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Mechanistic and Stereochemical Studies on Ferrier Reaction by Means of Chirally Deuterated Glucose

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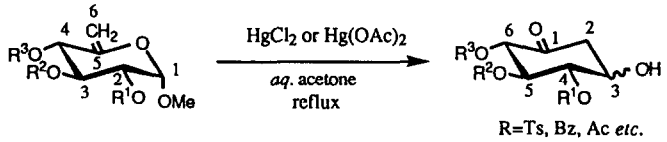
Abstract: *The mechanism of Ferrier reaction, cyclitol formation from 5-enopyranosides, was investigated by using (E)-selectively deuterated methyl [6-^{2}H]-2,3,4-tri-O-benzyl-α-D-xylo-hex-5-enopyranoside. The overall reaction was non-stereoselective with respect to the C-6 position of the substrate. Crucial organomercurial intermediates were isolated and characterized. The loss of stereochemical integrity was attributed mainly to the formation of an open-chain organomercurial and its rapid equilibrium. A mechanism involving radical intermediate is suggested.*

Introduction

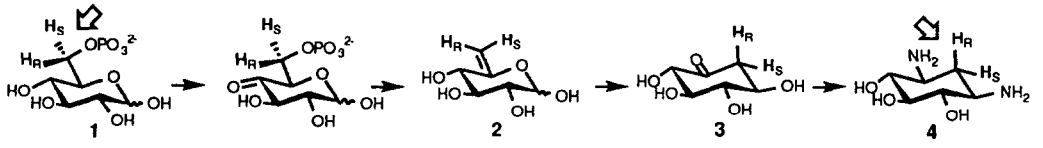
Conversion of carbohydrates into carbocycles is important and intriguing in organic synthesis as well as in biochemical transformation.[1] One such chemical approach is Ferrier reaction, which involves conversion of 5-enopyranosides to 2-deoxyinososе derivatives in the presence of Hg(II) salt as shown in Scheme 1.[2] This reaction has been recently used for the synthesis of natural products and carbocyclic analogs of carbohydrates.[3,4] Improvement and mechanistic studies of this reaction have also been reported.[2c,5,6]



R=Ts, Bz, Ac *etc.*

Scheme 1

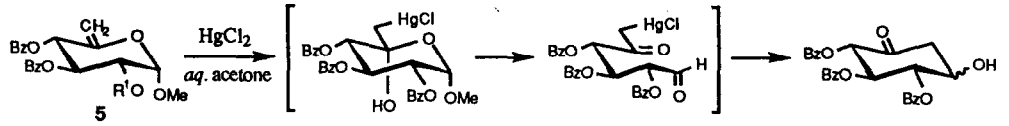
Biochemical counterpart is the reaction of 2-deoxy-*scyllo*-inososе synthase which catalyses multi-step conversion of D-glucose-6-phosphate (**1**) into 2-deoxy-*scyllo*-inososе (**3**).[7] 2-Deoxy-*scyllo*-inososе is a crucial precursor of the biosynthesis of 2-deoxystreptamine (**4**), a common central aglycon of major class of clinically important aminoglycoside antibiotics.[8] We and Akhtar *et al.* clarified a key intermediate in the 2-deoxy-*scyllo*-inososе synthase reaction to be a stereospecifically formed 5-enopyranose (**2**) as shown in Scheme 2, based on the chase experiment of chirally labeled D-glucose in the *in vivo* biosynthesis of **4**.[7,9,10]



Scheme 2

As to the mechanism of the chemical version, Ferrier *et al.* were able to isolate an organomercurial intermediate of methyl 2,3,4-tri-*O*-benzoyl-α-D-*xylo*-hex-5-enopyranoside (**5**) under relatively mild conditions, and showed that the reaction proceeds *via* oxymercuration to the enopyranoside double bond, acetal hydrolysis, and organomercurial mediated aldol-type condensation as shown in Scheme 3.[2d] However, the stereochemistry

of the overall reaction, in relation especially to the prochirality at C-6 of the starting material, has not been determined, which is quite contrastive to the corresponding biochemical version described above.

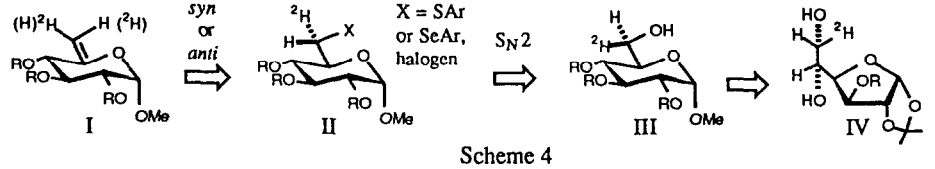


Scheme 3

This paper describes a closer insight into the mechanism of Ferrier reaction. Primary concern was the stereochemistry of cyclization from 5-enopyranosides, which was studied by chase experiment of stereoselectively deuterium labeled starting material, (*E*)-deuterated 5-enopyranoside, by using ^1H and ^2H NMR.

Preparation of (*E*)-deuterated 5-enopyranoside

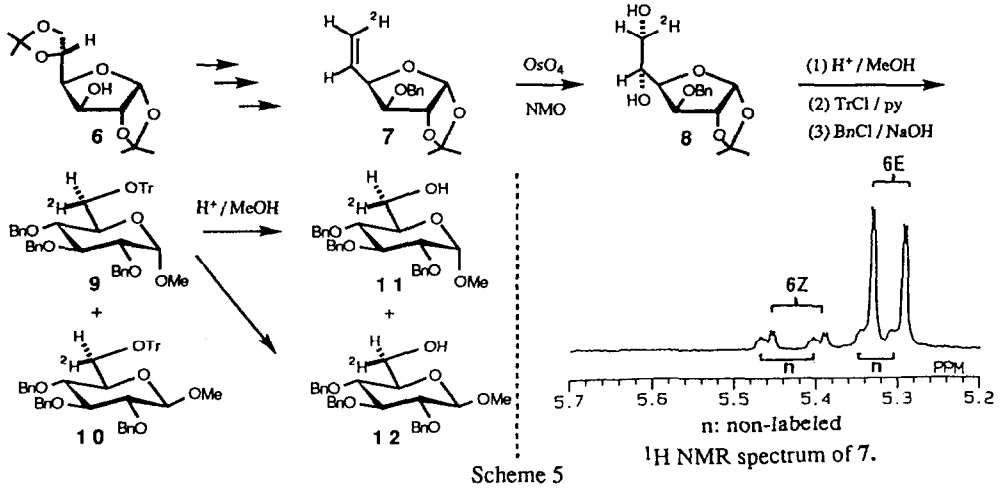
To study the fate of the C-6 hydrogens in 5-enopyranoside, selectively labeled (*E*)- or (*Z*)-[6-$^2H_1$]-5-enopyranoside was essential. The desired selectively deuterated precursors for Ferrier reaction was thought to be synthesized from a synthetic intermediate of chirally labeled glucose.[11,12] A protocol was designed to prepare methyl (6*E*)-[6-$^2H_1$]-6-deoxy-α-D-*xylo*-hex-5-enopyranoside (I) from the known (6*R*)-[6-$^2H_1$]-3-*O*-benzyl-1,2-*O*-isopropylidene-α-D-glucofuranose (IV (R=Bn))[11] as described in the retrosynthetic fashion in Scheme 4.



Scheme 4

The crucial steps were introduction of an appropriate leaving group at the C-6 of III and elimination reaction, both of which must proceed stereospecifically. Plausible methods of choice seemed to be stereospecific displacement at C-6, followed by either *anti*-specific dehydrohalogenation or *syn*-specific elimination of sulfoxide or selenoxide II.

