Translated from *Uspekhi Khimii*, **49**, 420-447 (1980) U.D.C. 547.45

Saccharinic Acids

R.A.Gakhokidze

Data on the chemistry of saccharinic acids are examined and described systematically. The alkaline degradation of mono-, oligo- and poly-saccharides is discussed, much attention being devoted to the conditions which influence the course of the reaction. It is shown that the nature of the alkali metal cation, the pH of the medium, temperature, and the structure of the carbohydrate play an important role. Data concerning the stabilisation of polysaccharides in alkali are described in detail. The problem of the applications of saccharinic acids is examined.
The bibliography includes 254 references.

CONTENTS

I. Introduction 222
II. The mechanism of the formation of saccharinic acids 223
III. The influence of the nature of the alkali metal cation, pH, and temperature on the formation of saccharinic acids 224
IV. The influence of substituents on the formation of saccharinic acids 225
V. The formation of saccharinic acids by the cleavage of oligo- and poly-saccharides with alkali 227
VI. The properties and applications of saccharinic acids 231

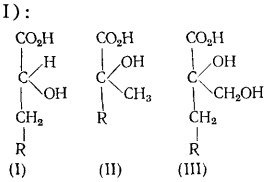
I. INTRODUCTION

The complex and varied reactions of carbohydrates in alkali have long attracted the attention of investigators. However, despite vigorous research, the interconversions and degradation reactions of carbohydrates in alkaline solutions have still been inadequately studied. The conversion of reducing sugars under the influence of aqueous bases includes the following processes[1-3]: mutarotation (anomerisation); epimerisation (the Lobry de Bruyn–van Ekenstein transformation); retroaldol cleavage, the products of which are capable of new reactions; saccharinic rearrangement. The formation of carbocyclic compounds[4-8], the Cannizzaro reaction[9], and intramolecular oxidation–reduction[10] are also possible. The formation of polymeric compounds[11] (probably via aldoxyloses at elevated temperatures[12]) has also been noted. In addition, sugars form complexes (saccharinates) with metal hydroxides[13-19]. Under the influence of alkalies, glycosylamines undergo the Amadori rearrangement[20]. Alkaline agents cause numerous carbohydrate derivatives to undergo intramolecular substitutions, for example the elimination of groups such as alkyl and arenesulphonyloxy-groups, halide ions, or nitrate and sulphate ions with the formation of an epoxy-ring (an intramolecular ether)[21,22] and migration of acyl groups[21], involving isomerisation via intramolecular transesterification. However, sugars are fairly resistant to the action of a base at 5°. Thus 85–90% of a sugar (*D*-glucose, *D*-mannose, and *D*-fructose) remains unchanged after prolonged contact (9 months) with dilute sodium hydroxide[23].

The present review is an attempt to describe the present state of the chemistry of saccharinic acids†. Saccharinic acids, which are formed from reducing carbohydrates under the influence of various alkalies, include all the monobasic hydroxy-acids (deoxyaldonic acids) with the empirical formula $C_nH_{2n}O_n$, which have the same compositions as the corresponding carbohydrates. The first mention of substances of this type dates back to 1838.[28,29] The first such substance investigated was erroneously assumed to be an isomer of saccharose (sucrose)—hence the name saccharinic acids.

† For review of earlier studies, see Refs.24–27.

Saccharinic acids can be synthesised from non-sugar-like compounds[30] and by the oxidation of the corresponding deoxysugars. The Grignard[31] and Fischer–Kiliani (the cyanohydrin method) reactions[32,33] have also been used to synthesise saccharinic acids and their derivatives. However, the present review deals with the problems of the formation of saccharinic acids from reducing carbohydrates in an alkaline medium in the absence of oxygen. In an alkaline medium in the presence of oxygen carbohydrates undergo both oxidation and alkaline degradation with formation of a complex mixture of products#. According to their carbon skeleton, saccharinic acids belong to three types: 3-deoxyaldonic (metasaccharinic) acids (I), 2-*C*-methylaldonic (saccharinic) acids (II), and 2-*C*-(hydroxymethyl)-3-deoxyaldonic (isosaccharinic) acids (III):



