Action of Strong Acids on Acetylated Glucosides

III.* Strong Acids and Aliphatic Glucoside Tetraacetates in Acetic Anhydride-Acetic Acid Solutions

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This paper deals with the conditions under which acetylated β-glucosides can be transformed into the corresponding α-glucosides. The catalysts used hitherto are stannic chloride[1], titanium tetrachloride[2], hydrogen bromide-mercuric bromide[3], and boron trifluoride[4]. None of these catalysts are suitable for a kinetic study of transglycosidation. Three of them are known to catalyze reactions of the Friedel-Crafts type, as is also the case with sulfuric acid. Reactions, catalyzed by sulfuric acid, however, might be expected to take place in uncolored, homogeneous solutions, and its action on acetylated glucosides has been investigated in solutions of acetic anhydride-acetic acid.

Relatively few kinetic investigations have been carried out previously in this field. Jungius[5] studied the transformation of β-glucose pentaacetate into the equilibrium mixture of α- and β-pentaacetates, catalyzed by zinc chloride in acetic anhydride, and found the reaction to be of the first order. Hann and Hudson[6] extended the experiments to a glycoside, methyl α-mannoside tetraacetate. The latter was transformed into α-mannose pentaacetate in a mixture of sulfuric acid, acetic anhydride and acetic acid. They found that the reaction is of the first order. Finally, Freudenberg and Soff[7] acetolyzed a number of glucosides and found that the composition of the final product is not constant. In addition to α- and β-glucose pentaacetate, varying amounts of glucose heptaacetate were found.
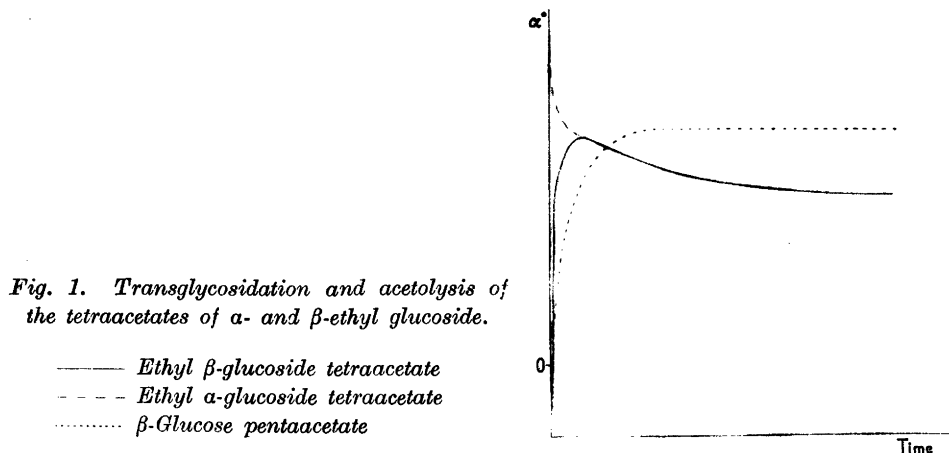
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* Part II. *Acta Chem. Scand.* 2 (1948) 534.

SELECTION OF THE EXPERIMENTAL CONDITIONS

The experiments of Jungius using zinc chloride as a catalyst, were first reproduced. The reaction was of the first order, but the velocity constant differed considerably from that obtained by Jungius. It was found that the velocity was dependent to a great extent upon the small amounts of acetic acid present in the anhydride or formed when the reagents were not perfectly anhydrous. It was possible to obtain higher values than those recorded by Jungius when working with very pure acetic anhydride under anhydrous conditions. On the addition of small amounts of acetic acid the velocity decreased considerably. Difficulty was experienced in obtaining reproducible results, and the experiments with zinc chloride were abandoned. In its place mixtures of acetic anhydride, acetic acid and strong acids were employed. The addition of acetic acid to the system is advantageous, as the system becomes buffered with respect to small amounts of moisture. The transformation of β-glucose pentaacetate into the equilibrium mixture was investigated with sulfuric acid as catalyst, but in this case also it was impossible to get perfectly reproducible results. The activity of the catalyst decreases with time, owing to the formation of sulfoacetic acid. With perchloric acid the velocity also descreases with time, but to a lesser extent. At the same time the solution turns yellow and then brown, rendering polarimetric measurements impossible. On account of these complications I have abstained from measuring exact velocity constants and have compared all reactions with a standard reaction, the transformation of β-glucose pentaacetate into the equilibrium mixture. Thus in all kinetic runs, a parallel run has been made with β-glucose pentaacetate in the same catalyst solution. Since two different catalytically active components appear to be present in the solution here (as will be clear from the following) the method is not entirely correct, and the results must be regarded as somewhat uncertain. This method, nevertheless, appears to offer the best solution of the problem of obtaining comparable results.