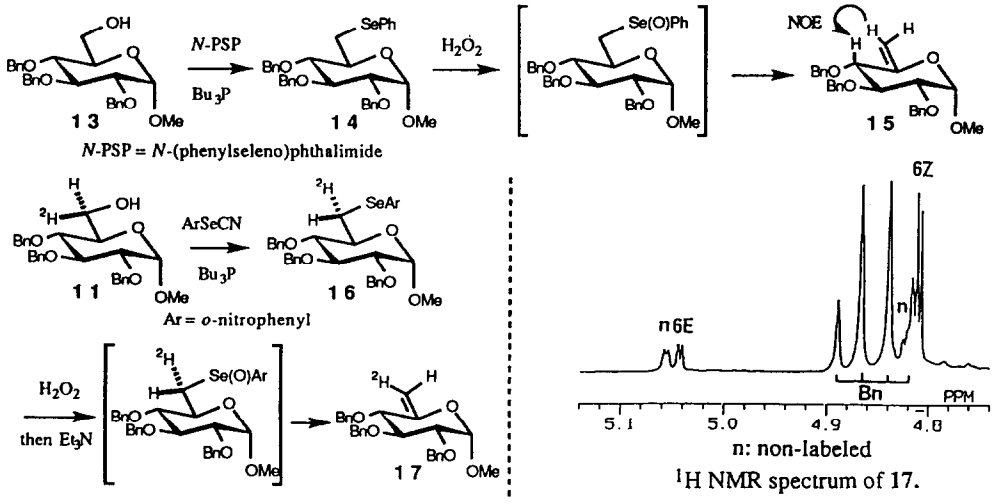
Alcohol (**11**) corresponding to III was prepared as shown in Scheme 5. (*Z*)-Labeled olefin **7** was prepared from **6** by the reported method.[11] The labeling pattern of **7** was closely analyzed by ^1H-NMR (in $CDCl_3$, see spectrum in Scheme 5). The olefinic protons of monodeuterated **7** were observed at δ 5.31 and 5.43 due to isotope shift (~ 0.02 ppm) from the olefinic protons (δ 5.33 and 5.45) of non-labeled **7**. Apparently,



Scheme 5

7 was a mixture of (*Z*)-labeled, (*E*)-labeled, and non-labeled components in a ratio of 7 : 1 : 1. Then, 7 was converted to **8** as described previously.[11] Methanolysis of **8** afforded a mixture of corresponding methyl α- and β-D-glucopyranosides (α : β = 3 : 1). The mixture was treated with chlorotriphenylmethane, and the remaining hydroxyl groups at C-2 and C-4 were benzylated to give anomers **9** and **10** which were isolated by column chromatography. The major anomer **9** was deprotected at C-6 under dilute sulfuric acid in refluxing MeOH to afford a mixture of anomers (α : β = 10 : 1), which was subjected to column chromatography to give chirally monodeuterated 2,3,4-tri-*O*-benzyl-D-glucopyranosides **11** and **12**.

In order to prepare a type-I olefin, we first attempted a method involving dehydrohalogenation, however, this approach turned out to be inappropriate because displacement of a mesylate of type-III precursor with iodide caused complete racemization at C-6. Our attention was then turned to a protocol involving elimination of selenoxide (Scheme 6). As a model study, non-deuterated methyl 2,3,4-tri-*O*-benzyl-α-D-glucopyranoside (**13**)[3a] was reacted with *N*-(phenylseleno)phthalimide-Bu_3P to afford selenide **14**,[13] which was further treated with H_2O_2 at various temperature. Usually, elimination of selenoxide was believed to proceed at 0 °C to room temperature,[14] however, no elimination was observed under these conditions and a complex mixture was formed when the mixture was heated to 60 °C. The yield of the desired olefin **15** was very low (14 %). To facilitate the elimination reaction, a more active eliminating group, *o*-nitrophenylselenoxide was introduced.[15] Treatment of **13** with *o*-nitrophenylselenocyanate-Bu_3P, followed by oxidation with H_2O_2 in the presence of Et_3N afforded, accompanying with spontaneous elimination at 60 °C, the desired olefin **15** in good yield. Using these manipulations, monodeuterated alcohol **11** was similarly converted to olefin **17** *via* selenide **16**.



^{1}H NMR spectrum of 17.

Scheme 6

The stereochemistry of the deuterated olefin **17** was firmly established by comparing ^{1}H NMR signals with those of non-labeled olefin **15**. Among the two olefinic protons (δ 4.82 and 5.06) of **15**, each having a small long-range coupling with C-4 proton (J = 1.7 Hz), NOE was observed only between the signal at δ 5.06 and the C-4 proton signal at δ 3.95. Thus, the signal at δ 4.82 is attributed to the (*Z*)-proton and the signal at δ 5.06 to the (*E*)-proton. Monodeuterated olefin **17** having one olefinic signal at δ 4.81 as a broad doublet (long-range coupling with C-4 proton) was determined to have (*E*)-geometry at C5 - C6 (see the spectrum of Scheme 6). The small signal at δ 5.04 was derived from the (*Z*)-labeled olefin, and signals at δ 4.83 and 5.06 were due to non-labeled contaminant in **17**. By estimating the deuterium content at each site by the NMR spectrum, the ratio of (*E*)-, (*Z*)- and non labeled olefins was determined to be unchanged (7 : 1 : 1) from the ratio of (*Z*)-, (*E*)- and non-labeled olefin at the stage of 7. Epimerization, if any, was negligible during the displacement and *syn* elimination process under these conditions.

Thus, stereoselectively deuterated (*E*)-olefin was successfully prepared from (6*R*)-[6-^{2}H]glucose derivative **8** without loss or randomization of the label and stereochemistry. Since the selenide displacement to **16** was believed to occur in a S_N2 manner (inversion) and selenoxide elimination to **17** should proceed in *syn* fashion, the product was expected to have the (*E*) geometry, and this was actually the case.

Ferrier reaction of (*E*)-[6-$^2H_1$]-5-enopyranoside

The resulting (*E*)-deuterated 5-enopyranoside **17** was subjected to the Ferrier reaction ($HgCl_2$ in acetone-water, reflux). As Gero *et al.* pointed out that treatment of **15** with $HgCl_2$ in aqueous acetone afforded a mixture of the cyclized products having either an axial or an equatorial hydroxyl group in a ratio of 3 : 1,[16] we also obtained a similar mixture of isomers, which in turn was separated by chromatography. The ^{1}H and ^{2}H NMR spectra of each isomeric 2-deoxyinososе derivatives **18** and **19** are displayed in Figure 1, along with the ^{2}H NMR (spectrum **a**, major (*E*): δ 5.07, minor (*Z*): δ 4.79) of starting material **17**. The C-2 methylene group in **18** and **19** appeared to be equally deuterated (spectrum **b** (**18**): δ 2.48 and 2.73, spectrum **c** (**19**): δ 2.41 and 2.70). In ^{1}H NMR of **18** and **19**, the signals of monodeuterated methylene group were observed (**18**: δ 2.46 and 2.73, **19**: δ 2.42 and 2.66) as broad doublet of equal intensity (spectrum A and B). These signals appeared with an isotope shift of ~ 0.03 ppm (**18**: δ 2.49, dd, J = 1.6 and 12.0 Hz and 2.76, dd, J = 4.8 and 12.3 Hz; **19**: δ 2.45, dd, J = 2.2 and 12.0 Hz and 2.68, dd, J = 4.5 and 12.0 Hz) from the signals of corresponding non-

