Chem. Ber. **113**, 489 – 510 (1980)

Sugar Enolones, XII[1]

Peroxidation of Pyranose-derived Enol Esters: An Efficacious Synthesis of Peracetylhexosuloses and their Conversion into γ-Pyrones *via* 3,2-Enolones

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Received April 23, 1979

Pyranose-derived 1,2-enol acetates of type **4** readily react with 3-chloroperbenzoic acid in ether to an anomeric mixture of glycos-2-uloses **6**, as is demonstrated by the conversions **7** → **11/12**, **18** → **19/20** and **21** → **22**. Structural and configurational assignments were based on NMR-data, on the characterization of hydrogenation products (**10** and **23**), and on the independent formation of **11**, **12**, and **22** by RuO_4-oxidation of the respective partially acetylated pyranoses **8**, **9**, and **23**. – Acid-catalyzed acetylation converts the glycos-2-uloses into their 2,2-diacetoxy derivatives (**13**, **24**, and **35**) with anomerization of β-isomers, whereas cautious treatment with acetyl chloride/pyridine affords the peracetylated 2,3-dehydropyranoses **15**, **17**, and **36** with retention of configuration at C-1. Mildly basic conditions initiate the elaboration of the γ-pyrone systems (**42/43**) *via* double elimination of acetic acid, the respective intermediates, 3,2-enolones **37α**, **37β**, and **38**, being readily isolable. The alternate triacetyl-enediolone **41**, allegedly[40] an intermediate in the conversion **11** → **42** could be excluded as an intermediate on the basis of its synthesis from tetraacetyl-glucose by oxidation and elimination of acetic acid (**44** → **45** → **41**).

Zucker-enolone, XII[1]

Peroxidation pyranoider Enolester: Eine ergiebige Synthese von Peracetyl-hexosulosen und ihre Umwandlung in γ-Pyrone über 3,2-Enolone

Von Pyranosen abgeleitete 1,2-Enolacetate des Typs **4** reagieren mit 3-Chlorperbenzoesäure in Ether glatt zu einem Gemisch anomerer Glycos-2-ulose-acetate **6**, wie anhand der Umwandlungen **7** → **11/12**, **18** → **19/20** und **21** → **22** gezeigt wird. Konstitution und Konfiguration der Produkte stützen sich auf NMR-Daten, auf die Charakterisierung von Hydrierungsprodukten (**10** bzw. **23**) sowie im Falle von **11**, **12** und **22** auf deren Bildung aus den entsprechenden partiell acetylierten Pyranosen **8**, **9** und **23** durch RuO_4-Oxidation. – Saure Acetylierung überführt die Glycos-2-ulosen in ihre 2,2-Diacetoxy-Derivate (**13**, **24** bzw. **35**) unter Anomerisierung der β-Isomeren; bei vorsichtiger Behandlung mit Acetylchlorid/Pyridin werden dagegen, unter Erhalt der Konfiguration an C-1, die peracetylierten 2,3-Dehydro-pyranosen **15**, **17** und **36** erhalten. Unter schwach basischen Bedingungen erfolgt die Ausbildung des γ-Pyron-Systems (**42/43**) durch doppelte Eliminierung von Essigsäure, wobei die Zwischenprodukte isolierbar sind und als die 3,2-Enolone **37α**, **37β** und **38** charakterisiert werden können. Hierbei konnte das aus der Tetraacetyl-glucose **44** durch Oxidation leicht darstellbare Triacetyl-endiolon **41**, das Zwischenprodukt des Übergangs **11** → **42** sein soll[40], als Intermediat ausgeschlossen werden.

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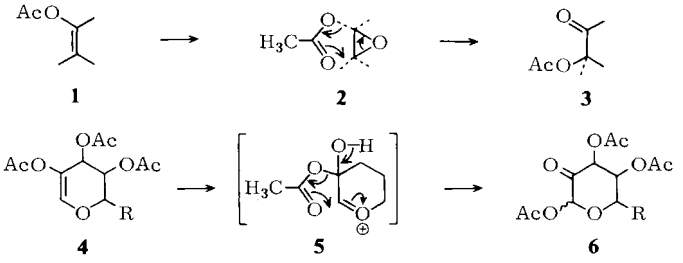
Peroxidation of enol acetates (**1** → **2**) followed by an intramolecular thermal or acid-catalyzed isomerization of the intermediate acetoxy epoxides (**2** → **3**) represents one of the pertinent methods for introduction of an acyloxy substituent next to a carbonyl function, and has been successfully used for the preparation of α-acetoxyaldehydes[3] and a variety of alicyclic α-acetoxyketones[4].



1 **2** **3**

4 **5** **6**

R = CH_2OAc, CH_3, H

Application of this reaction sequence to enol esters of pyranoses, of which peracetylated 2-hydroxyglycals **4** appear to be the most readily accessible[5], should similarly give peracyl-glycos-2-uloses **6**. Mechanistically, however, the peroxidation **4** → **6** is not anticipated to proceed via the α-acetoxy epoxides of type **2**, but is more likely to elaborate the C-2 carbonyl group via intermediates of type **5** due to the participative effect of the ring oxygen.

As to be demonstrated in the sequel with a number of pyranoid enol acetates (i. e. **7**, **18**, and **21**), such peroxidations are readily feasable, thus providing an efficient and versatile preparative route to peracetylated glycos-2-uloses of type **6**, which, heretofore, have only been postulated as intermediates in the formation of di-*O*-acetylkojic acid on oxidation of 2-OH group in otherwise acetylated pyranoses[6-10]. Their expectedly[11] high propensity for β-elimination also allowed the preparation of peracetylated 3,2-enolones and, thence, an evaluation of the mechanism underlying their conversion into γ-pyrones[12].

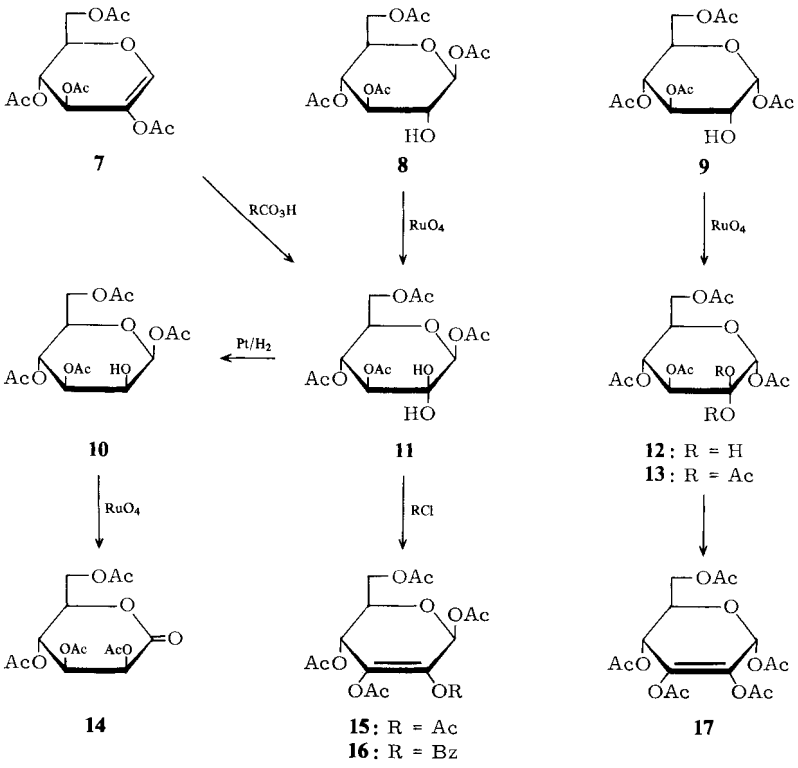
I. Preparation of Peracetyl-glycos-2-uloses and Configurational Assignments

Peroxidation of enediol acetates of type **4** to the respective peracetyl-glycos-2-uloses is readily accomplished by the reaction with 3-chloroperbenzoic acid in ether at room temperature, whereby usually the major product crystallizes from the reaction mixture as the monohydrate. Hereby, in the hexose-derived enol esters, i. e. **7** and **18**, the enolic double bond is preferentially attacked from the α-side, hence affording the β-anomers in yields of up to 60%, whilst in the pentose case (**21**) the steric preference is less pronounced due to the lack of directive influence from the 5-substituent.

When tetra-*O*-acetyl-1,5-anhydro-D-*arabino*-hex-1-enitol (**7**) is subjected to peroxidation[13] in ether, an approximate 2:1 mixture of tetra-*O*-acetyl-β-D-*arabino*-hexosulose (**11**) and its α-anomer **12** was obtained from which the major product crystallized as the monohydrate (**11**) in yields of up to 60%. Structural proof for **11** was readily provided by ^1H NMR data, as, e. g., by a singlet at $\delta = 5.60$ for the anomeric proton and by two OH-protons at 5.90 and 6.20 which were exchangeable by D_2O.

Spectroscopic evidence for the anomeric configuration could, however, only be derived from ^{13}C NMR data, i. e. the anomeric carbon at $\delta = 92.6$ with the comparatively small 1-H/C-1-coupling constant of 165 Hz indicating[15] the presence of the β-anomer.

Due to the lack of unequivocal comparative ^{13}C NMR data on hydrated 1-acylglycosuloses further proof for the β-configuration of **11** was required and provided chemically. Catalytic hydrogenation of **11**, although proceeding sluggishly and producing side products *via* concomitant transacetylations, afforded the known[16] 1,3,4,6-tetra-*O*-acetyl-β-D-mannopyranose (**10**) in 19% yield. Since deuteration under these conditions gave an exclusively C-2 deuterated **10**, a conceivable 1,2-enediol formation prior to or during H_2- or D_2-addition can be excluded, thus providing conclusive evidence for the β-configuration of **11** despite of the comparatively modest yield of isolated hydrogenation product. In addition, **11** could independently be prepared from 1,3,4,6-tetra-*O*-acetyl-β-D-glucopyranose (**8**) by oxidation with ruthenium tetroxide, whilst the corresponding α-D-glucopyranose-tetraacetate **9** when subjected to the same conditions gave the alternate α-D-*arabino*-hexosulose monohydrate **12** in high yield, with rotational data clearly differing from those of **11**. In this context, it is notable that the tetra-*O*-acetyl-β-D-mannose **10**, unlike its *gluco*-analog **8**, was not oxidised to the β-ulose **11** with ruthenium tetroxide, but formed the D-mannono-1,5-lactone **14** instead. In this case, obviously oxidation is preceeded by an *O*-1 → *O*-2 acetyl migration which is favored by the *cis*-relationship of substituents.