The structure of saccharinic acids has been reviewed[26]. Later the configuration of α-*D*-glucoisosaccharinic acid[36-38] and its lactone[39] was established by X-ray diffraction; both proved to be *erythro*-compounds. It has been shown by chemical methods[40] that α-*D*-glucosaccharinic acid has the *ribo*-configuration. The γ-lactone of α-*D*-glucosaccharinic acid (2-*C*-methyl-*D*-ribonic acid) and hamamelose (2-*C*-hydroxymethyl-*D*-ribose), whose structure has been established by an independent method, have the same absolute configurations, which has been confirmed by the transformation of each compound into 5-deoxy-2-*C*-methyl-*D*-ribitol[41]. Branched saccharinic acids[42] and di- and tri-deoxysaccharinic acids[43,44] have been detected in the conversion products of polymeric carbohydrates in alkali. Despite the fact that saccharinic

After the oxidation of *D*-glucose and cellobiose with oxygen in a highly alkaline medium, 13 and 19 monobasic acids were isolated respectively[34]. The isolation of 21 organic acids from the products of the oxidation of cellobiose by molecular oxygen in an alkaline medium has been reported[35].

acids are known to form in highly alkaline solutions, metasaccharinic acids and their sulphur-containing derivatives have been obtained by treating carbohydrates with neutral[45–48] or acid sulphite solutions (pH 4.4–6.0; 135 °C).[49–51]

The saccharinic rearrangement of a carbohydrate is undoubtedly of wider importance in nature than has been thought hitherto. Saccharinic acids have been found in plants[52,53]; they are apparently formed from monosaccharides in weakly alkaline media and probably give rise to deoxysugars with straight and branched carbon skeletons as a result of the reduction of the carboxy-group. However, deoxidation of sugars can also take place via reductive reactions of the alcoholic groups.

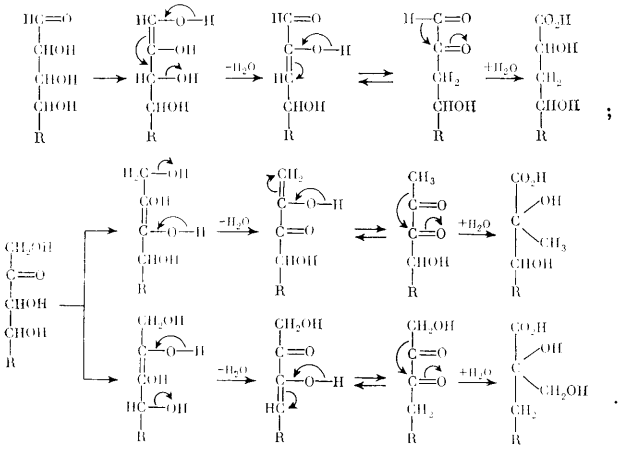
The application of gas chromatography[54–63], mass spectrometry[64–67], and spectrophotometry[68,69], as well as ion-exchange[70,71] and thin-layer[72] chromatography make it possible to determine saccharinic acids rapidly in the complex mixture obtained on alkaline degradation of carbohydrates.

II. THE MECHANISM OF THE FORMATION OF SACCHARINIC ACIDS

Numerous mechanisms have been proposed for the formation of saccharinic acids from reducing sugars. In order to account for the formation of saccharinic acids, Nef[11,73] proposed schemes according to which monoses are converted initially into biradicals in consequence of the elimination of water from an alcoholic group; the migration of hydrogen atoms from another, adjacent alcoholic group to a carbon atom involved in a saturated bond leads to the formation of an aldehydo-ketonic or diketonic form, which undergoes the benzilic acid rearrangement to saccharinic acids. However, this mechanism is complex and the formation of biradicals at a particular site in the chain is doubtful.

Other workers[74,75] modified Nef's scheme, postulating the formation of enediol oxides as intermediates in the isomerisation of carbohydrates. These substances are converted into diketones, which undergo the benzilic acid rearrangement. However, the formation of unsaturated epoxide structures is regarded as unlikely at the present time. It has been suggested[76] that saccharinic acids are formed via a mechanism involving the pinacol rearrangement via alcoholic epoxide forms. The formation of saccharinic acids via the recombination of carbohydrate fragments has been discussed[77,78].