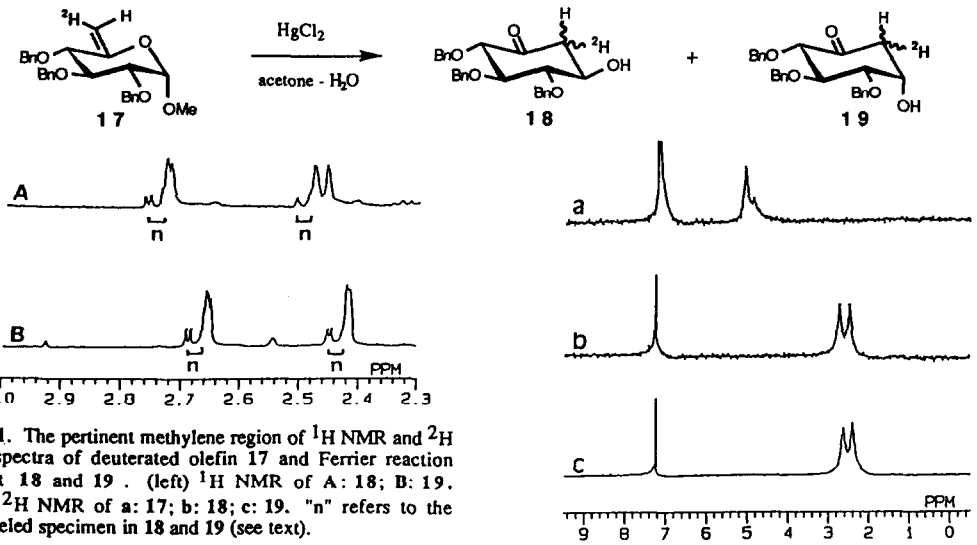
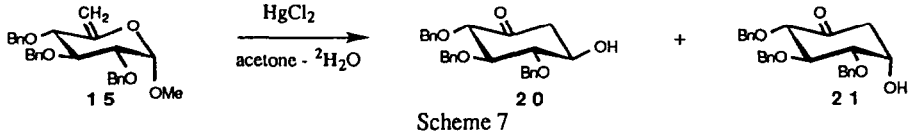


Figure 1. The pertinent methylene region of ^{1}H NMR and ^{2}H NMR spectra of deuterated olefin **17** and Ferrier reaction product **18** and **19** . (left) ^{1}H NMR of A: **18**; B: **19**. (right) ^{2}H NMR of **a**: **17**; **b**: **18**; **c**: **19**. "n" refers to the non-labeled specimen in **18** and **19** (see text).

labeled inososes. Apparently, stereochemical scrambling took place at the deuterated methylene site. Possible hydrogen-deuterium exchange at the methylene site after cyclization by keto-enol tautomerism was ruled out based on the findings that: (1) the ^{1}H NMR signal intensity of each methylene proton in the products **18** and **19** was equal corresponding to almost a half of other proton signals, and (2) similar treatment of non-labeled substrate **15** in acetone-deuterium oxide afforded 2-deoxyinososе derivatives **20** and **21** without any deuterium incorporation as judged by ^{1}H and ^{2}H NMR spectra (Scheme 7). It appears that the hydrogen and deuterium at C-6 of **17** were retained throughout the Ferrier reaction but stereochemical integrity of at C-6 was lost.

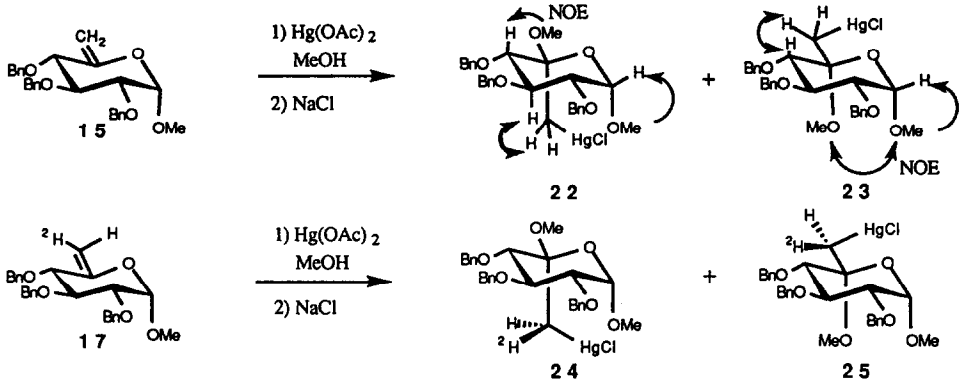


Scheme 7

Isolation and reaction of mercurial intermediates

From the mechanism proposed by Ferrier *et al.*, the reaction is supposed to proceed in 3 steps, *i.e.*, oxymercuration to the double bond, hydrolysis of acetals and intramolecular condensation of organomercurial.[2d] Each step bears possibility of the loss of stereochemical integrity at C-6 of the enopyranoside. We thus dissected Ferrier reaction to examine each step.

It was known that oxymercuration of enopyranosides performed in MeOH instead of aqueous acetone could suppress subsequent hydrolysis and oxymercuration products were isolated. Although methyl 6-acetoxymercuri-3,4-di-*O*-acetyl-2-benzylamino-2,6-dideoxy-5-methoxy-α-D-glucopyranoside and methyl 6-acetoxymercuri-3,4-di-*O*-benzoyl-2-*O*-p-toluenesulfonyl-6-deoxy-5-methoxy-α-D-glucopyranoside were isolated and characterized by Madi-Puskas *et al.*[6a] and Ferrier *et al.*,[2c] the stereochemistry at C-5 was not rigorously determined. To study facial selectivity of oxymercuration to the enopyranoside double bond, the non-labeled 5-enopyranoside **15** was treated with $Hg(OAc)_2$ in MeOH. Two products **22** and **23** were isolated by column chromatography in a ratio of 2 : 1 and characterized to be stereoisomers at C-5 as shown in Scheme 8.



Scheme 8

Stereochemistry of each product was determined by ^1H NMR NOE experiments. First, from ^{13}C NMR chemical shifts and ^1H NMR coupling constants, chair conformation was assigned for these two mercurials. Furthermore, for the major product **22**, NOEs were observed between the C-5 methoxy protons (δ 3.07, s) and the C-4 proton (δ 3.63, d, J = 9.5 Hz) and between the C-6 methylene protons (δ 2.10 and 2.32, d, J = 12.4 Hz) and C-3 proton (δ 3.89, d, J = 9.5 Hz). On the other hands in **23**, NOEs were observed between the C-6 methylene protons (δ 1.72 and 1.87, d, J=12.4 Hz) and C-4 proton (δ 3.28, d, J = 9.9 Hz), and between glycosidic methyl protons (δ 3.47, s) and the C-6 methoxy protons (δ 3.26, s) as shown in Scheme 8. Thus, the major product **22** was the 5*R* (*idose*-like) isomer and the minor product **23** was the 5*S* (*glucose*-like) isomer. The same reaction was carried out with the stereoselectively deuterated 5-enopyranoside **17**, and the isomers **24** and **25** were obtained similarly. Further, the deuterium-protium ratio at C-6 of each products **24** and **25**, shown in Figure 2, were completely identical with the ratio of that of the starting enopyranoside **17**. These results indicate that the oxymercuration step may afford (5*R*, 6*S*)- and (5*S*, 6*R*)- diastereoisomers. However, this cannot be the sole reason for the aforementioned stereochemical scrambling at C-6.

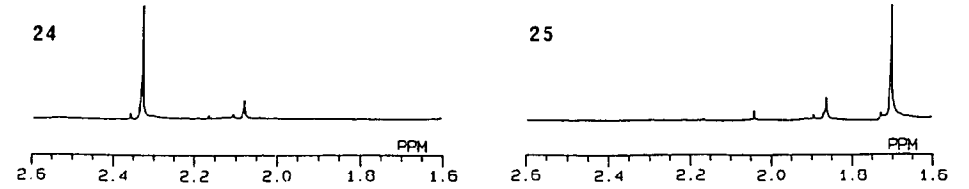
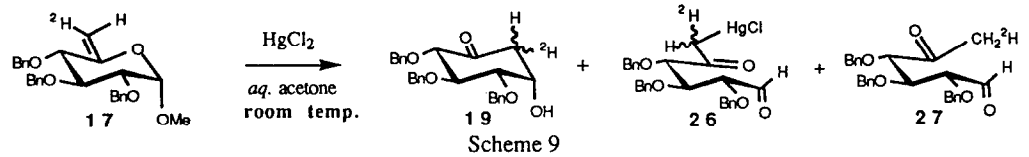


Figure 2. The pertinent methylene region of ^1H NMR spectra of deuterated methoxymercurials **24** and **25**.