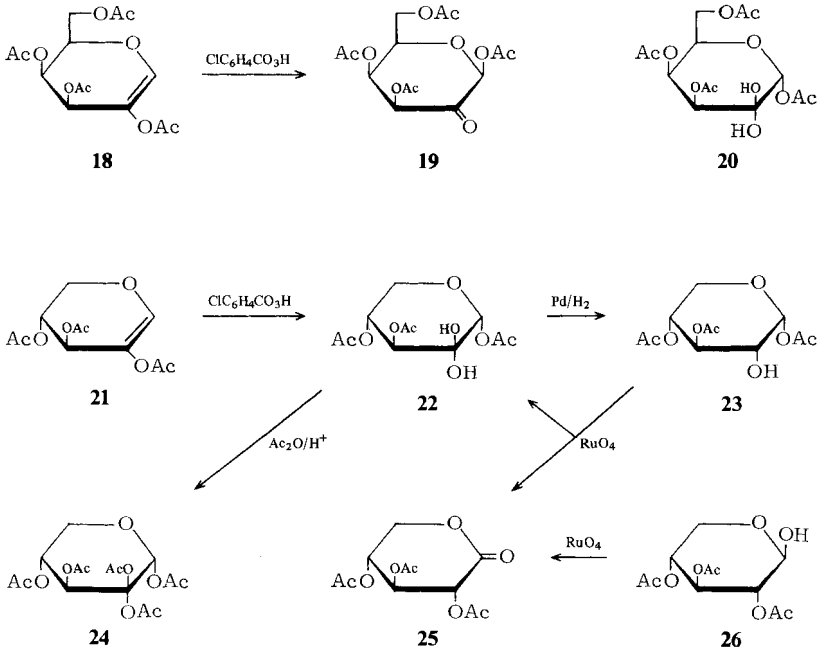
On acid-catalyzed acetylation, both the α-hexosulose **12** as well as its β-anomer **11** were converted into the same crystalline hexaacetate, which on the basis of its comparatively large C-1/1-H coupling constant of 183 Hz and its positive rotation clearly had the α-configuration **13**. Thus, not unexpectedly[17], acetylation of **11** is accompanied by a β → α-anomerization.

Under the standard conditions for base-catalyzed acetylation, e. g. pyridine/acetic anhydride or sodium acetate/acetic anhydride, the formation of enolones and of diacetyl-kojic acid is initiated from either of the anomeric hexosuloses (cf. below). This process, however, can largely be intercepted by acylation with acetyl chloride and limited amounts of pyridine in chloroform solution at 0°C, affording in good yields the pentaacetyl-2,3-enediols **15** (from β-hexosulose **11**) and **17** (from the α-isomer **12**), which were readily characterized as anomers by their distinct differences in optical rotations and in conformations (^5H_O-form for **15** *versus* the alternate $^OH_5$-form for **17** due to $J_{4,5}$-values of 1.5 and 9 Hz, respectively). Benzoylation of **11** similarly gave the 2-*O*-benzoyl analog **16** without apparent β → α-anomerization. Thus, in this way, a most ready access is provided to various acyl derivatives of 2,3-dehydropyranoses, of which only rather odd examples[18,19] appear to be known.

The facile peroxidation of glycalester **7** to its glycosulose **11** is readily transferable to analogues, such as the C-4-epimeric D-*lyxo* compound **18** or the pentose-derived D-*threo*-derivative **21**. In the former case, tetra-*O*-acetyl-β-D-*lyxo*-hexosulose (**19**) was preferentially formed and isolated as the nonhydrated ketone in 57% yield, whereas on reaction of **21** with 3-chloroperbenzoic acid in ether the hydrated α-D-*threo*-pentosulose **22** precipitated from the reaction mixture in essentially pure form. Both products were readily characterized by their rotational and spectral data, most significantly by their $J_{C\text{-}1/1\text{-}H}$-values of 169 Hz for **19** and 174 Hz for **22** which indicate[15] β- and α- configuration, respectively. Further evidence for the α-arrangement of **22** could be derived from the similarly high C-1/1-H-coupling constant (178 Hz) of the pentaacetate **24**, formed on acid-catalyzed acetylation, from its conversion into the known[20] 1,3,4-tri-*O*-acetyl-α-D-xylopyranose (**23**) by catalytic hydrogenation, and most convincingly, from an independent synthesis, in 66% yield, by oxidation of **23** with ruthenium tetraoxide in anhydrous tetrachloromethane. The absence of water appears to be essential for a clean conversion **23** → **22**, since otherwise, e. g. when using the more economic system[21] ruthenium dioxide/sodium metaperiodate/sodium hydrogen carbonate in tetrachloromethane/water, the oxidation is preceeded by an *O*-1 → *O*-2-acetyl migration to give, instead, xylonolactone **25**, which is similarly obtained by oxidation of the 2,3,4-triacetyl-xylose **26**.

Rotational behaviour of peracetyl-glycosuloses: In solvents like chloroform, tetrahydrofuran, or dry dimethylsulfoxide the glycosuloses **11**, **12**, **19**, **20**, and **22** showed definitive rotational values, that remained constant within days. In aqueous ethanol, however, or in water, extensive mutarotations are observed, which on the basis of TLC- and ^1H NMR monitoring proved to be due to α/β-equilibrations at the anomeric center. The two α-hexosuloses **12** and **20**, e. g., exhibited strongly positive initial rotations of +104 and +97°, respectively, which only slowly decreased; the corresponding β-anomers **11** and **19**, however, which had only small positive rotations of +9 and +18° after solution in water, underwent substantial upward mutarotation to +84 and +57°, respectively, yielding an α/β-equilibrium mixture that mostly consisted of the α-anomers (TLC

and ^{1}H NMR). Thus, the anomeric configuration of hexosuloses of type **6** may already be derived from their rotational behaviour in water. In the case of pentosuloses, however, the α/β-anomeric equilibrium is not as clearly shifted towards the α-anomer since **22** underwent rather complex rotational changes from +44 to a maximum at +81° wherefrom it slowly decreased.



18 **19** **20** **21** **22** **23** **24** **25** **26**

II. Reevaluation of *Maurer*'s Work on Acetylated Hexosones

When comparing the highly crystalline tetra-*O*-acetyl-β-D-*arabino*-hexosulose (**11**), as obtained above, with the "Tetraacetyl-glucoson-Hydrat" of alleged structure III, prepared according to *Maurer*[22] via chlorination of **8** and subsequent silver ion promoted hydrolysis of the dichlorides formed (I → II → III), the two products proved to be identical in all respects. Similarly, the product resulting from hydrogenation of III, formulated as IV[23], had constants that closely corresponded to those for 1,3,4,6-tetra-*O*-acetyl-β-D-mannopyranose (**10**). Thus it became apparent that not only the structural assignments in these papers[22,23] but those in related investigations[24-27] had to be revised. Such structural revisions, based on a partial repetition of *Maurer*'s work, are presented in the sequel, together with configurational assignments and a mechanistic assessment of the reactions involved.

As evidenced by TLC monitoring, the chlorination of **7** (=I) in ether at room temperature yields a mixture of two dichlorides, which in analogy to the steric course of the halogen addition to benzoyl analogs of **7**[1,28-30] should be the *cis*-adducts of β-D-*gluco* (**30**) and α-D-*manno* configuration (**31**), with the former preponderating. They are comparatively stable and hydrolyzed only by longer refluxing with silver carbonate in aqueous acetone. Hence, the hygroscopic, highly unstable dichloride, which occasio-

nally was obtained crystalline (m. p. 70 °C after sintering at 46 °C) and to which structure II was assigned[22] has to be allotted the 1,2-acetoxonium chloride structure **29** (R = Ac), since silver carbonate-induced hydrolysis in moist ether gave a high yield (90%[22]) of the β-hexosulose **11**. However, when the chlorination of **7** in ether is performed at 0 °C in the presence of moist silver carbonate or sodium hydrogen carbonate, an approximate 7:2:1 mixture of α-hexosulose-tetraacetate **12**, its β-anomer **11**, and the apparently more readily formed α-D-*manno*-dichloride **31** (R = Ac) is obtained, wherefrom **11** crystallizes in yield of 10 – 15%. Since the α-anomer **12** can be isolated from the filtrate in about 60% yield by simple elution from a silica gel column, the one batch operation **7** → **28** → **12** constitutes the preparatively most ready route to the product.

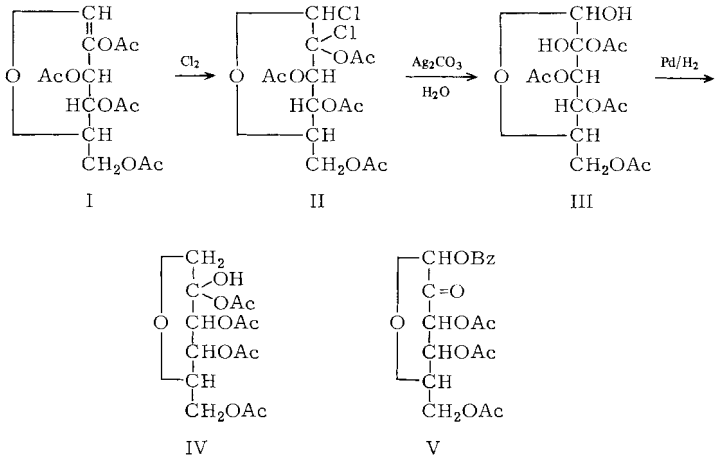
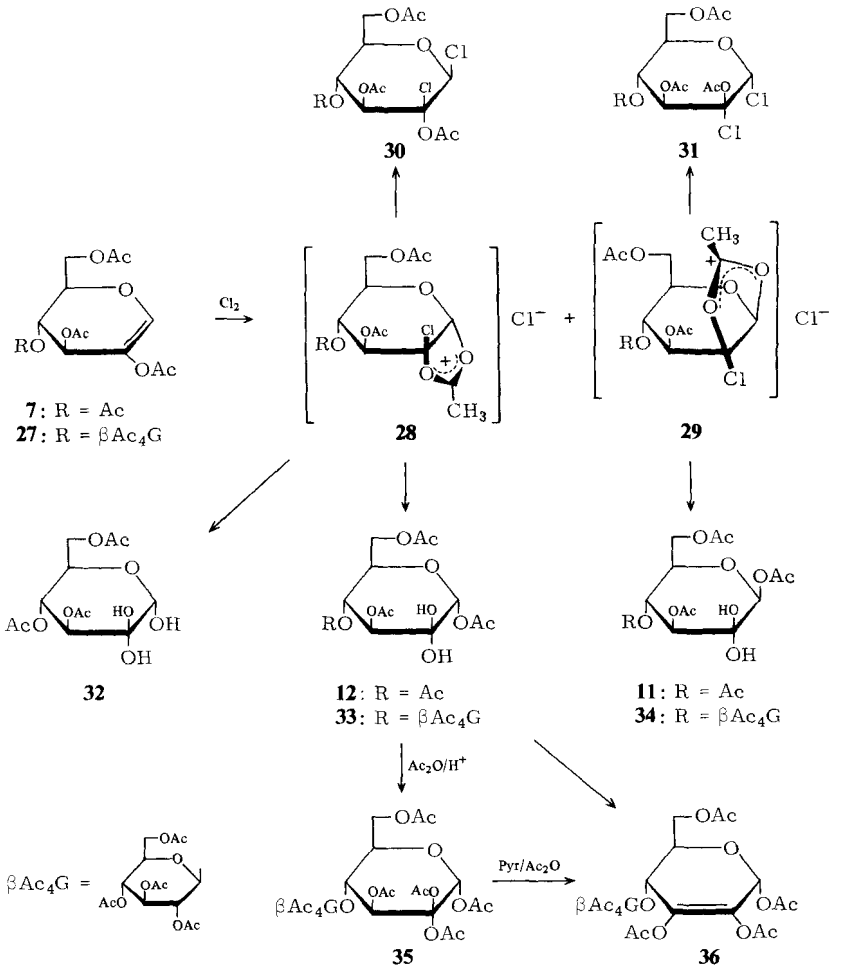


Fig. 1. Structures assigned by *Maurer*[22] to the product (III, now shown to be **11**) arising from the chlorination of tetraacetyl-2-oxyglucal I (**7**) and subsequent hydrolysis, and to products resulting from III by hydrogenation[23] (IV, revised: **10**) and benzoylation[27] (V, revised: **16**)

In view of these results, the partial formation of a "Triacetyl-glucoson-Hydrat" on extended exposure of the chlorination mixture to moist sodium hydrogen carbonate[26] can readily be rationalized as the outcome of hydrolysis of the anomeric acetyl group in either of the hexosuloses (**11** or **12**) or in their acetoxonium chloride precursors. On the basis of its high positive rotational value and its slow downward mutarotation ($[\alpha]_D^{19}$ = +104° → +84° (14 d) in aqueous ethanol[26]) the product constitutes the α-anomer of 3,4,6-tri-*O*-acetyl-D-*arabino*-hexopyranosulose monohydrate (**32**).

