %) was added to a solution of tetra-*O*-methylmannose[14] (3.87 g, 16.4 mmol), NMNO (2.98 g, 24.7 mmol), and activated molecular sieves in CH_2Cl_2 (30 mL) at 0 °C and then warmed up to room temperature. After stirring overnight, the reaction mixture was filtered through a short silica gel pad with ethyl acetate and concentrated under reduced pressure to give a colorless syrup which was purified by silica gel column chromatography (3:1 ether:hexanes) to give the lactone **2**[15] (3.73 g, 97%): ^{1}H NMR δ 3.40 (3H, s), 3.46 (3H, s), 3.49−3.53 (4H, m), 3.58 (3H, s), 3.70 (2H, m), 3.82 (1H, m), 4.06 (1H, d, J =2.74 Hz), 4.15 (1H, m); ^{13}C NMR δ 57.5, 58.6, 59.1, 59.4, 71.7, 77.0, 77.5, 78.1, 78.8, 168.8; IR ν (melt) 1775 cm^{-1}.

***S*-Ethyl 1-Deoxy-1-(2-furyl)-2,3,4,6-tetra-*O*-methyl-1-thio-α-D-mannopyranoside (4).** A solution of furan (1.1 mL, 15.0 mmol) in THF (10 mL) was treated with n-BuLi (4.5 mL, 2.0 M in pentane, 9.0 mmol) at −78 °C and the reaction mixture allowed to warm up to room temperature. After stirring for 2 h, the 2-lithiofuran solution was transferred by a cannula to a solution of the lactone (1.76 g, 7.5 mmol) in THF (25 mL) at −78 °C. The reaction mixture was stirred at this temperature for 2 h, warmed up to room temperature, and quenched with 10% NH_4Cl solution. The aqueous layer was extracted with ether (3 × 20 mL). The combined organic phase was washed with saturated sodium bicarbonate solution

(37) (a) Dale, J. K.; *J. Am. Chem. Soc.* **1924**, *46*, 1046. (b) Bonner, W. A. *J. Am. Chem. Soc.* **1958**, *80*, 3372.

(38) Crich, D.; Yao, Q. *J. Org. Chem.* **1996**, *61*, 3566.

and brine, dried (Na_2SO_4), and then concentrated under reduced pressure to give the hemiketal as an brown oil. Ethanethiol (2.3 mL, 31 mmoL) was added to a solution of hemiketal in CH_2Cl_2 (25 mL). The reaction mixture was cooled to −78 °C and $BF_3{\cdot}OEt_2$ (1.10 mL, 8.9 mmol) was added dropwise to the reaction mixture followed by warming up to 0 °C. After 20 min, the reaction was quenched with saturated sodium bicarbonate solution. The aqueous phase was extracted with CH_2Cl_2 (2 × 20 mL), and the combined organic layer was washed with brine, dried (Na_2SO_4), and concentrated to give a brown oil as a 6.5:1 mixture of isomers. Purification by column chromatography (silica gel, 2:1 hexanes:ether) gave **4** (2.164 g, 83%) and an unidentified isomer (0.21 g). **4**: $[\alpha]^{23}_D$ +22.5° (*c* 1.0); ^{1}H NMR δ 0.98 (3H, t, J = 7.5 Hz), 2.09−2.28 (2H, m), 3.13 (3H, s), 3.39 (3H, s), 3.41−3.50 (7H, m), 3.60 (1H, dd, J = 11.0, 2.0 Hz), 3.70 (1H, dd, J = 11.1, 5.6 Hz), 3.78 (1H, dd, J = 9.5, 3.0 Hz), 3.96 (1H, d, J = 3.1 Hz), 4.10 (1H, ddd, J = 10.0, 5.6, 2.0 Hz), 6.33 (1H, dd, J = 3.3, 1.8 Hz), 6.45 (1H, dd, J = 3.2, 1.0), 7.36 (1H, m); ^{13}C NMR δ 14.2, 22.3, 57.8, 59.2, 60.5, 61.0, 71.7, 73.0, 76.4, 80.1, 82.7, 89.2, 108.8, 110.5, 141.0, 151.9. Anal. Calcd for $C_{16}H_{26}O_6S$: C, 55.47; H, 7.56. Found: C, 55.20; H, 7.51. Isomer:[39] $[\alpha]^{23}_D$ +77.4° (*c* 1.0); ^{1}H NMR δ 1.1(3H, t, J = 3.8 Hz), 2.33 (2H, q, J = 7.3Hz), 3.16−3.23 (4H, m), 3.3 (1H, d, J = 9.4 Hz), 3.38 (3H, s), 3.35−3.70 (10H, m), 6.31 (1H, m), 6.52 (1H, dd, J = 3.2, 0.6 Hz), 7.4 (1H, d, J = 0.7 Hz); ^{13}C-NMR δ 13.6, 21.2, 59.3, 60.3, 60.8, 60.9, 71.3, 72.4, 79.5, 85.0, 86.7, 88.6, 109.4, 110.2, 142.5, 153.6.

Methyl 1-(2-Furyl)-2,3,4,6-tetra-*O*-methyl-α-D-mannopyranoside (5). To a stirred mixture of **4** (1.01 g, 2.92 mmol), MeOH (0.22 mL, 5.43 mmol), pyridine (0.36 mL, 4.38 mmol), and activated molecular sieves (500 mg) in CH_2Cl_2 (10 mL) was added silver triflate (0.91 g, 3.50 mmol), and the reaction mixture was stirred for 2 h at room temperature in the dark. The mixture was then filtered through a short pad of silica gel (1:1 hexanes:ethyl acetate with 1% Et_3N). The solvent was evaporated to give **5** in quantative yield: $[\alpha]^{23}_D$ +24.1° (*c* 1.0); ^{1}H NMR δ 3.01 (3H, s), 3.08 (3H, s), 3.39−4.52 (4H, m), 3.52 (3H, s), 3.53 (3H, s), 3.58 (1H, m), 3.67 (2H, m), 3.72 (1H, dd, J = 9.4, 3.2 Hz), 3.84 (1H, d, J = 3.2 Hz), 6.37(1H, dd, J= 3.3, 1.8Hz), 6.56 (1H, dd, J= 3.3, 0.6Hz), 7.40 (1H, m); ^{13}C NMR δ 49.1, 57.8, 59.3, 60.6, 60.8, 71.8, 72.6, 76.1, 78.9, 82.2, 89.2, 110.4, 110.5, 141.9, 150.3. Anal. Calcd for $C_{15}H_{24}O_7$: C, 56.95; H, 7.65. Found: C, 56.85; H, 7.62.

Isopropyl 1-(2-Furyl)-2,3,4,6-tetra-*O*-methyl-α-D-mannopyranoside (6). Reaction of **4** (0.95 g, 2.74 mmol), isopropyl alcohol (0.38 mL, 4.93 mmol), pyridine (0.34 mL, 4.11 mmol), silver triflate (0.854 g, 3.29 mmol), and activated molecular sieves in CH_2Cl_2 essentially as described for **5** gave **6** quantatively in the form of a colorless syrup: $[\alpha]^{23}_D$ +26.1° (*c* 1.0); ^{1}H NMR δ 0.72 (3H, d, J = 6.1 Hz), 1.15 (3H, d, J = 6.2 Hz), 3.14 (3H, s), 3.40−3.50 (4H, m), 3.54 (3H, s), 3.55 (3H, s), 3.67 (2H, m), 3.72−3.82 (3H, m), 3.90 (1H, d, J = 3.0 Hz), 6.37 (1H, dd, J = 3.3, 1.8 Hz), 6.56 (1H, dd, J = 3.3, 0.7 Hz), 7.38 (1H, m); ^{13}C NMR δ 22.7, 23.6, 57.8, 59.3, 60.7, 60.8, 65.6, 72.0, 72.8, 76.4, 79.1, 82.2, 99.0, 109.8, 110.8, 141.1, 151.7. Anal. Calcd for $C_{17}H_{28}O_7$: C, 59.29; H, 8.19. Found: C, 59.32; H, 8.24.