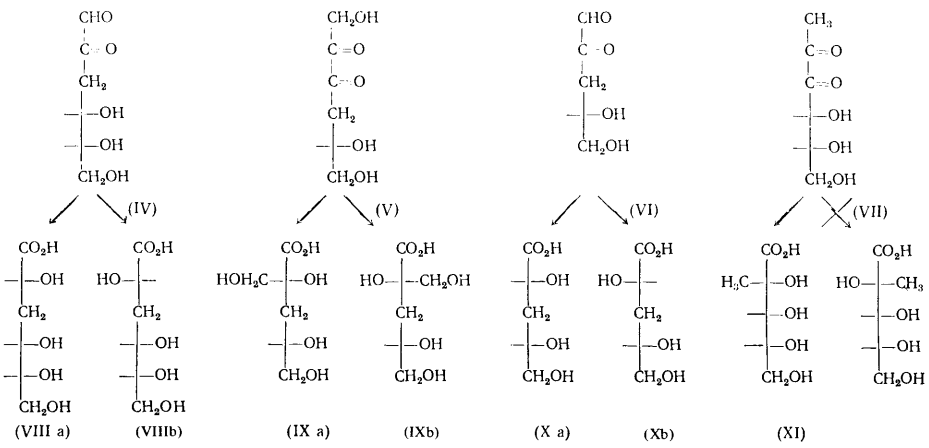
The ionic mechanism put forward by Isbell[79], who treats Nef's hypothesis from the standpoint of electronic ideas, has gained the widest currency at the present time. According to Isbell, the mechanism of the formation of saccharinic acid involves the following stages: (a) the formation and ionisation of the enediol; (b) β-elimination of a hydroxy- or alkoxy-group; (c) rearrangement to an α-dicarbonyl intermediate; (d) benzilic acid rearrangement with formation of saccharinic acid. Accordingly, the formation of saccharinic acids can be represented by the following reactions:



The postulated intermediate dicarbonyl compounds, involved in the formation of saccharinic acids, have been synthesised or isolated after the alkaline treatment of appropriately substituted sugars§. Their rapid conversion into saccharinic acids under the influence of lime water supports the Nef—Isbell mechanism. The proposed mechanism has been partly confirmed in experiments using labelled compounds[67,70,82,83].

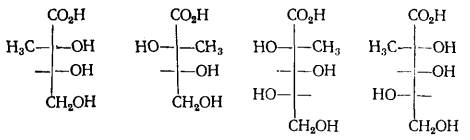
Two possible saccharinic acids are obtained from the intermediates (IV) and (V)—α- and β-*D*-glucosaccharinic acids (VIIIa, VIIIb) and α- and β-*D*-glucoisosaccharinic acids (IXa, IXb) respectively. Similarly in an alkaline medium compound (VI) gives rise to metasaccharinic acids with five carbon atoms (Xa, Xb).[84] However, treatment of compound (VII) with alkali yields only α-*D*-glucosaccharinic acid (XI)[54] (see Scheme 1).

Scheme 1



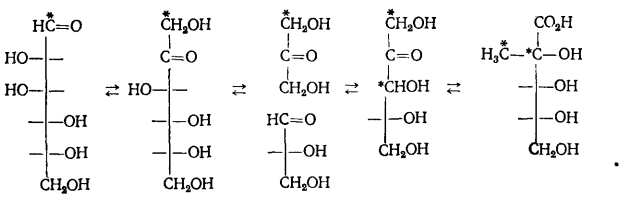
§ For details of the dicarbonyl derivatives of carbohydrates, see Theander[80] and Anet[81].

Since only compound (VII) has an asymmetric carbon atom adjoining the carbonyl group, it has been suggested[54] that the stereospecificity depends on the asymmetry of compound (VII), while compounds (IV) and (V) should give rise to two isomeric acids. Indeed treatment with alkali converts *D-arabino*-2-hexosulose (*D*-glucosone) preferentially into *D*-mannonic acid[85]. However, treatment of *D*-xylose[57] and *L*-sorbose[33] with calcium hydroxide yields respectively α- and β-*D*-xylosaccharinic acids (XIIa, XIIb) and α- and β-*L*-galactosaccharinic acids (XIIIa, XIIIb):

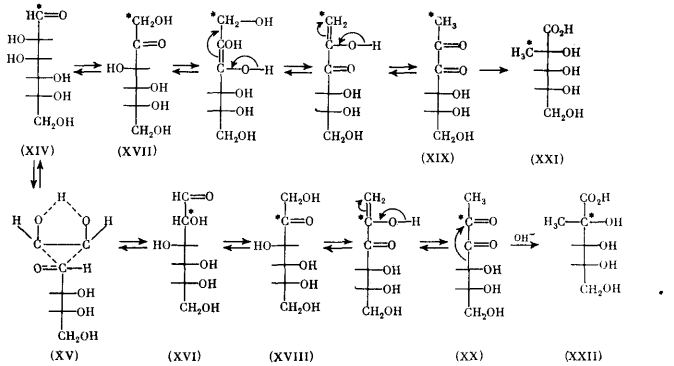


(XIIa) (XIIb) (XIIIa) (XIIIb)