Similarly, the „1-Benzoyl-3,4,6-triacetyl-glucoson" of alleged structure V, obtained on treatment of III (revised: β-ulose **11**) with benzoyl chloride/pyridine[27], proved to be the tetraacetyl-benzoyl derivative **16** of α-D-*erythro*-hex-2-enose on the basis of ^{1}H NMR data. Thus, the supposed conversion III → V[27] in fact represents the transformation **11** → **16**, i. e. the 2-*O*-benzoylation of the hexose-2,3-enediol formed under the reaction conditions.



Analogous structural revisions have to be performed with the products arising from the chlorination of hepta-*O*-acetyl-2-hydroxycellobial (**27**)[25]. At room temperature a mixture of the respective *cis*-adducts **30** and **31** (R = βAc_4G) is obtained, from which one is isolable in crystalline form[25]. On the basis of C-1- and C-2-resonances at δ = 87.3 and 101.7, respectively, and a $J_{C\text{-}1/1\text{-}H}$-coupling constant of 174 Hz[31], it proved to be the hepta-*O*-acetyl-2-*C*-chloro-β-D-cellobiosyl chloride **30** (R = βAc_4G). This dichloride was remarkably stable towards silver ion-promoted dechlorination, refluxing with silver perchlorate in moist acetone being required to effect reaction to the α-cellobiosulose monohydrate **33**, readily characterizable in crystalline form and by spectral data. A more facile approach to this product proved to be the direct hydrolysis with silver carbonate of the low temperature chlorine adducts **28/29**, affording a mixture of the anomeric cellobiosuloses (**33/34**) from which the α-isomer **33** crystallized in yields of up to 45%. With respect to its analytical data, its comparatively wide melting range

(125 – 135 °C) and its rotational behaviour, the product proved to be identical with the "Heptaacetyl-cellobioson-Hydrat" of *Maurer* and *Plötner*[25] that was thought to have a structure analogous to III. Similarly, the „Heptaacetyl-cellobioson" arising therefrom on treatment with acetic anhydride/pyridine *de facto* is the octaacetyl-2,3-enediol **36** as shown by ^{1}H NMR data. Since the same product was obtained on pyridine/acetic anhydride treatment of a "Nonacetyl-cellobioson-hydrat", which in turn had been prepared from dichloride **30** (R = βAc_4G) by heating with silver acetate/acetic anhydride[25], the α-configuration **35** can be assigned to this compound.

The D-*lyxo*-hexenitol **18**, i. e. the C-4 epimer of **7** would be expected to give an analogous series of reactions on chlorination and subsequent hydrolysis by treatment with silver carbonate, and indeed does. Following the procedure of *Maurer* and *Müller*[24], their "Tetraacetyl-galaktoson-hydrat" of presumed structure III was obtained and shown to be the tetra-*O*-acetyl-α-D-*lyxo*-hexulose **20** on the basis of NMR and rotational data.

In view of the somewhat complex inter-relationships between the chlorination and hydrolysis products of glycal esters **7**, **18**, and **27**, it is not surprising that *Maurer* could not unravel these intricacies completely with elemental analysis, rotational values, and chemical derivatization as the only structural tools. In contrast, and despite the extensive structural revision required, it appears outright astounding that *Maurer*, nearly half a century ago and in almost sheer isolation[32], was able to carry out these investigations with such remarkable results[21 – 27]. It is similarly characteristic that these results withstood later experimental investigations by a proficient contemporary[14] and eluded the evaluation of *Maurer*'s work by three competent reviewers[33,34], despite the fact, that *Isbell*[6] in 1944 had provided the mechanistic framework for understanding the reactions involved.

III. Formation of 3,2-Enolones and γ-Pyrones

On standing in pyridine solution any of the tetraacetyl-hexos-2-uloses is quantitatively converted into di-*O*-acetylkojic acid (**42**) as is readily demonstrated by their loss of optical rotation (fig. 2). Thereby, the α-compounds **12** and **20** show a gradual decrease of rotational values requiring two days for disappearance, whereas the respective β-anomers **11** and **19** not only react considerably faster but obviously elaborate an intermediate of distinctly negative rotation (fig. 2, lower curve). Similarly, the triacetylpentosulose **22** gives *O*-acetylpyromeconic acid (**43**) under these conditions.

Mechanistically, this conversion is proceeding via an initial 3,4-elimination of acetic acid to a 3,2-enolone of type **37**, wherefrom the γ-pyrone system is elaborated by abstraction of the acidic proton vinylogous to the carbonyl group and subsequent *O*-3 → *O*-2 acetyl migration through an orthoacid intermediate **39**. Such a mechanism has already been forwarded a decade ago[8,9] to account for the formation of **42** upon oxidation of 1,3,4,6-tetraacetyl-D-hexoses with dimethyl sulfoxide/acetic anhydride, and was subsequently substantiated by the analogous behaviour of the more stable benzoylated 3,2-enolones[1,28,29,35].

Unequivocal further evidence for such a course is provided by the isolation and characterization of the intermediate 3,2-enolones **37** and **38**. On quenching a pyridine solution of β-hexosulose **11** after reaching the rotational minimum (≈ 25 min, cf. fig. 2), the 1,3,6-triacetyl-enolone **37β** constitutes the major product aside some **42** and educt

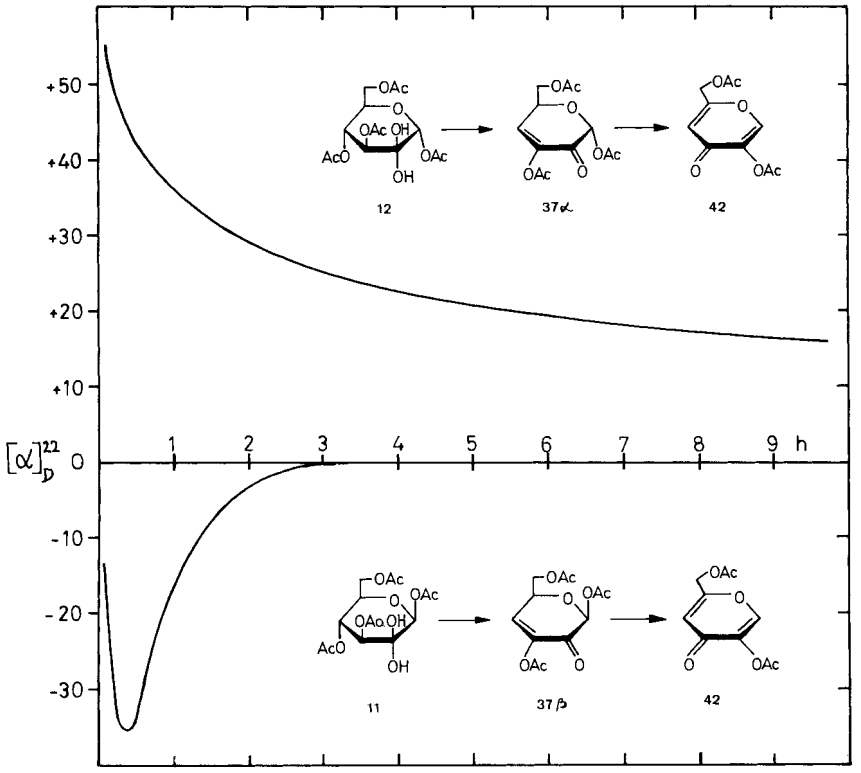
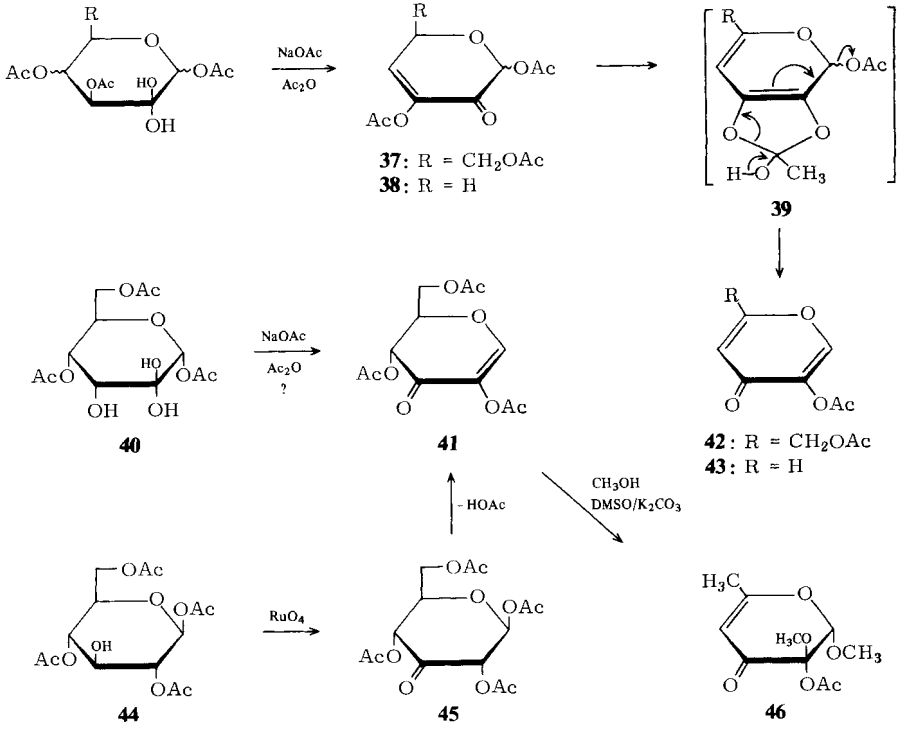


Fig. 2. Rotational changes during conversion of the 1,3,4,6-tetra-*O*-acetyl-D-*arabino*-hexos-2-uloses **11** and **12** into di-*O*-acetylkojic acid (**42**) in pyridine solution at 25 °C. The upper curve reaches zero after 48 h

(TLC) and can be separated therefrom by chromatography. Its structure and β-configuration unambiguously followed from ^{1}H NMR data, most notably from the 3.5 Hz doublet for the 4-H at $\delta = 6.74$[36]. Preparatively more convenient, i. e. without column separation, proved to be its isolation from a reaction mixture resulting from stirring **11** in moist 1,2-dimethoxyethane with sodium benzoate, which afforded yields of up to 70%. Similarly, when exposing either of the α-uloses **12**, **20**, or **22** to pyridine or, more simply, to sodium benzoate/1,2-dimethoxyethane, the respective α-enolones **37α** and **38α** were isolable and unequivocally characterized by their positive rotational values, by the negative sign of the long-wavelength Cotton effect, i. e. the enone R band in the 335 nm region[38], and by their $J_{4,5}$ coupling constants, being 2.5 and 4.0 Hz in the pentose-enolone **38α**, and 2.0 Hz in the hexose case **37α**[39].

Under the conditions for a base-catalyzed acetylation, such as sodium acetate/acetic anhydride or pyridine/acetic anhydride, the same conversions **11**/**12**, **19**/**20** → **37** → **42** and **22** → **38** → **43** are initiated, yet the respective uloses or enolone intermediates anomerized as evidenced by the isolation of approximate 1:1 mixtures of **37α**/**37β** and **38α**/**38β**. No other intermediates were isolable or detectable by TLC or

by ^{1}H NMR in any of these transformations, thus furnishing ample proof for the conversion of peracylated pyranos-2-uloses into γ-pyrones via 3,2-enolones of type **37** and **38**.