Methyl 2,3,4,6-Tetra-*O*-methyl-β-D-mannopyranoside (11). RuO_2 (4 mg, 5 mol %) was added to a biphasic solution of $NaIO_4$ (1.74 g, 8.01 mmol) in CCl_4 (10 mL), acetonitrile (5 mL), and water (15 mL), and after the mixture was stirred for 20 min, **5** (0.173 g, 0.55 mmol) in acetonitrile (5 mL) was added to the reaction mixture. The resulting yellow-green mixture was stirred strongly for 2 days at room temperature and then diluted with ethyl acetate. The aqueous phase was extracted with ethyl acetate (5 × 20 mL), and the combined organic phases were filtered through a pad of Celite, activated carbon, and sodium sulfate. The filtrate was concentrated to give the ulosonic acid **7** (124mg, 77%) as a pale blackish syrup: ^{1}H NMR δ 3.25 (3H, s), 3.42 (3H, s), 3.46−3.50 (4H, m), 3.51 (3H, s), 3.52−3.55 (5H, m), 3.66 (2H, m), 3.85 (1H, d, J = 2.6 Hz), 7.60 (1H, br); ^{13}C NMR δ 50.9, 58.0, 59.0, 60.6, 61.2, 71.1, 72.9, 75.5, 77.8, 82.2, 100.3, 168.7; IR ν (melt) 1783, 3443 (br) cm^{-1}. This crude acid (110 mg, 0.38 mmol) was dissolved in dry CH_2Cl_2 (10 mL) followed by the addition of Et_3N (78 mL, 0.56 mmol), and the reaction mixture treated with **10** (93 mg, 0.56 mmol) in the dark for 4 h. t-BuSH (0.4 mL, 3.74 mmol) was added and the reaction mixture photolyzed with a white tungsten light at 8 °C for 1 h. The reaction mixture was diluted with CH_2Cl_2 (20 mL) and washed with 10% aqueous ammonium chloride and saturated aqueous sodium bicarbonate. The organic phase was dried (Na_2SO_4) and concentrated. The methyl β-mannoside **11** (70 mg, 75%) was isolated by column chromatography (silica gel, 2:1 hexanes:ether): $[\alpha]^{23}_D$ −65.8° (*c* 1.0) (lit.[40] $[\alpha]^{20}_D$ −87° , $CHCl_3$); ^{1}H NMR δ 3.15 (1H, dd, J = 8.7, 3.1 Hz), 3.22−3.32 (2H, m), 3.37 (3H, s), 3.46 (3H, s), 3.49 (6H, s), 3.53−3.59 (4H, m), 3.63−3.68 (2H, m), 4.26 (1H, s); ^{13}C NMR 57.0, 57.3, 59.2, 60.6, 61.5, 71.8, 75.5, 76.6, 76.6, 83.9, 102.2.

Isopropyl 2,3,4,6-Tetra-*O*-methyl-β-D-mannopyranoside (12). Furan **6** (0.389 g, 1.13 mmol) was oxidized by catalytic amount of RuO_2 and $NaIO_4$ (3.56 g, 16.6 mmol) in CCl_4 (14 mL), acetonitrile (14mL), and water (21 mL) for 2 days as described for the formation of **11** above to give a mixture of the ulosonic acid **8** and the pyruvic acid **9** essentially quantatively: ^{1}H NMR (**8** and **9**, indistinguishable) δ 1.13 (6H, m), 3.38 (3H, s), 3.43 (4H, s), 3.48 (3H, s), 3.49 (4H, m), 3.55−3.70 (3H, m), 3.80−3.90 (2H, m), 7.70 (1H, br). **8**: ^{13}C NMR δ 23.0, 23.6, 57.9, 59.0, 60.7, 61.2, 69.4, 71.2, 73.0, 75.6, 78.3, 82.1, 100.6, 169.3; HRMS $(M - H)^{+\bullet}$ 321.1549, found 321.1547. **9**: ^{13}C NMR δ 23.3, 23.6, 58.2, 59.4, 60.8, 61.1, 69.4, 70.6, 73.9, 75.3, 79.5, 82.2, 101.8, 163.0, 194.2; HRMS $(M - H)^{+\bullet}$ 349.1498, found 349.1490. As described for **11**, this mixture was subjected to decarboxylation with **10** and t-BuSH with white light photolysis at 8 °C for 1hr to give **12** (50%, 43 mg) following isolation by column chromatography (silica gel, 2:1 hexanes:ether): $[\alpha]^{23}_D$ −103° (*c* 1.0); ^{1}H NMR δ1.12 (3H, d, J = 6.0 Hz), 1.22 (3H, d, J = 6.2 Hz), 3.15 (1H, dd, J = 8.4, 3.1 Hz), 3.20−3.31 (2H, m), 3.36 (3H, s), 3.46 (3H, s), 3.48 (3H, s), 3.5−3.7 (6H, m), 3.98 (1H, sept.J = 5.8 Hz), 4.43 (1H, s); ^{13}-CNMR δ 21.4, 23.4, 57.2, 59.2, 60.6, 61.6, 70.8, 72.0, 75.5, 76.5, 77.4, 84.0, 99.1. Anal. Calcd for $C_{13}H_{26}O_{6:}$ C, 56.10; H, 9.41. Found: C, 56.24; H, 9.20.

***S*-Ethyl 2,3,4,6-Tetra-*O*-benzyl-1-deoxy-1-(2-furyl)-1-thio-α-D-mannopyranoside (15). General Procedure for the Preparation of Thioglycosides.** A solution of furan (0.82 mL, 0.77 g, 11 mmol) in THF (20 mL) at −78 °C was treated with n-BuLi (4.13 mL, 2.0 M solution in pentane, 8.3 mmol). The reaction mixture was allowed to warm up to room temperature and stirred for 2 h. This 2-lithiofuran solution was then transferred by a cannula to a solution of **13**[41] (4.0393 g, 7.50 mmol) in THF (40 mL) at −78 °C. The reaction mixture was stirred at this temperature for 2 h. Water (100 mL) was poured in and the mixture warmed to room temperature. Extraction with CH_2Cl_2, drying with Na_2SO_4, and concentration *in vacuo* gave the hemiketal **14** as an oil which was subjected to the next reaction immediately. Ethanethiol (2.8 mL, 2.3 g, 38 mmol) was added to the solution of the hemiketal **14** in dry CH_2Cl_2 (50 mL). The solution was cooled to 0 °C and treated with $BF_3{\cdot}OEt_2$ (1.1 mL, 1.3 g, 8.9 mmol) for 5 min before quenching with saturated aqueous $NaHCO_3$. The organic phase was separated and further washed with saturated aqueous $NaHCO_3$ twice. Drying (Na_2SO_4) and evaporation of the solvent under vacuum yielded the thioglycoside **15** as a clear oil. The oil was purified by silica gel column chromatography (6:1 hexanes:ether with 1% Et_3N) to give 4.58 g (94%) pure thioglycoside **15**: $[\alpha]^{23}_D$ +13.3° (*c* 1.39) ^{1}H NMR δ 1.05 (3H, t, J = 7.5 Hz), 2.23 (1H, m), 2.33 (1H, m), 3.82 (1H, dd, J = 11.5, 1.7 Hz), 3.93 (1H, dd, J = 11.5, 5.5 Hz), 4.05 (1H, app t, J = 9.8 Hz), 4.24 (1H, d, J = 11.3 Hz), 4.27−4.37 (3H, m), 4.51 (1H, d, J = 11.3 Hz), 4.59 (1H, d, J = 11.9 Hz), 4.61 (1H, d, J = 10.9 Hz), 4.71 (2H, app s), 4.75 (1H, d, J

(39) Owing to insufficient spectral resolution, it is unclear whether this isomer differs from **4** in anomeric configuration or is the result of a manno- to gluco-isomerization.

(40) Bott, H. G.; Haworth, W. N.; Hirst, E. L. *J. Chem. Soc.* **1930**, 2653.

(41) (a) Lewis, M. D.; Cha, J.; Kishi, Y. *J. Am. Chem. Soc.* **1982**, *104*, 4976. (b) Lopez, R.; Fernandez-Mayoralas, A. *J. Org. Chem.* **1994**, *59*, 737.

= 11.9 Hz), 4.92 (1H, d, J = 10.9 Hz), 6.41 (1H, dd, J = 3.2, 1.8 Hz), 6.52 (1H, dd, J = 3.2, 0.9 Hz), 7.08−7.10 (2H, m), 7.19−7.39 (18H, m), 7.41 (1H, dd, J = 1.8, 0.9 Hz); ^{13}C NMR δ 14.4, 22.5, 69.4, 72.2, 73.3, 73.8, 74.7, 74.9, 75.1, 78.9, 81.3, 89.6, 109.1, 110.6, 127.2, 127.3, 127.5, 127.6, 127.7 (2C), 127.8, 127.9, 128.0, 128.2, 128.3, 128.4, 138.3, 138.4, 138.5, 138.7, 141.1, 152.3. Anal. Calcd for $C_{40}H_{42}O_6S$: C, 73.82; H, 6.50. Found: C, 73.90; H, 6.60.