SULFURIC ACID AS CATALYST

If the rotation of ethyl β-glucoside tetraacetate in a solution of sulfuric acid in acetic anhydride-acetic acid is observed, the following course of events will be seen to take place (Fig. 1). The rotation increases rapidly, passes through a maximum and then slowly decreases to a constant value, which is definitly less than that calculated under the assumption that only glucose pentaacetate is formed. On treating the α-glucoside in the same way, the rotation decreases rapidly to about the same value as that for the maximum mentioned above, and the values will then coincide with those for the β-gluco-

α°

Fig. 1.   Transglycosidation and acetolysis of
the tetraacetates of a- and β-ethyl glucoside.

———— Ethyl β-glucoside tetraacetate

– – – – Ethyl α-glucoside tetraacetate

·········· β-Glucose pentaacetate

Time

side. This sequence of events can be explained in the following way. First the glucoside is transformed into a mixture of the α- and β-glucosides, in which the α-form predominates (90 per cent). At the same time an acetolysis takes place although far more slowly. The final product contains α/β- glucose pentaacetate and glucose heptaacetate. These assumptions have been verified by experiments. The α-glucosides of ethyl, *iso*propyl, and *tertiary* butyl alcohol have been isolated from the reaction mixtures in good yields by the following procedure. When the solution of the β-glucoside showed maximum rotation, it was poured into ice water. From the resulting solution the crude α-glucoside could be separated and purified by recrystallization. The presence of glucose heptaacetate in the final product was demonstrated by acetyl group determinations. The percentage of glucose heptaacetate calculated from these analyses agreed fairly closely with that calculated from the final rotation (Table 1).

Table 1.   Products of the sulfuric acid catalyzed reaction.

Glucoside tetraacetate	% α-glucoside isolated under optimum conditions	% glucose heptaacetate in final product, calc. from	
		final rotation	acetyl group determination
α-Methyl	—	5	8
β-Ethyl	60	36	27
β-*iso*Propyl	70	82	90
β-*Tert*.butyl	30	44	55

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By varying the concentration of sulfuric acid the different steps can be
studied separately. For the first, rapid reaction a low concentration of sul-
furic acid is chosen, but for the acetolysis which is somewhat slow, a much
higher concentration is preferable. All kinetic runs, except where especially
mentioned, were carried out in a mixture of acetic anhydride-acetic acid, 10 : 3
by volume. The velocity constants (calculated for a first-order reaction and
expressed in Briggs logarithms) for the transglycosidation of ethyl and *iso*-
propyl-β-glucosides and for the standard reaction with different concentra-
tions of sulfuric acid are given in Table 2.

Table 2. Variation of the sulfuric acid concentration.

Glucoside tetraacetate	$C_{H_2SO_4}$	$k_{standard}$	$k_{standard}/C_{H_2SO_4}$	$k_{transglyc.}$	$k_{transglyc.}/k_{standard}$	$k_{ethyl}/k_{iso\text{-}propyl}$	Maximum rotation
α-Ethyl	0.698	0.019	0.027	0.12	6.3	—	5.11°
»	0.356	0.012	0.034	0.096	8.0	—	5.16
»	0.177	0.0040	0.023	0.056	14.0	—	5.18
»	0.094	0.0026	0.028	0.033	12.7	—	5.24
»	0.052	0.0011	0.021	0.019	17.3	—	5.24
»	0.027	0.00070	0.026	0.011	15.7	—	5.31
α-*iso*-Propyl	0.182	0.0059	0.032	0.254	43	3.1	5.52
»	0.092	0.0028	0.030	0.143	51	4.0	5.49
»	0.045	0.0011	0.024	0.064	58	3.4	5.51
»	0.031	0.00078	0.025	0.046	59	3.9	5.55
»	0.015	0.00035	0.023	0.021	60	—	5.54

The data in Table 2 show that:

1. The reproducibility of the experiments is not very high. The values
$k_{standard}/C_{H_2SO_4}$ do not vary consistently but seem to be disordered. This
is probably due to the formation of different amounts of sulfoacetic acid, and
the velocity constant may be regarded as a measure of the sulfuric acid pre-
sent in the solution.

2. The ratio $k_{transglyc.}/k_{standard}$ increases consistently with a decreasing
concentration of sulfuric acid. A plausible explanation of this may be found
in the fact that the catalytically active agent is different in the two reactions,
as is further discussed below. Another fact, which also indicates the presence
of two different catalysts, is that the maximum rotation increases with a
decreasing concentration of sulfuric acid. If $k_{acetolysis}/C_{H_2SO_4}$ is constant
just as $k_{standard}/C_{H_2SO_4}$, this variation of the maximum rotation is readily
understandable.

3. The values of $k_{isopropyl}/k_{ethyl}$ are disorded. The two glucosides being transformed by the same mechanism, the values should be constant.