This experimentally now well corroborated course is contrasted by the alternate mechanistic pathway of *Aspinall* and *King*[40], who proposed the triacetyl-enediolone **41** as the decisive intermediate, based on findings that **41** is formed on treatment of glycosulose **40** with sodium acetate/acetic anhydride and is converted into kojic acid diacetate (**42**) by pyridine/acetic anhydride. For clarification, the enediolone **41** was independently synthesized from 1,2,4,6-tetra-*O*-acetyl-β-D-glucopyranose (**44**) via oxidation to the 3-ulose **45** and subsequent β-elimination, employing either dimethyl sulfoxide/acetic anhydride[41] or ruthenium tetroxide and sodium hydrogen carbonate/dichloromethane as reagents. The product **41** had ^{1}H NMR data corresponding to those reported for the reduction product of an 1,2-orthoacid perester[40], yet – in contrast to the findings of *Aspinal* and *King*[40] – **41** proved to be a remarkable stable compound. Unlike the enolones **37** and **38** which on standing in pyridine solution are converted quantitatively into the respective γ-pyrones, the enediolone **41** is entirely unaffected by pyridine, by pyridine/acetic anhydride, by extended exposure to sodium acetate/acetic anhydride at room temperature[43], or by refluxing in toluene. This greater stability of **41** over **37** is not unexpected, since in the enolones the 5-H is considerably more acidic due to the vinylogous carbonyl function – an effect lacking in **41**.

The only reactions readily elicitable from enediolone **41** are, in fact, those that involve attack of a nucleophile at the anomeric carbon atom. On treatment with methanol/BF_3-etherate, a mixture of methyl glycosid-3-uloses is formed, whilst on reaction with methanol in dimethyl sulfoxide in the presence of potassium carbonate, the intermediate glycosid-3-uloses undergo further transformations. In an interesting series of highly stereoselective reactions, comprising elimination of acetic acid from the 3,4- and 5,6-positions[44], the 4,3-enolone **46** is formed and may be isolated in a yield of 31%, no kojic acid diacetate being detectable in the reaction mixture. Nonetheless, when introducing an acyloxy function at C-1, as effected by treatment with sodium benzoate/potassium carbonate in dimethyl sulfoxide, **41**, indeed, is converted gradually into diacetylkojic acid (**42**); it must be emphasized, however, that this conversion **41** → **42** does not involve a 4,5-elimination of acetic acid, but instead a rearrangement of intermediate tetraacyl-glycos-3-ulose of type **45** into the respective 2-ulose, which is then subject to a reaction sequence analogous to **12** → **37** → **39** → **42**. Thus, γ-pyrone formation from enediolones of type **41** also proceeds via 3,2-enolones as the decisive intermediates.

Grateful acknowledgement is made to the *Deutsche Forschungsgemeinschaft* and the *Fonds der Chemischen Industrie* for generously supporting this work. We are also indebted to Dr. *S. Nishiyama* and to Dipl.-Ing. *A. Löhe* for the performance of some experiments.

Experimental Part

Melting points and instruments as before[1]. – TLC Developers: A ethyl acetate/methanol/water (30:5:1), B benzene/ethyl acetate (7:3), C ethyl acetate/cyclohexane (7:3), D benzene/acetone (3:1), E ether/n-pentane (7:3). The spots were visualized by UV light or by spraying with 80% aqueous sulphuric acid and charring at 110°C for 5 min. – PLC: 1.5 mm layers of Kieselgel PF_{254} (Merck). – Column chromatography: Kieselgel 60 (70–230 mesh, Merck).

1,3,4,6-Tetra-O-acetyl-β-D-arabino-hexopyranos-2-ulose monohydrate (**11**)

a) *By peroxidation of tetra-O-acetyl-1,5-anhydro-D-arabino-hex-1-enitol* (**7**) *with 3-chloroperbenzoic acid:* A solution of **7**[5] (1.00 g, 3 mmol) in ether (10 ml) was mixed with 1.15 g (6 mmol) of 90% 3-chloroperbenzoic acid and was allowed to stand at room temperature for 20 h, resulting in the separation of crystals which were collected and washed several times with small quantities of dry ether. Allowing the mother liquor to stand at room temperature gave a second crop. This process was continued until the chloroperbenzoic acid started to crystallize: 605 mg (55%) of **11** as fine needles; m. p. 117–118°C[45]; $[\alpha]_D^{23}$ = +6.5° (*c* = 0.5, DMSO), –6.0° (*c* = 0.5, chloroform); mutarotation is observed in 20% aqueous ethanol [$[\alpha]_D^{21}$ = +4° (3 min) → +48.3° (96 h)] and in water [$[\alpha]_D^{23}$ = +8.8° (3 min) → +15° (15 min) → +21° (45 min) → +34° (2 h) → +55° (8 h) → +84° (2 d), *c* = 0.7][45].

IR (KBr): 3400 (OH), 1745 cm^{-1} (CO). – ^{1}H-NMR ([D_6]DMSO): δ = 1.91, 1.96, 2.00 and 2.10 (four 3 H-s, OAc), 4.0 (m, 3 H, 5-H, CH_2-6), 5.04 (d, *J* = 7 Hz, 1 H, 3-H), 5.07 (t, *J* = 7 Hz, 1 H, 4-H), 5.60 (s, 1 H, 1-H), 5.90 and 6.20 (two 1 H-s, 2-OH; disappearing on deuteration). – ^{13}C-NMR ([D_6]DMSO)[46]: δ = 192.3 s (C-2, carbonyl form), 169.9, 169.5, 169.3 and 168.9 (4 acetyl-C=O), 92.6 d (C-1, $J_{1\text{-H/C-1}}$ = 165 Hz), 91.5 s (C-2, hydrate form), 74.5 d (C-3), 71.3 d (C-5), 67.6 d (C-4), 61.8 t (C-6), 20.7, 20.6, 20.5 and 20.4 (4 acetyl-CH_3). – MS (70 eV): *m/e* = 304 (M^+ – HOAc), 262 (304 – CH_2CO).

$C_{14}H_{18}O_{10} \cdot H_2O$ (364.3) Calc. C 46.15 H 5.53 Found C 46.08 H 5.51

The mother liquor remaining after the isolation of **11** consisted of some **11**, 3-chlorobenzoic acid and, mainly, the α-anomer **12**, as evidenced by R_F values (0.40 for **11**, 0.48 for **12**, in C), by its rotation (+50° in $CHCl_3$) and slow downward mutarotation (from +80°) in water as well as by ^1H NMR data. Attempts to isolate **12** from this mixture in pure form (cf. below) were not very propitious.

b) *By peroxidation of* **7** *with perbenzoic acid:* 1.0 g of **7** (3 mmol) was added to an ethereal solution of perbenzoic acid (0.6 g in 15 ml), and the mixture was kept at room temperature for 2 days. The needles which had separated were collected and washed with small portions of ether: 250 mg (23%) of **11**, identical with the product described above (a)[13].

c) *By chlorination of* **7** *and subsequent hydrolysis:* Chlorine gas was passed through an ice-cooled solution of **7** (2.0 g, 6.1 mmol) in ether (20 ml) until a greenish color persisted (≈ 5 min). After stirring for another 10 min excess chlorine was removed by evaporation *in vacuo* followed by several reevaporations from ether. The residue was dissolved in ether (30 ml) and water (2–3 ml) was added with stirring which resulted in the separation of fine needles that were filtered off after standing overnight: 480 mg (20%) of essentially pure **11**, m. p. 112–113 °C[45].

From the ethereal mother liquor, the major product from this reaction, α-anomer **12**, was readily isolable (cf. below).

d) *By RuO_4 oxidation of 1,3,4,6-tetra-O-acetyl-β-D-glucopyranose* (**8**): To a solution of RuO_4 in CCl_4 – prepared by stirring a mixture of RuO_2 hydrate[47] (250 mg) in ethanol-free CCl_4 (20 ml) and $NaIO_4$ (1.5 g, 5 M excess) in water (15 ml) for 1.5 h at ambient temperature and subsequent removal of the aqueous phase – was added a solution of **8**[48] (170 mg, 0.5 mmol) in dichloromethane (5 ml). After 2 h at ambient temperature, isopropyl alcohol was added to reduce residual RuO_4, and the mixture was filtered (folded filter) and evaporated to dryness. Trituration of the residue with ether afforded 82 mg (60%) of crystalline **11**, identical in all respects with the product describe above.

1,3,4,6-Tetra-O-acetyl-α-D-arabino-hexopyranos-2-ulose monohydrate (**12**)

a) *By RuO_4 oxidation of 1,3,4,6-tetra-O-acetyl-α-D-glucopyranose* (**9**): 1.0 g (2.9 mmol) of **9**[20] was oxidised with RuO_4 in CCl_4 [prepared from RuO_2 hydrate in CCl_4 (1.3 g in 50 ml) and $NaIO_4$ in water (10 g in 50 ml)] as described above for the preparation of **11**. After 9 h at ambient temperature the reaction was quenched by the addition of 2-propanol (1.5 ml) and the mixture was filtered and evaporated to dryness *in vacuo* (finally 0.2 Torr) to give 0.87 g (79%) of **12** as a chromatographically uniform (TLC in B, C), analytically pure, amorphous product, softening around 50 °C. Crystallization from dry ether proceeded sluggishly, affording needles of m. p. 71–72 °C; $[\alpha]_D^{22}$ = +77° (*c* = 0.3, chloroform), no change after 24 h; $[\alpha]_D^{22}$ = +104° (*c* = 0.4, water) → +96° (24 h).

IR (KBr): 3430 cm^{-1} (OH). – ^1H-NMR ($CDCl_3$, after standing for 3 h[46]): δ = 2.09 (6H), 2.18 and 2.21 (3H each, 4 OAc), 4.2–4.5 (3H-m, 5-H and 6-H_2), 5.44 (t, 1H, $J_{3,4} = J_{4,5}$ = 10 Hz, 4-H), 5.65 (10 Hz-d, 1H, 3-H), 6.14 (1H-s, 1-H) for the nonhydrated form of **12**; the hydrate exhibits 1-H at 6.03, 3-H and 4-H at 5.3 and slightly different acetoxy resonances. – ^{13}C-NMR ($CDCl_3$): δ = 190.9 (C-2, keto form), 169.8–168.7 (acetyl-C=O), 93.5 and 90.9 (C-1 of hydrated form with $J_{C\text{-}1/1\text{-}H}$ = 176 Hz and of keto form with *J* = 181 Hz), 92.9 (C-2, hydrate form), 74.9 (C-3), 70.2 (C-5), 68.8 (C-4), 61.2 (C-6).

$C_{14}H_{18}O_{10} \cdot H_2O$ (364.3) Calc. C 46.15 H 5.53 Found C 46.40 H 5.61

b) *By chlorination of* **7** *and subsequent hydrolysis:* A gentle stream of chlorine gas was passed into a vigorously stirred ice-cooled mixture of **7** (2.0 g, 6 mmol), silver carbonate (3.0 g), ether (100 ml), and water (0.15 ml). After 20 min excesse chlorine was removed by concentration *in va-*

cuo to about 50 ml, and the mixture was stirred for another 30 min at room temperature and kept overnight in a refrigerator. The precipitate consisting of β-hexosulose **11** and silver salts, was filtered off, and by extraction with chloroform, evaporation of the extract and trituration with ether gave 300 mg (14%) of **11**, m. p. 116–117 °C. The ethereal filtrate, containing the α-ulose **12** ($R_F \approx 0.5$ in C), about 5–10% of α-D-*manno*-dichloride **31** ($R_F = 0.8$) and traces only of β-ulose **11** ($R_F = 0.42$), was evaporated to dryness and the residue was purified by fast elution (3–4 h) from a silica gel column (2 × 40 cm) with ethyl acetate/cyclohexane (7:1). Concentration of the fraction eluted second gave 1.3 g (59%) of amorphous **12**, identical in all respects with the product described under a). Crystallization could be induced on longer standing in dry ether in a refrigerator.