Methyl 2,3,4,6-Tetra-*O*-benzyl-1-(2-furyl)-α-D-mannopyranoside (16). Standard Procedure for the Glycosylation Reactions. To a well stirred mixture of **15** (263.2 mg, 0.404 mmol), MeOH (24.6 μL, 19.5 mg, 0.607 mmol), pyridine (49.1 μL, 48.0 mg, 0.607 mmol), and activated 4 A molecular sieves (∼150 mg) in CH_2Cl_2 (8 mL) was added silver triflate (114.3 mg, 0.445 mmol), and the reaction mixture stirred for 15 min at room temperature in the dark. The mixture was then filtered through a short pad of silica gel (4:1 hexanes: ether with 1% Et_3N). The solvent was removed under reduced pressure to yield the crude methyl mannoside **16** as an oil. The pure product (243.3 mg, 97%) was obtained by flash column chromatography (silica gel, 4:1 hexanes:ether with 1% Et_3N) as an oil: $[\alpha]^{23}_D$ +11.3° (*c* 1.76); ^{1}H NMR δ 3.06 (3H, s), 3.80−3.93 (3H, m), 4.02 (1H, app t, J = 9.7 Hz), 4.18−4.26 (3H, m), 4.46 (1H, d, J = 11.5 Hz), 4.60 (1H, d, J = 11.7 Hz), 4.62−4.70 (3H, m), 4.76 (1H, d, J = 12.0 Hz), 4.93 (1H, d, J = 10.8 Hz), 6.43 (1H, dd, J = 3.2, 1.8 Hz), 6.61 (1H, dd, J = 3.2, 0.9 Hz), 7.05−7.10 (2H, m), 7.19−7.39 (18H, m), 7.41 (1H, dd, J = 1.8, 0.9 Hz); ^{13}C NMR δ 49.3, 69.5, 72.1, 73.4 (2C), 74.2, 74.6, 75.1, 77.0, 81.2, 99.6, 110.5, 110.8, 127.2, 127.4, 127.48 (2C), 127.54, 127.7, 127.9, 127.98, 128.01, 128.29 (2C), 128.33, 138.4, 138.5, 138.6, 138.7, 141.9, 150.8. Anal. Calcd for $C_{39}H_{40}O_7$: C, 75.46; H, 6.50. Found: C, 75.30; H, 6.51.

2,3,4,6-Tetra-*O*-allyl-D-mannopyranosyl Chloride (25). A mixture of D-mannose (18.02 g, 0.100 mol), 2-methoxyethanol (80 mL, 1.0 mol), benzene (20 mL), and *p*-toluenesulfonic acid monohydrate (190 mg, 1.0 mmol) was heated to 110−120 °C under a Dean−Stark water separator for 5 h. The solution was cooled to room temperature and Et_3N (2 mL) was added. The solvent was removed under reduced pressure at 65 °C, giving 2-methoxyethyl mannopyranoside **23** as a syrup. The syrup was dissolved in 500 mL of DMF, followed by the addition of allyl bromide (51.9 mL, 72.6 g, 600 mmol). To this solution cooled to 0 °C was added sodium hydride (24.00 g, 60% in mineral oil, 600 mmol) portionwise over 1 h, and the resulting mixture was stirred overnight. The reaction mixture was poured into ice water (1 L) and extracted with ether (5 × 400 mL). The organic phase was dried (Na_2SO_4) and concentrated *in vacuo*. The so-obtained oil was taken up in petroleum ether (500 mL) and washed with acetonitrile (4 × 200 mL). The combined acetonitrile solution was concentrated under reduced pressure to afford the title compound **24** (38.13 g, 96%) as a pale yellow oil, which was shown by NMR to be a mixture of two anomers containing a very small amount of the β-isomer. This oil was used without further purification. α-Anomer: ^{1}H NMR δ 3.37 (3H, s), 3.49−3.83 (10H, m), 3.98−4.20 (7H, m), 4.35 (1H, ddt, J = 12.3, 5.8, 1.4 Hz), 4.86 (1H, d, J = 1.8 Hz), 5.09−5.35 (8H, m), 5.82−6.01 (4H, m); ^{13}C NMR δ 58.8, 66.2, 69.1, 70.9, 71.3, 71.4, 71.6, 72.1, 73.7, 74.5, 74.7, 79.3, 97.9, 116.2, 116.3, 116.5, 117.1, 134.7, 134.8, 134.9 (2C). To a solution of **24** (38.13 g, 95.7 mmol) in CH_2Cl_2 (500 mL) at 0 °C was added cautiously a solution of $TiCl_4$ in CH_2Cl_2 (115 mL, 1.0 M solution, 115 mmol) over 15 min. TLC showed that the reaction was essentially over after the addition. After 30 min of further stirring at 0 °C the reaction was quenched with saturated aqueous sodium bicarbonate, and the mixture was filtered through Celite. The organic layer was separated, and the aqueous layer was further extracted twice with CH_2Cl_2. The combined organic solution was dried (Na_2SO_4) and the solvent evaporated under vacuum to yield **25** (34.33 g, 100%) as an oil which was somewhat unstable and immediately subjected to the subsequent reaction: ^{1}H NMR δ 3.58−3.85 (4H, m), 3.85−4.20 (9H, m), 4.29 (1H, ddt, J = 12.4, 5.6, 1.5 Hz), 5.05−5.35 (8H, m), 5.75−5.95 (4H, m), 6.03 (1H, d, J = 1.6 Hz); ^{13}C NMR δ 68.1, 71.3, 72.1, 72.2, 73.8, 73.9, 74.3, 77.5 (2C), 91.6, 116.5, 117.0 (2C), 118.0, 134.3, 134.5 (2C), 134.7. Anal. Calcd for $C_{18}H_{27}ClO_5$: C, 60.25; H, 7.58. Found: C, 59.97; H, 7.68.

2,3,4,6-Tetra-*O*-allyl-D-mannono-1,5-lactone (26). The mannosyl chloride **25** (34.33 g, 95.7 mmol) was dissolved in 200 mL of THF and treated with 200 mL of 2 M aqueous HCl at room temperature for 30 h. The solution was poured into 400 mL of saturated aqueous sodium bicarbonate and extracted with ether (4 × 200 mL). The ether layers were dried (Na_2SO_4) and concentrated *in vacuo*, affording tetraallylmannose **22** (31.53 g, 97%) as a slightly yellow oil which was mainly the α-anomer and subjected to the following reaction without further purification. α-Anomer: ^{1}H NMR δ 3.15 (1H, br), 3.53−3.80 (5H, m), 3.90−4.20 (8H, m), 4.35 (1H, ddt, J = 12.7, 5.8, 1.5 Hz), 5.10−5.37 (9H, m), 5.83−6.02 (4H, m); ^{13}C NMR δ 69.7, 70.9, 71.0, 72.1, 72.2, 73.8, 74.8, 75.2, 79.1, 92.8, 116.49, 116.54, 117.3, 117.4, 134.5, 134.86, 134.94, 135.0. To a stirred solution of oxalyl chloride (8.89 mL, 12.9 g, 102 mmol) in CH_2Cl_2 (250 mL) cooled at −78 °C was added a solution of DMSO (14.5 mL, 15.9 g, 204 mmol) in CH_2Cl_2 (30 mL). After 2 min of stirring, **22** (31.53 g, 92.62 mmol) in 80 mL of CH_2Cl_2 was added within 5 min. The resulting reaction mixture was stirred at this low temperature for 15 min before Et_3N (64.5 mL, 46.9 g, 463 mmol) was added. After stirring for another 5 min, the mixture was allowed to warm up to room temperature and quenched with water (400 mL). The organic layer was separated and the aqueous layer was washed with CH_2Cl_2 (2 × 150 mL). The combined organic layers were dried (Na_2SO_4) and concentrated under vacuum. The crude product was purified by column chromatography (silica gel, 3:1 hexanes:ethyl acetate) to give the lactone (28.85 g, 92%) as a pale yellow oil: $[\alpha]^{23}_D$ +41.4° (*c* 1.82); ^{1}H NMR δ 3.67 (1H, app s), 3.69 (1H, app s), 3.73 (1H, dd, J = 7.0, 1.7 Hz), 4.06−4.35 (10H, m), 4.47 (1H, ddt, J = 12.9, 5.0, 1.6 Hz), 5.14−5.38 (8H, m), 5.80−6.01 (4H, m); ^{13}C NMR δ 69.3, 70.8, 71.8, 71.9, 72.4, 75.1, 75.6, 76.9, 78.5, 117.35, 117.45, 117.9, 118.2, 133.5, 133.9, 134.2, 134.3, 169.2. Anal. Calcd for $C_{18}H_{26}O_6$: C, 63.89; H, 7.74. Found: C, 63.52; H, 7.63.