For methyl glucoside the rates for transglycosidation and acetolysis are of the same magnitude and are also roughly equal to that for the standard reaction. This complicates the kinetic analysis. Since there is no great difference between the velocities, it is clear that the maximum obtained for the other β-glucosides, which is dependent upon the accumulation of the α-glucoside, does not appear in the case of methyl-β-glucoside. Freudenberg and Soff found a minimum for methyl α-glucoside tetraacetate. The other α-glucosides do not show such a minimum, owing to the fact that the acetolysis is so slow, that the β-glucose pentaacetate, formed under Walden's inversion from the α-glucoside, does not accumulate but is quickly transformed into the equilibrium mixture.

In all the runs 0.500 g of glucoside in 20 ml of a solution of sulfuric acid in acetic anhydride-acetic acid 10 : 3 was employed. The rotation was measured at 20.0° in 2 dm tubes. The concentration of sulfuric acid differed for the determination of the two constants for each glucoside (0.1 C for the transglycosidation and 1.5 C for the acetolysis). The final rotations were measured in the runs with the stronger catalyst. The final rotation for glucose pentaacetate is $+ 4.90°$ under these conditions.

The rate of transglycosidation is greater for the *isopropyl* than for the ethyl glucoside. As a general rule the glucosides of secondary alcohols are transformed much more readily than those of primary alcohols. From the maximum rotation the ratio between α- and β-glucoside in equilibrium can be calculated as 9 : 1, in close agreement with the value found by Piel and Purves [8], for the transglycosidation of benzyl β-glucoside tetraacetate with titanium tetrachloride in chloroform. The percentage of glucose tetraacetate in the final product also increases in the series: methyl $<$ *prim*.alkyl $<$ *sec*.-alkyl, as indicated by the final rotation, decreasing in the same series. The results for the different glucosides are summarized in Table 3.

The β-glucoside of *tertiary* butanol differs from the others. Here the course is more complicated. It has been proved that the transformation into the α-glucoside takes place very rapidly. With small amounts of sulfuric acid as a catalyst, the rotation first passes through a maximum, then through a minimum and finally reaches a constant value. This might be explained as follows: First, the α-glucoside, which is responsible for the maximum, accumulates owing to the rapid transglycosidation. The acetolysis also takes place rapidly, although not so fast as the transglycosidation, and after a while β-glucose pentaacetate begins to accumulate, giving a minimum in the rotation. The final mixture consists as usual of α- and β-glucose pentaacetate and glucose heptaacetate. The percentage of the latter is much lower than in the case of

Table 3. *Velocity constants for transglycosidation and acetolysis of some acetylated alkyl glucosides.*

Glucoside tetraacetate	$k_{transglyc.}$	$k_{acetolysis}$	Final rotation a_D^{20}
α-Methyl	~ 1	~ 1	+ 4.96°
β-Methyl	~ 1	~ 1	4.25
α-Ethyl	13	0.11	3.40
β-Ethyl	15	0.07	3.53
β-n-Propyl	14	0.08	2.71
β-n-Butyl	14	0.05	2.65
β-iso-Butyl	10	0.05	2.24
α-iso-Propyl	50	0.08	1.25
β-iso-Propyl	50	0.08	1.25
β-Pentyl (3)	29	0.04	1.10
β-Cyclopentyl	44	0.05	1.14
β-Cyclohexyl	61	0.06	0.90
β-Cycloheptyl	70	0.08	1.12

secondary glucosides, which may be connected with the fast acetolysis. With very small concentrations of sulfuric acid, smaller than the concentration of the glucoside, the reaction stops after some time. If more sulfuric acid is added, the reaction will start again. A probable explanation is that the sulfuric acid is consumed in the formation of butyl sulfuric acid.

The effect of the solvent upon these reactions has also been studied. The results are given in Tables 4, 5, and 6.

Table 4. *a/β-Transformations in solutions of different acetic acid concentration.*
$$C_{H_2SO_4} = 0.196.$$

Substance	% Ac$_2$O	% AcOH	k	$k_{relative}$
β-Glucose pentaacetate	100	0	0.17	9.4
»	80	20	0.0052	2.9
»	60	40	0.0030	1.7
»	40	60	0.0018	1
Ethyl β-glucoside tetraacetate	100	0	0.19	29
»	80	20	0.090	14
»	60	40	0.025	3.8
»	40	60	0.0065	1

Table 5. The effect of an inert solvent upon the α/β-transformation.

$C_{H_2SO_4}$	Substance	% Ac_2O	% CCl_4	k
0.147	β-Glucose			
	pentaacetate	100	0	0.0030
»	»	80	20	0.0030
»	»	60	40	0.0027
0.040	Ethyl β-glucoside			
	tetraacetate	100	0	0.084
»	»	80	20	0.086
»	»	60	40	0.092

Table 6. Acetolysis of ethyl β-glucoside tetraacetate in solutions of different acetic acid concentrations. $C_{H_2SO_4} = 1.2$.

% Ac_2O	% AcOH	k	Final rotation
100	0	0.027	3.00
80	20	0.0044	3.42
60	40	0.0017	3.84

As usual, the values are somewhat inaccurate owing to the formation of sulfoacetic acid, but they show clearly how the velocity decreases with an increasing concentration of acetic acid and that the addition of an inert solvent does not appreciably alter the velocity. The transglycosidation is more affected by the acetic acid than is the standard reaction. The different values of the final rotation in Table 6 depend on differences in composition and cannot be explained by solvent effects upon the rotation.