1,3,4,6-Tetra-O-acetyl-β-D-mannopyranose (**10**): β-Ulose **11** (800 mg, 2.5 mmol) was added to a prehydrogenated suspension of platinum oxide (600 mg) in ethyl acetate (25 ml) and hydrogenation was continued until 1 equiv. of H_2 had been consumed (6 h – 2 days), whereafter TLC revealed the presence of **10** ($R_F = 0.3$ in B) aside two faster moving ($R_F \approx 0.45$) and some slower moving products. The mixture was filtered and the filtrate was evaporated to dryness. Toluene was destilled over the residue which was then dissolved in a small quantity of ether. On standing at 5 °C, prisms separated which were filtered (filtrate cf. below) and recrystallized from ether: 145 mg (19%); m. p. 164 °C, $[\alpha]_D^{21} = -24°$ ($c = 0.7$, chloroform) (lit.[48] m. p. 164–165 °C, $[\alpha]_D^{30} = -23.6°$, $c = 1.4$, chloroform).

^{1}H-NMR ([D$_6$]DMSO): δ = 2.01 and 2.03 (2 s, 3H and 9H, 4 OAc), 4.00 (m, 4H, 2-, 5-H and 6-CH$_2$), 5.06 (dd, 1H, $J_{2,3} = 3$ and $J_{3,4} = 9.5$ Hz, 3-H), 5.21 (t, 1H, $J_{3,4} = J_{4,5} \approx 10$ Hz, 4-H), 5.50 (5 Hz-d, 1H, 2-OH; exchangeable on deuteration), 5.84 (d, 1H, $J_{1,2} = 1$ Hz, 1-H).

Separation of the ethereal mother liquor on a silica gel column by elution with benzene/ethyl acetate (7:3) afforded the two faster moving (TLC in B) components as syrups of $[\alpha]_D^{23} = +35.6°$ ($c = 0.5$, chloroform) (10% yield), and $[\alpha]_D^{23} = +26.1°$ (8%). The negative osazone test with 2,4-dinitrophenylhydrazine and their MS (FD) data (M^+ at $m/e = 391/392$ each) indicated them to be penta-*O*-acetylhexitols, apparently formed via transacetylations.

Deuteration of **11** in the fashion described above for hydrogenation afforded the 2-deuterio derivative as indicated by ^{1}H NMR: the quartet for 3-H at δ = 5.06 appears as a 9.5 Hz-doublet and the intensity of the 4H-multiplet around 4.00 is reduced by 1H; since the anomeric proton (s at δ 5.84) had an intensity of exactly 1H, deuterium incorporation had not occured at C-1. It appears likely that the product of m. p. 158 °C and $[\alpha]_D = -3.2°$ (ethanol), which *Maurer* and *Böhme*[23] obtained in 75% yield on Pd catalyzed[49] hydrogenation of „Tetraacetyl-glucosonhydrat III" (revised formula: **11**) in 50% aqueous acetic acid, and to which they assigned structure IV, in fact is tetraacetyl-β-D-mannose **10**, all the more as on treatment with pyridine/acetic anhydride a pentaacetate is formed whose constants (m. p. 116 °C and $[\alpha]_D = -25°$ in chloroform) correlate well with those for penta-*O*-acetyl-β-D-mannopyranose [(m. p. 117–118 °C and $[\alpha]_D^{20} = -25.2°$ ($c = 0.3$, chloroform)[50]].

2-C-Acetoxy-1,2,3,4,6-penta-O-acetyl-α-D-glucopyranose (**13**): Ulose monohydrate **11** or **12** (0.55 g, 1.5 mmol) was added to a mixture of acetic anhydride (10 ml) and perchloric acid (70%, 2 drops) with vigorous stirring. After standing for 1 h at 10 °C the mixture was diluted with dichloromethane and successively washed with $NaHCO_3$ solution (3 x) and water, dried (Na_2SO_4) and evaporated. Two reevaporations *in vacuo* from toluene followed by dissolution in ether and treatment with n-hexane afforded crystals which were recrystallized from ether: 210 mg (31%) of **13**; m. p. 135 °C, $[\alpha]_D^{21} = +41.3°$ ($c = 0.8$, benzene).

^{1}H-NMR ([D$_6$]DMSO): δ = 1.96, 2.00, 2.02 (6H), 2.15 and 2.19 (5 s, 6 OAc), 4.10 (m, 3H, 5-H and 6-CH$_2$), 5.19 (t, 1H, J = 10 Hz, 4-H), 5.46 (d, 1H, J = 10 Hz, 3-H), 6.72 (s, 1H, 1-H). – ^{13}C-NMR ([D$_6$]DMSO): δ = 169.85, 169.35, 169.05, 168.20, 168.47 and 168.31 (6 acetyl-

C = O), 99.15 s (C-2), 88.03 d (C-1, $J_{1\text{-H/C-1}}$ = 183 Hz), 70.58 d, 68.81 d, and 65.80 d (C-3, -4, -5), 61.07 t (C-6).

$C_{18}H_{24}O_{13}$ (448.4) Calc. C 48.21 H 5.39 Found C 48.24 H 5.37

2,3,4,6-Tetra-O-acetyl-D-mannono-1,5-lactone (**14**): To a solution of **10** (700 mg, 2.0 mmol) in dichloromethane (12 ml) were added ruthenium dioxide (160 mg), sodium metaperiodate (600 mg), and water (10 ml). The mixture was constantly stirred with occasional additions of metaperiodate until the colour turned permanently yellow. Excess of the tetroxide was destroyed by the addition of a few drops of isopropyl alcohol and the mixture was filtered. The aqueous layer was separated, washed several times with dichloromethane, and the washings were added to the organic layer. The organic solution was then washed with water, dried (Na_2SO_4), and evaporated *in vacuo*. The residue was dissolved in ether and the ethereal solution on standing afforded 240 mg (35%) of crystalline **14**, m. p. 109 – 110 °C; $[\alpha]_D^{21}$ = +56° (3 min) → +78° (5 min) → 71° (24 h) → +53° (10 days) (*c* = 1, chloroform).

^{1}H-NMR ([D_6]DMSO): δ = 2.03, 2.07 (6H) and 2.09 (3 s, 4 OAc), 4.27 (m, 2H, 6-H_2), 4.98 (narrow m; 2H, 4-H and 5-H), 5.42 (m, 1H, 3-H), 5.98 (d, $J_{2,3}$ = 4 Hz, 1H, 2-H). – MS (70 eV): *m/e* = 347 (M^+), 304 (M^+ – CH_2CO), 273 (M^+ – CH_2OAc).

$C_{14}H_{18}O_{10}$ (346.3) Calc. C 48.56 H 5.24 Found C 48.48 H 5.26

Penta-O-acetyl-β-D-erythro-hex-2-enopyranose (**15**): A solution of β-hexosulose **11** (550 mg, 1.5 mmol) in chloroform (12 ml) was cooled to −10 °C, followed successively by the addition of acetyl chloride (0.60 ml) in chloroform (3 ml) and precooled pyridine (0.75 ml). After 20 h at 0 °C an approximate 4:1 mixture of **15** and kojic acid diacetate (**42**) (TLC in C) had formed, from which **15** was isolated by dilution with chloroform, washed with water, N H_2SO_4, aqueous $NaHCO_3$ solution and, again, water, to give a syrup on evaporation to dryness which crystallized on trituration with ethanol. Recrystallization from ethanol yielded 384 mg (64%) of **15** as needles, m. p. 85 °C, $[\alpha]_D^{21}$ = +165° (*c* = 0,3, chloroform).

^{1}H-NMR ($CDCl_3$): δ = 6.64 (1H-s, 1-H), 5.66 (1H-d, $J_{4,5}$ = 1.5 Hz, 4-H), 4.40 (3H-m, 5-H and 6-H_2), acetyl resonances at 2.17 (6H), 2.13 and 2.10 (6H). – ^{13}C-NMR ($CDCl_3$): δ = 170.4, 169.5, 167.6 and 166.6 (acetyl-CO), 135.2 and 134.8 (C-2 and -3), 87.1 d (C-1, $J_{1\text{-H/C-1}}$ = 178 Hz), 74.9 d (C-4), 65.8 d (C-5), 62.7 t (C-6), 21.0, 20.8, 20.7, 20.4 and 20.2 (acetyl-CH_3).

$C_{16}H_{20}O_{11}$ (388.3) Calc. C 49.48 H 5.19 Found C 49.44 H 5.16

Unlike educt **11**, the enediol acetate **15** is stable in pyridine solution, even on heating, or towards sodium acetate/acetic anhydride at room temperature.

1,3,4,6-Tetra-O-acetyl-2-O-benzoyl-β-D-erythro-hex-2-enopyranose (**16**): To an ice-cooled solution of β-hexosulose **11** (1.82 g, 5 mmol) in chloroform (15 ml) was added, consecutively, a solution of benzoyl chloride (1.1 ml, 1.6 mol. equiv.) in chloroform (5 ml) and precooled pyridine (2 ml) in chloroform (5 ml). The mixture was kept overnight at 0 – 5 °C, whereafter TLC showed the presence of **16** (R_F = 0.65 in chloroform/acetone 7:3), besides some di-*O*-acetylkojic acid (**42**), and traces of enolone **37β** (R_F = 0.3 and 0.43, resp.). Dilution with chloroform (50 ml), followed by washing with ice-water, N H_2SO_4, aqueous $NaHCO_3$ solution, and again water, afforded a syrup upon drying (Na_2SO_4) and evaporation *in vacuo*, which crystallized upon trituration with ethanol: 1.25 g (55%) of **16** as needles, m. p. 116 °C after recrystallization from ethanol; $[\alpha]_D^{23}$ = +148° (*c* = 1, chloroform).

^{1}H-NMR ($CDCl_3$): δ = 2.05, 2.09, 2.13 and 2.15 (four 3H-s, 4 OAc), ≈4.5 (3H-m, 5-H, 6-H_2), 5.74 (d, 1H, $J_{4,5}$ = 1.5 Hz, 4-H), 6.79 (1H-s, 1-H), 7.6 and 8.10 (3H-m and 2H-q, C_6H_5).

$C_{21}H_{22}O_{11}$ (450.4) Calc. C 56.00 H 4.93 Found C 55.88 H 4.86

On the basis of mode of preparation and physical data [m. p. 116°C, $[\alpha]_D^{19} = +144.3°$ (c = 1.3, chloroform)], the „1-Benzoyl-3,4,6-triacetyl-glucoson" of structure V, obtained by *Maurer* and *Petsch*[27] on treatment of „Tetraacetyl-glucoson-Hydrat" (III, revised structure: **11**) with benzoyl chloride/pyridine, is, in fact, identical with **16**.

Penta-O-acetyl-α-D-erythro-hex-2-enopyranose (**17**): Treatment of α-hexosulose **12** (550 mg, 1.5 mmol), in chloroform solution, with acetyl chloride/pyridine as described for **11** (cf. above), and analogous work-up of the reaction mixture afforded 350 mg (60%) of **17** as well-shaped prisms of m. p. 141°C (ethanol), $[\alpha]_D^{23} = +59°$ (c = 0.4, chloroform). ^{1}H NMR data correspond with those of the β-anomer **15** except for minor differences in chemical shifts and $J_{4,5}$ = 9 instead of 1.5 Hz.