It has been shown with the aid of labelled hexoses[82,83] that different acids arise via different mechanisms. Treatment of *D*-[1-^{14}C] galactose with $Ca(OH)_2$ yielded α-*D*-galactometasaccharinic acid. It was found that 95% of the initial activity was located in the carboxy-group, which is fully consistent with the Nef–Isbell mechanism. Under the same conditions, α-*D*-glucoisosaccharinic acid, in which 94% of the initial activity was contained in $C_{(2)}$, was obtained from [1-^{14}C] lactose; this is also fully consistent with the Nef–Isbell mechanism. However, treatment of *D*-[1-^{14}C] mannose with calcium hydroxide led to the formation of α-*D*-glucosaccharinic acid containing 39% of the initial activity in the CH_3 group and 57% is $C_{(2)}$. In contrast to these observations, the Nef–Isbell mechanism predicts that the radioactivity should appear wholly in the CH_3 group. To account for this phenomenon, it has been suggested[86] that *D*-mannose undergoes rapid retroaldol decomposition under the reaction conditions and that labelled [1,3-^{14}C] hexose is reformed from the resulting dihydroxyacetone and *D*-glyceraldehyde and undergoes a further rearrangement with formation of [2,2'-^{14}C] saccharinic acid.



However, this hypothesis was rejected by Sowden and coworkers[26,82]. They believe that the recombination of trioses should lead to a uniform distribution of the radioactivity in the ketohexose between $C_{(1)}$ abd $C_{(2)}$. According to Isbell's scheme, this would lead to α-*D*-glucosaccharinic acid in which the $C_{(2)}$ atom and the carbon atom in CH_3 would be equally radioactive. The isomerisation of *D*-[1,^{14}C] mannose (XIV) to *D*-[2-^{14}C] glucose (XVI) as a result of the intramolecular rupture of the bond between $C_{(2)}$ and $C_{(3)}$ in the intermediate (XV) has been suggested[87]. *D*-[1-^{14}C] fructose (XVII) and *D*-[2-^{14}C] fructose (XVIII) can give rise, via the Isbell and intramolecular mechanisms respectively, to α-*D*-glucosaccharinic acid with the radioactivity in the methyl group [compound (XXI)] and at $C_{(2)}$ [compound (XXII)]:



(XIV) (XVII) (XIX) (XXI)

(XV) (XVI) (XVIII) (XX) (XXII)

However, the hypothesis of the migration of the methyl and [CH_2OH–CHOH–CHOH] groups respectively in the dicarbonyl intermediates (XIX) and (XX) does not take into account the experimental results, and the formation of α-*D*-glucosaccharinic acid with a reduced radioactivity (2%) in the carboxy-group when the methyl group migrates in compound (XX) weakens this hypothesis. Furthermore, *D*-fructose, prepared from *D*-[1-^{14}C] mannose under conditions analogous to those used to obtain α-*D*-glucosaccharinic acid, contained 98% of the radioactivity in $C_{(1)}$.[23]

According to another mechanism[23], α-*D*-glucosaccharinic acid can be formed from a hexose via a 3-deoxydicarbonyl intermediate. In fact this product gives rise to metasaccharinic acids only[81,88,89]. Thus the problem of the mechanism of the formation of *D*-glucosaccharinic acid remains virtually open.

The formation of saccharinic acids with four, five, and six carbon atoms from *D*-xylose and *D*-fructose[56], as well as the detection of α-*D*-glucosaccharinic acid in the products of the interaction of $Ca(OH)_2$ with glycerose[90] show that the reaction proceeds via a mechanism involving fragmentation and recombination together with direct isomerisation.