PERCHLORIC ACID AS A CATALYST

In addition to sulfuric acid, some other acids such as perchloric acid, boron trifluoride and p-toluene sulfonic acid have been investigated. Of these, p-toluene sulfonic acid is too weak to permit a study of the reaction. The two remaining acids behave somewhat similarly, and since perchloric acid is easier to work with, this acid has been used in most experiments. The use of both acids is accompanied by the disadvantage that they react with the solvent, producing a yellow to brown coloration, that often renders polarimetric readings impossible. On account of this 'humification' only fast reactions can be followed to equilibrium. Consequently, the reaction of tert.butyl β-glucoside tetraacetate has been studied more thoroughly. The final product in this case

is glucose pentaacetate. The final rotation found is in perfect agreement with that calculated under the assumption that only glucose pentaacetate is formed, and α-pentaacetate has been isolated in a good yield from the reaction mixture. The rotation shows no maximum or minimum during the reaction. Efforts to calculate the velocity constant under the assumption that the reaction proceeds as follows:

tert. butyl β-glucoside tetraacetate → α-glucose pentaacetate → α/β glucose pentaacetate
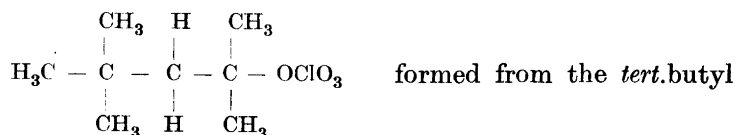
have failed, indicating that the reaction is more complicated. Most probably transglycosidation occurs simultaneously with the other reactions and has a comparable rate. This view is supported by the fact that a maximum was obtained when *iso*propyl β-glucoside tetraacetate was treated with a solution of 5 ml of perchloric acid (about 70 per cent) in 50 ml acetic anhydride. In the same experiment the final rotation was very low, indicating the presence of glucose heptaacetate. The kinetic analysis of the runs with *tert.*butyl β-glucoside shows that the velocity of the acetolysis is approximately of the same order as that of the standard reaction. The velocity of the standard reaction is directly proportional to the concentration of perchloric acid. (Table 7.)

Table 7. Transformation of β-glucose pentaacetate with perchloric acid as catalyst.

C_{HClO_4}	k	k/C_{HClO_4}
0.88	0.7	0.8
0.44	0.23	0.52
0.22	0.11	0.50
0.11	0.055	0.50

During some of the experiments light-yellow crystals were deposited from the reaction solution. The crystals were separated and proved to be explosive. They were practically insoluble in acetic anhydride and chloroform but soluble in a mixture of acetone and water, the solution becoming strongly acid. This points to an organic perchlorate. The equivalent weight of the substance was determined at 213 by titrating the acetone-water solution with standard sodium hydroxide.

The substance might possibly be *iso*octyl perchlorate.

$$
\begin{array}{ccccc}
 & CH_3 & H & CH_3 & \\
 & | & | & | & \\
H_3C - & C - & C - & C - & OClO_3 \\
 & | & | & | & \\
 & CH_3 & H & CH_3 &
\end{array}
$$
formed from the *tert.*butyl

groups via *iso*butene and *iso*octene.

Variation of the solvent gives the same results with perchloric acid as with sulfuric acid.

The methyl, ethyl and *iso*propyl β-glucosides have also been examined. In no case could the final rotation be observed, and the rotation showed no maximum when moderate concentrations of perchloric acid in the usual solvent mixture were used. (For very strong solutions see above.) .

DISCUSSION

The behaviour of strong acids in acetic anhydride, aceticacid mixtures has been reviewed and further investigated by Mackenzie and Winter [9a]. The latter have also studied the kinetics of the Thiele acetylation [9b]. The following conclusions may be drawn from these papers. From conductivity measurements it is shown that perchloric acid is a strong and sulfuric acid a weak electrolyte in acetic acid. The acidity can be measured with the acid of the chloranil electrode or by the indicator method and defined by $(pH)^{AcOH}$ or by Hammet's acidity function. Thus $(pH)^{AcOH}$ for 1.0 C. solutions of trichloroacetic, sulfuric and perchloric acid in acetic acid is — 0.83, — 3.23 and — 4.4 respectively. When acetic anhydride is added to the system, $(pH)^{AcOH}$ decreases. This decrease is rather small for perchloric acid but very great for sulfuric acid, $(pH)^{AcOH}$ having a value as low as — 12.9 for a 0.7 C solution of sulfuric acid in 30 per cent acetic anhydride. Solutions with such extremely low $(pH)^{AcOH}$ values are called 'superacidic'. There are probably two acid ions in the 'superacidic' solution. $AcOH_2^+$ and Ac^+. The latter would probably be responsible for the extremely low $(pH)^{AcOH}$ values *. The existence of two different acid catalysts is also proved by the kinetic experiments. When the Thiele acetylation of benzoquinone is performed with perchloric acid as catalyst, the rate of the reaction increases with the concentration of the acid. The $(pH)^{AcOH}$ of the solution of course decreases simultaneously. The same is true when sulfuric acid is used as catalyst, but perchloric acid is the stronger catalyst. Yet, for solutions of the same molarity, $(pH)^{AcOH}$ is about six units lower in the solution of sulfuric acid. Mackenzie and Winter also investigate the effect of the solvent upon the Thiele acetylation. Their results are more accurate, but in other respects they correspond well with those found in the present investigation.