***S*-Ethyl 2,3,4,6-Tetra-*O*-allyl-1-deoxy-1-(2-furyl)-1-thio-α-D-mannopyranoside (28).** A solution of furan (1.33 mL, 1.24 g, 18.2 mmol) in THF (30 mL) at −78 °C was treated with n-BuLi (6.4 mL, 2.0 M solution in pentane, 12.8 mmol). The reaction mixture was allowed to warm up to room temperature and stirred for 2 h. This 2-lithiofuran solution was then transferred by a cannula to a solution of **26** (4.1112 g, 12.15 mmol) in THF (50 mL) at −78 °C. The reaction mixture was stirred at this temperature for 2 h. Water (100 mL) was poured in and the mixture warmed to room temperature. Extraction with CH_2Cl_2, drying with Na_2SO_4, and concentration *in vacuo* gave the hemiketal **27** as an oil. This oil was taken up in dry CH_2Cl_2 (80 mL), and ethanethiol (4.5 mL, 3.8 g, 61 mmol) was added. The solution was cooled to 0 °C and treated with $BF_3{\cdot}OEt_2$ (1.6 mL, 1.8 g, 13 mmol) for 5 min before being quenched with saturated aqueous $NaHCO_3$. The organic phase was separated and washed additionally with saturated aqueous $NaHCO_3$ twice. Drying (Na_2SO_4) and evaporation of the solvent under vacuum yielded the thioglycoside as a brown oil. The oil was purified by column chromatography (silica gel, 8:1 hexanes:ethyl acetate with 1% Et_3N), giving 5.021 g (92%) of pure thioglycoside **28**: $[\alpha]^{23}_D$ +17.9° (*c* 0.95) ^{1}H NMR δ 1.02 (3H, t, J = 7.5 Hz), 2.16 (1H, m), 2.27 (1H, m), 3.67−3.82 (5H, m), 3.98−4.24 (8H, m), 4.35 (1H, ddt, J = 12.3, 5.7, 1.5 Hz), 4.98−5.37 (8H, m), 5.57 (1H, m), 5.83−6.02 (3H, m), 6.35 (1H, dd, J = 3.2, 1.8 Hz), 6.46 (1H, dd, J = 3.2, 0.8 Hz), 7.39 (1H, dd, J = 1.7, 0.9 Hz); ^{13}C NMR δ 14.3, 22.3, 69.4, 71.1, 72.2, 73.5, 73.7, 73.9, 74.9, 78.2, 80.4, 89.6, 109.0, 110.5, 116.4, 116.5, 116.8, 116.9, 134.7, 134.98, 135.04 (2C), 140.9, 152.1. Anal. Calcd for $C_{24}H_{34}O_6S$: C, 63.97; H, 7.61. Found: C, 64.06; H, 7.70.

Methyl 2,3,4,6-Tetra-*O*-allyl-1-(2-furyl)-α-D-mannopyranoside (32). To a well stirred mixture of **28** (484.7 mg, 1.076 mmol), methanol (65.4 μL, 51.7 mg, 1.61 mmol), pyridine (131 μL, 128 mg, 1.61 mmol), and activated 4 A molecular sieves (∼300 mg) in dichloromethane was added silver triflate (304.1 mg, 1.18 mmol), and the reaction mixture was stirred for 15 min at room temperature in the dark. The mixture was then filtered through a short pad of silica gel (6:1 hexanes:

ethyl acetate with 1% Et_3N). The solvent was removed under vacuum, yielding the crude methyl mannoside as an oil. The pure product (425 mg, 94%) was obtained by flash column chromatography (silica gel, 6:1 hexanes:ethyl acetate with 1% Et_3N) as an oil: $[\alpha]^{23}_D$ +23.4° (*c* 3.45); ^{1}H NMR δ 3.02 (3H, s), 3.65−3.78 (6H, m), 3.91 (1H, m), 3.96 (1H, d, J = 3.1 Hz), 4.06−4.23 (5H, m), 4.37 (1H, ddt, J = 12.3, 5.7, 1.4 Hz), 5.03 (2H, m), 5.10−5.36 (6H, m), 5.51 (1H, m), 5.85−6.02 (3H, m), 6.38 (1H, dd, J = 3.3, 1.8 Hz), 6.54 (1H, dd, J = 3.3, 0.9 Hz), 7.41 (1H, dd, J = 1.8, 0.9 Hz); ^{13}C NMR δ 49.2, 69.5, 71.0, 72.3, 73.0, 73.3, 73.9, 74.5, 76.4, 80.2, 99.5, 110.4, 110.6, 116.5 (3C), 116.9, 134.9, 135.0, 135.1 (2C), 141.7, 150.5. Anal. Calcd for $C_{23}H_{32}O_7$: C, 65.70; H, 7.67. Found: C, 65.25; H, 7.61.

1,2:3,4-Di-*O*-isopropylidene-6-*O*-[2,3,4,6-tetra-*O*-allyl-1-(2-furyl)-α-D-mannopyranosyl]-α-D-galactopyranose (35). The thioglycoside **28** (949.9 mg, 2.108 mmol) and **29** (603.6 mg, 2.319 mmol) were azeotroped three times from toluene. They were then diluted with anhydrous CH_2Cl_2 (15 mL). The solution was then treated with pyridine (0.26 mL, 0.25 g, 3.2 mmol), 4 A molecular sieves, and silver triflate (595.8 mg, 2.319 mmol) for 30 min according to the above general glycosylation protocol for the preparation of **32** to give the disaccharide **35** in 89% (1.223 g) yield after column chromatography (silica gel, 4.5:1 hexanes:ethyl acetate with 1% Et_3N): $[\alpha]^{23}_D$ −15.5° (*c* 1.00); ^{1}H NMR δ 1.28 (3H, s), 1.32 (3H, s), 1.35 (3H, s), 1.54 (3H, s), 3.32 (1H, dd, J = 10.6, 4.8 Hz), 3.52 (1H, dd, J = 10.6, 6.8 Hz), 3.68−3.90 (7H, m), 3.93 (1H, dd, J = 9.4, 3.0 Hz), 4.00 (1H, d, J = 3.0 Hz), 4.03−4.21 (6H, m), 4.25 (1H, dd, J = 5.0, 2.4 Hz), 4.34 (1H, ddt, J = 12.5, 5.6, 1.5 Hz), 4.53 (1H, dd, J = 7.9, 2.4 Hz), 5.01 (2H, m), 5.10−5.37 (6H, m), 5.47 (1H, d, J = 5.0 Hz), 5.55 (1H, m), 5.86−6.01 (3H, m), 6.35 (1H, dd, J = 3.2, 1.8 Hz), 6.53 (1H, dd, J = 3.2, 0.8 Hz), 7.35 (1H, J = 1.7, 0.8 Hz); ^{13}C NMR δ 24.4, 25.0, 25.9, 26.1, 61.5, 67.1, 69.3, 70.6, 70.7, 71.2, 71.3, 72.2, 73.0, 73.4, 73.6, 74.5, 76.6, 80.0, 96.2, 99.5, 108.4, 109.1, 110.5 (2C), 116.2, 116.4, 116.5 (2C), 135.1, 135.3, 135.4 (2C), 141.5, 150.9. Anal. Calcd for $C_{34}H_{48}O_{12}$: C, 62.95; H, 7.46. Found: C, 62.97; H, 7.49.

Methyl 2,3,4-Tri-*O*-acetyl-6-*O*-[2,3,4,6-tetra-*O*-allyl-1-(2-furyl)-α-D-mannopyranosyl]-α-D-glucopyranoside (38). A mixture of **28** (1.091 g, 2.421 mmol), **30** (0.853 g, 2.663 mmol), and DTBMP (0.597 g, 2.905 mmol) was dried by azeotropic evaporation with toluene three times with a rotary evaporator. This mixture was then dissolved in anhydrous THF (15 mL), and crushed activated 4 A molecular sieves (~0.4 g) were added. Treatment with silver triflate (0.747 g, 2.905 mmol) according to the standard glycosylation protocol described for the preparation of **32** gave the disaccharide **38** in 86% (1.469 g) yield after column chromatography (neutral alumina, 3:1 hexanes:ethyl acetate): $[\alpha]^{23}_D$ +95.1° (*c* 1.00); ^{1}H NMR δ 1.92 (3H, s), 1.98 (3H, s), 2.06 (3H, s), 3.06 (1H, dd, J = 11.1, 1.8 Hz), 3.38 (3H, s), 3.46 (1H, dd, J = 11.1, 6.8), 3.65−3.89 (8H, m), 3.97 (1H, d, J = 3.0 Hz), 4.05−4.18 (5H, m), 4.33 (1H, ddt, J = 12.7, 5.6, 1.3 Hz), 4.83−4.91 (3H, m), 5.01 (2H, m), 5.10−5.25 (6H, m), 5.40, (1H, app t, J = 9.7 Hz), 5.52 (1H, m), 5.85−5.98 (3H, m), 6.36 (1H, dd, J = 3.2, 1.8 Hz), 6.52 (1H, dd, J = 3.2, 0.9 Hz), 7.35 (1H, dd, J = 1.8 Hz, 0.9 Hz); ^{13}C NMR δ 20.5, 20.6, 20.7, 55.1, 61.0, 67.9, 69.0, 69.3, 70.4, 70.8, 71.1, 72.2, 73.2, 73.4, 73.7, 74.2, 76.7, 79.9, 96.3, 99.4, 110.5, 110.7, 116.1, 116.4, 116.5, 116.8, 135.0, 135.07, 135.11, 135.2, 141.7, 150.4, 169.5, 170.1 (2C) Anal. Calcd for $C_{35}H_{48}O_{15}$: C, 59.31; H, 6.83. Found: C, 59.53; H, 6.93.

