Stereoselective Syntheses of α-D- and β-D-Ribofuranosides Catalyzed by the Combined Use of Silver Salts and Their Partners

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(Received April 6, 1994)

α-D-Ribofuranosides are stereoselectively synthesized in high yields from 2,3,5-tri-*O*-benzyl-1-*O*-iodoacetyl-D-ribofuranose (**1**) and trimethylsilylated nucleophiles by the use of silver salts in the coexistence of 3 molar amounts of lithium perchlorate, while β-D-ribofuranosides are prepared predominantly in high yields by the reaction of **1** and trimethylsilylated nucleophiles or 2,3,5-tri-*O*-benzyl-D-ribofuranose and free alcohols by using [diphenyltin sulfide/silver salt] or [Lawesson's reagent/silver salt] combined catalyst system.

To develop a useful method for stereoselective construction of the glycosidic linkages is a matter of utmost concern in carbohydrate chemistry because the carbohydrate parts of glycoproteins, glycolipids, antibiotics, and immunodeterminants play significant roles biologically. Many methods for the stereoselective synthesis of glycopyranosides have been reported, whereas a few examples have been known concerning the stereoselective synthesis of glycofuranosides. Most of the stereoselective synthesis of ribofuranosides are carried out by starting from 1-*O*-acetyl-D-ribofuranoses,[1,2] D-ribofuranosyl fluorides[3] or 1-chloro-D-ribofuranuronic acids.[4] There have been reported, however, a few methods on the glycosylation reaction starting from easily available C-1 free D-ribofuranoses. That is; (1) stereoselective syntheses of α-D- and β-D-ribofuranosyl disaccharides from protected ribofuranoses under basic conditions (NaH and *t*-BuOK),[5] (2) stereoselective synthesis of α-D-ribofuranosides starting from **2** and alcohols or trimethylsilylated nucleophiles with μ-oxohexabutyldiphosphorus-(2+) bis(trifluoromethanesulfonate), prepared from tributylphosphine oxide and trifluoromethanesulfonic anhydride (triflic anhydride),[6] and (3) stereoselective syntheses of α-D- and β-D-ribofuranosides from **2** and alcohols or trimethylsilylated nucleophiles by the combined use of [catecholato(2−)-*O*,*O*']oxotitanium and triflic anhydride.[7]

Recently, an efficient method was reported from our laboratory concerning the stereoselective synthesis of β-D-ribofuranosides from 2,3,5-tri-*O*-benzyl-1-*O*-trimethylsilyl-D-ribofuranose and alkyl trimethylsilyl ethers by using 1.5 molar amount of diphenyltin sulfide (Ph_2Sn=S) and 0.03 molar amount of trimethylsilyl trifluoromethanesulfonate (TMSOTf).[8] On the other hand, α-D-ribofuranosides were obtained in high yields with high stereoselectivity by addition of lithium perchlorate to the above reaction system.[8]

In the previous communications, simpler and more convenient methods have been reported for the catalytic and stereoselective syntheses of α-D- and β-D-ribofuranosides starting from stable 1-*O*-iodoacetyl-D-ribofuranose by combined use of silver salts and lithium perchlorate or Ph_2Sn=S (catalytic).[9] Also, Lawesson's reagent was effective as a partner of silver salts in the above reaction.[10] Further, C-1 free ribofuranose (**2**) was used as a glycosyl donor in the synthesis of β-D-ribofuranosides catalyzed by [Ph_2Sn=S/silver salt] and [Lawesson's reagent/silver salt] combined catalyst systems.[10]

In this paper, we would like to describe in full the efficient method for the stereoselective syntheses of α-D-ribofuranosides from **1** and trimethylsilylated nucleophiles by using silver salts in the coexistence of lithium perchlorate and of β-D-ribofuranosides by using [Ph_2Sn=S/silver salt] or [Lawesson's reagent/silver salt] combined catalyst system in the above reaction under mild conditions. Synthesis of β-D-ribofuranosides from C-1 free ribofuranose (**2**) and free alcohols by using the above combined catalyst systems is also described.

Results and Discussion

Synthesis of α-D-Ribofuranosides. First, the reaction of 2,3,5-tri-*O*-benzyl-1-*O*-bromoacetyl-D-ribofuranose with 2 molar amounts of 3-phenylpropyl trimethylsilyl ether was tried by using 0.2 molar amount of silver hexafluoroantimonate in several solvents and the corresponding ribofuranoside was obtained in high yield when dichloromethane or diethyl ether was used as a solvent (Table 1, Entries 1—5). The results indicated that 1-*O*-acyl-D-ribofuranose was effectively activated by silver salt such as silver hexafluoroantimonate by choosing suitable solvents. Next, the same reaction was carried out with 3-phenylpropyl trimethylsilyl ether (1.2 molar amount) by using 0.2 molar amount of silver salts such as $AgClO_4$, $AgSbF_6$, or AgOTf in dichloromethane and the best result was given when silver perchlorate was used (Table 1, Entries 6—8), but the yield was moderate and stereoselectivity was low. Then, several acyloxy groups, leaving groups at C-1 position of ribofuranose, were screened using 0.2 molar amount of silver perchlorate in the above reactions, and good yields were given in cases of using iodoacetyloxy and bromoacetyloxy groups (Table 1, Entries 6 and 9—13), though stereoselectivity was poor. Then, the effect of additives in the above mentioned reaction was further examined in order to achieve highly stereoselective α-glycosylation reaction.

Successful methods for the synthesis of α-D-ribofu-

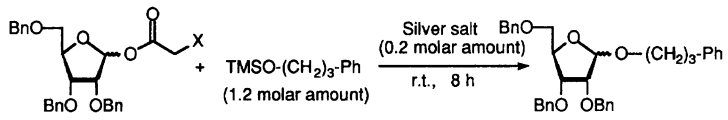


Table 1. Effects of Solvents, Silver Salts, Leaving Groups, and Lithium Perchlorate

Entry	X	Silver salt	$LiClO_4$/molar amount	Solvent	Yield/%[a]	α/β[b]
1[c]	Br	$AgSbF_6$	—	CH_2Cl_2	92	25/75
2[c]	Br	$AgSbF_6$	—	CH_3CN	Trace	—
3[c]	Br	$AgSbF_6$	—	Toluene	47	51/49
4[c]	Br	$AgSbF_6$	—	Benzene	80	37/63
5[c]	Br	$AgSbF_6$	—	Et_2O	91	37/63
6	Br	$AgClO_4$	—	CH_2Cl_2	72	49/51
7	Br	$AgSbF_6$	—	CH_2Cl_2	59	63/37
8	Br	AgOTf	—	CH_2Cl_2	41	72/28
9	I	$AgClO_4$	—	CH_2Cl_2	73	37/63
10	Cl	$AgClO_4$	—	CH_2Cl_2	12	64/36
11	OMe	$AgClO_4$	—	CH_2Cl_2	17	56/44
12	Ac	$AgClO_4$	—	CH_2Cl_2	40	76/24
13	H	$AgClO_4$	—	CH_2Cl_2	64	25/75
14	Br	$AgClO_4$	3	Et_2O	17	73/27
15	Br	$AgClO_4$	3	CH_2Cl_2	91	86/14
16	I	$AgClO_4$	3	CH_2Cl_2	90	96/4
17	Ac	$AgClO_4$	3	CH_2Cl_2	94	92/8
18	H	$AgClO_4$	3	CH_2Cl_2	87	79/21

a) Isolated yield. b) Determined by HPLC analysis. c) Two molar amounts of 3-phenylpropyl trimethylsilyl ether were used.