The results of the latter can be explained by the following hypothesis: Let it be assumed that the sulfuric acid chiefly occurs as the mixed anhydride, acetyl sulfuric acid. This catalyzes the standard reaction and also the normal

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* This is not actually stated in the paper of Mackenzie and Winter.

acetolysis of the glucoside to glucose pentaacetate. The velocity of these reactions should be directly proportional to the concentration of sulfuric acid, as is also found for the standard reaction. The acetyl sulfuric acid, however, cannot catalyze the transglycosidation. It dissociates to a small extent according to the reaction:

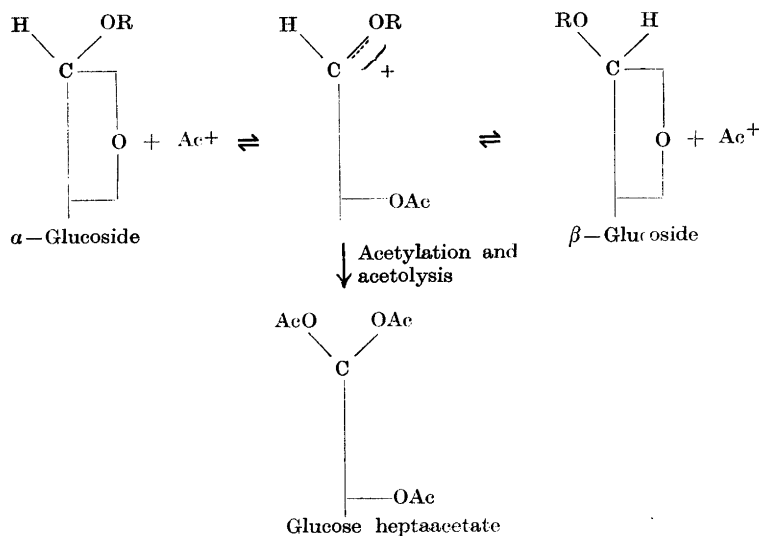$$AcOSO_3H \rightleftharpoons Ac^+ + HSO_4^-$$
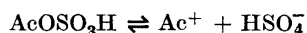
The acetyl cation, responsible for the 'superacidity', is a very strong acid, that catalyzes the transglycosidation similarly to titanium tetrachloride or boron trifluoride. The degree of dissociation decreases with increasing concentration of acetylsulfuric acid, and therefore the ratio $k_{transglyc.}/C_{H_2SO_4}$ must also decrease.

The perchloric acid is completely dissociated, and therefore the catalyst must be the $AcOH_2^+$ ion. The standard reaction and the acetolysis are catalyzed more strongly by perchloric acid than by sulfuric acid. (Tables 2 and 7.) The superacidity and the concentration of the acetyl cation, however, are very small, and consequently the rate of the transglycosidation is low.

Before any mechanism for the transglycosidation can be discussed, it must be ascertained whether the reaction in intramolecular. This seems most probable. The yield of the reaction being high, it would be difficult to understand how all the alkoxyl groups, if once free, could find their way back again in this strongly acetylating medium. That the reaction really is intramolecular has been proved for the analogous catalysis with titanium tetrachloride in chloroform, where no consecutive reactions occur. A mixture of isopropyl β-glucoside tetraacetate and ethyl β-cellobioside heptaacetate was treated with titanium tetrachloride in absolute chloroform. From the reaction mixture only isopropyl α-glucoside tetraacetate and ethyl α-cellobioside heptaacetate could be isolated and in good yields, showing that the reaction must be intramolecular.