$C_{16}H_{20}O_{11}$ (388.3) Calc. C 49.48 H 5.19 Found C 49.45 H 5.16

1,3,4,6-Tetra-O-acetyl-β-D-lyxo-hexopyranos-2-ulose (**19**): 3-Chloroperbenzoic acid (1.5 g, 6 mmol, of 90% commercial product) was added portionswise during 3 h to a well-stirred solution of tetra-*O*-acetyl-1,5-anhydro-D-*lyxo*-hex-1-enitol[51] (**18**) (1.00 g, 3 mmol) in ether (30 ml), giving a clear solution after about 6 h. The mixture was kept at room temperature for another 30 h whereafter TLC indicated the absence of educt in favor of one single product (**19**, R_F = 0.25 in C). Addition of n-pentane in small portions over a longer period (1 – 2 d) and standing at 5 – 8°C resulted in gradual crystallization: 620 mg (57%) of a product with m. p. 48 – 50°C and $[\alpha]_D^{22} = +5.3°$ (c = 0.15, chloroform), which consisted of an approximate 5 : 1 mixture of β-ulose **19** (R_F = 0.25 in C) and its monohydrate (R_F = 0.40). Fractionated crystallization from relatively large quantities of ether gave the pure keto form (**19**) as needles of m. p. 58 – 60°C and $[\alpha]_D^{22} = +2.9°$ (c = 0.3, chloroform); $[\alpha]_D^{23} = +18°$ (c = 0.2, water) after 4 min → +26° (4 h) → +31° (1 d) → +57° (5 d).

^{1}H-NMR ($CDCl_3$): δ = 2.09, 2.24, 2.16 and 2.24 (four 3H-s, 4 OAc), 4.23 (6 Hz-d, 2H, 6-H_2), 4.57 (1 H-dt, $J_{4,5}$ = 2 and $J_{5,6}$ = 6 Hz, 5-H), 5.73 (1 H-d, $J_{3,4}$ = 4 Hz, 3-H), 5.82 (1 H-dd, 4-H), 6.22 (1 H-s, 1-H). – ^{13}C-NMR ($CDCl_3$): δ = 190.3 (C-2, keto form), 169 – 167 (acetyl-C=O), 90.7 d (C-1, $J_{1\text{-H/C-1}}$ = 169 Hz), 73.5 d (C-3), 71.5 d (C-5), 67.3 d (C-4), 61.8 t (C-6), 20.7 – 20.4 (acetyl-CH_3).

$C_{14}H_{18}O_{10}$ (346.3) Calc. C 48.56 H 5.24 Found C 48.65 H 5.30

1,3,4,6-Tetra-O-acetyl-α-D-lyxo-hexopyranos-2-ulose monohydrate (**20**): Chlorine gas was passed through an ice-cooled ethereal solution of tetraacetyl-hexenitol **18**[51] (3.2 g, 10 mmol, in 50 ml) until a slightly green color appeared (≈ 5 min). After stirring for another 10 min excess chlorine was removed by evaporation *in vacuo* and two subsequent reevaporations from ether. The residue was dissolved in ether (30 ml) followed by addition of water (1.5 ml) and of silver carbonate (1.5 g) in small portions to control CO_2 formation. After stirring for 30 min the mixture was filtered and the residue was washed with chloroform (3 × 50 ml). Filtrate and washings were taken to dryness and the remaining syrup, consisting of **20**, its β-anomer **19**, and of some proportion of the 1,2-dihalides (TLC in C), was quickly eluted from a silica gel column (2 × 40 cm) with ethyl acetate/cyclohexane (7 : 1). On concentration of the major fraction (eluted second), dissolution of the residue in chloroform, and addition of ether, **20** precipitated: 1.46 g (40%), m. p. 96 – 97°C, $[\alpha]_D^{23} = +47.1°$ (c = 1.0, chloroform); $[\alpha]_D^{23} = +98°$ (5 min) → +75° (4 d) (c = 0.8, water).

^{1}H-NMR ($CDCl_3$[46]): δ = 2.08, 2.12, 2.16 and 2.20 (four 3H-s, 4 OAc), 4.18 (d, 2 H, $J_{5,6}$ = 6 Hz, 6-H_2), 4.74 (dt, 1 H, $J_{4,5}$ = 1 Hz, 5-H), 5.80 (t, 1 H, $J_{3,4}$ = 4 Hz, 4-H), 5.88 (d, 1 H, 3-H), 6.15 (s, 1 H, 1-H).

$C_{14}H_{18}O_{10} \cdot H_2O$ (364.3) Calc. C 46.15 H 5.53 Found C 46.08 H 5.49

For a product ("Tetraacetyl-galaktoson-hydrat" of alleged structure III), prepared similarly, *Maurer* and *Müller*[24] reported m. p. 96 °C and $[\alpha]_D^{20} = +45.7°$ ($c = 0.3$, chloroform), as well as mutarotation in water ($+98.9 \rightarrow +1.4°$ after 105 d).

1,3,4-Tri-O-acetyl-α-D-threo-pentopyranos-2-ulose monohydrate (**22**)

a) *By peroxidation of tri-O-acetyl-1,5-anhydro-D-threo-pent-1-enitol* (**21**): To an ethereal solution of **21**[51] (2.00 g, 7.7 mmol, in 40 ml) was added 3-chloroperbenzoic acid (90%, 2.96 g, 15.4 mmol), and the mixture was allowed to stand at room temperature for 24 h. The platelets that had separated were collected and washed with small quantities of ether. The filtrate was evaporated to dryness and the residue was dissolved in 1,2-dichloroethane and filtered to remove 3-chloroperbenzoic acid. Concentration of the filtrate and trituration of the residue with ether gave a second crop of **22**. The mother liquor on standing afforded further quantities of the product. Total yield 990 mg (47%); m. p. 117 – 118 °C, $R_F = 0.6$ in A, $[\alpha]_D^{22} = +57°$ ($c = 0.4$, tetrahydrofuran), constant after 24 h; $[\alpha]_D^{22} = +44°$ ($c = 0.9$, water) after 3 min $\rightarrow +73°$ (5 min) $\rightarrow +81°$ (30 min) $\rightarrow +78°$ (2 h) $\rightarrow +65°$ (24 h) $\rightarrow +46°$ (72 h).

^{1}H-NMR ([D$_6$]DMSO): δ = 1.98, 2.07, and 2.15 (three 3 H-s, 3 OAc), 3.62 (dd, 1 H, $J_{4,5a} = 10$, $J_{4,5e} = 6$, and $J_{5a,5e} = 14$ Hz, axial 5-H), 3.80 (dd, 1 H, equat. 5-H), 5.02 (dt, 1 H, $J_{3,4} = 10$ Hz, 3-H), 5.72 (s, 1 H, 1-H), 6.37 and 6.45 (two 1 H-s, 2-OH; signals disappearing on deuteration). – ^{13}C-NMR ([D$_6$]DMSO): δ = 169.8, 169.6, and 169.0 (3 acetyl-C=O), 93.3 d (C-1, $J_{1\text{-H/C-1}} = 174$ Hz), 91.5 s (C-2), 72.3 d (C-3), 68.0 d (C-4), 60.3 t (C-5), 20.7, 20.6, and 20.4 (3 acetyl-CH$_3$). – MS (70 eV): *m/e* = 232 (M^+ – HOAc), 215 (M^+ – H$_2$O and OAc), 155 (215 – HOAc).

$C_{11}H_{16}O_9$ (292.2) Calc. C 45.21 H 5.52 Found C 45.16 H 5.36

b) *By RuO_4 oxidation of 1,3,4-tri-O-acetyl-α-D-xylopyranose* (**23**): To a RuO_4 solution – prepared by stirring a mixture of RuO_2 hydrate[47] (400 mg) in ethanol-free CCl_4 (25 ml) and $NaIO_4$ (2.0 g) in 15 ml of water for 1.5 h at ambient temperature, followed by removal of the aqueous phase – was added 300 mg (1.1 mmol) of **23**[52] in dichloromethane (5 ml). After 2 h at ambient temperature the excess RuO_4 was destroyed by the addition of 2-propanol followed by filtration and evaporation to dryness. The residue crystallized on trituration with ether: 210 mg (66%) of **22**, m. p. 118 – 119 °C, identical with respect to rotation, IR, and NMR data with the product described above.

2-C-Acetoxy-1,2,3,4-tetra-O-acetyl-α-D-xylopyranose (**24**): Pentosulose **22** (150 mg, 0.5 mmol) was added with stirring to cold (≈ 10 °C) acetic anhydride (8 ml) containing 3 drops of 70% $HClO_4$, and the mixture was kept at 10 °C for 45 min, followed by dilution with dichloromethane and stirring into ice-water. Washing of the organic phase with water, sat. aqueous $NaHCO_3$, and water, and evaporation to dryness left a syrup that crystallized on trituration with ether/n-hexane. Recrystallization from the same solvents afforded 60 mg (31%) of **24**; m. p. 108 – 109 °C; $[\alpha]_D^{23} = 0°$ ($c = 0.5$, chloroform).

^{1}H-NMR ($CDCl_3$): δ = 2.20, 2.18, 2.11, 2.08, and 2.02 (five 3 H-s, 5 OAc), 3.70 (dd, 1 H, $J_{4,5a} = 10$, $J_{5a,5e} = 12$ Hz, axial 5-H), 4.00 (dd, 1 H, $J_{4,5e} = 6$ Hz, equat. 5-H), 5.22 (dt, 1 H, $J_{3,4} = 10$ Hz, 4-H), 5.58 (10 Hz-d, 1 H, 3-H), 6.84 (s, 1 H, 1-H). – ^{13}C-NMR ($CDCl_3$): δ = 169.9 – 167.9 (acetyl-C=O), 99.0 s (C-2), 87.9 d (C-1, $J_{1\text{-H/C-1}} = 178$ Hz), 68.3 and 65.8 (C-3/C-4), 61.1 t (C-5), 20.7 – 20.4 (acetyl-CH$_3$).

$C_{15}H_{20}O_{11}$ (376.3) Calc. C 47.87 H 5.36 Found C 47.80 H 5.31

1,3,4-Tri-O-acetyl-α-D-xylopyranose (**23**): To a prehydrogenated suspension of platinum oxide (600 mg) in ethyl acetate (20 ml) was added the monohydrate **22** (100 mg, 0.34 mmol), and the hydrogenation was continued for 6 h, whereafter TLC indicated the presence of only one product (**23**). Evaporation of the mixture to dryness and processing of the residue as described for the iso-

lation of **10** (cf. above) afforded **23** as fine needles (35 mg, 37%) of m. p. 142 °C and $[\alpha]_D^{21}$ = +116° (*c* = 0.3, chloroform), identical with an authentic sample prepared from acetobromo-D-xylose[52].

^{1}H-NMR ([D$_6$]DMSO): δ = 2.00, 2.05, and 2.16 (three 3H-s, 3 OAc), 3.80 (m, 3H, 2-H, 5-CH$_2$), 4.87 (dt, 1H, $J_{3,4}$ = $J_{4,5a}$ = 10 and $J_{4,5e}$ = 5 Hz, 4-H), 5.16 (t, 1H, $J_{2,3}$ = 10 Hz, 3-H), 5.58 (6 Hz-d, 1H, OH; signal disappearing on deuteration), 6.00 (d, 1H, $J_{1,2}$ = 4 Hz, 1-H).