Methyl 2,3-*O*-Isopropylidene-4-*O*-[2,3,4,6-tetra-*O*-allyl-1-(2-furyl)-β-D-mannopyranosyl]-α-L-rhamnopyranoside (41). The donor **28** (449.0 mg, 0.996 mmol) and **31** (324.5 mg, 1.487 mmol) were dried by azeotropic evaporation with toluene three times with a rotary evaporator. This mixture was then dissolved in anhydrous THF (8 mL) and treated with DTBMP (306.9 mg, 1.495 mmol), 4 A molecular sieves, and silver triflate (307.2 mg, 1.196 mmol) according to the standard glycosylation method for the preparation of **32** to give the **41** in 75% (452 mg) yield after column chromatography (silica gel, 7:1 hexanes:ethyl acetate with 1% Et_3N): $[\alpha]^{23}_D$ −9.3° (*c* 1.08); ^{1}H NMR δ 0.99 (3H, d, J = 6.4 Hz), 1.27 (3H, s), 1.40 (3H, s), 3.15 (1H, dd, J = 9.3, 6.7 Hz), 3.33 (3H, s), 3.55 (1H, m), 3.68−4.25 (15H, m), 4.34 (1H, ddt, J = 12.2, 5.9, 1.3, Hz), 4.71 (1H, app s), 5.00 (2H, m), 5.10−5.25 (4H, m), 5.31 (2H, m), 5.60 (1H, m), 5.88−6.03 (3H, m), 6.34 (1H, dd, J = 3.2, 1.8 Hz), 6.55 (1H, dd, J = 3.3, 0.9 Hz), 7.35 (1H, dd, J = 1.8 Hz, 0.9 Hz); ^{13}C NMR δ 17.4, 26.3, 27.7, 54.7, 64.7, 68.8, 71.2, 72.4, 73.4, 73.7, 73.9, 74.5, 75.8, 76.0, 77.1, 77.6, 80.4, 97.8, 100.7, 108.5, 110.6, 111.4, 115.7, 116.1, 116.2, 116.3, 135.1, 135.36, 135.44, 135.6, 140.9, 150.4. Anal. Calcd for $C_{32}H_{46}O_{11}$: C, 63.35; H, 7.64. Found: C, 62.97; H, 7.47.

Methyl 2,3,4,6-Tetra-*O*-acetyl-1-(2-furyl)-α-D-mannopyranoside (33). General Protocol for Protecting Group Exchanges. Method A. A solution of **32** (94.8 mg, 0.225 mmol) and DABCO (12.6 mg, 0.112 mmol) in 90% aqueous ethanol (5 mL) was heated to about 50 °C, followed by the addition of $(Ph_3P)_3RhCl$ (21 mg, 0.023 mmol). The suspension was gently refluxed for 6 h. Water (10 mL) was poured into the reaction mixture, and the mixture was extracted with CH_2Cl_2 (3 × 10 mL). The combined organic solution was dried (Na_2SO_4) and concentrated *in vacuo*. The ^{1}H NMR spectrum showed that all of the allyl protecting groups were converted to 1-propenyl groups. The residue was taken up in 85% aqueous acetone (5 mL) and was treated with NMNO (111 mg, 0.948 mmol) and a catalytic amount of OsO_4 for 10 h. A black residue was obtained after removal of the solvent under vacuum which was directly taken up in CH_2Cl_2 (10 mL) and treated with acetic anhydride (0.21 mL, 0.23 g, 2.2 mmol) and DMAP (5.6 mg, 0.046 mmol) overnight. The reaction was quenched with saturated aqueous $NaHCO_3$ (15 mL). Extraction with CH_2Cl_2, drying with Na_2SO_4, and evaporation of the solvent gave crude **33**, which was purified by column chromatography (silica gel, 2:1 hexanes:ethyl acetate with 1% Et_3N). The yield was 69.7 mg (72%): $[\alpha]^{23}_D$ +13.5° (*c* 1.35); ^{1}H NMR δ 1.88 (3H, s), 1.97 (3H, s), 2.06 (3H, s), 2.10 (3H, s), 3.09 (3H, s), 3.99 (1H, ddd, J = 10.1, 5.8, 2.8 Hz), 4.24 (1H, dd, J = 12.1, 2.8 Hz), 4.34 (1H, dd, J = 12.1, 5.8 Hz), 5.29 (1H, app t, J = 10.0 Hz), 5.53 (1H, dd, J = 10.0, 3.4 Hz), 5.63 (1H, d, J = 3.4 Hz), 6.34 (1H, dd, J = 3.3, 1.8 Hz), 6.49 (1H, dd, J = 3.3, 0.9 Hz), 7.38 (1H, dd, J = 1.8, 0.9 Hz); ^{13}C NMR δ 20.3, 20.6, 20.7 (2C), 49.7, 66.1, 69.5, 69.6, 70.1, 98.8, 110.0, 110.9, 143.0, 148.2, 169.2, 169.77, 169.84, 170.6. Anal. Calcd for $C_{19}H_{24}O_{11}$: C, 53.27; H, 5.65. Found: C, 53.16; H, 5.80.

Method B for Protecting Group Exchange. To a solution of the mannoside **32** (424.9 mg, 1.010 mmol) and DABCO (11.3 mg, 0.101 mmol) in dry THF (20 mL) was added $[(Ph_2MeP)_2(COD)IrPF_6]$ (43 mg, 0.051 mmol), and the red suspension was deoxygenated by bubbling with dry nitrogen for 10 min. The catalyst was then activated with dry hydrogen for 10 min while the red color disappeared. To effect the isomerization, the solution was further degassed for 5 min and stirred for 2 h at room temperature. Evaporation of the solvent gave the tetra-1-propenyl-protected mannoside, which was then treated by the same procedure as in method A with OsO_4 (catalytic), NMNO (497 mg, 4.24 mmol), acetic anhydride (0.92 mL, 1.0 g, 9.8 mmol), and DMAP (25 mg, 0.20 mmol) to afford the acetyl-protected mannoside **33** in a yield of 332 mg (77%).

1,2:3,4-Di-*O*-isopropylidene-6-*O*-[2,3,4,6-tetra-*O*-acetyl-1-(2-furyl)-α-D-mannopyranosyl]-α-D-galactopyranose (36). Method A. Following the standard procedure for protecting group exchanges described for the preparation of **33**, disaccharide **35** (265 mg, 0.408 mmol) was first treated with $(Ph_3P)_3RhCl{\cdot}2H_2O$ (78.5 mg, 0.082 mmol) and DABCO (22.8 mg, 0.203 mmol) in refluxing 90% ethanol (10 mL) and then with a small crystal of OsO_4 and NMNO (201 mg, 1.72 mmol) in 85% aqueous acetone (10 mL), followed by acetylation with acetic anhydride (0.37 mL, 0.40 g, 3.9 mmol) and DMAP (20 mg, 0.16 mmol) in CH_2Cl_2, to give the title compound **36** (174 mg) as a colorless crystalline solid with an overall yield of 65% after silica gel chromatography purification (2:1 hexanes:ethyl acetate with 1% Et_3N): mp 120−121 °C; $[\alpha]^{23}_D$ −23.2° (*c* 1.71); ^{1}H NMR δ 1.27 (3H, s), 1.34 (3H, s), 1.36 (3H, s), 1.59 (3H, s), 1.87, (3H, s), 1.97 (3H, s), 2.07 (3H, s), 2.10 (3H, s), 3.38 (1H, dd, J = 10.5, 4.0 Hz), 3.54 (1H, dd, J = 10.5, 7.0 Hz), 3.98 (1H, m), 4.14 (1H, dd, J = 7.9, 1.7 Hz), 4.28 (4H, m), 4.57 (1H, dd, J = 7.9, 2.4 Hz), 5.30 (1H, app t, J = 10.0 Hz), 5.48 (1H, d, J = 4.9 Hz), 5.53 (1H, dd, J = 10.0, 3.4 Hz), 5.67 (1H, d, J = 3.4 Hz), 6.32 (1H, dd, J = 3.3, 1.7 Hz), 6.50 (1H, dd, J = 3.3, 0.9 Hz), (1H, dd, J = 1.7, 0.9 Hz); ^{13}C NMR δ 20.3, 20.6,

20.7 (2C), 24.1, 25.0, 25.8, 26.0, 62.4, 62.6, 65.9, 67.3, 69.4, 69.7, 70.2, 70.6 (2C), 71.2, 96.1, 98.3, 108.7, 109.1, 110.0, 110.7, 142.7, 148.6, 169.2, 169.7, 169.8, 170.6. Anal. Calcd for $C_{30}H_{40}O_{16}$: C, 54.88; H, 6.14. Found: C, 55.03; H, 6.24.