III. THE INFLUENCE OF THE NATURE OF THE ALKALI METAL CATION, pH, AND TEMPERATURE ON THE FORMATION OF SACCHARINIC ACIDS

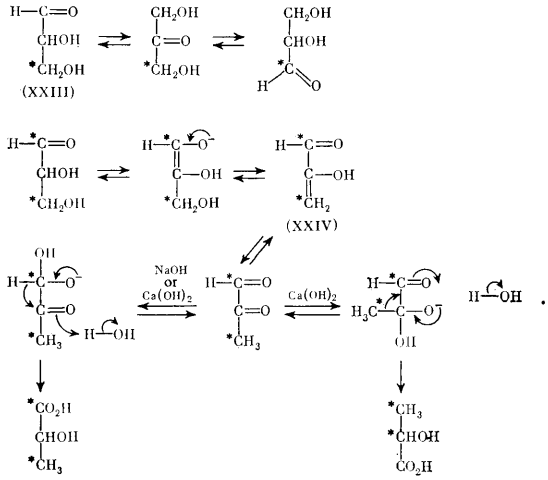
Early studies by Kiliani and Nef[26] showed that glucose is converted into glucosaccharinic acids under the influence of calcium hydroxide, while treatment of the sugar with sodium hydroxide leads mainly to metasaccharinic acid and insignificant amounts of isosaccharinic acid¶. An analogous result was obtained when *D*-fructose was treated with a concentrated solution of sodium hydroxide; *D*-glucosaccharinic acid was not detected, but it was the main product on treatment of *D*-fructose with $Ca(OH)_2$.[56] After treating *D*-xylose with $Ca(OH)_2$, α- and β-*D*-xylosaccharinic acids together with other acids were isolated[56]. Consequently the influence of

¶ *D*-[1-^{14}C]galactose and *D*-[1-^{14}C] mannose isomerise on treatment with $Ca(OH)_2$ to α-*D*-galactometasaccharinic acid and α-*D*-glucosaccharinic acid respectively[82]. It has been shown[91] that the yields of *D*-glucometasaccharinic and α-*D*-glucosaccharinic acids become comparable at high calcium ion concentrations.

the nature of the cation on the mechanism of the formation of saccharinic acid is evident and can be attributed to the kinetic effect[92]†.

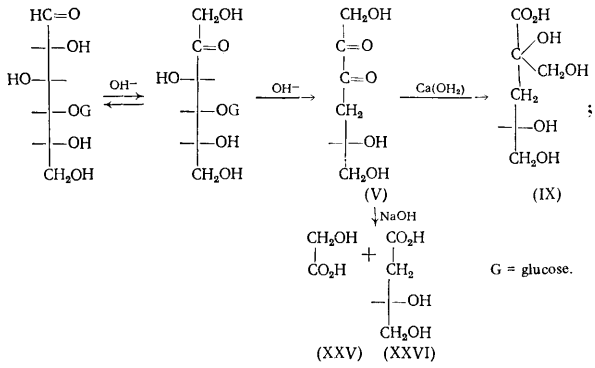
It has been shown[90] that *D*-[3-^{14}C]glycerose (XXIII) isomerises in 1.68 *N* NaOH at 25 °C to lactic acid, where the radioactivity is distributed only between the $C_{(1)}$ and $C_{(3)}$ atoms. An analogous result was obtained on treating *D*-[1-^{14}C]glucose with 3 *N* NaOH at 25 °C.[97] In contrast to this, *D*-[2-^{14}C]glycerose isomerises in saturated lime water at 25 °C to lactic acid with 37, 13 and 50% of the initial radioactivity in the $C_{(1)}$, $C_{(2)}$, and $C_{(3)}$ atoms respectively[90].

Evidently the epimerisation glycerose ⇋ 1,3-dihydroxypropanone is faster in an alkaline medium than the saccharinic rearrangement. In an alkaline medium a hydoxide ion adds to the aldehyde carbonyl of the α-dicarbonyl intermediate [methylglyoxal (XXIV)]. In the presence of $Ca(OH)_2$ the hydroxide ion attacks the ketone carbonyl group in (XXIV), which can probably be accounted for by the stabilisation of the transition state as a result of interaction with the divalent calcium ion and subsequent migration of the methyl group. *D,L*-Lactic acid is the main product of the alkaline degradation of 1-O-substituted fructose[86] and 6-O-substituted sugars—6-O-methyl-*D*-glucose[98] and melibiose)6-O-α-*D*-galactopyranosyl-*D*-glucose).[99,100]



The intermediate in the formation of isosaccharinic acids postulated by the Nef–Isbell theory, namely 4-deoxy-*D*-glycerohexose-2,3-diulose (V), was isolated[110] on treating maltose with sodium hydroxide; treatment with calcium hydroxide yielded only traces of compound (V). Compound (V), isolated on treatment with an aqueous solution of calcium hydroxide, was converted almost quantitatively into *D*-glucoisosaccharinic acid. The α-diketo-group in the sugar molecule is also subjected to extremely vigorous attack by alkalies, which leads to the dissociation of the carbon–carbon bond. Calcium ions catalyse the benzilic acid rearrangement of diulose to saccharinic acids, i.e. (V) → (IX), while sodium ions promote cleavage into fragments (Scheme 2).

