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THE SELECTIVE BOND CLEAVAGE OF D-GLUCOSE AND D-GALACTOSE BY THE TITANIUM(IV) CHLORIDE-CATALYZED PHOTOREACTION

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Photoreaction of D-glucose and D-galactose in methanol in the presence of titanium(IV) chloride induced a selective bond cleavage at the C5 - C6 position, and produced pentodialdose derivatives.

Previously we reported that the irradiation of a ketone in methanol in the presence of titanium(IV) chloride induced a C - C bond formation between ketone and alcohol molecules to produce a 1,2-diol.[1] The reaction has been schemed as involving metal- and photo-induced electron transfer from alcohol to ketone, followed by a proton transfer to produce radical species, all the processes occurring consecutively within the coordination sphere of the metal ion. These findings led us to seek a method of cyclization utilizing a molecule having both carbonyl and hydroxyl groups within a molecule, and we chose carbohydrates as a possible candidate. Actually, however, the irradiation of D-glucose and D-galactose induced a selective cleavage of the C - C bond, instead of the expected bond formation to produce a carbocyclic ring system.

A methanol solution (200 cm^3) of D-glucose (1, 2.0 g) and titanium(IV) chloride (1.5 cm^3) was irradiated with a high-pressure mercury lamp in a quartz tube for 24 h. The deep blue solution was neutralized with dil $NaOH_{aq}$, and the solid material was filtered off. The filtrate was evaporated to dryness and the whole residue was shaken with ethyl acetate several times. The combined extract was concentrated in vacuo and the residue (1,8 g) was distilled under reduced pressure. After some amount of forerun, the main fraction (1.4 g) was obtained as an oil, bp 89 - 90 °C/0.07 mmHg.[2] Although the fraction (named fraction A) indicated only one peak on a HPLC (column: LiChrosorb RP-18, RP-8, or Si 60), the following facts revealed that the fraction A was a mixture of α- and β-isomers of D-xylo-pentodialdose derivative 2a. Thus the reaction was now proved to be a selective C5 - C6 bond cleavage of 1 giving the main product in 60% yield.

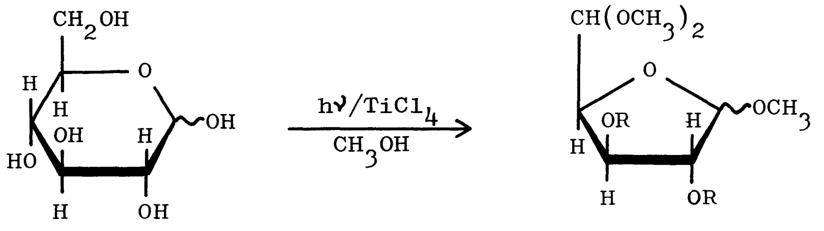
The ^{1}H-NMR spectrum of the fraction A showed a couple of singlets of methoxyl at δ 3.3 - 3.5, 9H, a broad singlet of hydroxyl at δ 3.7, 2H (disappeared by D_2O), and multiplets of other protons at δ 4.0 - 5.0, 5H. Although the spectrum was consistent with the structure 2a, the conclusive information on the structure was derived from the analysis on its derivatives.

Acetylation of the fraction A produced two products B and C, which were separated on a preparative GLC. ^{13}C-NMR spectrum of the major fraction B, which was obtained in pure state, showed the presence of two acetal carbons (δ 107.3 and 102.1), three methoxyl carbons (δ 80.67, 78.91, and 74.36), three secondary alcohol carbons (δ 55.62, 54.45, and 52.96), and acetyl carbons (δ 169.4 and 20.76). Its ^{1}H-NMR spectrum also indicated the presence of two acetyl groups (δ 2.14, s, 3H and δ 2.16, s, 3H), three methoxyl groups (δ 3.39, s, 3H, δ 3.43, s, 3H, and δ 3.47, s, 3H), and five other protons (δ 4.15 - 5.55, m, 5H). Although the minor fraction C was not completely freed from the fraction B, the subtraction of the ^{13}C-NMR spectrum of the fraction B from that of the fraction C gave a very similar spectrum of the former. We assigned the two components as either α- or β-isomer of methyl D-xylo-pentodialdoside dimethyl acetal diacetate (2b) respectively. The spectroscopic data for the fraction C are as follows; ^{13}C-NMR: δ 101.4 and 100.5 for acetal, δ 77.53, 74.50, and 73.90 for methoxyl, δ 55.78, 54.45, and 53.02 for alcohol, and δ 169.4 and 20.75 for acetyl carbons. ^{1}H-NMR: δ 2.13 - 2.18, 6H for acetyl, δ 3.39 - 3.44, 9H for methoxyl, and δ 4.20 - 5.55, 5H for other protons.