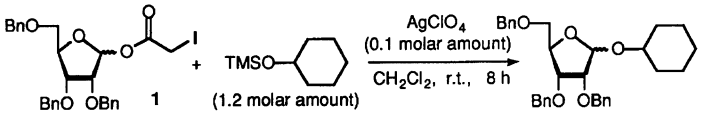


Table 2. Effect of The Amount of Lithium Perchlorate

Entry	$LiClO_4$/molar amount	Yield/%[a]	α/β[b]
1	0.2	81	28/72
2	0.5	92	57/43
3	1.0	96	94/6
4	2.0	87	97/3
5	3.0	98	97/3

a) Isolated yield. b) Determined by HPLC analysis.

ranosides have already been reported using trityl perchlorate or the combination of tin(IV) chloride and tin(II) triflate in coexistence of lithium perchlorate from 1-*O*-acetyl-D-ribofuranose and alcohols or trimethylsilylated nucleophiles.[2] The addition of lithium perchlorate was also effective in the synthesis of α-D-ribofuranosides by using [catecholato(2−)-*O*,*O*′]oxotitanium and triflic anhydride.[7] Accordingly, the glycosylation reaction of four kinds of 1-*O*-acyl-D-ribofuranoses (having bromoacetyloxy, iodoacetyloxy, acetoacetyloxy, and acetyloxy groups at C-1 position) with 3-phenylpropyl trimethylsilyl ether (1.2 molar amount) was tried in the coexistence of 3 molar amounts of lithium perchlorate under the above reaction conditions, and yields and stereoselectivity were improved in all cases (Table 1, Entries 15—18). The best result in both yield and stereoselectivity was given in the case when 1-*O*-iodoacetyl-D-ribofuranose (**1**) was employed as a glycosyl donor. In the previous communication,[9] it was noted that the choice of iodoacetyloxy group as a leaving group was pertinent while the corresponding ribofuranoside was obtained in low yield when 1-*O*-bromoacetyl-D-ribofuranose was used in diethyl ether (Table 1, Entry 14). It suggested that dichloromethane was the best solvent in the synthesis of α-D-ribofuranosides. Further, the amount of lithium perchlorate was examined in the reaction of **1** and cyclohexyl trimethylsilyl ether (1.2 molar amount) by using 0.1 molar amount of silver perchlorate and satisfactory stereoselectivity was achieved when more than equimolar amount of lithium perchlorate was employed (Table 2).

In a similar manner, the reaction with trimethylsilylated nucleophiles afforded the corresponding α-D-ribofuranosides in high yields; that is, methyl trimethylsi-

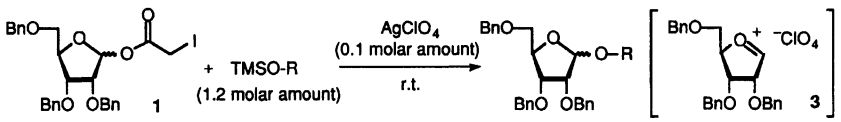
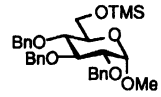
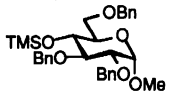
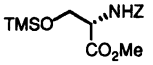
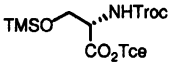


Table 3. Synthesis of α-D- and β-D-Ribofuranosides

Entry	ROTMS	Method A		Method B		Method C	
		Yield/%[a]	α/β[b]	Yield/%[a]	α/β[b]	Yield/%[a]	α/β[b]
1	Me–OTMS	95	90/10	95	5/95	—	—
2	$C_{18}H_{37}$–OTMS	99	95/5	97	5/95	96	4/96
3	Ph-$(CH_2)_3$–OTMS	96	96/4	91	5/95	—	—
4	Cyclohexyl–OTMS	98	97/3	93	4/96	—	—
5	3β-Cholestanyl–OTMS	92	97/3	83	5/95	90	3/97
6		99	88/12	88	11/89	93	11/89
7		99	88/12	59	31/69	60	32/68
8		96	83/17	96	9/91	90	9/91
9		81	87/13	82	8/92	—	—

Method A: silver perchlorate (0.1 molar amount), lithium perchlorate (3 molar amounts), dichloromethane, r.t., 3—8 h, Method B: silver perchlorate (0.1 molar amount), diphenyltin sulfide (0.2 molar amount), benzene, r.t, 3 h, Method C: silver perchlorate (0.1 molar amount), Lawesson's reagent (0.05 molar amount), toluene, r.t., 3 h. a) Isolated yield. b) Determined by HPLC analysis.

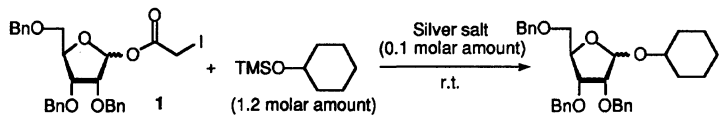


Table 4. Effect of Silver Salts

Entry	Silver salt	Method A		Method B	
		Yield/%[a]	α/β[b]	Yield/%[a]	α/β[b]
1	$AgClO_4$	97	98/2	92	5/95
2	$AgSbF_6$	95	97/3	88	4/96
3	AgOTf	98	97/3	92	4/96
4	$AgPF_6$	—	—	N.R.	—
5	$AgBF_4$	—	—	N.R.	—

Method A: lithium perchlorate (3 molar amounts), dichloromethane, 3—8 h, Method B: diphenyltin sulfide (0.2 molar amount), benzene, 3 h. a) Isolated yield. b) Determined by HPLC analysis.

lyl ether (95% yield, α/β=90/10, unpublished data), octadecyl trimethylsilyl ether (99% yield, α/β=95/5, unpublished data), 3β-cholestanyl trimethylsilyl ether (92% yield, α/β=97/3), and methyl 2,3,4-tri-*O*-benzyl-6-*O*-trimethylsilyl-α-D-glucoside (99% yield, α/β=88/22) (see Table 3, method A). The reaction also proceeded very smoothly when silver hexafluoroantimonate or silver triflate was used instead of silver perchlorate in the above reaction (Table 4, method A).

At present, the reaction is assumed to proceed via the intermediate **3** (Table 3) formed from **1** and silver salts in the coexistence of lithium perchlorate. The intermediate **3** is efficiently stabilized by the stable perchlorate anion located at β-side of the anomeric center so that the corresponding α-D-ribofuranosides would exclusively be formed by the attack of nucleophiles to the anomeric carbon from α-side.

Further, when the above α-glycosylation reaction was tried with **1** and cyclohexanol (1.2 molar amount) instead of cyclohexyl trimethylsilyl ether by using 0.1 molar amount of silver perchlorate, nearly the same result was given (97% yield, α/β=96/4).

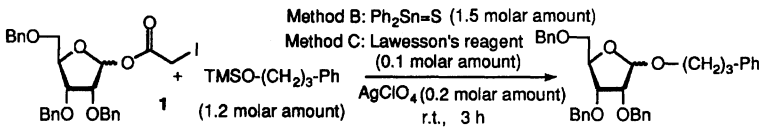


Table 5. Effect of Solvents

Entry	Solvent	Method B		Method C	
		Yield/%[a]	α/β[b]	Yield/%[a]	α/β[b]
1	CH_2Cl_2	85	8/92	85	8/92
2	1,2-Dichloroethane	90	6/94	90	7/93
3	Benzene	96	6/94	89	5/95
4	Toluene	92	4/96	93	5/95
5	Et_2O	83	32/68	85	16/84
6	CH_3CN	32	39/61	77	7/93

a) Isolated yield. b) Determined by HPLC analysis.

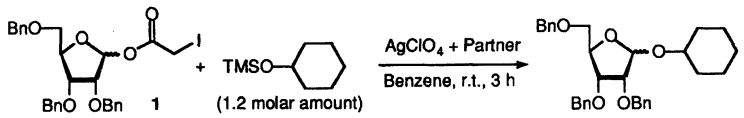
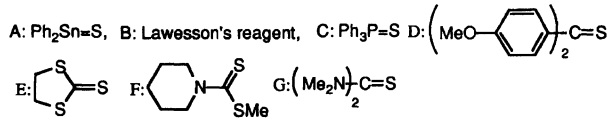


Table 6. Effect of the Partner of Silver Perchlorate

Entry	$AgClO_4$/molar amount	Partner/mol%		Yield/%[a]	α/β[b]
1	0.2	A	150	89	5/95
2	0.2	A	100	91	4/96
3	0.2	A	40	92	3/97
4	0.2	A	20	85	5/95
5	0.1	A	20	93	4/96
6	0.2	B	40	83	5/95
7	0.2	B	20	84	5/95
8	0.2	B	10	92	6/94
9	0.1	B	5	93	5/95
10	0.1	C	20	N.R.	—
11	0.1	D	20	71	6/94
12	0.1	E	20	N.R.	—
13	0.1	F	20	55	24/76
14	0.1	G	20	N.R.	—
15	0.1	—	—	22	70/30

a) Isolated yield. b) Determined by HPLC analysis.



Synthesis of β-D-Ribofuranosides—Combined Use of Silver Salts and Diphenyltin Sulfide—. In our previous communication,[8] a successful method has been reported for the synthesis of β-D-ribofuranosides using 0.03 molar amount of TMSOTf and 1.5 molar amount of $Ph_2Sn=S$ from 1-*O*-trimethylsilyl-D-ribofuranose and alkyl trimethylsilyl ethers. Then, the effect of solvents on the glycosylation reaction of **1** with 3-phenylpropyl trimethylsilyl ether was screened in several solvents by using 0.2 molar amount of silver perchlorate together with 1.5 molar amount of $Ph_2Sn=S$, and benzene gave the best yield and β-selectivity (Table 5, method B). Next, the amount of $Ph_2Sn=S$ was examined in the reaction of **1** and cyclohexyl trimethylsilyl ether by using 0.2 molar amount of silver perchlorate (Table 6) and the best result was given when 0.4 molar amount of $Ph_2Sn=S$ was used. Accordingly, the ratio of $Ph_2Sn=S$ to silver perchlorate 2 : 1 was used in subsequent experiments.