Scheme 2



It has been shown[102] that treatment of 4-O-substituted *D*-glucose with sodium hydroxide results in the formation of large amounts of fragmentation products—glycolic acid (XXV) and *D*-3,4-dihydroxybutyric acid (XXVI). The formation of formic and lactic acids in concentrated sodium hydroxide solution is accelerated on raising the temperature. The temperature dependence of the relative amounts of acids obtained when hydrocellulose is acted upon by NaOH has been demonstrated[58].

A change in the pH of the reaction medium has a considerable influence on the formation of saccharinic acids as a function of the concentration of the alkali and sugar. For example, *D*-glucose gives rise to a greater amount of acid at low hydroxide concentrations than at high concentrations[91]. The main products of the alkaline degradation of cellobiose with sodium hydroxide are isosaccharinic acids together with small amounts of 2-deoxytetronic, 3-deoxypentonic, and 3,4-dideoxypentonic acids[43,103,104], while on treatment of cellobiose with bicarbonate the latter predominate[43].

IV. THE INFLUENCE OF SUBSTITUENTS ON THE FORMATION OF SACCHARINIC ACIDS

1. The Influence of the 1-O-Substituent

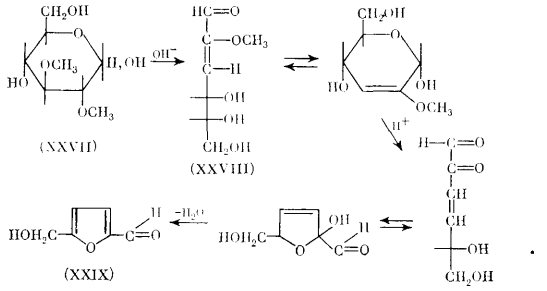
Acetal-O-substituted carbohydrates (alkyl glycosides[105–108], sucrose[109], and trehalose[109]) are usually stable in alkaline solutions free from oxygen and undergo alkaline hydrolysis only under severe conditions, for example, on treatment with a 10% NaOH solution for several hours at 170 °C. However, the glycosides derived from phenols, enols, and alcohols substituted by an electronegative group in the β-position are sensitive to the action of alkalies[110].

1-O-Substituted ketoses are converted into the usual saccharinic acids. For example, treatment of 1-O-methyl-*D*-fructose with lime water gives rise to the formation of α-*D*-glucosaccharinic acid with a higher yield (together with *D,L*-lactic acid) than that obtained from *D*-fructose[86]. When *D*-fructose 1,6-diphosphate is acted upon by alkali (0.46 *N* NaOH at 100 °C, 15 min), α-*D*-glucosaccharinic acid 6-phosphate is formed[111], while alkaline degradation of *D*-glucose 6-phosphate leads to the formation of the 6-phosphate of *D*-glucometasaccharinic acid[112].

† Many reactions of sugars depend on the nature of the cation of the alkali. For example, in the Lobry de Bruyn–van Ekenstein reaction divalent metal hydroxides are somewhat more effective (at comparable concentrations) than sodium or potassium hydroxide. The calcium ion has a stronger influence than the barium ion[93,94]. In methylation with dimethyl sulphate sodium hydroxide is more effective than potassium hydroxide[93]. The tendency towards the formation of an alkoxide in the reaction of cellulose with alkali increases in the sequence LiOH < NaOH < KOH < RbOH < CsOH < organic quaternary bases[96].

2. The Influence of the 2-O-Substituent

2-O-Substituted aldoses are relatively stable in alkaline solutions and do not give rise to saccharinic acids[113-115]. The absorption spectrum of 2,3-di-O-methyl-*D*-glucose (XXVII) in an alkaline solution corresponds to the 1,2-unsaturated carbonyl derivative (XXVIII), which is readily converted into 5-hydroxymethylfurfural (XXIX) under acid conditions[115].