Method B. Following Method B for the preparation of **33**, with $[(Ph_2MeP)_2(COD)IrPF_6]$ (22 mg, 0.025 mmol) as the catalyst, the title compound **36** (252 mg) was obtained in 75% yield from disaccharide **35** (331 mg, 0.510 mmol), a catalytic amount of OsO_4, NMNO (269 mg, 2.29 mmol), acetic anhydride (0.48 mL, 0.52 g, 5.1 mmol), and DMAP (25 mg, 0.20 mmol).

Methyl 2,3,4-Tri-*O*-acetyl-6-*O*-[2,3,4,6-tetra-*O*-acetyl-1-(2-furyl)-α-D-mannopyranosyl]-α-D-glucopyranoside (39). Method B. Following the standard procedure (Method B for the preparation of **33**), disaccharide **38** was treated with $[(Ph_2MeP)_2(COD)IrPF_6]$ in THF at room temperature followed by OsO_4 and NMNO in 85% aqueous acetone, and acetic anhydride, DMAP, and pyridine in CH_2Cl_2. The crude product was purified by column chromatography (neutral alumina, 3:2 hexanes:ethyl acetate). Recrystallization in ether and hexanes gave disaccharide **39** as colorless crystals in 71% yield: mp 174−176 °C; $[\alpha]^{23}_D$ +75.2°; ^{1}H NMR δ 1.88 (3H, s), 1.92 (3H, s), 1.96 (3H, s), 1.98 (3H, s), 2.06 (3H, s), 2.08 (3H, s), 2.12 (3H, s), 3.08 (1H, dd, J = 10.6, 1.8 Hz), 3.45 (1H, dd, J = 10.6, 8.5 Hz), 3.49 (3H, s), 3.94 (1H, m), 4.20−4.28 (3H, m), 4.75 (1H, dd, J = 10.5, 9.2 Hz), 4.82 (1H, dd, J =10.2, 3.7 Hz), 4.95 (1H, d, J = 3.7 Hz), 5.27 (1H, app t, J = 9.9 Hz), 5.44 (1H, dd, J = 10.2, 9.3 Hz), 5.52 (1H, dd, J = 10.1, 3.4 Hz), 5.63 (1H, d, J = 3.4 Hz), 6.33 (1H, dd, J = 3.3, 1.8 Hz), 6.49 (1H, dd, J = 3.3, 0.9 Hz), 7.37 (1H, dd, J = 1.8, 0.9 Hz); ^{13}C NMR δ 20.3, 20.5, 20.6 (2C), 20.70 (2C), 20.75, 55.3, 62.0, 62.5, 65.9, 67.9, 69.3, 69.5, 69.7, 69.9, 70.0, 70.9, 96.1, 98.3, 110.2, 111.1, 143.0, 148.1, 169.1, 169.7, 169.8 (2C), 169.9, 170.2, 170.6. Anal. Calcd for $C_{31}H_{40}O_{19}$: C, 51.96; H, 5.63. Found: C, 51.90; H, 5.73.

Methyl 2,3-*O*-Isopropylidene-4-*O*-[2,3,4,6-tetra-*O*-acetyl-1-(2-furyl)-β-D-mannopyranosyl]-α-L-rhamnopyranoside (42). To a solution of **41** (445 mg, 0.733 mmol) in 5 mL of anhydrous DMSO was added *t*-BuO$^-$K$^+$ (0.400 g, 3.27 mmol). The reaction was heated to 85−90 °C for 1.5 h. After cooling to room temperature, the black solution was poured into 25 mL of water and extracted with ether (5 × 15 mL). The combined ether solution was further washed with water (4 × 10 mL). The organic solution was dried with Na_2SO_4 and concentrated in *vacuo* to give 420 mg of a brown oil. The ^{1}H NMR of the oil indicated that all the allyl ether functions were isomerized to the corresponding enol ethers. The oil was taken up in 85% aqueous acetone (15 mL) and treated with OsO_4 and NMNO (0.365 g, 3.12 mmol) and then with acetic anhydride (0.65 mL, 0.70 g, 6.9 mmol), pyridine (0.56 mL, 0.55 g, 6.9 mmol), and DMAP (4.2 mg, 0.035 mmol) as described above for the preparation of **33** to afford 0.257 g of title compound **42** as a clear oil after column chromatography (silica gel, 3:2 hexanes:ethyl acetate) purification: $[\alpha]^{23}_D$ −24.7° (*c* 0.75); ^{1}H NMR δ 0.89 (3H, d, J = 6.4 Hz), 1.32 (3H, s), 1.49 (3H, s), 1.86 (3H, s), 1.98 (3H, s), 2.05(3H, s), 2.08 (3H, s), 3.27 (1H, dd, J = 9.9, 7.2 Hz), 3.30 (3H, s), 3.61 (1H, m), 4.06 (1H, app d, J = 5.6), 4.09−4.31 (3H, m), 4.38 (1H, dd, J = 12.4, 3.2 Hz), 4.74 (1H, app s), 5.41 (1H, app t, J = 9.9 Hz), 5.49 (1H, dd, J = 10.2, 3.1 Hz), 5.74 (1H, d, J = 3.1 Hz), 6.33 (1H, dd, J = 3.3, 1.8 Hz), 6.56 (1H, dd, J = 3.3, 0.8 Hz), 7.33 (1H, dd, J = 1.8, 0.8 Hz); ^{13}C NMR δ 17.0, 20.4, 20.7, 20.78, 20.82, 26.5, 27.9, 54.7, 61.8, 64.1, 65.8, 69.8, 70.0, 70.3, 76.2, 77.18, 77.20, 97.5, 99.8, 109.0, 110.5, 111.9, 142.3, 148.2, 169.4, 169.7, 170.1, 170.8. Anal. Calcd for $C_{28}H_{38}O_{15}$: C, 54.72; H, 6.23. Found: C, 54.36; H, 6.58.

Methyl 3,4,5,7-Tetra-*O*-acetyl-α-D-*manno*-2-heptulopyranosidonic Acid (34). Typical Procedure for Oxidative Cleavage of Furan to Carboxylic Acid. KIO_4 (505.1 mg, 2.20 mmol) was added to a biphasic solution of **33** (112.0 mg, 0.261 mmol) in CCl_4 (4 mL), acetonitrile (4 mL), and water (6 mL). The pH of the aqueous layer was adjusted to 7−8 with solid potassium carbonate. To this suspension was added catalytic RuO_2, and the resulting dark green mixture was strongly stirred at room temperature overnight. The mixture was diluted with a large amount of ethyl acetate, and the separated organic layer was dried with Na_2SO_4 and filtered. The filtrate was concentrated under reduced pressure to yield 105.8 mg (∼100%) of **34** as a black residue which was not further purified at this stage: ^{1}H NMR δ 1.96 (3H, s), 2.05 (3H, s), 2.10 (3H, s), 2.11 (3H, s), 3.33 (3H, s), 3.96 (1H, ddd, J = 10.1, 5.8, 2.5 Hz), 4.22 (1H, dd, J = 12.4, 2.5 Hz), 4.33 (1H, dd, J = 12.4, 5.8 Hz), 5.26 (1H, app t, J = 10.1 Hz), 5.37 (1H, dd, J = 10.1, 3.3 Hz), 5.61 (1H, d, J = 3.3 Hz), 7.05 (1H, br); ^{13}C NMR δ 20.5 (2C), 20.6, 20.7, 51.5, 62.2, 65.1, 69.1, 69.5, 70.6, 99.1, 166.3, 169.0, 169.6, 169.7, 171.0.