We next attempted to isolate organomercurials under the same conditions to those of Ferrier *et al.* Under relatively mild conditions (room temperature),[2d] deuterated enopyranoside **17** gave organomercurial **26** and cyclitol **19**, the latter being probably formed through the third step (cyclization of organomercurial). Further, **26** was not quite stable, and a part of the organomercurial was converted to methyl ketone **27** (Scheme 9). The ^1H NMR spectrum of **26** showed two singlet signals (δ 2.47 and 2.71) due to the methylene site, however, both intensities were about a half of the remaining non-labeled sites (Figure 3). The ^2H NMR spectrum of **26** also showed two signals of equal intensity at δ 2.45 and 2.70. Apparently, the stereochemical integrity at C-6 was lost in **26**. In addition, the ^1H NMR signal intensities of two methylene hydrogen of **19** obtained simultaneously were also about a half of other hydrogens in the molecule (data not shown). Thus, **19** obtained under the relatively mild conditions had the same deuterium distribution to the product yielded under the more vigorous reaction conditions. These results strongly suggest that the loss of stereochemical integrity at C-6 during Ferrier reaction may be due to an intrinsic nature of the intermediate of cyclization stage. An additional support was provided by an experiment using isolated methoxymercurial **24**, in which **24** was subjected to the treatment with $Hg(OAc)_2$ / saturated aqueous NaCl and turned out to give mercurial **26**. The product showed a deuterium ratio of the methylene hydrogens at C-6 again as 1 : 1 (data not shown). This result further implies the above-mentioned hypothesis that loss of stereochemical integrity occurs at ring-opening and cyclization stage.



Scheme 9

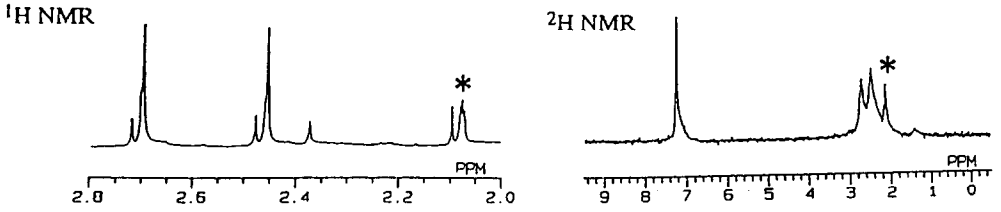


Figure 3. ^1H NMR and ^2H NMR of open-chain organomercurial intermediate **26**. "*" is the monodeuterated methyl signal of contaminated **27**.

Discussion

Based on isotope-tracer experiment with stereoselectively monodeuterated **17** and isolation of the relevant intermediates, the overall Ferrier reaction appeared to be non-stereoselective with respect to C-6 of the starting material. First, the facial selectivity (2 : 1) of the oxymercuration to the double bond of the precursory enopyranoside **15** causes partial, but not all, stereochemical scrambling. Since chair conformation could be assigned to the starting enopyranoside **15** (and **17**), the major isomer of the oxymercuration was determined to be formed through axial approach of mercuric acetate to the *exo*-olefin attached to the six-membered ring. It is well precedented that, in the electrophilic reactions, axial approach of electrophile is predominant,[17] and this tendency is ascribed mainly to 1,2-steric interaction between allylic hydrogen and the approaching reagent. The same was true in the above oxymercuration. Since the compound **15** has one such allylic hydrogen at C-4, it seems reasonable that the idose-type of (5*R*) product (**22**) turned out to be predominant. Conversely, 1,3-steric interaction between the glycosidic methyl group and mercuric acetate might reduce selective formation of 5*R* isomer to some extent. Although the standard Ferrier reaction is performed in the presence of water instead of methanol, the facial selectivity of oxymercuration may not be varied significantly. Thus, it seems inappropriate that the complete racemization at C-6 of the substrate during Ferrier reaction is ascribed to the facial selectivity of oxymercuration.

As mentioned above, complete loss of stereochemical integrity at C-6 took place in the overall Ferrier reaction, and racemization at C-6 was observed at the stage of open-chain mercurial **26**. These results appear to indicate rapid equilibrium involving C-Hg bond cleavage occur in **26** to form sp^2-natured carbon at C-6. Since the C-6 methylene group is far from the stereogenic moiety in **26**, diastereoselective equilibrium does not take place. To get an insight into the nature of C-Hg bond of **26**, the reaction pathway of C-Hg bond cleavage was studied by the use of semi-empirical molecular orbital calculations on the model compound, (1-chloromercurio)acetone (**28**) (Figure 4). MNDO-PM3 calculations with MOPAC (version 6.01)[18] indicated homolytic cleavage of C-Hg bond in **28** was energetically the most preferable pathway. The resulting energy profile of such fission was as follow; (1) the energy difference between the most stable conformer of the ground state of **28** (dihedral angle of O-C-C-Hg is 180°) and the state of acetone radical with HgCl radical was 31 kcal/mol; and (2) the energy difference from the reactive conformer of **28** (dihedral angle of O-C-C-Hg is 90°) and the transition state with the C-Hg bond cleaved was 34 kcal/mol. The C-Hg bond is extremely weak and fission of the bond can take place to form radical species even at room temperature. Thus, although it is to be experimentally proved, the most plausible reason for the loss of stereochemical integrity at C-6 during Ferrier reaction is the formation of radical intermediate, which in turn is a reactive species in the cyclization step. While the formation of enol or mercuric enolate as a reactive species cannot completely be ruled out, it is less likely because deuterium exchange did not take place as mentioned already. Isolation, characterization and reaction of α-keto organomercurials were reported previously.[19,20]

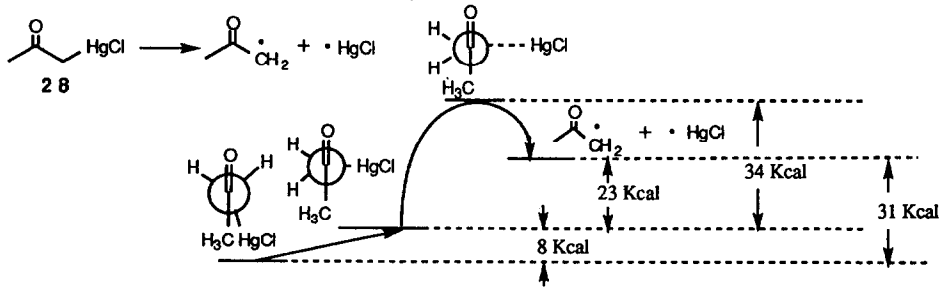
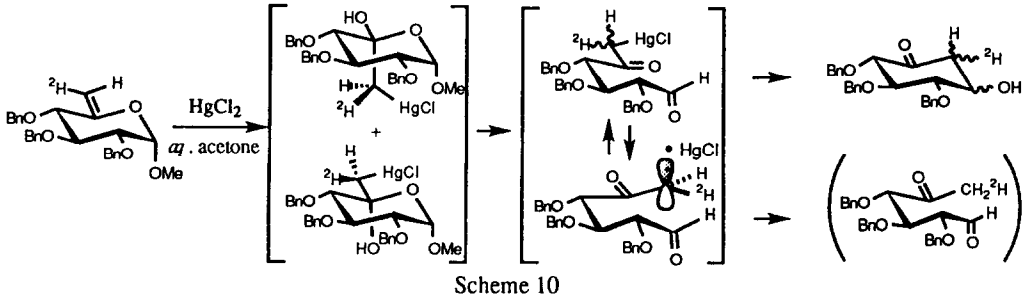


Figure 4. Energy diagram of homolysis of C-Hg bond in **28**.