Further, the reaction proceeded smoothly even when 0.2 molar amount of $Ph_2Sn=S$ and 0.1 molar amount of silver perchlorate (Table 6) or silver triflate were used (Table 4, method B); namely, the glycosylation proceeded smoothly under mild conditions without using typical Lewis acids such as TMSOTf shown in our previous work[8] and by using a catalytic amount of $Ph_2Sn=S$.

When the reaction was carried out with various trimethylsilylated nucleophiles, the corresponding β-D-ribofuranosides were obtained in high yields except in the case of using methyl 2,3,6-tri-*O*-benzyl-4-*O*-trimethylsilyl-α-D-glucoside as a nucleophile by using 0.1 molar amount of silver perchlorate as summarized in Table 3 (method B); methyl trimethylsilyl ether (95% yield, α/β=5/95, unpublished data), octadecyl trimethylsilyl ether (97% yield, α/β=5/95, unpublished data), 3β-cholestanyl trimethylsilyl ether (83% yield, α/β=5/95) and methyl 2,3,4-tri-*O*-benzyl-6-*O*-trimethylsilyl-α-D-glucoside (88% yield, α/β=11/89).

At present, the reaction is assumed to proceed by the promotion of the new active acidic species **4**, a new type catalyst, generated from silver salt (a rather weak Lewis acid) and neutral compounds including sulfur atoms in the molecule such as $Ph_2Sn{=}S$ as shown in Fig. 1. Further, it is assumed that thermodynamically more stable β-anomer was exclusively produced under the present conditions just as known in the ordinary glycosylation reaction using a Lewis acid.

When the above β-glycosylation reaction of **1** and cyclohexanol (1.2 molar amount) was tried instead of cyclohexyl trimethylsilyl ether by using 0.1 molar amount of silver perchlorate and 0.2 molar amount of $Ph_2Sn{=}S$, the corresponding ribofuranoside was afforded in lower yield (76% yield, α/β=5/95).

Synthesis of β-D-Ribofuranosides—Combined Use of Silver Salts and Lawesson's Reagent—. Next, a partner of silver salts other than $Ph_2Sn{=}S$ was examined. The glycosylation reactions of **1** and cyclohexyl trimethylsilyl ether (1.2 molar amount) were tried by combined use of 0.1 molar amount of silver perchlorate and 0.2 molar amount of several partners in benzene, and the corresponding ribofuranoside was obtained in high yield when 0.1 molar amount of Lawesson's reagent which exists as a dimeric structure was used as a partner of silver salts. Further, it was interesting to note that the reaction was not promoted by combined use of silver perchlorate and $Ph_3P{=}S$ which had a similar structure whereas some of thiocarbonyl compounds (Table 6, D-G) slightly promoted the reaction.

Next, the effect of the ratio of silver perchlorate to Lawesson's reagent was examined. When the above reactions were carried out by using 0.2 molar amount of silver perchlorate together with 0.4, 0.2, and 0.1 molar amount of Lawesson's reagent, use of 0.1 molar amount of Lawesson's reagent gave the best result, and it was made clear that the yield was decreased when an excess amount of Lawesson's reagent was used (Table 6). Further, the effect of solvents was screened in the reaction of **1** and 3-phenylpropyl trimethylsilyl ether by using 0.2 molar amount of silver perchlorate and 0.1 molar amount of Lawesson's reagent, and toluene gave the best result (Table 5, method C). Some trimethylsilylated nucleophiles were applied to the above reaction by using 0.1 molar amount of the catalyst system and the corresponding ribofuranosides were obtained in good yields except the case when methyl 2,3,6-tri-*O*-benzyl-4-*O*-trimethylsilyl-α-D-glucoside was used (Table 3, method C).

At present, the reaction is considered to be catalyzed by the new active species (**5** and/or **6**) generated from silver salts and Lawesson's reagent as shown in Fig. 1.

Synthesis of β-D-Ribofuranosides from C-1 Free Ribofuranose and Free Alcohols. Next, in order to find a more convenient glycosylation method, a direct catalytic coupling of C-1 free ribofuranose and free alcohols in the presence of [$AgClO_4$/Lawesson's reagent] or [$AgClO_4/Ph_2Sn{=}S$] combined catalyst system was studied with the expectation that C-1 hydroxy group of ribofuranose could be successfully activated by using the above mentioned catalyst systems under mild conditions.

Concerning glycosylation reaction of C-1 free sugars with alcohols, it was recently reported that combined use of $Yb(OTf)_3$ and methoxyacetic acid effectively promoted the reaction in dichloromethane or 1,2-dichloroethane.[11] Further, the reactions of C-1 free sugars with phenols or naphthols were catalyzed by the combined use of TMSOTf and silver perchlorate.[12]

When the reaction of 2,3,5-tri-*O*-benzyl-D-ribofuranose (**2**) and cyclohexanol (1.2 molar amount) was tried in the presence of 0.2 molar amount of silver perchlorate alone in benzene at room temperature, only the starting ribofuranose **2** was recovered. On the other hand, when the reaction was carried out by combined use of silver perchlorate (0.2 molar amount) and Lawesson's reagent (0.1 molar amount) or $Ph_2Sn{=}S$ (0.4 molar amount), the corresponding ribofuranoside was obtained in moderate yield (Table 7, Entries 1 and 13). It was considered that promotion of the reaction was inhibited by water formed during the reaction; therefore, several molecular sieves (MS) were added to the reaction mixture to remove water formed during the glycosylation. When the experiments were tried after stirring the mixture of silver perchlorate, MS, and Lawesson's reagent for 15 min at room temperature, the best result was given in the case of using MS-3A (Table 7, Entries 2, 4, and 6). When the reactions were performed after stirring for 60 min in the above experiments, the yield decreased irrespective of the kind of MS (Table 7, Entries 3, 5, and 7). The results suggested that the catalyst might be decomposed by stirring with MS for a long time. After screening several solvents in the presence of MS-3A, it was made clear that toluene and benzene were the solvents of choice with respect to chemical yield and stereoselectivity (Table 7, Entries 2 and 8—12). Further, when the effect of silver salts was examined, use of silver perchlorate gave the best result ($AgClO_4$: 95% yield, α/β=4/96, $AgSbF_6$: 92% yield, α/β=3/97, AgOTf: 26% yield, α/β=28/72).

Next, diphenyltin sulfide was used as a partner of sil-

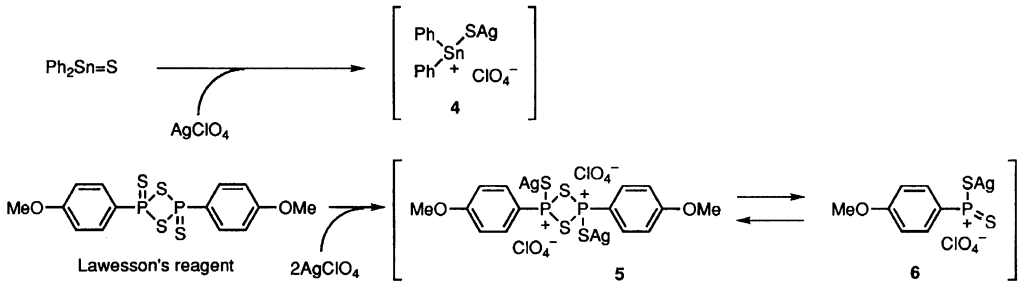


Fig. 1. Active species generated from silver perchlorate and diphenyltin sulfide or Lawesson's reagent.