Methylation of the fraction A produced two methylated compounds, α- and β-2c, which were separated on a preparative GLC. Both indicated similar mass spectra; CI-Mass: m/z 206 and 205 ($M^+ - OCH_3$, base peak). EI-Mass: m/z 205 ($M^+ - OCH_3$), 173, 161, 145, 117, 101, 89, and 75 (base peak).

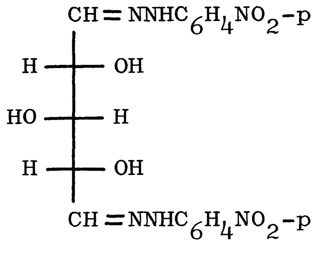
Finally bis-p-nitrophenylhydrazone 3 prepared from the fraction A was shown identical with the authentic sample (mp and mixed mp 192 °C).[3)]

The lower-boiling material was mainly 4, a product from methanol under the present irradiation conditions,[4)] thus indicating that the multiple bond cleavage to produce smaller fragments was occurring only to a minor extent.



1

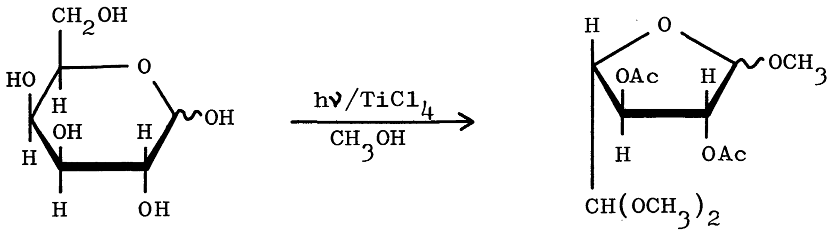
2 a: R = H
b: R = CH_3CO
c: R = CH_3



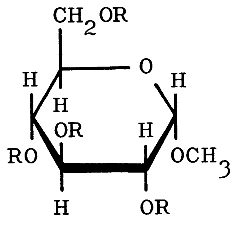
3

$ClCH_2CH(OCH_3)_2$

4

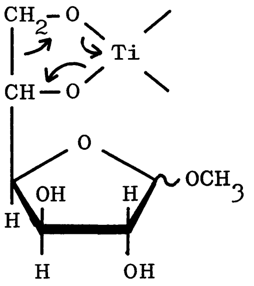


5 6



7 a: $R = H$

b: $R = CH_3CO$



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The same type reaction was also observed with D-galactose (5), which produced 6 after the acetylation. However, methyl α-glucopyranoside (7a) did not undergo the present reaction, and tetraacetate 7b was recovered after the acetylation.

It is known that D-glucose and D-galactose, under acidic conditions in methanol, produce the corresponding methyl α- and β-furanosides as primary products, which ultimately isomerize to the stable methyl pyranosides.5) We schemed the present reaction as involving an electron transfer within a titanium chelate formed from the 1,2-diol system of the furanoside as shown in 8. In our previous studies of the titanium(IV) chloride-catalyzed photoreaction of ketones and alcohols, we have observed that the reaction proceeded only with primary alcohols, probably because the primary alcohols are more likely to coordinate to the titanium ion. The good selectivity as observed in the present reaction could be rationalized by the same trend that the reaction would proceed most efficiently at the 1,2-diol system including primary alcohol. The lack of the reactivity of 1,2-diol system containing only secondary alcohols was evident from the inertness of 7a, which can not isomerize to the more unstable furanoside.

Recently the photoreaction of D-fructose in the presence of iron(III) chloride was reported to produce D-erythrose as a single product.6) This reaction is an oxidative bond cleavage at the carbonyl position, and is analogous to the reaction pattern by lead(IV) acetate. Our reaction is characteristic in that it induces a specific bond cleavage which otherwise needs a protection of the particular hydroxyl groups.[3)]

The present reaction is a formal reversal of our previously-reported C - C bond formation under the same reaction conditions. We have found that aldehydes are more reluctant to the bond-forming reaction than ketones, although aldehydes do undergo the reaction under appropriate conditions.[7)] The problem of the reversibility of the reaction will be discussed elsewhere.

References

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4) Confirmed by a control experiment.
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