It seems worth-noting that methoxymercurials **22** and **23** were separately treated with $HgCl_2$ in aqueous acetone to give in both cases a mixture of isomeric 2-deoxyinososes, and the isomer ratios were almost the same as from the enopyranoside **15** under the normal conditions. The tendency of formation of an axially oriented hydroxyl group at C-3 of the products remains to be solved. Bender *et al.* recently reported similar observations. Several (*E*)- and (*Z*)-6-*O*-acetyl-5-enopyranosides were subjected to Ferrier reaction to yield fully functionalized inosose derivatives.[21] The oxymercuration step was reported to give two isomers as was observed in our study. Further, the isomer ratio of the newly formed hydroxyl groups (C-2 and C-3 of inososes) in the cyclized products were totally unrelated to the isomer ratio of the oxymercuration products. These results may support our suggestion that radical cyclization of organomercurial operates in Ferrier reaction as shown in Scheme 10.



Scheme 10

Experimental

Melting points were measured on a Yanagimoto hot stage apparatus and are uncorrected. Infrared spectra were obtained with a Hitachi Model 260-10 grating spectrophotometer. ^{1}H NMR spectra were recorded with either a JEOL FX-200, GSX-270, or a GSX-500 spectrometer using tetramethylsilane as an internal standard. ^{13}C NMR spectra were recorded on a JEOL FX-200, GSX-270 or a GSX-500 spectrometer in a $CDCl_3$ solution using the central line of the solvent signal as the chemical shift standard (δ = 77.0 ppm). ^{2}H NMR spectra were recorded with a JEOL GSX-500 spectrometer in a $CHCl_3$ or C_6H_6 solution using natural abundance ^{2}H signal of $CHCl_3$ (δ = 7.26 ppm) or C_6H_6 (δ = 7.20 ppm) as an internal standard. Optical rotations were measured using a JASCO DIP-360 digital polarimeter. HREIMS spectra were recorded on a Hitachi M-80A or JEOL JMS-AX505HA mass spectrometer with an acceleration voltage at 70 eV. HRFABMS spectra were measured on a JEOL JMS-HX110H spectrometer (FAB gun, Xe; matrix, glycerol). All reactions were carried out under inert argon or nitrogen atmosphere. Chromatographic separations were carried out with Merck Kieselgel 60, 70-230 mesh columns. The "work up as usual" refers to washing of the combined organic layer with 1N-HCl, saturated aqueous $NaHCO_3$ and brine, drying over anhydrous Na_2SO_4, and filtration and evaporation of the solvent.

Methyl (6*R*)-[6-^{2}H$_1$]-2,3,4-tri-*O*-benzyl-6-*O*-triphenylmethyl-α-D-glucopyranoside (9) and methyl (6*R*)-[6-^{2}H$_1$]-2,3,4-tri-*O*-benzyl-6-*O*-triphenylmethyl-β-D-glucopyranoside (10).

To a solution of 671 mg (2.16 mmol) of **8**[11] in 12 ml of MeOH was added 0.1 ml of concentrated sulfuric acid and the resulting mixture was stirred at 80 °C for 22 hr. The reaction mixture was concentrated to about 6 ml, then diluted with EtOAc, and water was added. Layers were separated and the aqueous layer was further extracted with EtOAc (20 ml x 5). After work up as usual, 542 mg of a crude triol was obtained. To a solution of 519 mg (1.82 mmol) of the triol in 2 ml of pyridine was added 740 mg (5.55 mmol) of chlorotriphenylmethane and 100 mg of *N*-dimethylaminopyridine, and the mixture was stirred at 60 °C for 1 hr. After being cooled to room temperature, the mixture was diluted with ether and water was added. Layers were separated and the aqueous layer was further extracted with EtOAc (50 ml x 3). After work up as usual, products were purified with column chromatography to give 752 mg of a diol mixture. To a solution of the mixture (718 mg, 1.36 mmol) in 5 ml of dimethylsulfoxide was added finely powdered sodium hydroxide (200 mg) and benzyl chloride (0.4 ml, 439 mmol, 3.5 mmol). The mixture was stirred at room temperature for 30 min. The whole mixture was diluted with ether, then added to cold 1N-HCl solution for neutralization. The whole was transferred into a separatory funnel, and the organic layer was separated. The aqueous layer was reextracted with ether (20 ml x 3). After work up as usual, the products were purified by column chromatography (hexane : EtOAc = 10 : 1) to give **9** (747 mg, 52 %) and **10** (205 mg, 14 % for 3 steps). **9**; $[\alpha]_D^{25}$ +17.1° (*c* = 1.03, $CHCl_3$); IR ($CHCl_3$): 3020, 2910, 1425, 1360, 1065 cm^{-1}; ^{1}H NMR (270 MHz): δ 3.44 (3H, s, OMe), 3.48 (1H, d, *J* = 2.0 Hz, H-6), 3.61 (1H, t, *J* = 9.4 Hz, H-4), 3.62 (1H, dd, *J* = 3.1 and 9.3 Hz, H-2), 3.79 (1H, dd, *J* = 2.0 and 9.5 Hz, H-5), 3.96 (1H, t, *J* = 9.3 Hz, H-3), 4.29 (1H, d, *J* = 10.9 Hz, Bn), 4.68 (1H, d, *J* = 10.9 Hz, Bn), 4.73 (1H, d, *J* = 12.1 Hz, Bn), 4.75 (1H, d, *J* = 3.1 Hz, H-1), 4.80 (1H, d, *J* = 10.0 Hz, Bn), 4.83 (1H, d, *J* = 12.1 Hz, Bn), 4.94 (1H, d, *J* = 10.0 Hz, Bn), 7.20-7.65 (aromatic); ^{13}C NMR (67.5 MHz): δ 54.90, 70.20, 73.33, 74.95, 75.94, 78.13, 80.22, 82.27, 86.29, 97.88, 126.90, 127.5-128.7, 137.92, 138.30, 138.70, 143.96. *Anal.* Calcd. for $C_{47}H_{45}{}^2HO_6$: C, 79.75; H+^{2}H, 6.55. Found, C, 79.65; H+^{2}H, 6.60. **10**; $[\alpha]_D^{25}$ +4.3° (*c* = 1.09, $CHCl_3$); IR ($CHCl_3$): 3020, 2910, 1425, 1360, 1070, 1045 cm^{-1}; ^{1}H NMR (270 MHz): δ 3.41 (1H, dd, *J* = 2.0 and 9.5 Hz, H-5), 3.54 (1H, dd, *J* = 8.2 and 9.4 Hz, H-2), 3.58 (1H, d, *J* = 2.0 Hz, H-6), 3.61 (1H, t, *J* = 9.4 Hz, H-4), 3.66 (3H, s, OMe), 3.81 (1H, t, *J* = 9.2 Hz, H-3), 4.37 (1H, d, *J* = 9.9 Hz, Bn), 4.38 (1H, d, *J* = 8.1 Hz, H-1), 4.69 (1H, d, *J* = 10.9 Hz, Bn), 4.76 (1H, d, *J* = 11.1 Hz, Bn), 4.79 (1H, d, *J* = 10.8 Hz, Bn), 4.90 (1H, d, *J* = 11.1 Hz, Bn), 4.97 (1H, d, *J* = 10.8 Hz, Bn), 7.20-7.65 (aromatic); ^{13}C NMR (67.5 MHz): δ 56.58, 74.49, 74.82, 75.01, 75.93, 77.19, 77.87, 82.61, 84.65, 104.58, 126.90, 127.5-128.7, 137.92, 138.49, 138.63, 143.90. *Anal.* Calcd for $C_{47}H_{45}{}^2HO_6$: C, 79.75; H+^{2}H, 6.55. Found, C, 79.80; H+^{2}H, 6.73.

Methyl (6*R*)-[6-^{2}H$_1$]-2,3,4-tri-*O*-benzyl-α-D-glucopyranoside (11) and methyl (6*R*)-[6-^{2}H$_1$]-2,3,4-tri-*O*-benzyl-β-D-glucopyranoside (12).