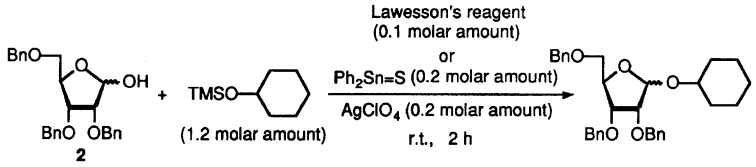


Table 7. Effects of MS and Solvents

Entry[a)]	MS	Solvent	Preparation of catalyst/min	Yield/%[b)]	α/β[c)]
1	—	Benzene	15	73	5/95
2	3A	Benzene	15	**94**	**5/95**
3	3A	Benzene	60	57	14/86
4	4A	Benzene	15	29	33/67
5	4A	Benzene	60	5	52/48
6	5A	Benzene	15	88	7/93
7	5A	Benzene	60	20	37/63
8	3A	Toluene	15	**95**	**4/96**
9	3A	CH_2Cl_2	15	91	7/93
10	3A	1,2-Dichloroethane	15	91	5/95
11	3A	Et_2O	15	70	15/85
12	3A	CH_3CN	15	N.R.	—
13	—	Benzene	2	72	4/96
14	3A	Benzene	2	**92**	**4/96**
15	3A	Toluene	2	88	4/96
16	3A	1,2-Dichloroethane	2	82	6/94
17	3A	Benzene	15	**91**	**4/96**

a) Entries 1—12: Lawesson's reagent was used; Entries 13—17: Diphenyltin sulfide was used. b) Isolated yield. c) Determined by HPLC analysis.

ver perchlorate in the above reaction. On the basis of the above data, subsequent experiments (Table 7, Entries 13—17 and Table 8) were carried out by adding MS-3A to the stirred mixture of silver perchlorate and its partner in a suitable solvent. Similar good results were obtained when the reactions were carried out after stirring silver perchlorate and Ph_2Sn=S in benzene for 2 or 15 min (Table 7, Entries 14 and 17). The reaction carried out by using catalyst system composed of $AgClO_4$/Ph_2Sn=S 1/2 and 1/1 afforded ribofuranoside in the same yield ($AgClO_4$, 0.2 molar amount, Ph_2Sn=S, 0.4 molar amount: 92% yield α/β=4/96, $AgClO_4$, 0.2 molar amount, Ph_2Sn=S, 0.2 molar amount: 92% yield, α/β=4/96). Accordingly, the conditions such that silver perchlorate and Ph_2Sn=S mol ratio was 1:1, and stirring for 2 min in benzene before the reaction were chosen.

Several alcohols which were newly added in this paper were applied to the above reaction by using the 0.2 molar amount of catalyst systems and the corresponding ribofuranosides were obtained in good yields (Table 8); that is, octadecanol, methyl 2,3,6-tri-*O*-benzyl-α-D-glucoside, and *N*-benzyloxycarbonyl-L-serine methyl ester. When *N*-benzyloxycarbonyl-L-serine methyl ester was used as a nucleophile, a better result was given by using [$AgClO_4$/Lawesson's reagent] combined catalyst system compared with that of $AgClO_4$ and Ph_2Sn=S.

It is concluded that (1) the combined use of silver salts and lithium perchlorate effectively achieved the stereoselective synthesis of α-D-ribofuranosides in high yield from **1** and alkyl trimethylsilyl ether or alcohols and (2) the combined use of silver salts and Ph_2Sn=S or Lawesson's reagent effectively catalyzed the synthesis of β-D-ribofuranosides from **1** and alkyl trimethylsilyl ethers or C-1 free ribofuranose and free alcohols.

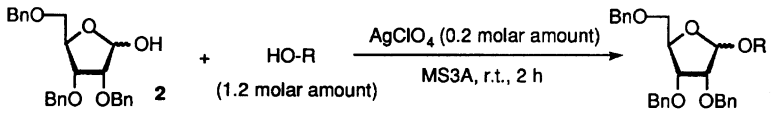
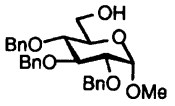
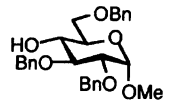
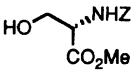


Table 8. Synthesis of β-D-Ribofuranosides from 2,3,5-Tri-*O*-benzyl-D-ribofuranose (**2**) and Alcohols

Entry	ROH	Method B		Method C	
		Yield/%[a]	α/β[b]	Yield/%[a]	α/β[b]
1	Ph–$(CH_2)_3$–OH	95	4/96	97	5/95
2	$C_{18}H_{37}$–OH	84	10/90	95	4/95
3	Cyclohexanol	92	4/96	93	5/95
4	3β-Cholestanol	90	4/96	90	4/96
5		89	13/87	79	24/76
6		67	28/72	61	30/70
7		77	46/54	96	9/91

Method B: diphenyltin sulfide (0.2 molar amount), benzene, Method C: Lawesson's reagent (0.1 molar amount), toluene. a) Isolated yield. b) Determined by HPLC analysis.

Experimental

All melting points are uncorrected. IR spectra were determined on a Horiba FT-300 spectrometer. ^{1}H NMR spectra were recorded on a JEOL JNM-EX270L spectrometer with tetramethylsilane as an internal standard. Microanalyses were performed with a Yanako C, H, N analyzer. Optical rotations were measured with a JASCO DIP-360 digital polarimeter. Purification of products was performed by column chromatography on silica gel (Merck, Art. 7734 Kieselgel 60) or preparative TLC on silica gel (Wacogel B-5F).

2,3,5-tri-*O*-benzyl-D-ribofuranose (**2**)[13] and 1-*O*-acetyl-2,3,5-tri-*O*-benzyl-β-D-ribofuranose[14] were prepared by the previously reported method. Dichloromethane, 1,2-dichloroethane, and acetonitrile were distilled successively from P_2O_5, and CaH_2, and stored over molecular sieves (MS). Diethyl ether was distilled from Na metal. Toluene and benzene were distilled from P_2O_5 and stored over MS.

Preparation of 2,3,5-Tri-*O*-benzyl-1-*O*-iodoacetyl-D-ribofuranose (1). To a suspension of KF (18 molar amount) in acetonitrile (3.8 ml) was added a solution of 2,3,5-tri-*O*-benzyl-D-ribofuranose (**2**; 2.6 mmol) and iodoacetyl chloride (1.65 molar amount) in dichloromethane (10 ml). After being stirred for 12—36 h at room temperature, the mixture was filtered through a glass filter and concentrated. The residue was purified by deactivated silica-gel column chromatography (SiO_2/H_2O=3/1, w/w) to give **1** as a mixture of α- and β-anomers (ca. 1:5) in 79% yield.

1β: Mp 79—81 °C (benzene–hexane); $[\alpha]_D^{28}$ +32.4° (*c* 1.01, $CHCl_3$); IR (KBr) 1736 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ=3.45 and 3.50 (2H, AB, *J*=10.4 Hz, $COCH_2I$), 3.59 (1H, dd, *J*=11.0 and 4.5 Hz, 5A-H), 3.72 (1H, dd, *J*=11.0 and 3.1 Hz, 5B-H), 3.92 (1H, d, *J*=4.6 Hz, 2-H), 4.13 (1H, dd, *J*=7.8 and 4.6 Hz, 3-H), 4.35—4.45 (1H, m, 4-H), 4.42 and 4.55 (2H, AB, *J*=11.9 Hz, CH_2Ph), 4.50 and 4.57 (2H, AB, *J*=12.2 Hz, CH_2Ph), 4.62 and 4.76 (2H, AB, *J*=12.2 Hz, CH_2Ph), 6.18 (1H, s, 1-H), 7.2—7.5 (15H, m); ^{13}C NMR ($CDCl_3$) δ=100.36 (C-1), 167.44 (C=O). Found: C, 57.31; H, 4.98%. Calcd for $C_{28}H_{29}O_6I$: C, 57.15; H, 4.97%.

1α: ^{1}H NMR ($CDCl_3$) δ=6.30 (1H, d, *J*=4.3 Hz, 1-H).

Preparation of 2,3,5-Tri-*O*-benzyl-1-*O*-bromoacetyl-D-ribofuranose (7) and 2,3,5-Tri-*O*-benzyl-1-*O*-chloroacetyl-D-ribofuranose (8). These compounds were prepared according to the method for the preparation of **1** and were obtained as a mixture of α- and β-anomers (**7α**:**7β**=ca. 2:13, **8α**:**8β**=ca. 2:9).

7β: IR (neat) 1753 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ=3.52 and 3.58 (2H, AB, *J*=12.7 Hz, $COCH_2Br$), 3.56 (1H, dd, *J*=11.0 and 4.3 Hz, 5A-H), 3.70 (1H, dd, *J*=11.0 and 2.8 Hz, 5B-H), 3.94 (1H, d, *J*=4.6 Hz, 2-H), 4.15 (1H, dd, *J*=7.6 and 4.6 Hz, 3-H), 4.35—4.45 (1H, m, 4-H), 4.41 and 4.54 (2H, AB, *J*=11.9 Hz, CH_2Ph), 4.46 and 4.53 (2H, AB, *J*=11.9 Hz, CH_2Ph), 4.61 and 4.74 (2H, AB, *J*=11.9 Hz, CH_2Ph), 6.20 (1H, s, 1-H), 7.2—7.4 (15H, m); ^{13}C NMR ($CDCl_3$) δ=99.82 (C-1), 165.26 (C=O). Found: C, 61.73; H, 5.39%. Calcd for $C_{28}H_{29}O_6Br$: C, 62.11; H, 5.40%.

7α: ^{1}H NMR ($CDCl_3$) δ=6.33 (1H, d, *J*=4.3 Hz, 1-H).