1,2:3,4-Di-*O*-isopropylidene-6-*O*-(3,4,5,7-tetra-*O*-acetyl-α-D-*manno*-2-heptulopyranosidonic acid)-α-D-galactopyranose (37). Disaccharide **36** (237.2 mg, 0.361 mmol) was oxidized by a catalytic amount of RuO_2 and KIO_4 (697.9 mg, 3.03 mmol) in CCl_4 (7 mL), CH_3CN (7 mL), and water (10.5 mL) buffered at pH 7−8 with potassium carbonate according to the standard protocol for the cleavage of the furan group. The title ulosonic acid **37** (226 mg) was obtained in essentially quantitative yield: ^{1}H NMR δ 1.31 (3H, s), 1.33 (3H, s), 1.41 (3H, s), 1.57 (3H, s), 1.96 (3H, s), 2.07 (3H, s), 2.10 (3H, s), 2.11 (3H, s), 3.60−3.72 (2H, m), 4.03 (1H, m), 4.19 (1H, dd, J = 7.9, 1.9 Hz), 4.22−4.37 (4H, m), 4.60 (1H, dd, J = 7.9, 2.5 Hz), 5.28 (1H, app t, J = 10.2 Hz), 5.36 (1H, dd, J = 10.2, 3.2 Hz), 5.48 (1H, d, J = 4.9 Hz), 5.62 (1H, d, J = 3.2 Hz), 9.21 (1H, br); ^{13}C NMR δ 14.1, 20.5, 20.7, 20.8, 24.2, 25.0, 25.8, 26.0, 60.4, 62.0, 64.9, 65.0, 67.4, 69.3, 69.7, 70.5, 70.6, 71.2, 96.1, 98.5, 109.0, 109.6, 166.2, 169.0, 169.6, 169.8, 171.1.

Methyl 2,3,4-Tri-*O*-acetyl-6-*O*-(3,4,5,7-tetra-*O*-acetyl-α-D-*manno*-2-heptulopyranosidonic acid)-α-D-glucopyranoside (40). Ulosonic acid glycoside **40** was obtained in essentially quantitative yield (163 mg) from **39** (168 mg, 0.235 mmol) according to the standard protocol: ^{1}H NMR δ 1.96 (3H, s), 2.00 (3H, s), 2.03 (3H, s), 2.06 (3H, s), 2.09 (3H, s), 2.10 (3H, s), 2.15 (3H, s), 3.47 (3H, s), 3.45−3.49 (1H, m, overlap with the singlet at 3.47 ppm), 3.55 (1H, dd, J = 9.9, 8.3 Hz), 4.03−4.13 (1H, m), 4.21−4.35 (3H, m), 4.82 (1H, dd, J = 10.4, 9.2 Hz), 4.82 (1H, dd, J = 10.2, 3.7 Hz), 4.96 (1H, d, J = 3.6 Hz), 5.26 (1H, app t, J = 9.9 Hz), 5.36 (1H, dd, J = 10.2, 3.2 Hz), 5.49 (1H, app t, J = 9.7 Hz), 5.61 (1H, d, J = 3.2 Hz); ^{13}C NMR δ 20.51 (2C), 20.59 (2C), 20.63, 20.66, 20.75, 55.4, 62.2, 63.2, 65.0, 67.6, 69.1, 69.2, 69.5, 69.8, 70.7, 70.8, 96.2, 98.1, 165.7, 169.1, 169.7 (2C), 170.0, 170.1, 170.3, 171.0.

Methyl 2,3-*O*-Isopropylidene-4-*O*-(3,4,5,7-tetra-*O*-acetyl-α-D-*manno*-2-heptulopyranosidonic acid)-β-L-rhamnopyranoside (43) and the Keto Acid 44. Oxidation of **42** according to the standard procedure using excess (three times) of KIO_4 and catalytic RuO_2 gave an approximately 4:1 mixture of title compound **43** and the keto acid **44** in essentially quantitative yield after 2 weeks of stirring: ^{1}H NMR δ 1.29 (3H, d, J = 6.5 Hz), 1.33 (3H, s), 1.52 (3H, s), 1.98 (3H, s), 2.06 (3H, s), 2.09 (3H, s), 2.13 (3H, s), 3.37 (3H, s), 3.40 (1H, dd, J = 9.8, 6.7 Hz), 3.70 (1H, m), 4.03−4.27 (4H, m), 4.34 (1H, dd, J = 12.0, 2.2 Hz), 4.84 (1H, app s), 5.28−5.38 (2H, m), 5.59 (1H, d, J = 2.2 Hz), 9.60 (1H, br); ^{13}C NMR δ 17.3, 20.57 (2C), 20.65, 20.8, 26.4, 27.5, 54.8, 61.5, 63.7, 64.8, 69.3, 70.1, 71.2, 75.9, 76.7, 80.9, 97.4, 99.7, 109.6, 165.3, 168.8, 169.6, 169.9, 171.4. Keto acid **44** was characterized by the presence of an additional resonance in the ^{13}C-NMR spectrum at δ 192.4.

Methyl 2,3,4,6-Tetra-*O*-acetyl-β-D-mannopyranoside (46). Decarboxylation Protocol A. The crude acid **34** (103 mg, 0.253 mmol) was dissolved in anhydrous CH_2Cl_2 (10 mL) followed by the addition of Et_3N (88 μL, 64 mg, 0.63 mmol). The solution was treated with **10** (72 mg, 0.38 mmol) in the dark for 4 h. t-BuSH (0.29 mL, 232 mg, 2.6 mmol) was injected and the mixture was photolyzed with a tungsten light at 0 °C for 1 h. The reaction mixture was diluted with 20 mL of CH_2Cl_2 and washed with 10% aqueous ammonium chloride and saturated aqueous sodium bicarbonate. The organic solution was dried (Na_2SO_4) and concentrated under reduced pressure to give a mixture containing the β-mannoside and the 2-pyridyl *tert*-butyl disulfide. Pure **46** (73 mg, 80%) was isolated by column chromatography (silica gel, 2:1 hexanes:ethyl acetate) and recrystallization from isopropyl alcohol: mp 158−159 °C (lit.[37] mp 161 °C); $[\alpha]^{23}_D$ −45.6° (*c* 0.63) (lit.[37] $[\alpha]_D^{20}$ −47°); ^{1}H NMR δ 1.99 (3H, s), 2.05 (3H, s), 2.10 (3H, s), 2.19 (3H, s), 3.53 (3H, s), 3.67 (1H, ddd, J = 9.8, 5.3, 2.6 Hz), 4.16 (1H, dd,

J = 12.2, 2.6 Hz), 4.32 (1H, dd, J = 12.2, 5.3 Hz), 4.56 (1H, d, J = 1.1 Hz), 5.05 (1H, dd, J = 10.0, 3.3 Hz), 5.27 (1H, app t, J = 9.9 Hz), 5.48 (1H, dd, J = 3.3, 0.9 Hz); ^{13}C NMR δ 20.5, 20.6, 20.67, 20.74, 57.4, 62.4, 65.9, 68.5, 71.0, 72.3, 99.6, 169.5, 169.9, 170.3, 170.7.

1,2:3,4-Di-*O*-isopropylidene-6-*O*-(2,3,4,6-tetra-*O*-acetyl-*β*-D-mannopyranosyl)-α-D-galactopyranose (47). Decarboxylation Protocol B. Crude **37** (107 mg, 0.163 mmol) in anhydrous benzene (8 mL) was treated with sodium hydride (7.2 mg 60% in mineral oil, 0.18 mmol). After stirring for 30 min, a tiny drop of pyridine was added, followed by the addition of oxalyl chloride (16 μL, 23 mg, 0.18 mmol). The reaction mixture was stirred for 1 h and cannulated into a suspension of anhydrous **45** (98 mg, 0.65 mmol, dried at 100 °C under vacuum for 5 h) and t-BuSH (0.28 mL, 224 mg, 2.5 mmol) in benzene (10 mL). The resulting reaction mixture was stirred under ambient laboratory light for 15 h and then filtered through a short pad of silica gel (2:1 hexanes:ethyl acetate) to give a yellow oily residue after concentration under reduced pressure. Purification by column chromatography (silica gel, 2:1 hexanes:ethyl acetate with 1% Et_3N) afforded the title β-mannoside **47** (56 mg, 58%) as a clear oil: $[\alpha]^{23}_D$ −65.3° (*c* 0.58); ^{1}H NMR δ 1.320 (3H, s), 1.324 (3H, s), 1.44 (3H, s), 1.51 (3H, s), 1.99 (3H, s), 2.04 (3H, s), 2.09 (3H, s), 2.17 (3H, s), 3.67 (1H, ddd, J = 9.8, 5.3, 2.6 Hz), 3.77 (1H, dd, J = 12.7, 8.6 Hz), 3.96−4.02 (2H, m), 4.14 (1H, dd, J = 12.3, 2.5 Hz), 4.19 (1H, dd, J = 7.9, 1.5 Hz), 4.29 (1H, app d, J = 4.9, 2.5 Hz), 4.31 (1H, dd, J = 12.3, 5.3 Hz), 4.58 (1H, dd, J = 7.9, 2.5 Hz), 4.87 (1H, d, J = 1.0 Hz), 5.07 (1H, dd, J = 10.0, 3.4 Hz), 5.25 (1H, app t, J = 9.9 Hz), 5.49−5.51 (2H, m); ^{13}C NMR δ 20.6, 20.7, 20.81, 20.84, 24.3, 25.0, 25.9, 29.7, 62.5, 66.1, 68.2, 68.9, 69.1, 70.4, 70.7, 71.0, 71.3, 72.3, 96.2, 98.7, 108.8, 109.4, 169.7, 169.9, 170.2, 170.8. Anal. Calcd for $C_{26}H_{38}O_{15}$: C, 52.88; H, 6.49. Found: C, 53.05; H, 6.63.