From Table 3 it is apparent that a striking connection exists between the rate of the transglycosidation and the yield of glucose heptaacetate in the final product. The faster transglycosidation takes place, the greater will be the quantity of glucose heptaacetate found in the final product. This indicates that transglycosidation and the formation of heptaacetate have one step in common. A plausible explanation is that the reactions proceed in the sequence:

H\   OR   H\   OR   RO   H
 \C——   \C ⫽/+   \C——
  | | |
  O + Ac+ ⇌ | ⇌   O + Ac⁺
  | |——OAc |
a—Glucoside   β—Glucoside

                   | Acetylation and
                   ↓ acetolysis

                AcO   OAc
                   \C/
                    |
                    |——OAc
             Glucose heptaacetate

With neutral acids, for example boron trifluoride in an inert solvent, the mechanism would be

H\   OR   H\   OR   RO   H
 \C——   \C ⫽/+   \C——
  | | |
  O + BF₃ ⇌ | ⇌   O + BF₃
  | |——OBF₃ |——
                      ‾
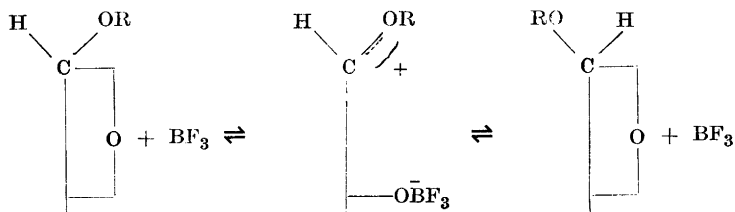
The effect of the aglucon upon the rate of transglycosidation is also predictable. A — I substituent (electron repellant) will increase the — E activity of the oxygen, which increases in the series:

$$-O-CH_3 \; < \; O-CH_2-CH_3 \; < \; O-CH\begin{matrix} CH_3 \\ \\ CH_3 \end{matrix} \; < \; O-C\begin{matrix} CH_3 \\ | \\ CH_3 \end{matrix}CH_3$$
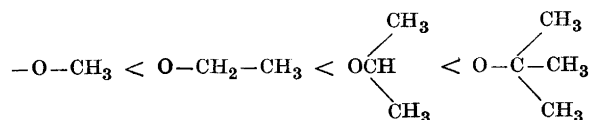
The greater the $-E$ activity of the alkoxyl, the lower will be the energy of the intermediate cation and also of the transition state leading to that cation.
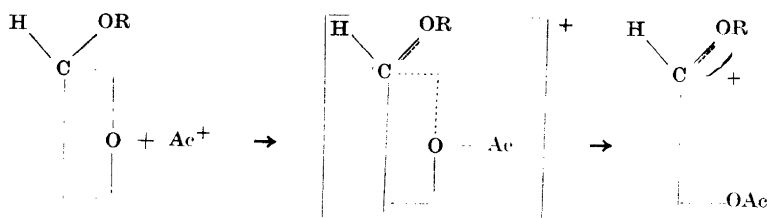
Thus both the velocity of formation and the concentration of the interme-
diate cation will be favoured by a high —I activity of the alkyl group. This
means that the rate of transglycosidation and the yield of glucose heptaacetate
will increase in the series: methyl $<$ *prim.*alkyl $<$ *sec.*alkyl $<$ *tert.*alkyl *.
This is the sequence found by experiment, with the exception that the yield
of glucose heptaacetate is too small in the case of the *tert.*butyl glucoside,
probably on account of the very rapid normal acetolysis. Unpublished experi-
ments show that glucosides of alcohols, substituted with halogen, that is to
say with +I substituents, are transglycosidated at a much lower rate than
the unsubstituted glucosides.

An attack of the acid upon the other acetalic oxygen will be counteracted
by the electron attraction of the oxygen atoms on the carbon atoms 4 and 6.

EXPERIMENTAL

Materials

Acetic acid, acetic anhydride and carbon tetrachloride of laboratory reagent grade
were distilled under the exclusion of moisture, and the middle fraction (60 %) collected.
C. P. sulfuric acid was taken as 98 % pure. C. P. perchloric acid (70 %) was standardized
by titration. The synthesis of the glucosides investigated is described in an earlier
communication [10].

Procedure

The reaction mixture consisted of the solvent, acetic anhydride and acetic acid in the
ratio 10 : 3 (except when solvent effects were investigated), of the sugar derivative in low
concentration (C = 0.05) and an acid catalyst. The acid was dissolved in the chilled
solvent and the solution allowed to stand in the dark room, electrically thermostatted
to 20.0 ± 0.2°. After about half-an-hour, 20 ml of the solution were added to 0.5 g of
fine-ground glucose derivative. Dissolution was complete in a few seconds. The mixture
was then transferred to a 2 dm polarimeter tube and the rotation was determined at
appropriate intervals. The initial rotation was determined by dissolving the substance in

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* The yield of heptaacetate also depends upon the velocity of 'acetylation and acetolysis',
which is here assumed to be independent of the nature of the alkyl group.

the solvent without any catalyst. For consecutive reactions, the maximum value could be taken as the final value for the first reaction where the latter was much faster than the second reaction. For the second reaction the choice of an appropriate initial value for the calculation of the first order velocity constant presented no difficulties. In each run, except when solvent effects were studied, a parallel run was made with β-glucose pentaacetate. When the solvent effects were studied, the acid catalyst was dissolved in pure acetic anhydride and the different dilutions effected immediately before the runs. All the three or four runs in a series were made at the same time.

Typical runs

Table 8. Transglycosidation of ethyl β-glucoside tetraacetate.