8β: IR (neat) 1765 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ=3.55 (1H, dd, *J*=11.2 and 4.0 Hz, 5A-H), 3.70 (1H, dd, *J*=11.2 and 3.0 Hz, 5B-H), 3.72 and 3.81 (2H, AB, *J*=15.2 Hz, $COCH_2Cl$), 3.94 (1H, d, *J*=4.6 Hz, 2-H), 4.16 (1H, dd, *J*=7.8 and 4.6 Hz, 3-H), 4.3—4.45 (1H, m, 4-H), 4.41 and 4.55 (2H, AB, *J*=11.9 Hz, CH_2Ph), 4.45 and 4.52 (2H, AB, *J*=11.9 Hz, CH_2Ph), 4.62 and 4.70 (2H, AB, *J*=11.9 Hz, CH_2Ph),

6.22 (1H, s, 1-H), 7.15—7.45 (15H, m); ^{13}C NMR ($CDCl_3$) δ=100.16 (C-1), 165.95 (C=O). Found: C, 67.37; H, 5.80%. Calcd for $C_{28}H_{29}O_6Cl$: C, 67.67; H, 5.88%.

8α: ^{1}H NMR ($CDCl_3$) δ=6.37 (1H, d, J=4.3 Hz, 1-H).

Preparation of 1-*O*-Acetoacetyl-2,3,5-tri-*O*-benzyl-D-ribofuranose (9). To a solution of **2** (7.1 mmol) and 4-dimethylaminopyridine (0.2 molar amount) in dichloromethane (30 ml) was added dropwise diketene (2 molar amounts) at 0 °C. After being stirred for 20 min at 0 °C and for 3 h at room temperature, the solvent was evaporated and the residue was purified by chromatographing twice over silica gel (first; benzene, then AcOEt/hexane=1/3. second; AcOEt/hexane=1/4) to give **9** as a mixture of α- and β-anomers in 86% yield. The pure β-anomer (**9β**) was obtained by recrystallization and used as such.

9β: Mp 80—81 °C (benzene–hexane); $[\alpha]_D^{26}$ +50.9° (c 1.01, $CHCl_3$); IR (KBr) 1753, 1712 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ=2.12 (3H, s, CH_3), 3.23 (2H, s, $COC\underline{H}_2COCH_3$), 3.56 (1H, dd, J=10.9 and 4.1 Hz, 5A-H), 3.71 (1H, dd, J=10.9 and 3.0 Hz, 5B-H), 3.97 (1H, d, J=4.3 Hz, 2-H), 4.13 (1H, dd, J=7.9 and 4.3 Hz, 3-H), 4.38 (1H, m, 4-H), 4.40 and 4.54 (2H, AB, J=11.9 Hz, CH_2Ph), 4.46 and 4.54 (2H, AB, J=11.6 Hz, CH_2Ph), 4.62 and 4.75 (2H, AB, J=12.2 Hz, CH_2Ph), 6.21 (1H, s, 1-H), 7.2—7.5 (15H, m); Enol form of **9β** was observed by ^{1}H NMR ($CDCl_3$) δ=6.27 (1/16H, s, 1H); ^{13}C NMR ($CDCl_3$) δ=99.71 (C-1), 165.82 (ester C=O), 200.05 (C=O). Found: C, 71.44; H, 6.46%. Calcd for $C_{30}H_{32}O_7$: C, 71.41; H, 6.39%.

Preparation of 2,3,5-Tri-*O*-benzyl-1-*O*-methoxyacetyl-D-ribofuranose (10). To a solution of **2** (0.59 mmol) in pyridine (1 ml) was added methoxyacetyl chloride (1.4 molar amount) at 0 °C. After being stirred for 10 min at room temperature, the mixture was poured into saturated aqueous $NaHCO_3$ cooled with ice, extracted with AcOEt, washed with saturated aqueous $CuSO_4$, dried over Na_2SO_4, and concentrated. The residue was purified by deactivated silica-gel column chromatography (SiO_2/H_2O=3/1, w/w) to give **10** as a mixture of α- and β-anomers (ca. 1:9) in 75% yield.

10β: $[\alpha]_D^{26}$ +52.4° (c 1.00, $CHCl_3$); IR (neat) 1763 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ=3.32 (3H, s, OCH_3), 3.56 (1H, dd, J=11.2 and 4.1 Hz, 5A-H), 3.71 (1H, dd, J=11.2 and 3.0 Hz, 5B-H), 3.76 and 3.86 (2H, AB, J=16.8 Hz, $COC\underline{H}_2OCH_3$), 3.93 (1H, d, J=4.6 Hz, 2-H), 4.15 (1H, dd, J=7.9 and 4.6 Hz, 3-H), 4.35—4.45 (1H, m, 4-H), 4.40 and 4.54 (2H, AB, J=11.9 Hz, CH_2Ph), 4.47 and 4.55 (2H, AB, J=12.2 Hz, CH_2Ph), 4.63 and 4.77 (2H, AB, J=12.2 Hz, CH_2Ph), 6.28 (1H, s, 1-H), 7.2—7.45 (15H, m); ^{13}C NMR ($CDCl_3$) δ=99.14 (C-1), 169.06 (C=O). Found: C, 70.56; H, 6.60%. Calcd for $C_{29}H_{32}O_7$: C, 70.71; H, 6.55%.

10α: ^{1}H NMR ($CDCl_3$) δ=6.43 (1H, d, J=4.3 Hz, 1-H).

Preparation of α-D-Ribofuranoside. A typical reaction procedure is described for the reaction of **1** and cyclohexyl trimethylsilyl ether; to a suspension of silver perchlorate (0.015 mmol) and lithium perchlorate (0.45 mmol) in dichloromethane (2.5 ml) was added a solution of **1** (0.15 mmol) and cyclohexyl trimethylsilyl ether (0.18 mmol) in dichloromethane (3.5 ml) at room temperature. After stirring the reaction for 8 h, saturated aqueous $NaHCO_3$ was added to quench it. The mixture was filtered through a celite pad, extracted with AcOEt, washed with saturated aqueous NaCl, dried over Na_2SO_4, and concentrated. The residue was purified by TLC (silica gel) to give cyclohexyl 2,3,5-tri-*O*-benzyl-α-D-ribofuranoside (95% yield) and the corresponding β-anomer (3% yield): $[\alpha]_D^{27}$ +100° (c 1.00, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ=1.1—2.05 (10H, m), 3.36 (1H, dd, J=10.6 and 4.3 Hz, 5A-H), 3.46 (1H, dd, J=10.6 and 3.6 Hz, 5B-H), 3.61 (1H, m, $OC\underline{H}(CH_2)CH_2$), 3.76 (1H, dd, J=6.8 and 4.0 Hz, 2-H), 3.84 (1H, dd, J=6.8 and 4.3 Hz, 3-H), 4.24 (1H, m, 4-H), 4.41 and 4.48 (2H, AB, J=12.2 Hz, CH_2Ph), 4.52 and 4.72 (2H, AB, J=12.9 Hz, CH_2Ph), 4.61 and 4.72 (2H, AB, J=12.2 Hz, CH_2Ph), 5.18 (1H, d, J=4.0 Hz, 1-H), 7.15—7.45 (15H, m); ^{13}C NMR ($CDCl_3$) δ=99.98 (C-1), lit,[7] $[\alpha]_D^{24}$ +97.9° (c 1.0, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ=5.17 (1H, d, J=4.0 Hz, 1-H), ^{13}C NMR ($CDCl_3$) δ=99.70 (C-1).

Physical properties of other products are as follows:

Methyl 2,3,5-Tri-*O*-benzyl-α-D-ribofuranoside. $[\alpha]_D^{29}$ +69.7° (c 1.00, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ=3.33 (1H, dd, J=10.4 and 4.3 Hz, 5A-H), 3.40 (1H, dd, J=10.4 and 4.0 Hz, 5B-H), 3.46 (3H, s, OCH_3), 3.76 (1H, dd, J=6.8 and 4.0 Hz, 2-H), 3.81 (1H, dd, J=6.8 and 2.6 Hz, 3-H), 4.25 (1H, m, 4-H), 4.40 and 4.48 (2H, AB, J=11.9 Hz, CH_2Ph), 4.57 and 4.64 (2H, AB, J=12.2 Hz, CH_2Ph), 4.57 and 4.68 (2H, AB, J=12.9 Hz, CH_2Ph), 4.87 (1H, d, J=4.0 Hz, 1-H), 7.1—7.4 (15H, m); ^{13}C NMR ($CDCl_3$) δ=102.30 (C-1), lit,[7] $[\alpha]_D^{24}$ +78.0° (c 1.8, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ=4.87 (1H, d, J=4.2 Hz, 1-H); ^{13}C NMR ($CDCl_3$) δ=102.43 (C-1), lit,[15] ^{1}H NMR ($CDCl_3$) δ=4.86 (1H, bd, J=4.0 Hz, 1-H).