To a solution of 748 mg (1.06 mmol) of **9** in 10 ml of MeOH and 2 ml of THF was added 0.2 ml of concentrated H_2SO_4 and the resulting mixture was heated with stirring under reflux for 30 min. The mixture

was cooled to room temperature, concentrated to *ca.* 5 ml, then diluted with ether, and water was added. The whole mixture was transferred into a separatory funnel and the organic layer was separated, and the aqueous layer was further extracted with ether (30 ml x 3). After work up as usual, the mixture (714 mg) was purified by column chromatography (hexane : EtOAc = 7 : 1 to 2 : 1) to give **11** (375 mg, 76 %) and **12** (42 mg, 9 %). **11**; $[\alpha]_D^{25}$ +17.1° (*c* = 1.33, $CHCl_3$); IR ($CHCl_3$): 3600, 3020, 2925, 1460, 1215, 1065 cm^{-1}; ^1H NMR (270 MHz): δ 2.40 (1H, br), 3.36 (3H, s, OMe), 3.49 (1H, dd, *J* = 3.4 and 9.5 Hz, H-2), 3.51 (1H, t, *J* = 9.2 Hz, H-4), 3.64 (1H, dd, *J* = 2.6 and 9.3 Hz, H-5), 3.74 (1H, d, *J* = 2.6 Hz, H-6), 3.99 (1H, t, *J* = 9.2 Hz, H-3), 4.57 (1H, d, *J* = 3.4 Hz, H-1), 4.65 (1H, d, *J* = 11.1 Hz, Bn), 4.67 (1H, d, *J* = 11.9 Hz, Bn), 4.78 (1H, d, *J* = 11.1 Hz, Bn), 4.83 (1H, d, *J* = 11.2 Hz, Bn), 4.88 (1H, d, *J* = 11.1 Hz, Bn), 4.98 (1H, d, *J* = 11.2 Hz, Bn), 7.20-7.60 (aromatic); ^{13}C NMR (50 MHz): δ 55.01, 60.81 (t, *J* = 21 Hz), 70.52, 73.21, 74.81, 75.51, 77.23, 79.80, 81.75, 97.94, 123.4-129.4, 137.9-138.4. HREIMS: Calcd. for $C_{27}H_{28}{}^2HO_6$ (M^+-CH_3), 450.2027; Found, 450.2036. **12**; mp 73-75 °C, $[\alpha]_D^{25}$ +7.50° (*c* = 1.15, $CHCl_3$); IR ($CHCl_3$): 3600, 3020, 2925, 1460, 1220, 1075 cm^{-1}; ^1H NMR (500 MHz): δ 1.95 (1H, br), 3.36 (1H, dd, *J* = 2.4 and 9.5 Hz, H-5), 3.40 (1H, dd, *J* = 8.0 and 9.2 Hz, H-2), 3.57 (3H, s, OMe), 3.58 (1H, t, *J* = 9.4 Hz, H-4), 3.67 (1H, t, *J* = 9.2 Hz, H-3), 3.87 (1H, d, *J* = 2.4 Hz, H-6), 4.35 (1H, d, *J* = 8.0 Hz, H-1), 4.64 (1H, d, *J* = 10.9 Hz, Bn), 4.71 (1H, d, *J* = 11.3 Hz, Bn), 4.81 (1H, d, *J* = 10.8 Hz, Bn), 4.86 (1H, d, *J* = 10.9 Hz, Bn), 4.91 (1H, d, *J* = 11.3 Hz, Bn), 4.93 (1H, d, *J* = 10.8 Hz, Bn) and 7.20-7.60 (aromatic); ^{13}C NMR (50 MHz): δ 57.25, 61.56 (t, *J* = 22 Hz), 74.78, 74.93, 75.02, 75.80, 77.50, 82.34, 84.41, 104.74, 123.4-129.4, 137.9-138.4. *Anal.* Calcd for $C_{28}H_{31}{}^2HO_6$: C, 72.24; H+^{2}H, 6.93. Found: C, 72.42; H+^{2}H, 6.74.

Methyl 2,3,4-tri-*O*-benzyl-6-deoxy-6-phenylseleno-α-D-glucopyranoside (14).

To a solution of 111 mg (0.24 mmol) of **13**[3a] in 1 ml of THF was added 0.5 ml (2.0 mmol) of tributylphosphine and 150 mg (0.50 mmol) of *N*-(phenylseleno)phthalimide. The resulting mixture was stirred at 0 °C for 1 hr, then diluted with ether, and water was added to the mixture. The whole mixture was transferred into a separatory funnel, the organic layer was separated and the aqueous layer was further extracted with ether. After work up as usual, product was purified by column chromatography (hexane : EtOAc = 10 : 1 to 2 : 1) to give **14** (91 mg, 63 %). $[\alpha]_D^{25}$ + 21.8° (*c* = 0.74, $CHCl_3$); IR ($CHCl_3$): 3010, 2950, 1455, 1360, 1075, 1045 cm^{-1}; ^1H NMR (270 MHz): δ 2.94 (1H, dd, *J* = 8.1 and 12.0 Hz, H-6a), 3.29 (1H, dd, *J* = 2.5 and 12.0 Hz, H-6b), 3.37 (1H, t, *J* = 9.1 Hz, H-4), 3.39 (3H, s, OMe), 3.53 (1H, dd, *J* = 3.5 and 9.3 Hz, H-2), 3.88 (1H, ddd, *J* = 2.5, 8.1 and 9.1 Hz, H-5), 3.98 (1H, t, *J* = 9.2 Hz, H-3), 4.55 (1H, d, *J* = 10.8 Hz, Bn), 4.57 (1H, d, *J* = 3.3 Hz, H-1), 4.64 (1H, d, *J* = 11.9 Hz, Bn), 4.78 (1H, d, *J* = 12.0 Hz, Bn), 4.81 (1H, d, *J* = 10.6 Hz, Bn), 4.90 (1H, d, *J* = 10.6 Hz, Bn), 4.97 (1H, d, *J* = 10.6 Hz, Bn) 7.20-7.60 (aromatic); ^{13}C NMR (50 MHz, $CDCl_3$): δ 30.18, 55.24, 70.14, 73.32, 75.13, 75.74, 80.03, 81.52, 81.87, 97.83, 126.5-128.92, 131.99, 137.99. *Anal.* Calcd for $C_{34}H_{36}O_5Se$: C, 67.65; H, 6.01. Found: C, 67.39; H, 6.05.

Methyl 2,3,4-tri-*O*-benzyl-6-deoxy-α-D-*xylo*-hex-5-enopyranoside (15)

To a solution of **14** (78 mg, 0.13 mmol) in 1 ml of THF was added 150 μl of 30 % H_2O_2. The mixture was stirred at 0°C for 17 hr, and then heated with stirring at 60 °C for 48 hr. The reaction mixture was diluted with ether, and water was added. After work up as usual, the residue (78 mg) was purified by column chromatography (hexane : EtOAc = 7 : 1 to 4 : 1) to give **15** (7.8 mg, 14 %).[3a,16]

Methyl (6*S*)-[6-$^2H_1$]-2,3,4-tri-*O*-benzyl-6-deoxy-6-(*o*-nitrophenyl)seleno-α-D-glucopyranoside (16).