β-Glucose pentaacetate and ethyl β-glucoside tetraacetate, 0.500 g of each, dissolved in 20 ml of 0.178 C sulfuric acid in acetic anhydride-acetic acid, 10 : 3. t = 20° C. Rotations determined in 2 dm tubes. (The table gives only a part of the observed values.)

Time min.	a-Glucose pentaacetate		Ethyl β-glucoside tetraacetate	
	a_D°	k	a_D°	k
0	0.37		− 1.20	
2	0.49	0.0057	+ 0.29	0.058
4	0.52	36	1.38	56
6	0.66	48	2.16	54
8	0.70	41	2.83	54
10	0.75	38	3.35	54
12	0.85	40	3.79	55
14	0.95	42	4.14	56
16	1.00	40	4.42	58
18	1.03	38	4.71	63
20	1.11	39	4.81	62
30	1.46	40	5.18	
40	1.78	40	5.18	
50	2.11	42	5.18	
60	2.35	41	5.16	
70	2.57	41	5.13	
	4.93			

Mean value 0.0040   Mean value 0.056

It has not been possible to interpret the observed values for the *tert.*butyl glucoside by any simple assumptions. The values $(a_D)_{calc}$ in Table 10 are calculated under the assumption that the reaction proceeds as follows:

$$\beta\text{-glucoside} \xrightarrow{k_1} \beta\text{-pentaacetate} \xrightarrow{k_2} a/\beta\text{-pentaacetate}.$$

Table 9. Acetolysis of n-propyl β-glucoside tetraacetate.

β-Glucoside pentaacetate and n-propyl β-glucoside tetraacetate, 0.500 g of each, dissolved in 20 ml of 1.4 C sulfuric acid in acetic anhydride-acetic acid, 10 : 3. t = 20° C. Rotation determined in 2 dm tubes.

Time min	β-Glucose pentaacetate		n-Propyl β-glucoside tetraacetate	
	a_D°	k	a_D°	k
0	0.37		− 1.14	
2	1.20	0.044	+ 2.40	
4	1.99	48	3.86	
6	2.57	48	4.39	
8	3.10	50	4.64	
10	3.50	50	4.70	
12	3.75	49	4.73	
15	4.08	50	4.70	
27	4.83		4.48 *	
37	4.91		4.32	0.0041
47	4.93		4.18	40
60	4.93		4.00	42
75	4.93		3.86	39
90			3.74	37
120			3.50	38
150			3.26	41
215			3.00	42
490	4.93		2.71	
	4.93		2.71	
	Mean value 0.049		Mean value 0.0040	

$k_1 = k_2 = 0.024$. They deviate consistently over the whole range, however, so that the assumption cannot be valid. The reaction must be of a more complex nature, probably including a transglycosidation. An evaluation would be very difficult to carry out and of little value. The final rotation, + 4.62° agrees closely with the value + 4.60°, calculated under the assumption that α- and β-glucose pentaacetate are the only final products.

iso-Octyl perchlorate

At the end of the experiment described above, pale yellow crystals appeared in the reaction mixture. These crystals were collected on a filter and washed with a small amount of acetic anhydride. They were almost insoluble in acetic anhydride and chloroform but easily soluble in a mixture of water and acetone. From this solvent the sub-

* Chosen as initial value.

Table 10. Acetolysis of tert.butyl β-glucoside tetraacetate with perchloric acid as catalyst.

β-Glucose pentaacetate and tert.butyl β-glucoside tetraacetate, 0.500 g of each, dissolved in 20 ml of 0.11 C perchloric acid in acetic anhydride-acetic acid, 10 : 3. t = 20° C. Rotations determined in 2 dm tubes. (The table gives only a part of the observed values.)

Time min	β-Glucose pentaacetate		Tert. butyl β-glucoside tetraacetate	
	a°_D	k	$(a^{\circ}_D)_{Found.}$	$(a^{\circ}_D)_{Calc}$
0	0.37		− 0.84	
2	0.79	0.022	+ 0.79	− 0.20
4	1.17	22	1.11	+ 0.39
6	1.56	23	1.36	0.89
8	1.87	23	1.59	1.34
10	2.19	23	1.72	1.73
12	2.45	23	1.96	
14	2.65	23	2.11	2.40
16	2.86	23	2.24	
18	3.05	23	2.39	2.80
20	3.28	24	2.54	
30	3.98	25	3.12	
40	4.41 ·	27	3.50	4.31
50	4.62		3.75	
60	4.74		3.99	
75	4.76		4.14	
90	4.76		4.30	
115			4.46	
145			4.62	
			4.62	

Mean value 0.024

stance could not be recovered and the solution became strongly acid. The crystals had no melting point but decomposed violently when heated. The presence of halogene was proved by the Beilstein test. These facts indicate an organic perchlorate. The solution of the substance in acetone-water was titrated with sodium hydroxide and the equivalent weight of the substance determined at 213. It is probable that the substance is isooctyl perchlorate $C_8H_{17}ClO_4$

(212.7)	Calc.	C	45.1	H	8.06	Cl	16.7
	Found*	»	43.3	»	5.00	»	15.7

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* Since the substance is explosive, the results of the combustrin analyses can not be stressed upon very much. The equivalent weight determination, howeves, is perfectly reproducible.