Octadecyl 2,3,5-Tri-*O*-benzyl-α-D-ribofuranoside. Mp 32.5—33 °C (EtOH); $[\alpha]_D^{27}$ +58.7° (c 1.00, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ=0.88 (3H, t, J=6.6 Hz, CH_3), 1.25 (30H, s), 1.67 (2H, m, $CH_2C\underline{H}_2CH_2O$), 3.36 (1H, dd, J=10.6 and 4.3 Hz, 5A-H), 3.45 (1H, dd, J=10.6 and 3.6 Hz, 5B-H), 3.52 (1H, dt, J=10.2 and 6.9 Hz, $OC\underline{H}_2CH_2$), 3.75 (1H, dt, J=10.2 and 6.9 Hz, $OC\underline{H}_2CH_2$), 3.78 (1H, d, J=4.0 Hz, 2-H), 3.83 (1H, dd, J=6.8 and 4.0 Hz, 3-H), 4.23 (1H, m, 4-H), 4.42 and 4.49 (2H, AB, J=11.9 Hz, CH_2Ph), 4.54 and 4.70 (2H, AB, J=12.5 Hz, CH_2Ph), 4.62 and 4.68 (2H, AB, J=12.2 Hz, CH_2Ph), 5.01 (1H, d, J=4.0 Hz, 1-H), 7.2—7.4 (15H, m); ^{13}C NMR ($CDCl_3$) δ=101.22 (C-1), lit,[7] $[\alpha]_D^{23}$ +60.8° (c 1.23, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ=5.00 (1H, d, J=4.3 Hz, 1-H); ^{13}C NMR δ=101.24 (C-1).

3-Phenylpropyl 2,3,5-Tri-*O*-benzyl-α-D-ribofuranoside. $[\alpha]_D^{26}$ +74.1° (c 1.00, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ=2.00 (2H, m, $CH_2C\underline{H}_2CH_2Ph$), 2.72 (2H, m, $CH_2CH_2C\underline{H}_2Ph$), 3.36 (1H, dd, J=10.6 and 4.3 Hz, 5A-H), 3.45 (1H, dd, J=10.6 and 3.6 Hz, 5B-H), 3.56 (1H, dt, J=13.0 and 9.9 Hz, $C\underline{H}_2CH_2CH_2Ph$), 3.7—3.9 (3H, m, 2-H, 3-H and $C\underline{H}_2CH_2CH_2Ph$), 4.26 (1H, m, 4-H), 4.42 and 4.49 (2H, AB, J=12.2 Hz, CH_2Ph), 4.55 and 4.71 (2H, AB, J=12.6 Hz, CH_2Ph), 4.64 and 4.69 (2H, AB, J=12.5 Hz, CH_2Ph), 5.00 (1H, d, J=4.0 Hz, 1-H), 7.1—7.4 (20H, m); ^{13}C NMR ($CDCl_3$) δ=101.44 (C-1). Found: C, 77.67; H, 7.12%. Calcd for $C_{35}H_{38}O_5 \cdot 0.14H_2O$: C, 77.68; H, 7.13%.

3β-Cholestanyl 2,3,5-Tri-*O*-benzyl-α-D-ribofuranoside. Mp 108—111.5 °C (hexane); $[\alpha]_D^{27}$ +85.0° (c 1.00, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ=0.5—2.0 (40H, m), 0.64 (3H, s, CH_3), 0.81 (3H, s, CH_3), 3.34 (1H, dd, J=10.6 and 4.0 Hz, 5A-H), 3.44 (1H, dd, J=10.6 and 4.0 Hz, 5B-H), 3.58 (1H, m), 3.73 (1H, dd, J=6.8 and 4.2 Hz, 2-H), 3.81 (1H, dd, J=6.8 and 4.0 Hz, 3-H), 4.23 (1H, q, J=4.0 Hz, 4-H), 4.40 and 4.47 (2H, AB, J=12.2 Hz, CH_2Ph), 4.53 and 4.71 (2H,

AB, J=12.9 Hz, CH_2Ph), 4.61 and 4.70 (2H, AB, J=12.4 Hz, CH_2Ph), 5.15 (1H, d, J=4.2 Hz, 1-H), 7.15—7.45 (15H, m); ^{13}C NMR ($CDCl_3$) δ=99.68 (C-1), lit,[7] mp 112—112.4 °C; $[\alpha]_D^{26}$+84.5° (c 1.0, $CHCl_3$); ^1H NMR ($CDCl_3$) δ=5.15 (1H, d, J=4.2 Hz, 1-H); ^{13}C NMR ($CDCl_3$) δ=99.70 (C-1).

Methyl 2,3,4-Tri-*O*-benzyl-6-*O*-(2,3,5-tri-*O*-benzyl-α-D-ribofuranosyl)-α-D-glucopyranoside. $[\alpha]_D^{29}$+69.5° (c 1.00, $CHCl_3$); ^1H NMR ($CDCl_3$) δ=3.33 (3H, s, CH_3), 3.39 (1H, dd, J=10.7 and 4.1 Hz), 3.4—3.52 (2H, m), 3.62—3.82 (3H, m), 3.83—4.0 (3H, m), 4.16 (1H, dd, J=11.2 and 2.6 Hz), 4.21 (1H, m), 4.4—4.8 (10H, m), 4.42 and 4.50 (2H, AB, J=12.2 Hz, CH_2Ph), 4.81 and 4.94 (2H, AB, J=11.2 Hz, CH_2Ph), 5.15 (1H, bs), 7.15—7.45 (30H, m); ^{13}C NMR ($CDCl_3$) δ=98.04, 101.92, lit,[7] $[\alpha]_D^{26}$+82.0° (c 1.0, $CHCl_3$); ^1H NMR ($CDCl_3$) δ=5.14 (1H, d, J=2.3 Hz); ^{13}C NMR ($CDCl_3$) δ=102.07 (C-1).

Methyl 2,3,6-Tri-*O*-benzyl-4-*O*-(2,3,5-tri-*O*-benzyl-α-D-ribofuranosyl)-α-D-glucopyranoside. $[\alpha]_D^{26}$+25.9° (c 1.00, $CHCl_3$); ^1H NMR ($CDCl_3$) δ=3.20 (2H, m), 3.39 (3H, s, CH_3), 3.35—4.7 (9H, m), 3.85 (1H, t, J=9.2 Hz), 4.17 (1H, t, J=9.2 Hz), 4.33 and 4.40 (2H, AB, J=12.2 Hz, CH_2Ph), 4.43 and 4.56 (2H, AB, J=12.5 Hz, CH_2Ph), 4.61 and 4.74 (2H, AB, J=12.2 Hz, CH_2Ph), 4.90 and 5.06 (2H, AB, J=11.4 Hz, CH_2Ph), 5.63 (1H, d, J=4.3 Hz), 7.0—7.5 (30H, m); ^{13}C NMR ($CDCl_3$) δ=97.79, 101.71. Found: C, 73.82; H, 6.76%. Calcd for $C_{54}H_{58}O_{10}\cdot 0.64H_2O$: C, 73.82; H, 6.80%.

***N*-(Benzyloxycarbonyl)-*O*-(2,3,5-tri-*O*-benzyl-α-D-ribofuranosyl)-L-serine Methyl Ester.** $[\alpha]_D^{25}$+56.3° (c 1.01, $CHCl_3$); IR (neat) 1726 cm^{-1}; ^1H NMR ($CDCl_3$) δ=3.33 (1H, dd, J=10.6 and 4.0 Hz, 5A-H), 3.41 (1H, dd, J=10.6 and 3.8 Hz, 5B-H), 3.67 (3H, s, CO_2CH_3), 3.81 (1H, dd, J=6.3 and 4.0 Hz, 2-H), 3.85 (1H, dd, J=6.3 and 2.8 Hz, 3-H), 3.90 (1H, dd, J=10.4 and 3.1 Hz, $OC\underline{H}_2CH(NHZ)CO_2CH_3$), 4.14 (1H, dd, J=10.4 and 3.1 Hz, $OC\underline{H}_2CH(NHZ)CO_2CH_3$), 4.21 (1H, m, 4-H), 4.35—4.7 (3H, m, CH_2Ph and $OCH_2C\underline{H}(NHZ)CO_2CH_3$), 4.39 and 4.48 (2H, AB, J=11.9 Hz, CH_2Ph), 4.50 and 4.65 (2H, AB, J=12.5 Hz, CH_2Ph), 4.95 (1H, d, J=4.0 Hz, 1-H), 5.05 and 5.12 (2H, AB, J=12.2 Hz, CH_2Ph), 6.37 (1H, d, J=8.9 Hz, N$\underline{H}$Z), 7.15—7.4 (20H, m); ^{13}C NMR ($CDCl_3$) δ=101.08 (C-1), 156.33, 170.91, lit,[7] $[\alpha]_D^{27}$+53.2° (c 1.0, $CHCl_3$); ^1H NMR ($CDCl_3$) δ=4.95 (1H, d, J=4.0 Hz, 1-H); ^{13}C NMR ($CDCl_3$) δ=101.08 (C-1), 156.35, and 170.92.