2,3,4-Tri-O-acetyl-D-xylono-1,5-lactone (**25**)

a) *By oxidation of 2,3,4-tri-O-acetyl-β-D-xylopyranose* (**26**): A solution of 1.0 g (3.7 mmol) of **26**[52] in dichloromethane (10 ml) was well stirred with a mixture of RuO_2 (150 mg), $NaIO_4$ (400 mg), $NaHCO_3$ (100 mg), and water (10 ml). Further quantities of $NaIO_4$ were added until the reaction mixture turned yellow. After work-up as described for the conversion of **8** → **11** and recrystallization from ether/pentane mixture gave 550 mg (55%) of **25** as colorless prisms; m. p. 43–44 °C, $[\alpha]_D^{21}$ = −20.4° (3 min) → −75.0° (steady, 2.5 h) (*c* = 1.0, chloroform).

^{1}H-NMR ([D$_6$]DMSO): δ = 2.08, 2.09, and 2.12 (three 3H-s, 3 OAc), 4.34 (dq, 1H, $J_{4,5}$ = 3.5, $J_{3,5}$ = 1.0 and $J_{5,5'}$ = 13 Hz, 5-H), 4.90 (q, 1H, $J_{4,5'}$ = 3.0, $J_{5,5'}$ = 13 Hz, 5'-H), 5.24 (m, 2H, 3- and 4-H), 5.80 (d, $J_{2,3}$ = 8 Hz, 1H, 2-H).

$C_{11}H_{14}O_8$ (274.2) Calc. C 48.18 H 5.15 Found C 48.09 H 5.13

b) *By oxidation of* **23**: Treatment of **23** (700 mg) in a manner analogous to that described under a) afforded 140 mg (20%) of a product identical in all respects with lactone **25**.

2,3,6-Tri-O-acetyl-2-C-chloro-4-O-(2,3,4,6-tetra-O-acetyl-β-D-glucopyranosyl)-β-D-glucopyranosyl chloride (Hepta-O-acetyl-2-C-chloro-β-D-cellobiosyl chloride) (**30**, R = βAc$_4$G): In adaptation of the procedure of *Maurer* and *Plötner*[25] chlorine gas was passed into an ice-cooled ethereal solution of heptaacetyl-cellobial (**27**, 3.1 g in 200 ml) until a yellow color persisted, followed by stirring for 30 min at ambient temperature. Evaporation to dryness left a sirupy 3:1 mixture of the β-D-*gluco*-chloride (**30**, R_F = 0.70 in 1:1 ethyl acetate/dichloromethane) and α-D-*manno*-isomer (**31**, R_F = 0.65) aside some of the ulose **33** (R_F ≈ 0.3). By standing in ethanol at 0–5 °C overnight, most of **30** crystallized: 1.2 g (35%), prisms of m. p. 156–158 °C. Two recrystallizations from ethanol raised the m. p. to 162–164 °C; $[\alpha]_D^{25}$ = −5.9° (*c* = 1.5, chloroform).

^{1}H-NMR (CDCl$_3$): δ = 1.99, 2.02, 2.04, 2.06, 2.10, 2.13, and 2.16 (seven 3H-s, 7 OAc), 3.6–5.3 (unresolved multiplets, ring CH, CH$_2$), 5.91 (d, 1H, $J_{3,4}$ = 8.0 Hz, 3-H), 6.57 (s, 1H, 1-H). – ^{13}C-NMR (CDCl$_3$): δ = 170.3–168.1 (7 acetyl-C=O), 101.7 s (C-2), 100.9 d (C-1', $J_{C\text{-}1/1\text{-}H}$ = 162 Hz), 87.3 d (C-1, $J_{C\text{-}1,1\text{-}H}$ = 174 Hz), 77.3, 72.9, 72.7, 72.4, 72.1, 71.7 and 68.0 (C-3,-4,-5,-2',-3',-4',-5'), 61.7 t (C-6 and -6'), 21.7–20.6 (3 s, acetyl-CH$_3$).

$C_{26}H_{34}Cl_2O_{17}$ (689.4) Calc. C 45.29 H 4.97 Cl 10.29 Found C 45.24 H 4.91 Cl 10.21

For the analogously prepared "Heptaacetyl-2-oxy-cellobial-dichlorid" of unknown configuration, *Maurer* and *Plötner*[25] reported m. p. 158 °C and $[\alpha]_D^{20}$ = −5.74° (*c* = 1.66, chloroform), indicating it to be **30** (R = βAc$_4$G).

1,3,6-Tri-O-acetyl-4-O-(2,3,4,6-tetra-O-acetyl-β-D-glucopyranosyl)-α-D-arabino-hexopyranos-2-ulose monohydrate (**33**): Chlorine gas was passed into a thoroughly stirred mixture of heptaacetyl-cellobial **27** (5.1 g, 8.1 mmol), silver carbonate (2.8 g, 2 molar equiv.), ether (400 ml), and water (1.5 ml) for about 15 min, whereafter excess chlorine was removed by concentration of the suspension *in vacuo* to about 300 ml. After standing in a refrigerator for 2–3 h the voluminous precipitate formed was filtered off (filtrate cf. below) and freed from the inorganic salts by extraction with chloroform. On addition of n-pentane to the chloroform solution until beginning turbidity the product gradually crystallized and was collected after standing overnight:

2.4 g (45%) of **33** as needles exhibiting a comparatively wide melting range of 125 – 135 °C; $[\alpha]_D^{25}$ = +46.3° (*c* = 1, chloroform), $[\alpha]_D^{23}$ = +41° (*c* = 0.8, 20% aqueous ethanol) → +36° (2 d) → +32° (7 d).

^{1}H-NMR ([D$_6$]DMSO): δ = 1.93, 1.97, 1.99, 2.04, 2.06, 2.08, and 2.12 (seven 3 H-s, 7 OAc), 3.7 – 5.4 (several unresolved multiplets, 12 H), 5.72 (s, 1 H, 1-H), 6.26 and 6.34 (two 1 H-s, 2 OH, disappearing on deuteration). – ^{13}C-NMR ([D$_6$]DMSO): δ = 170.2 – 168.9 (6 s, acetyl-C = O), 99.8 d (C-1′, $J_{C\text{-}1/1\text{-}H}$ = 165 Hz), 93.0 d (C-1, $J_{C\text{-}1/1\text{-}H}$ = 178 Hz), 91.7 s (C-2), 75.9 d (C-4), 72.1, 71.2, 70.6, 70.3, and 67.8 (d each, C-2′, -3′, -4′, -5′, -5), 62.0 and 61.6 (t, each, C-6 and -6′), 20.8 – 20.1 (5 s, acetyl-CH$_3$).

$C_{26}H_{36}O_{19}$ (652.5) Calc. C 47.87 H 5.56 Found C 47.77 H 5.48

The "Heptaacetyl-cellobioson-Hydrat" of *Maurer* and *Plötner*[25] to which a structure corresponding to III was assigned, similarly showed varying m. p. (121 – 138 °C) and gradual mutarotation in aqueous ethanol from +43.8 → 39.9 (3 d) → 32.6° (20 d), and, on this basis, is α-cellobiosulose **33**.

The ethereal mother liquor remaining after removal of the major portion of **33** together with the silver salts contained some of the dichlorides (R_F = 0.7 and 0.65 in C) and substantial amounts of the β-cellobiosulose-heptaacetate **34** (s for 1-H at δ = 5.94) aside further **33** (1-H at δ = 5.72).

1,2,3,6-Tetra-O-acetyl-1,5-anhydro-4-O-(2,3,4,6-tetra-O-acetyl-β-D-glucopyranosyl)-α-D-erythro-hex-2-enopyranose (**36**): A solution of α-cellobiosulose **33** (1.0 g, 1.5 mmol) in 15 ml acetic anhydride/pyridine (1 : 1) was kept at room temperature for 4 h and subsequently evaporated to dryness *in vacuo*. Several reevaporations from ethanol gave a crystalline residue, which was recrystallized from ethanol: 0.82 g (80%) of **36**; m. p. 174 – 175 °C, $[\alpha]_D^{23}$ = +2.6° (*c* = 1, chloroform).

^{1}H-NMR ([D$_6$]DMSO): δ = 1.94, 1.98, 2.01, 2.03, 2.09, 2.10, 2.12, and 2.16 (eight 3 H-s, 8 OAc), 3.6 – 3.8 and 3.9 – 4.6 (several m, 7 H, ring-CH, CH$_2$), 4.70 (d, 1 H, $J_{1',2'}$ = 8 Hz, 1′-H), 5.1 (3 H-m, 2′-, 3′-, 4′-H), 6.31 (s, 1 H, 1-H).

$C_{28}H_{36}O_{19}$ (676.6) Calc. C 49.70 H 5.36 Found C 49.61 H 5.27

On account of mode of preparation and physical data [m. p. 172 °C, $[\alpha]_D^{20}$ = +2.4° (*c* = 1.7, chloroform)] the "Heptaacetyl-cellobioson" of *Maurer* and *Plötner* to which a structure corresponding V was assigned on the basis of analytical data[25], is, in fact, **36**. Indeed, the C,H-values for heptaacetyl-cellobioson and for the octaacetate **36** are too close as to allow their differentiation.

1,3,6-Tri-O-acetyl-4-deoxy-β-D-glycero-hex-3-enopyranos-2-ulose (**37β**): A mixture of β-hexosulose **11** (550 mg, 1.5 mmol), sodium benzoate (650 mg), and 1,2-dimethoxyethane (15 ml) was stirred for 6 h at ambient temperature whereafter TLC indicated the absence of educt in favor of the enolone **37β** with only traces of kojic acid diacetate (**42**) detectable. Filtration, evaporation *in vacuo*, brief trituration of the residue, in ethanol solution, with a basic ion exchange resin (Lewatit MP 5080, OH-form) for removal of benzoic acid, and evaporation of the filtrate gave a syrup (290 mg, 65%); $[\alpha]_D^{23}$ = −41° (*c* = 1, chloroform).

^{1}H-NMR ($CDCl_3$): δ = 2.10, 2.16, and 2.26 (three 3 H-s, 3 OAc), 4.4 (2 H-m, 6-H$_2$), 4.98 (1 H-m, 5-H), 6.31 (1 H-s, 1-H), 6.74 (1 H-d, $J_{4,5}$ = 3.5 Hz,4-H[36]).

$C_{12}H_{14}O_8$ (286.2) Calc. 50.35 H 4.93 **37β**: Found C 49.98 H 4.85
37α: Found C 50.24 H 4.84

On exposure of β-hexosulose **11** (600 mg) to sodium acetate/acetic anhydride (150 mg in 15 ml) at room temperature, TLC in n-pentane/ethyl acetate (5 : 2) indicated the gradual consumption of

11 which after 8 h had reacted completely to an approximate 20:1 mixture of enolone **37** and kojic acid diacetate (**42**). Work-up by stirring into ice-water, extraction with dichloromethane, washing of the extract with aqueous $NaHCO_3$ solution and water, drying (Na_2SO_4), and evaporation to dryness *in vacuo* afforded a syrup (340 mg) which purified on a silica gel column by fast elution with n-pentane/ethyl acetate (5:2): 250 mg (56%) of **37** as an approximate 1:1 mixture of α- and β-anomers (TLC in E, ^{1}H-NMR).

1,3,6-Tri-O-acetyl-4-deoxy-α-D-glycero-hex-3-enopyranos-2-ulose (**37α**): Tetraacetyl-α-hexosulose **12** (450 mg) was subjected to treatment with sodium benzoate in 1,2-dimethoxyethane as described above for the β-anomer and was processed in an analogous manner to yield 210 mg (59%) of **37α** as a chromatographically homogeneous syrup of $[\alpha]_D^{23} = +33°$ (c = 0.6, chloroform).