Isolation of the α-glucoside from the reaction mixture

Ethyl β-glucoside tetraacetate (2 g) was dissolved in 0.2 C sulfuric acid in acetic anhydride-acetic acid 10 : 3 (30 ml). The rotation was followed in the polarimeter and when maximum rotation was observed, the solution was poured into ice water (200 ml) containing sodium acetate (5 g). A very small amount of crystals were separated. The mixture was extracted with ether, the ether solution washed with dilute sodium carbonate and water, dried over calcium chloride and concentrated. The residue was recrystallized from ethanol. Yield, 1.25 g. M. p. 60—61° *. One further recrystallization from ethanol yielded the pure ethyl α-glucoside tetraacetate, melting at 61—62°.

iso Propyl α-glucoside tetraacetate (2 g) was treated analogously, but in this case crystals of the α-glucoside separated in the ice water solution in a good yield (1.4 g). M. p. 81—82°. Two recrystallizations from ethanol yielded the pure substance. M. p. 85—86°.

*tert.*Butyl β-glucoside tetraacetate (1.2 g) was dissolved in 0.07 C sulfuric acid in acetic anhydride-acetic acid, 10 : 3 (50 ml). After ten minutes the mixture was poured into ice water (500 ml) containing sodium acetate (5 g). This solution was extracted with ether (2 × 100 ml). The ether solution was diluted with light petroleum (150 ml), washed with sodium carbonate solution and finally with water (4 × 350 ml), dried over calcium chloride and concentrated. The residue was recrystallized from light petroleum. Yield 0.35 g. M. p. 60—62°. Further recrystallizations from light petroleum yielded pure *tert.* butyl α-glucoside tetraacetate. M. p. 69—70°.

Investigation of the products of acetolysis

Methyl α-glucoside tetraacetate and the β-glucoside tetraacetates of ethyl, *isopropyl* and *tert.*butyl alcohol (1 g of each) were dissolved in 1.4 C sulfuric acid in acetic anhydride-acetic acid, 10 : 3 (20 ml). After 24 hours the solutions were poured into ice water (500 ml) with sodium acetate (10 g). The mixtures were extracted with ether (3 × 100 ml), the ether solutions washed with sodium carbonate solution and with water, dried over calcium chloride and concentrated. The residues were dried in a vacuum over phosphorus pentoxide, paraffin and potassium hydroxide. They were analyzed with respect to acetyl groups. The values found were: methyl 55.6 %, ethyl 56.4 %, *iso*propyl 60.5 %, and *tert.*butyl 58.4 %. The percentage of glucose heptaacetate calculated from these values compared with that calculated from the final rotation of the solutions, will be found in table 1.

Simultaneous transformation of *iso*propyl β-glucoside and ethyl β-cellobioside

A solution of *iso*propyl β-glucoside tetraacetate (1 g), ethyl β-cellobioside heptaacetate (1 g) and titanium tetrachloride (1 g) in absolute chloroform (60 ml) was heated for 90 minutes on the steam bath. When cold, the mixture was shaken with bicarbonate solution, washed with water, dried over calcium chloride, and concentrated in a vacuum. The residue was recrystallized from ethanol (20 ml). 0.75 g of white crystals separated. M. p. 176—178°. After one further recrystallization from ethanol the melting point was

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* All melting points uncorrected.

177—179°, alone or in admixture with an authentic sample of ethyl α-cellobioside hepta-acetate.

The mother liquor from the first recrystallization was diluted with water (20 ml). A small amount of precipitate was formed which was discarded. When the solution was further diluted with water (150 ml) crystals of *iso*propyl α-glucoside tetraacetate separated. Yield 0.66 g. M. p. 84.5—85.5°. Mixed m. p. with an authentic sample 85—86°.

SUMMARY

The transglycosidation and acetolysis of some alkyl glucoside tetraacetates, catalyzed by strong acids, has been investigated in acetic anhydride-acetic acid solutions. The results are summarized below.

1. The rate of transglycosidation increases in the series:
methyl < *primary* alkyl < *secondary* alkyl < *tertiary* alkyl.

2. The yield of glucose heptaacetate by the acetolysis increases in the series methyl < *prim.*alkyl < *sec.*alkyl.

3. Two different acid catalysts seem to be present in a solution of sulfuric acid in acetic anhydride-acetic acid. Only the stronger of these, probably the acetyl cation, can catalyze the transglycosidation.

4. A reasonable mechanism for the transglycosidation, which also explains the formation of glucose heptaacetate, is given.

5. A new compound, probably isooctyl perchlorate, has been isolated when *tert.* butyl β-glucoside tetraacetate was acetolyzed with perchloric acid as catalyst.

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