***N*-(2,2,2-Trichloroethoxycarbonyl)-*O*-(2,3,5-tri-*O*-benzyl-α-D-ribofuranosyl)-L-serine 2,2,2-Trichloroethyl Ester.** $[\alpha]_D^{26}$+35.5° (c 1.17, $CHCl_3$); IR (neat) 1743 cm^{-1}; ^1H NMR ($CDCl_3$) δ=3.38 (1H, dd, J=10.6 and 4.0 Hz, 5A-H), 3.44 (1H, dd, J=10.6 and 4.0 Hz, 5B-H), 3.85 (1H, dd, J=6.1 and 4.0 Hz, 2-H), 3.90 (1H, dd, J=6.1 and 2.1 Hz, 3-H), 4.02 (1H, dd, J=10.5 and 3.3 Hz, $OC\underline{H}_2CH(NHTroc)CO_2Tce$), 4.21 (1H, dd, J=10.5 and 3.0 Hz, $OC\underline{H}_2CH(NHTroc)CO_2Tce$), 4.30 (1H, m, 4-H), 4.42 and 4.49 (2H, AB, J=12.2 Hz, CH_2Ph), 4.45—4.87 (9H, m), 5.02 (1H, d, J=4.0 Hz, 1-H), 6.96 (1H, d, J=8.9 Hz, N$\underline{H}$Troc), 7.15—7.5 (15H, m); ^{13}C NMR ($CDCl_3$) δ=100.58 (C-1), 154.70, 168.61. Found: C, 50.26; H, 4.43; N, 1.67%. Calcd for $C_{34}H_{35}NO_9Cl_6$: C, 50.15; H, 4.33; N, 1.72%.

Synthesis of β-D-Ribofuranosides from 2,3,5-Tri-*O*-benzyl-1-*O*-iodoacetyl-D-ribofuranose (1) and Trimethylsilylated Alcohols—Combined Use of Silver Salts and Diphenyltin Sulfide or Lawesson's Reagent—. A typical procedure is described for the reaction of **1** and cyclohexyl trimethylsilyl ether using the [$AgClO_4$/Ph_2Sn=S] combined catalyst system; to a stirred solution of $AgClO_4$ (0.015 mmol) in benzene (1 ml) was added a solution of Ph_2Sn=S (0.03 mmol) in benzene (1.5 ml). After stirring the mixture for 2 min, a solution of **1** (0.15 mmol) and cyclohexyl trimethylsilyl ether (0.18 mmol) in benzene (3.5 ml) was added to the catalyst system and stirring was continued for 3 h. Saturated aqueous $NaHCO_3$ was added to the reaction mixture, which was then filtered through a celite pad, extracted with AcOEt, washed with saturated aqueous NaCl, dried over Na_2SO_4, and concentrated. The residue was purified by TLC (silica gel) to give cyclohexyl 2,3,5-tri-*O*-benzyl-β-D-ribofuranoside (89% yield) and the corresponding α-anomer (4% yield): $[\alpha]_D^{27}$ −1.6° (c 1.0, $CHCl_3$); ^1H NMR ($CDCl_3$) δ=1.1—1.9 (10H, m), 3.53 (1H, dd, J=10.4 and 6.1 Hz, 5A-H), 3.55 (1H, m, $OC\underline{H}(CH_2)CH_2$), 3.60 (1H, dd, J=10.4 and 4.1 Hz, 5B-H), 3.83 (1H, d, J=4.6 Hz, 2-H), 4.01 (1H, dd, J=6.6 and 4.6 Hz, 3-H), 4.32 (1H, m, 4-H), 4.46 and 4.56 (2H, AB, J=11.9 Hz, CH_2Ph), 4.52 and 4.57 (2H, AB, J=12.2 Hz, CH_2Ph), 4.64 (2H, AB, J=12.5 Hz, CH_2Ph), 5.17 (1H, s, 1-H), 7.2—7.4 (15H, m); ^{13}C NMR ($CDCl_3$) δ=103.04 (C-1), lit,[7] $[\alpha]_D^{24}$ −0.8° (c 1.0, $CHCl_3$); ^1H NMR ($CDCl_3$) δ=5.17 (1H, d, J=1.3 Hz, 1-H); ^{13}C NMR ($CDCl_3$) δ=103.19 (C-1).

Physical properties of other products are as follows:

Methyl 2,3,5-Tri-*O*-benzyl-β-D-ribofuranoside. $[\alpha]_D^{28}$+23.8° (c 1.00, $CHCl_3$); ^1H NMR ($CDCl_3$) δ=3.34 (3H, s, OCH_3), 3.50 (1H, dd, J=10.6 and 5.6 Hz, 5A-H), 3.61 (1H, dd, J=10.6 and 3.8 Hz, 5B-H), 3.83 (1H, d, J=4.6 Hz, 2-H), 4.02 (1H, dd, J=6.9 and 4.6 Hz, 3-H), 4.35 (1H, m, 4-H), 4.43 and 4.54 (2H, AB, J=11.9 Hz, CH_2Ph), 4.52 and 4.58 (2H, AB, J=12.1 Hz, CH_2Ph), 4.59 and 4.66 (2H, AB, J=11.9 Hz, CH_2Ph), 4.92 (1H, s, 1-H), 7.2—7.4 (15H, m); ^{13}C NMR ($CDCl_3$) δ=106.16 (C-1), lit,[7] $[\alpha]_D^{20}$+20.0° (c 3.7, dioxane); ^1H NMR ($CDCl_3$) δ=4.91 (1H, s, 1-H), ^{13}C NMR ($CDCl_3$) δ=106.30 (C-1), lit,[15] ^1H NMR ($CDCl_3$) δ=4.89 (1H, s, 1-H).

Octadecyl 2,3,5-Tri-*O*-benzyl-β-D-ribofuranoside. Mp 41—41.5 °C (EtOH); $[\alpha]_D^{26}$ + 7.4° (c 1.0, $CHCl_3$); ^1H NMR ($CDCl_3$) δ=0.88 (3H, t, J=6.6 Hz, CH_3), 1.25 (30H, s), 1.47 (2H, m, $CH_2C\underline{H}_2CH_2O$), 3.32 (1H, dt, J=9.6 and 6.6 Hz, $OC\underline{H}_2CH_2$), 3.51 (1H, dd, J=10.6 and 5.9 Hz, 5A-H), 3.61 (1H, dd, J=10.6 and 3.8 Hz, 5B-H), 3.66 (1H, dt, J=9.6 and 6.9 Hz, $OC\underline{H}_2CH_2$), 3.86 (1H, dd, J=4.6 and 1.0 Hz, 2-H), 4.01 (1H, dd, J=6.9 and 4.6 Hz, 3-H), 4.33 (1H, m, 4-H), 4.46 and 4.57 (2H, AB, J=11.9 Hz, CH_2Ph), 4.53 and 4.58 (2H, AB, J=12.2 Hz, CH_2Ph), 4.62 and 4.69 (2H, AB, J=11.9 Hz, CH_2Ph), 5.01 (1H, d, J=1.0 Hz, 1-H), 7.2—7.4 (15H, m); ^{13}C NMR ($CDCl_3$) δ=105.25 (C-1), lit,[7] $[\alpha]_D^{23}$+9.4° (c 1.2, $CHCl_3$); ^1H NMR ($CDCl_3$) δ=5.01 (1H, d, J=1.0 Hz, 1-H), ^{13}C NMR ($CDCl_3$) δ=105.23 (C-1).