CD (tetrahydrofuran): $\Delta\varepsilon = -0.84$ (335 nm). – ^{1}H-NMR ($CDCl_3$): δ = 2.10, 2.13, 2.24 (three 3H-s, 3 OAc), ≈4.5 (2H-m, 6-H_2), 5.05 (1H-q, $J_{5,6}$ = 5.5 Hz, 5-H), 6.34 (1H-s, 1-H), 6.70 (1H-d, $J_{4,5}$ = 2.0 Hz, 4-H[39]).

1,3-Di-O-acetyl-4-deoxy-α-D-pent-3-enopyranos-2-ulose [(2R)-2,4-Diacetoxy-2H-pyran-3(6H)-one] (**38α**): On stirring of triacetyl-α-pentosulose **22** (440 mg, 1.5 mmol) in 1,2-dimethoxyethane (15 ml) in the presence of sodium benzoate (650 mg), educt disappeared within 3–4 h at ambient temperature in favor of the α-pentenolone (TLC in B). Filtration, removal of the solvent, and, subsequently, of residual benzoic acid by briefly stirring, in ethanol solution, with a basic ion exchange resin (Lewatit MP 5080, OH-form), followed by evaporation to dryness gave a sirupy residue that spontaneously crystallized on trituration with little ethanol: 210 mg (65%), well-formed prisms, m. p. 63–64 °C, $[\alpha]_D^{23} = +75.1°$ (c = 1.4, chloroform).

CD (tetrahydrofuran): $\Delta\varepsilon = -1.12$ (334 nm). – ^{1}H-NMR ([D_6]DMSO): δ = 2.27 (6H-s, 2 OAc), 4.53 (q, 1H, $J_{4,5}$ = 4.0, $J_{5,5'}$ = 15 Hz, 5-H), 4.65 (q, 1H, $J_{4,5'}$ = 2.5 Hz, 5′-H), 6.12 (s, 1H, 1-H), 7.15 (q, 1H, 4-H).

$C_9H_{10}O_6$ (214.2) Calc. C 50.47 H 4.71 Found C 50.39 H 4.66

When treated with sodium acetate/acetic anhydride at ambient temperature **22** is converted into an anomeric mixture of **38α**/**38β** as evidenced by nearly complete loss of rotation.

5-Acetoxy-2-(acetoxymethyl)-4H-pyran-4-one (Di-O-acetylkojic acid) (**42**): Standing in pyridine solution at room temperature converted each of the 1,3,4,6-tetra-*O*-acetyl-β-D-hexosuloses **11** or **19** quantitatively into **42** within 2–3 h, as evidenced by TLC and by the decrease of rotational values to zero (see fig. 2). The product is readily isolated therefrom by removal of the solvent *in vacuo* (finally 1 Torr) and trituration with diisopropyl ether, affording **42** yields of 80–85%.

Monitoring the conversion **11** → **42** in pyridine solution polarimetrically (cf. fig. 2) and quenching the reaction after 25 min by the addition of ice-water gave a mixture which contained educt, **42**, and an intermediate spot, identical with enolone **37β** in several solvent systems. Hereby, system E was particularly suited for differentiating between enolones **37β**, **37α**, and the isomeric enediolone **41**. In fact, the latter was not detectable in any of the tetraacetyl-hexosulose→ kojic acid diacetate conversions.

The conversion of β-D-*lyxo*-hexosulose **19** into **42** via enolone **37β** is similarly borne out by the rotational changes occuring: $[\alpha]_D^{22} = -9°$ (c = 0.3, pyridine) after 4 min → −27° (10 min) → −35.5° (25 min) → −25° (45 min) → −14° (1 h) → −4° (2 h) → 0 (2.5 h), the minimum reached after 25 min representing the intermediate enolone.

The formation of di-*O*-acetylkojic acid (**42**) from the respective α-hexosuloses **12** and **20** in pyridine solution proceeded approximately 15 times slower than with the β-anomers, requiring at ambient temperature about 48 h for completion as evidenced by TLC and the gradual decrease of positive rotation (cf. fig. 2). Exposure of any of the hexosuloses (**11**, **12**, **19**, or **20**) to

pyridine/acetic anhydride, to dimethyl sulfoxide/acetic anhydride at room temperature, or to sodium acetate/acetic anhydride (10 min, 60 °C) resulted in practically quantitative formation of **42**.

3-Acetoxy-4H-pyran-4-one (O-Acetylpyromeconic acid) (**43**): A solution of α-pentosulose **22** (290 mg, 1 mmol) in pyridine (8 ml) was kept at ambient temperature for 24 h, whereafter TLC indicated the absence of educt. The solvent was removed *in vacuo* and the residue was dissolved in chloroform and washed with N H_2SO_4, water and dried (Na_2SO_4). Evaporation to dryness gave a crystalline mass that was filtered with ethanol: 110 mg (67%) of prisms, m. p. 92 – 93 °C (lit.[53] 93.0 – 93.5 °C). – ^{1}H-NMR ([D_6]DMSO): δ = 2.27 (3H-s, OAc), 6.53 (d, 1H, $J_{5,6}$ = 6 Hz, 5-H), 8.18 (q, 1H, $J_{2,6}$ = 0.9 Hz, 6-H), 8.42 (0.9 Hz-d, 1H, 2-H).

Treatment of **22** with pyridine/acetic anhydride or sodium acetate/acetic anhydride afforded the same product.

(2R, 3S)-3,5-Diacetoxy-2-acetoxymethyl-2,3-dihydro-4H-pyran-4-one (2,4,6-Tri-O-acetyl-1-deoxy-D-erythro-hex-1-enopyranos-3-ulose) (**41**)

a) *From 1,2,4,6-tetra-O-acetyl-β-D-glucopyranose* (**44**) *by RuO_4 oxidation and elimination of acetic acid:* To a stirred mixture of RuO_2 hydrate[47] (100 mg), $NaIO_4$ (20 g), CCl_4 (25 ml), dichloromethane (25 ml), and water (40 ml) was added 700 mg (2 mmol) of **44**[54], followed by stirring overnight at room temperature. After addition of isopropyl alcohol (1 ml) for quenching excess oxidant the mixture was filtered and the organic layer of the filtrate was washed with water and dried (Na_2SO_4). Evaporation to dryness left the tetra-*O*-acetyl-β-D-*ribo*-hexosulose (**45**) as a chromatographically homogeneous syrup (620 mg, 88%), which was refluxed for 1.5 h in benzene solution (10 ml) in the presence of $NaHCO_3$ (500 mg) and water (0.8 ml). Filtration, drying (Na_2SO_4), and evaporation *in vacuo* gave a syrup which was purified by fast elution from a silica gel column (2 × 10 cm) with benzene/acetone (15 : 1): 370 mg (56%) of **41** as a chromatographically uniform (R_F = 0.65 in D), solid, which eventually crystallized from ether: prisms of m. p. 75 °C, $[\alpha]_D^{20}$ = +218° (*c* = 1.1, $CHCl_3$) (lit.: syrup, $[\alpha]_D$ = +156° in $CHCl_3$[40] and m. p. 72 °C, $[\alpha]_D^{22}$ = +219° in methanol[42]).

MS (70 eV): *m/e* = 286 (0.8%, M^+), 244 (5, M – CH_2=C=O), 184 (9, 244 – AcOH), and 142 (16, 184 – CH_2=C=O). – ^{1}H-NMR ($CDCl_3$): δ = 2.12, 2.18, and 2.22 (three 3H-s, 3 OAc), 5.65 (d, 1H, $J_{4,5}$ = 12 Hz, 4-H), and 7.42 (s, 1H, 1-H).

$C_{12}H_{14}O_8$ (286.2) Calc. C 50.35 H 4.93 Found C 50.36 H 5.02

The product is unaffected (TLC) by pyridine, pyridine/acetic anhydride, and sodium acetate/acetic anhydride at ambient temperature for days. On exposure to sodium benzoate/potassium carbonate in dimethyl sulfoxide in a manner analogous to the preparation of **46** (cf. below), the formation of diacetylkojic acid (**42**) is induced and completed after 3 – 4 days standing.

b) *From* **44** *by treatment with DMSO/acetic anhydride:* A solution of 700 mg (2 mmol) of **44**[55] in dimethyl sulfoxide (3 ml) and acetic anhydride (2 ml) was kept at ambient temperature for 40 h and then poured into ice-water; the syrup that separated was dissolved in chloroform, the solution washed with water and dried (Na_2SO_4). Removal of the solvent *in vacuo* left a syrupy enediolone **41** (R_F = 0.65 in D, detectable by UV), which is contaminated by a slightly faster moving substance (ca. 10%, detectable by sulfuric acid spray only) which most probably is the 3-*O*-(methylthiomethyl) ether of **44**. Separation by PLC with benzene/acetone (3 : 1), elution of the corresponding zone with acetone, and evaporation gave **41** as an amorphous solid (290 mg, 51%) of $[\alpha]_D^{20}$ = +216° (*c* = 0.9, $CHCl_3$), identical in all respects with the product described under a).

Varying the ratio DMSO/acetic anhydride, or reaction time, and/or temperature did not significantly suppress the formation of the side-product, the removal of which impaired the yield on **41**

(51%). In view of these results the isolation of **41** in crystalline form and a yield of 95% on treatment of **44** with DMSO/acetic anhydride[42] appears highly questionable.

(2S,3S)-3-Acetoxy-2,3-dihydro-2,3-dimethoxy-6-methyl-4H-pyran-4-one (**46**): A mixture of triacetyl-enediolone **41** (150 mg, 0.5 mmol), K_2CO_3 (110 mg, 0.8 mmol), dimethyl sulfoxide (2 ml), and methanol (0.4 ml) was stirred for 3 d at ambient temperature, followed by dilution with chloroform, thorough washing with water, drying (Na_2SO_4), and evaporation to dryness. The brown syrup showed spots (TLC in D) at R_F = 0.81 (major product **46**) and at 0.61, 0.52, and 0 (minor components, only detectable by H_2SO_4). Separation by elution from a silica gel column (0.7 × 16 cm) with benzene/acetone (15:1), and evaporation of the fast-moving fraction gave a crystalline residue, which was recrystallized from n-hexane/chloroform: 35 mg (31%) of **46** as plates, m. p. 128–129°C, $[\alpha]_D^{21}$ = +234° (*c* = 0.5, chloroform).

CD (methanol): $\Delta\varepsilon$ = 0.92 (255 nm), −0.07 (284), +1.2 (317). – MS (70 eV): *m/e* = 230 (0.05%, M^+), 188 (2, M − CH_2=C=O), 170 (7.9, M − HOAc), 146 (14), 128 (57) 104 (base peak, 146 − CH_2=C=O). – ^{1}H-NMR ($CDCl_3$): δ = 2.03 (3H-s, 6-CH_3), 2.17 (3H-s, OAc), 3.34 and 3.51 (two 3H-s, 2 OCH_3), 5.34 (d, 1H, 2-H), 6.00 (s, 1H, 5-H).

$C_{10}H_{14}O_6$ (230.2) Calc. C 52.17 H 6.13 Found C 52.14 H 6.20

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[46] On dissolution of tetraacetyl-hexosulose monohydrates **11**, **12**, or **20** in $CDCl_3$ or DMSO dehydration occures gradually to yield after standing for a few hours a mixture mainly containing the keto form. This behaviour, which has been observed with other hexosuloses too[35], is clearly evident from the different chemical shifts for the anomeric protons of keto form and hydrated species (Δ ≈ 0.1 ppm) and, most notably, from the presence of two resonances for C-2, i. e. around δ = 92 [$>C(OH)_2$] and ≈ 190 ($>C=O$). This behaviour seems to be more pronounced in the α-anomers.
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