To a solution of **11** (414 mg, 0.89 mmol) in 3 ml of pyridine was added 1 ml of Bu_3P and 600 mg of (*o*-nitrophenyl)selenocyanate.[13] The mixture was stirred at room temperature for 24 hr, then water was added. The whole mixture was transferred into a separatory funnel, and then extracted twice with EtOAc. After work up as usual, the mixture (1.96 g) was purified by column chromatography (hexane : EtOAc = 10 : 1 to 2 : 1) to give **16** (514 mg, 89 %). mp 75-78 °C; $[\alpha]_D^{25}$ +16.0° (*c* = 0.60, $CHCl_3$); IR ($CHCl_3$): 3000, 2920, 1505, 1340, 1065 cm^{-1}; ^1H NMR (270 MHz): δ 2.74 (1H, d, *J* = 8.8 Hz, H-6), 3.36 (3H, s, OMe), 3.39 (1H, t, *J* = 9.1 Hz, H-4), 3.55 (1H, dd, *J* = 3.5 and 9.4 Hz, H-2), 3.90 (1H, t, *J* = 9.2 Hz, H-5), 3.99 (1H, t, *J* = 9.2 Hz, H-3), 4.55

(1H, d, J = 3.3 Hz, H-1), 4.65 (1H, d, J=11.1 Hz, Bn), 4.66 (1H, d, J = 11.9 Hz, Bn), 4.80 (1H, d, J = 11.9 Hz, Bn), 4.82 (1H, d, J = 10.6 Hz, Bn), 4.97 (1H, d, J = 10.5 Hz, Bn), 5.01 (1H, d, J = 11.1 Hz, Bn) and 7.20-7.70 (aromatic); ^{13}C NMR (125 MHz): δ 28.16 (t, J = 26 Hz), 55.43, 69.53, 73.37, 75.24, 76.44, 80.06, 81.51, 81.96, 97.96, 125.31, 126.26, 127.6-128.4, 129.34, 133.56, 138.02, 138.13, 138.60, 146.87. HREIMS: Calcd for $C_{34}H_{34}{}^2H_1O_7NSe$ (M^+-CH_3OH), 618.1376; Found, 618.1374.

Methyl (*E*)-[6-$^2H_1$]-2,3,4-tri-*O*-benzyl-6-deoxy-α-D-*xylo*-hex-5-enopyranoside (17)

To a solution of **16** (514 mg, 0.79 mmol) in 4 ml of THF was added 1 ml of 30 % H_2O_2 and the mixture was stirred at room temperature for 5 hr. To the mixture was then added 3 ml of triethylamine and the whole was heated with stirring at 60 °C for 36 hr. The reaction mixture was diluted with ether, and water was added. The whole mixture was transferred into a separatory funnel, and extracted repeatedly with ether. After work up as usual, the mixture (528 mg) was purified with column chromatography (hexane : EtOAc = 7 : 1 to 4 : 1) to give **17** (212 mg, 60 %). mp 50-51 °C; $[\alpha]_D^{25}$ -35.4° (c = 0.43, $CHCl_3$); IR ($CHCl_3$): 3020, 2950, 1655, 1460, 1095 ;^{1}H NMR (500 MHz, C_6D_6): δ 3.21 (3H, s, OMe), 3.57 (1H, dd, J = 3.2 and 9.2 Hz, H-2), 3.92 (1H, dd, J = 1.9 and 9.1 Hz, H-4), 4.25 (1H, t, J = 9.1 Hz, H-3), 4.44 (1H, d, J = 11.9 Hz, Bn), 4.56 (1H, d, J = 11.9 Hz, Bn), 4.65 (1H, d, J = 11.0 Hz, Bn), 4.66 (1H, d, J = 3.3 Hz, H-1), 4.70 (1H, d, J = 11.0 Hz, Bn), 4.82 (1H, d, J = 1.9 Hz, H-6), 4.83 (1H, d, J = 11.6 Hz, Bn), 4.87 (1H, d, J = 11.6 Hz, Bn) 7.20-7.60 (aromatic); ^{13}C NMR (125 MHz, $CDCl_3$): δ 55.44, 73.59, 74.46, 75.75, 79.22, 79.48, 81.16, 96.52 (t, J = 26 Hz), 99.02, 127.6-128.5, 137.90, 153.57. HREIMS: Calcd for $C_{28}H_{29}{}^2HO_5$ (M^+), 447.2156; Found, 447.2122.

Ferrier reaction of monodeuterated enopyranoside 17.

To a solution of **17** (43 mg, 0.10 mmol) in 3 ml of acetone was added $HgCl_2$ (52 mg, 0.19 mmol) in 1.5 ml of water. The mixture was heated with stirring under reflux for 1.5 hr, cooled to room temperature, and then water was added. The mixture was extracted repeatedly with EtOAc. After work up as usual, the products were purified by column chromatography (hexane : EtOAc = 2 : 1) to give **18** (3.8 mg, 9 %) and **19** (20.2 mg, 49 %). **18**; $[\alpha]_D^{25}$ -8.30° (c = 0.13, $CHCl_3$); IR ($CHCl_3$): 3560, 3025, 2920, 1740, 1205, 1080 cm^{-1}; ^{1}H NMR (500 MHz): δ 2.40 (1H, brs, -OH), 2.46, (1/2 H, d, J = 10.9 Hz, H-6), 2.73 (1/2 H, d, J = 4.7 Hz, H-6), 3.67-3.73 (3H, m), 4.15 (1H, m), 4.54 (1H, d, J = 11.3 Hz, Bn), 4.70 (1H, d, J = 11.5 Hz, Bn), 4.74 (1H, d, J = 11.5 Hz, Bn), 4.91(1H, d, J = 11.3 Hz, Bn), 4.92 (1H, d, J = 11.5 Hz, Bn), 4.99 (1H, d, J = 11.0 Hz, Bn), 7.20-7.60 (aromatic). HREIMS: Calcd for $C_{27}H_{27}{}^2HO_5$ (M^+), 433.1998; Found, 433.2007. **19**; $[\alpha]_D^{25}$ -59.4° (c = 0.20, $CHCl_3$); IR ($CHCl_3$): 3560, 3025, 2920, 1740, 1205, 1080; ^{1}H NMR (500 MHz): δ 2.42 (1/2 H, brs, H-6), 2.49 (1H, s, OH), 2.66 (1H, d, J = 2.8 Hz, H-6), 3.79 (1H, dt, J = 2.8 and 6.9 Hz, H-4), 4.03 (2H, m, H-2 and 3), 4.23 (1H, brt, J = 2.8 Hz, H-3), 4.56 (1H, d, J = 11.9 Hz, Bn), 4.72 (1H, d, J = 11.3 Hz, Bn), 4.80 (1H, d, J=10.9 Hz, Bn), 4.81 (1H, d, J = 10.9 Hz, Bn), 4.92 (1H, d, J = 10.9 Hz, Bn), 4.95 (1H, d, J = 11.9 Hz, Bn), 7.20-7.60 (aromatic). HREIMS: Calcd for $C_{27}H_{27}{}^2HO_5$ (M^+), 433.1998; Found, 433.2000.

Ferrier reaction of non-labeled enopyranoside 15 in deuterium oxide.

To a solution of **15** (62 mg, 0.14 mmol) in 2 ml of acetone was added $HgCl_2$ (90 mg, 0.33 mmol) in 1 ml of deuterium oxide. The mixture was heated with stirring under reflux for 1.5 hr, cooled to room temperature, and the solvent was evaporated. EtOAc was added to the residue, and then saturated aqueous NaCl was added. The whole mixture was transferred into a separatory funnel, and extracted repeatedly with EtOAc. After work up as usual, products were purified by column chromatography (hexane : EtOAc = 2 : 1) to give **20** (4.5 mg, 9 %) and **21** (21.8 mg, 49 %), which were characterized by previously reported spectral data.[16]

Oxymercuration of non-labeled olefin 15 in MeOH.