3-Phenylpropyl 2,3,5-Tri-*O*-benzyl-β-D-ribofuranoside. $[\alpha]_D^{26}$+11.2° (c 1.00, $CHCl_3$); ^1H NMR ($CDCl_3$) δ=1.80 (2H, tt, J=7.3 and 6.6 Hz, $CH_2C\underline{H}_2CH_2Ph$), 2.59 (2H, t, J=7.3 Hz, $CH_2CH_2C\underline{H}_2Ph$), 3.35 (1H, dt, J=9.6 and 6.6 Hz, $C\underline{H}_2CH_2CH_2Ph$), 3.49 (1H, dd, J=10.6 and 5.9 Hz, 5A-H), 3.61 (1H, dd, J=10.6 and 4.0 Hz, 5B-H), 3.70 (1H, dt, J=9.6 and 6.6 Hz, $C\underline{H}_2CH_2CH_2Ph$), 3.85 (1H, bd, J=4.6 Hz, 2-H), 4.02 (1H, dd, J=6.9 and 4.6 Hz, 3-H), 4.34

(1H, m, 4-H), 4.47 and 4.57 (2H, AB, J=11.9 Hz, CH_2Ph), 4.52 and 4.56 (2H, AB, J=12.2 Hz, CH_2Ph), 4.62 and 4.68 (2H, AB, J=12.2 Hz, CH_2Ph), 5.00 (1H, s, 1-H), 7.1—7.4 (20H, m); ^{13}C NMR ($CDCl_3$) δ=105.34 (C-1). Found: C, 77.87; H, 7.18%. Calcd for $C_{35}H_{38}O_5$: C, 78.04; H, 7.11%.

3β-Cholestanyl 2,3,5-Tri-*O*-benzyl-β-D-ribofuranoside. Mp 83—83.5 °C (EtOH); $[\alpha]_D^{26}$+4.5° (c 1.0, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ=0.5—2.0 (40H, m), 0.64 (3H, s, CH_3), 0.75 (3H, s, CH_3), 3.45—3.65 (1H, m), 3.51 (1H, dd, J=10.6 and 5.9 Hz, 5A-H), 3.60 (1H, dd, J=10.6 and 4.0 Hz, 5B-H), 3.83 (1H, d, J=4.9 Hz, 2-H), 4.00 (1H, dd, J=6.9 and 4.9 Hz, 3-H), 4.31 (1H, m, 4-H), 4.45 and 4.56 (2H, AB, J=11.9 Hz, CH_2Ph), 4.52 and 4.58 (2H, AB, J=12.2 Hz, CH_2Ph), 4.64 (2H, AB, J=12.9 Hz, CH_2Ph), 5.17 (1H, s, 1-H), 7.2—7.4 (15H, m); ^{13}C NMR ($CDCl_3$) δ=103.00 (C-1), lit,[7] mp 83.5—84.0 °C; $[\alpha]_D^{26}$+4.3° (c 1.0, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ=5.17 (1H, d, J=1.1 Hz, 1-H); ^{13}C NMR ($CDCl_3$) δ=103.00 (C-1).

Methyl 2,3,4-Tri-*O*-benzyl-6-*O*-(2,3,5-tri-*O*-benzyl-β-D-ribofuranosyl)-α-D-glucopyranoside. Mp 76—78 °C (Et_2O–hexane); $[\alpha]_D^{26}$+14.3° (c 1.01, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ=3.29 (3H, s, CH_3), 3.35—3.63 (5H, m), 3.71 (1H, m), 3.85—4.07 (4H, m), 4.33 (1H, m), 4.4—5.02 (13H, m), 5.07 (1H, s), 7.2—7.4 (30H, m); ^{13}C NMR ($CDCl_3$) δ=97.79, 105.68, lit,[7] $[\alpha]_D^{26}$+13.8° (c 1.1, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ=5.06 (1H, s, 1-H); ^{13}C NMR ($CDCl_3$) δ=105.78 (C-1).

Methyl 2,3,6-Tri-*O*-benzyl-4-*O*-(2,3,5-tri-*O*-benzyl-β-D-ribofuranosyl)-α-D-glucopyranoside. $[\alpha]_D^{27}$+14.6° (c 1.00, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ=3.36 (3H, s, CH_3), 3.4—3.98 (10H, m), 4.24 (1H, m), 4.35—4.55 (8H, m), 4.56 (1H, d, J=3.6 Hz), 4.60 and 4.75 (2H, AB, J=12.2 Hz, CH_2Ph), 4.82 and 4.95 (2H, AB, J=10.4 Hz, CH_2Ph), 5.39 (1H, d, J=3.0 Hz), 7.15—7.45 (30H, m); ^{13}C NMR ($CDCl_3$) δ=98.04, 106.43. Found: C, 74.30; H, 6.67%. Calcd for $C_{54}H_{58}O_{10}\cdot 0.33H_2O$: C, 74.30; H, 6.77%.

***N*-(Benzyloxycarbonyl)-*O*-(2,3,5-tri-*O*-benzyl-β-D-ribofuranosyl)-L-serine Methyl Ester.** $[\alpha]_D^{24}$+14.2° (c 1.01, $CHCl_3$); IR (neat) 1724 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ=3.36 (1H, dd, J=10.9 and 4.6 Hz, 5A-H), 3.56 (1H, dd, J=10.9 and 3.3 Hz, 5B-H), 3.62 (3H, s, CO_2CH_3), 3.71 (1H, dd, J=10.6 and 4.0 Hz, $OC\underline{H}_2CH(NHZ)CO_2CH_3$), 3.83 (1H, d, J=4.3 Hz, 2-H), 4.01 (1H, dd, J=7.6 and 4.3 Hz, 3-H), 4.10 (1H, dd, J=10.6 and 4.0 Hz, $OC\underline{H}_2CH(NHZ)CO_2CH_3$), 4.24 (1H, m, 4-H), 4.3—4.65 (5H, m, $2CH_2Ph$ and $OCH_2C\underline{H}(NHZ)CO_2CH_3$), 4.58 and 4.64 (2H, AB, J=11.9 Hz, CH_2Ph), 4.96 (1H, s, 1-H), 5.09 (2H, AB, J=12.5 Hz, CH_2Ph), 6.08 (1H, d, J=8.3 Hz, $N\underline{H}Z$), 7.2—7.4 (20H, m); ^{13}C NMR ($CDCl_3$) δ=105.30 (C-1), 156.03, 170.42, lit,[7] $[\alpha]_D^{26}$+13.9° (c 1.1, $CHCl_3$); ^{1}H NMR ($CDCl_3$) δ=4.95 (1H, s, 1-H); ^{13}C NMR ($CDCl_3$) δ=105.27 (C-1), 155.99, and 170.40.

***N*-(2,2,2-Trichloroethoxycarbonyl)-*O*-(2,3,5-tri-*O*-benzyl-β-D-ribofuranosyl)-L-serine 2,2,2-Trichloroethyl Ester.** $[\alpha]_D^{26}$+6.8° (c 0.92, $CHCl_3$); IR (neat) 1741 cm^{-1}; ^{1}H NMR ($CDCl_3$) δ=3.41 (1H, dd, J=10.9 and 3.3 Hz, 5A-H), 3.64 (1H, dd, J=10.9 and 2.6 Hz, 5B-H), 3.86 (1H, d, J=4.3 Hz, 2-H), 3.90 (1H, dd, J=11.2 and 4.6 Hz, $OC\underline{H}_2CH(NHTroc)CO_2Tce$), 4.1—4.25 (2H, m, 4-H and $OC\underline{H}_2CH(NHTroc)CO_2Tce$), 4.13 (1H, dd, J=7.9 and 4.3 Hz, 3-H), 4.36 and 4.47 (2H, AB, J=11.9 Hz, CH_2Ph), 4.52—4.8 (9H, m), 4.99 (1H, s, 1-H), 6.71 (1H, d, J=8.6 Hz, $N\underline{H}Troc$), 7.2—7.4 (15H, m); ^{13}C NMR ($CDCl_3$) δ=105.79 (C-1), 154.56, 168.16. Found: C, 50.00; H, 4.49; N, 1.66%. Calcd for $C_{34}H_{35}NO_9Cl_6$: C, 50.15; H, 4.33; N, 1.72%.

Synthesis of β-D-Ribofuranosides from 2,3,5-Tri-*O*-benzyl-D-ribofuranose (2) and Alcohols—Combined Use of Silver Salts and Diphenyltin Sulfide or Lawesson's Reagent—. A typical procedure is described for the reaction of **2** and cyclohexanol by using the [$AgClO_4$/Lawesson's reagent] combined catalyst system; to a stirred solution of $AgClO_4$ (0.015 mmol) in toluene (1 ml) was added a suspension of Lawesson's reagent (0.0075 mmol) in toluene (1.5 ml). After stirring the mixture for 15 min, MS3A (30 mg) and a mixed solution of **2** (0.15 mmol) and cyclohexanol (0.18 mmol) in toluene (3.5 ml) was successively added to the catalyst system and stirring was continued for 2 h. Saturated aqueous $NaHCO_3$ was added to the reaction mixture, which was then filtered through a celite pad, extracted with AcOEt, washed with saturated aqueous NaCl, dried over Na_2SO_4, and concentrated. The residue was purified by TLC (silica gel) to give cyclohexyl 2,3,5-tri-*O*-benzyl-β-D-ribofuranoside (88% yield) and the corresponding α-anomer (5% yield).

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