(XXVII) (XXVIII) (XXIX)

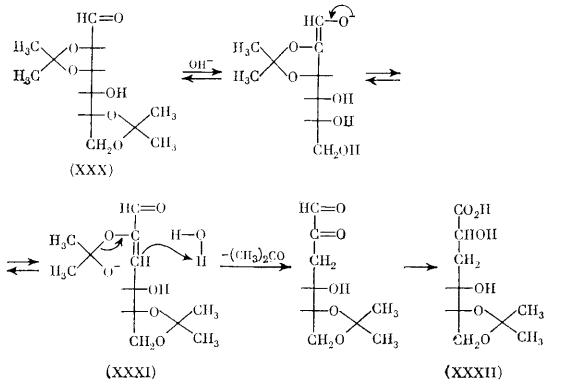
Substitution at $C_{(2)}$ prevents the formation of saccharinic acid as a result of the inability of the carbohydrate residue at CO_2 to ionise. However, it has been shown for xylans isolated from wood and containing 4-O-methyl-α-*D*-glucopyranosyluronic acid residues at $C_{(2)}$,[116] 2-O-*D*-xylopyranosyl-*L*-arabinose[113], 2-O-(4-O-methyl-α-*D*-glucuronopyranosyl)-*D*-xylose[117], and 4-O-β-*D*-glucopyranosyl)-2-O-methyl-β-*D*-glucose (2-O-methylcellobiose)[118] that the 2-O-substituent does not inhibit the degradation process at high temperatures. In 1 *M* NaOH (in the absence of oxygen) 2,3,4-tri-O-methyl-*D*-glucose decomposes fully after 5 h at 100 °C. Formic, acetic, lactic, glycolic, and glyceric acids were isolated from the reaction mixture. Under analogous conditions, 2-O-methylcellobiose is fully converted after 4 h. Apart from the products obtained from 2,3,4-tri-O-methyl-*D*-glucose, *D*-glucose and saccharinic acids were detected in the reaction products[118]. In both cases the 4-O-substituted compound (XXVIII) was identified. The main product of the conversion of 2-deoxy-*D*-*arabino*-hexose under the influence of alkali is 3,6-anhydro-2-deoxy-*D*-*arabino*-hexose[119].

3. The Influence of the 3-O-Substituent

Alkaline degradation of 3-O-substituted sugars, namely 3-O-methyl-*D*-glucose[120], 3-O-methyl-*D*-fructose[120], 3-O-ethyl-*D*-glucose[121], 3-O-n-propyl-*D*-glucose[121], 3-O-n-butyl-*D*-glucose[121], 3-O-benzyl-*D*-glucose[121], 3-O-methane-sulphonyl-*D*-glucose[121], and 3-O-toluene-*p*-sulphonyl-*D*-glucose[121], leads to the preferential formation of α- and β-*D*-glucometasaccharinic acids: the degradation proceeds more readily in lime water than in a solution of sodium hydroxide of the same normaility[120]. The conversion of 3,6-anhydro-*D*-glucose in lime water[122] leads to the formation of mainly *D*-glucometasaccharinic acid (apart from traces of lactic, glyceric, and 2-deoxypentonic acids, which are obtained in sodium hydroxide solutions). The main product of the alkaline degradation of 3-O-methyl-*D*-xylose with calcium hydroxide[123] is 3-deoxy-*threo*-pentonic acid, but a small amount of 3-deoxy-*erythro*-pentonic acid was also detected. Glycosyl phosphates and other non-reducing phosphates are resistant to the action of alkalies. However, compounds such as glycerose 3-phosphate, *D*-ribose 3-phosphate, and *D*-glucose 3-phosphate readily undergo β-elimination with formation of *D,L*-lactic, *D*-glucometasaccharinic, and 3-deoxypentonic acids[124].

3, 6-Di-O-methyl-*D*-glucose[98] and 6-O-β-*D*-glucopyranosyl-3-O-methyl-*D*-glucose[125] are converted into 6-O-methyl-*D*-glucometasaccharinic and 6-O-β-*D*-glucopyranosyl-*D*-glucometasaccharinic acids under the influence of $Ca(OH)_2$ at room temperature. Alkaline degradation of 3-O-methyl-*D*-glucose 6-(dihydrogen phosphate) leads to the formation of the 6-(dihydrogen phosphates) of *D*-glucometasaccharinic acids[126], while the conversion of *D*-arabinose 3,5-(hydrogen phosphate) or *D*-xylose 3,5-(hydrogen phosphate) results in the formation of a mixture of 3-deoxy-5-phospho-*D*-*erythro*-pentonic and 3-deoxy-5-phospho-*D*-*threo*-pentonic acids[127].

2-O-Substituted aldoses are stable in relation to the action of alkali, but 2,3; 5,6-di-O-isopropylidene-*D*-mannose (XXX) is converted under the influence of calcium hydroxide[128] into 5,6-O-isopropylidene-*D*-glucometasaccharinic acids (XXXII), since β-elimination leads to the removal of the 2,3-O-isopropylidene group#.