Methyl 2,3,4-Tri-*O*-acetyl-6-*O*-(2,3,4,6-tetra-*O*-acetyl-*β*-D-mannopyranosyl)-α-D-glucopyranoside (48). Following decarboxylation protocol B, **40** (163 mg, 0.235 mmol) was converted to the corresponding acyl chloride with sodium hydride (10 mg, 60% in mineral oil, 0.26 mmol), oxalyl chloride (23 μL, 33 mg, 0.26 mmol), and a tiny drop of DMF followed by the treatment with sodium salt **45** and t-BuSH to give crude β-linked disaccharide **48**. Purification by column chromatography (2:1 hexanes:ethyl acetate) and recrystallization (hexanes and ether) gave disaccharide **48** (102 mg, 67%) as an amorphous solid: mp 125−126 °C (lit.[42] mp 127−128 °C); $[\alpha]^{23}_D$ +35.7° (*c* 1.05) (lit.[42] $[\alpha]^{23}_D$ +35°); ^{1}H NMR δ 1.99 (3H, s), 2.00 (3H, s), 2.02 (3H, s), 2.04 (3H, s), 2.07 (3H, s), 2.10 (3H, s),2.17 (3H, s), 3.36 (3H, s), 3.56 (1H, dd, J = 11.3, 8.2 Hz), 3.66 (1H, ddd, J = 9.8, 5.4, 2.4 Hz), 3.88−3.98 (2H, m), 4.30 (1H, dd, J = 12.1, 2.3 Hz), 4.32 (1H, dd, J = 12.2, 5.4 Hz), 4.70 (1H, d, J = 0.9 Hz), 4.81−4.96 (3H, m) 5.05 (1H, dd, J = 10.1, 3.3 Hz), 5.25 (1H, app t, J = 9.9 Hz), 5.46 (1H, app t, J = 9.7 Hz), 5.52 (1H, dd, J = 3.3, 0.9 Hz); ^{13}C NMR δ 20.5, 20.62, 20.65, 20.68, 20.7, 20.8 (2C), 55.1, 62.3, 65.8, 68.3, 68.5, 69.18, 69.24, 69.9, 70.8, 70.9, 72.4, 96.2, 99.3, 169.6, 169.85, 169.95 (2C), 170.1, 170.2, 170.7.

Isopropyl 2,3,4,6-Tetra-*O*-methyl-*β*-D-mannopyranoside (12) via the Thioesters 51 and 52. A mixture of ulosonic and keto acids **8** and **9** (300 mg), prepared, as described under **12** above, was taken up in dry benzene (3 mL) and treated with sodium hydride (46 mg, 60% in mineral oil, 1.15 mmol). One drop of DMF was added to the reaction mixture followed by addition of oxalyl chloride (99 μL, 1.15 mmol). After stirring for 2 h, the solvent was evaporated under reduced pressure and the pale blackish mixture containing the acid chlorides was dissolved in dry CH_2Cl_2 (10 mL). DMAP (138 mg, 1.15 mmol) was added to reaction mixture followed by the additon of **50** (329.6 mg, 1.15 mmol). After stirring overnight, the reaction mixture was quenched with saturated ammonium chloride solution, the aqueous phase was extracted with ethyl acetate (3 × 10 mL), and the combined organic phases were concentrated. The residue was purified by column chromatography (silica gel, 2:1 hexanes:ethyl acetate) to give a mixture (1:1.6 ratio) of the two thioesters **51** and **52** (388 mg, 70% based on **6**). IR ν (melt) 1738, 1679 cm^{-1}; ^{1}H NMR (for **51** and **52**, signals indistinguishable) δ 1.01 (3H, d, J = 6.2 Hz), 1.11 (3H, d, J = 6.2 Hz), 1.18 (8H, m), 3.34 (3H, s), 3.38 (3H, s), 3.45−3.55 (8H, m), 3.57−3.70 (3H, m), 3.77−3.95 (2H, m), 6.82 (1H, dd, J =7.5, 1.7 Hz), 7.27 (1H, td, J = 7.8, 1.8 Hz), 7.34 (1H, dd, J = 8.0, 1.6 Hz), 7.96 (1H, dd, J = 7.8, 1.4 Hz); ^{13}C NMR (**51**) δ 23.4, 23.7, 27.6, 28.0, 38.4, 40.2, 57.9, 59.7, 60.6, 61.2, 67.3, 71.5, 74.2, 75.1, 78.6, 82.8, 94.7, 102.0, 127.8, 128.1, 128.8, 143.7, 146.6, 199.7; ^{13}C NMR (**52**) δ 23.2, 23.7, 27.8, 27.8, 38.0, 40.3, 58.2, 59.5, 60.6 (2C), 68.0, 71.2, 73.8, 75.8, 78.3, 82.5, 94.5, 101.1, 128.0, 128.4, 128.8, 143.6, 146.0, 191.0, 192.2. To a solution of this mixture of thioesters (68 mg) in dry benzene (1.2 mL) was added AIBN (3 mg) and Bu_3SnH (47 mL, 0.18 mmol), and the reaction mixture was refluxed for 2 h under argon. The solvent was then evaporated and the residue purified by column chromatography (silica gel, 2:1 hexanes:ethyl acetate with 1% Et_3N) to give **12** (22 mg, 68%) identical with the sample isolated above.

Thiol Ester 53. Furan **42** (0.205 g, 0.334 mmol) was oxidized by catalytic RuO_2 and $NaIO_4$ in CCl_4, CH_3CN, and water essentially according to the standard protocol except that the solution was heated under reflux for 24 h rather than simply stirring at room temperature. In this manner the crude acid **43** was isolated (156 mg, 76%), free of the keto acid **44**. This acid was converted to the corresponding acid chloride by treatment with sodium hydride, oxalyl chloride, and DMF. The acid chloride was then converted, by treatment with **50**, to **53**, as a pale yellow oil (80 mg, 27%); ^{1}H NMR δ 1.15 (3H, d, J = 6.3 Hz), 1.29 (3H, s), 1.42 (3H, s), 1.50 (3H, s), 1.55 (3H, s), 1.93 (3H, s), 1.96 (3H, s), 2.01 (3H, s), 2.02 (3H, s), 3.32 (3H, s), 3.45 (1H, m), 3.63 (1H, m), 3.70 (2H, dd, J = 47.8, 13.4 Hz), 4.00−4.15 (4H, m), 4.37 (1H, dd, J = 12.1, 3.5Hz), 4.78 (1H, s), 5.27 (1H, dd, J = 10.2, 3.1 Hz), 5.36 (1H, t, J = 10.1 Hz), 5.53 (1H, d, J = 3.1 Hz), 6.84 (1H, td, J = 7.8, 2.0 Hz), 7.22−7.35 (2H, m), 7.95 (1H, dd, J = 7.8, 1.1 Hz); ^{13}C NMR δ 17.5, 20.6, 20.7 (3C), 26.3, 27.8, 28.0, 28.2, 38.6, 39.9, 54.7, 61.3, 64.0, 65.5, 69.6, 70.4, 70.5, 76.1, 77.4, 78.7, 94.4, 97.4, 101.4, 109.2, 128.0, 128.3, 128.6, 143.2, 146.1, 168.8, 169.5, 169.8, 170.4, 196.4; IR ν (melt) 1684, 1754 cm^{-1}. Anal. Calcd for $C_{35}H_{47}IO_{15}S$: C, 48.50; H, 5.47. Found: C, 48.68; H, 5.52.

Acknowledgment. We are grateful to the NSF (CHE 9222697) for support of this work. D.C. is a Fellow of the A. P. Sloan Foundation.

Supporting Information Available: ^{1}H- and ^{13}C-NMR spectra of **7**, **8** + **9**, **34**, **37**, **40**, **43** + **44**, and **51** + **52** (14 pages). This material is contained in libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.

JO960799Q

(42) Wulff, G.; Wichelhaus, J. *Chem. Ber.* **1979**, *112*, 2847.