To a solution of **15** (36 mg, 0.080 mmol) in 2 ml of MeOH was added $Hg(OAc)_2$ (53 mg, 0.17 mmol) and the mixture was stirred at room temperature for 2 hr. To the reaction mixture was added *ca.* 10 ml of saturated aqueous NaCl solution. After several minutes, the whole mixture was extracted with EtOAc. After work up as usual, products were purified by column chromatography (hexane : EtOAc = 3 : 1 to 1 : 1) to give

methyl 2,3,4-tri-*O*-benzyl-6-chloromercuri-6-deoxy-5-methoxy-β-L-idopyranoside **22** (38 mg, 67 %) and methyl 2,3,4-tri-*O*-benzyl-6-chloromercuri-6-deoxy-5-methoxy-α-D-glucopyranoside **23** (18 mg, 31 %). **22**; $[\alpha]_D^{25}$ -2.72° (*c* = 3.06, $CHCl_3$); IR ($CHCl_3$): 3000, 2920, 1445, 1350, 1060 cm^{-1}; ^1H NMR (270 MHz): 2.10 (1H, d, *J* = 12.4 Hz, H-6a), 2.32 (1H, d, *J* = 12.4 Hz, H-6b), 3.07 (3H, s, OMe), 3.45 (3H, s, OMe), 3.56 (1H, dd, *J* = 4.2 and 9.5 Hz, H-2), 3.63 (1H, d, *J* = 9.5 Hz, H-4), 3.89 (1H, t, *J* = 9.5 Hz, H-3), 4.64 (1H, d, *J* = 4.2 Hz, H-1), 4.66 (1H, d, *J* = 12.0 Hz, Bn), 4.75-4.85 (4H, Bn), 4.93 (1H, d, *J* = 11.4 Hz, Bn), 7.15-7.35 (aromatic); ^{13}C NMR (67.5 MHz, $CDCl_3$): δ 34.64, 48.51, 56.74, 73.55, 75.44, 75.70, 78.22, 79.09, 79.89, 98.68, 104.83, 127.7-129.3, 137.08, 137.89, 138.38. *Anal.* Calcd for $C_{29}H_{33}O_6ClHg$: C, 48.81; H, 4.66. Found: C, 49.02; H, 4.86. **23**; $[\alpha]_D^{25}$ +34.5° (*c* = 1.34, $CHCl_3$); IR ($CHCl_3$): 3000, 2920, 1450, 1355, 1060 cm^{-1}; ^1H NMR (270 MHz): 1.72 (1H, d, *J* = 12.3 Hz, H-6), 1.87 (1H, d, *J* = 12.4 Hz, H-6), 3.26 (3H, s, OMe), 3.28 (1H, d, *J* = 9.9 Hz, H-4), 3.47 (3H, s, OMe), 3.57 (1H, dd, *J* = 4.9 and 9.5 Hz, H-2), 4.28 (1H, t, *J* = 9.9 Hz, H-3), 4.50 (1H, d, *J* = 4.9 Hz, H-1), 4.64 (1H, d, *J* = 12.2 Hz, Bn), 4.78 (1H, d, *J* = 11.8 Hz, Bn), 4.81 (1H, d, *J* = 12.2 Hz, Bn), 4.89 (1H, d, *J* = 10.7 Hz, Bn), 5.01 (1H, d, *J* = 11.8 Hz, Bn), 5.02 (1H, d, *J* = 10.7 Hz), 4.93 (1H, d, *J* = 11.4 Hz, Bn), 7.15-7.35 (aromatic); ^{13}C NMR (67.5 MHz, $CDCl_3$): δ 35.09, 49.09, 58.48, 73.57, 75.03, 75.92, 78.20, 80.35, 82.33, 100.38, 103.51, 127.6-129.3, 137.38, 138.07, 138.57. *Anal.* Calcd for $C_{29}H_{33}O_6ClHg$: C, 48.81; H, 4.66. Found: C, 49.06; H, 4.96.

Oxymercuration of monodeuterated olefin 17 in MeOH.

By the procedure described for the preparation of **22** and **23**, 45 mg of monodeuterated olefin **17** was treated with 72 mg of $HgCl_2$ in 2 ml of MeOH to give **24** (35 mg, 49 %) and **25** (24 mg, 33 %). **24**; $[\alpha]_D^{20}$ -4.16° (*c* = 1.07, $CHCl_3$); IR ($CHCl_3$): 3000, 2920, 1445, 1350, 1065 cm^{-1}; ^1H NMR (500 MHz): 2.30 (1H, s, H-6), 3.06 (3H, s, OMe), 3.44 (3H, s, OMe), 3.56 (1H, dd, *J* = 4.0 and 9.3 Hz, H-2), 3.63 (1H, d, *J* = 9.5 Hz, H-4), 3.88 (1H, t, *J* = 9.5 Hz, H-3), 4.64 (1H, d, *J* = 4.2 Hz, H-1), 4.66 (1H, d, *J* = 10.6 Hz, Bn), 4.77 (1H, d, *J* = 10.0 Hz, Bn), 4.78 (1H, d, *J* = 11.1 Hz, Bn), 4.80 (1H, 1H, d, *J* = 10.0 Hz), 4.81 (1H, d, *J* = 11.1 Hz, Bn), 4.93 (1H, d, 10.6 Hz, Bn), 7.15-7.35 (aromatic); ^{13}C NMR (67.5 MHz, $CDCl_3$): δ 48.52, 56.73, 73.52, 75.43, 75.70, 78.19, 79.01, 79.89, 98.69, 104.78, 127.7-129.3, 137.08, 137.89, 138.41. HRFABMS: Calcd for $C_{29}H_{33}{}^2HO_6Hg^{35}Cl$ ($M+H^+$), 716.1813; Found, 716.1808. **25**; $[\alpha]_D^{20}$ +32.8° (*c* = 1.03, $CHCl_3$); IR ($CHCl_3$): 3000, 2920, 1445, 1350, 1065 cm^{-1}; ^1H NMR (500 MHz): δ 1.70 (1H, s, H-6), 3.26 (3H, s, OMe), 3.28 (1H, d, *J* = 9.4 Hz, H-4), 3.47 (3H, s, OMe), 3.58 (1H, dd, *J* = 4.4 and 9.7 Hz, H-2), 4.28 (1H, t, *J* = 9.5 Hz, H-3), 4.50 (1H, d, *J* = 4.4 Hz, H-1), 4.65 (1H, d, *J* = 11.5 Hz, Bn), 4.79 (1H, d, *J* = 11.9 Hz, Bn), 4.81 (1H, d, *J* = 11.5 Hz, Bn), 4.87 (1H, 1H, d, *J* = 10.4 Hz), 5.00 (1H, d, *J* = 11.0 Hz, Bn), 5.01 (1H, d, *J* = 10.4 Hz, Bn), 7.15-7.35 (aromatic); ^{13}C NMR (67.5 MHz, $CDCl_3$): δ 49.07, 58.47, 73.57, 75.03, 75.89, 78.20, 80.39, 82.39, 100.40, 103.50, 127.7-129.2, 137.40, 138.07, 138.53. HRFABMS: Calcd for $C_{29}H_{33}{}^2HO_6Hg^{35}Cl$ ($M+H^+$), 716.1813; Found, 716.1793

Isolation of monodeuterated organomercurial.

To a solution of **17** (41 mg, 0.092 mmol) in 1 ml of acetone was added $HgCl_2$ (90 mg, 0.33 mmol) in 0.5 ml of water. The mixture was stirred at room temperature for 3.5 hr, and then water was added. The mixture was extracted repeatedly with EtOAc. After work up as usual, the products were purified by column chromatography (hexane : EtOAc = 2 : 1) to give 26 mg of **26** and 10 mg of **19**. Trace amount of **20** being observed on TLC was not isolated. The presence of small amount of methyl ketone **27** was observed by ^1H NMR spectrum. **26**: ^1H NMR (500 MHz): δ 2.47 (1/2 H, s, H-6), 2.70 (1/2 H, d, H-6), 3.94 (1H, d, *J* =4.9 Hz, H-4), 4.11 (1H, d, *J* = 4.3 Hz, H-2), 4.25 (1H, dd, *J* = 4.3 and 4.9 Hz, H-3), 4.44-4.61 (5H, m), 4.73 (1H, d, *J* = 12.1 Hz, Bn), 7.10-7.35 (aromatic), 9.86 (1H, s, aldehyde).

Conversion of methoxymercurial 24 to open-chain mercurial 26.

To a solution of **24** (17 mg, 0.024 mmol) in 1.5 ml of acetone was added $HgCl_2$ (71 mg, 0.26 mmol) in 0.5 ml of water. The mixture was stirred at room temperature for 2 hr, and then saturated aqueous NaCl was added. The mixture was extracted repeatedly with EtOAc. After work up as usual, products were purified by

column chromatography (hexane : EtOAc = 2 : 1) to give 15 mg of **26** with a small amount of **27**. ^{1}H NMR of the product was identical with the product from **17**.

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