(XXX) (XXXI) (XXXII)

4. The Influence of the 4-O-Substituent

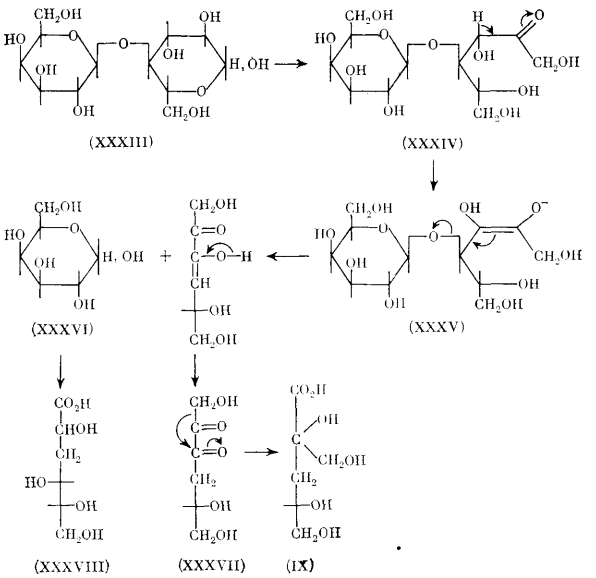
The alkaline degradation of 4-O-substituted sugars leads to the formation of isosaccharinic acids. For example, the main products of the degradation of 4-O-methyl-*D*-glucose[54,102,129,130], 4-O-methyl-*D*-fructose[129], and 4,6-O-benzylidene-*D*-glucose[128] are *D*-glucoisosaccharinic acids. Treatment of 4,6-di-O-methyl-*D*-glucose with alkali[98] results in the formation of 5-O-methyl-α-*D*-glucoisosaccharinic acid. Treatment of *D*-glucose 4,6-(hydrogen phosphate) with alkali leads to the formation of a mixture of 2-*C*-(hydroxymethyl)-3-deoxy-5-phospho-*D*-*erythro*-pentonic and the corresponding *threo*-pentonic acids (5-phospho-*D*-glucoisosaccharinic acids).[127] 4-O-Methyl-*D*-xylose is converted into *D*-xyloisosaccharinic acids in alkali.[131]

The formation of saccharinic acids from 4-O-substituted sugars takes place more slowly than from 3-O-substituted sugars. 4-O-Substituted ketoses decompose at a higher rate than the related aldoses, which is consistent with the Nef–Isbell mechanism. However, lactose and lactulose are converted more slowly than maltose or maltulose. Cellobiose decomposes at approximately the same rate as lactose.

Compound (XXX) remains unchanged at 25 °C in saturated lime water free from oxygen as a result of the inability of the initial anion (XXXI) to be converted into an α-diketone and subsequently into compound (XXXII). However, at 100 °C dissociation takes place with formation of compound (XXXII).

5. The Influence of the 6-O-Substituent

Substitution at $C_{(6)}$ activates attack by alkali on the hydroxy-groups at $C_{(3)}$ or $C_{(4)}$. For example, 3,6- and 4,6-di-O-methyl-*D*-glucoses decompose faster in lime water than the corresponding 3- and 4-O-methyl-*D*-glucoses. When *D*-glucose is treated with calcium hydroxide, the product is mainly α-*D*-glucosaccharinic acid (together with a small amount of *D*-glucoisosaccharinic acids), while analogous treatment of 6-O-substituted *D*-glucose leads to the formation of α- and β-*D*-glucometasaccharinic acids. It has been shown[98,99] that the main products of the conversion of 6-O-substituted sugars are *D*,*L*-lactic acid and 6-O-substituted metasaccharinic acid.



V. THE FORMATION OF SACCHARINIC ACIDS BY THE CLEAVAGE OF OLIGO- AND POLY-SACCHARIDES WITH ALKALI

Treatment of polysaccharides with alkalies has been described in detail in a number of reviews[110,132-137]. This section deals with the formation of saccharinic acids in the absence of oxygen. Alkaline degradation of polysaccharides proceeds under these conditions with formation of definite types of saccharinic acids characteristic of the bonds present in the polysaccharide, and chain branching has a specific influence on the cleavage process.

1. Glycans with (1→4)-Linkages

(*a*) *Lactose and Lactulose.* It has been known for a long time that reducing disaccharides with (1 → 4)-bonds are cleaved by lime water with formation of α-*D*-isosaccharinic acid. Thus early investigations[138] showed that alkaline degradation of lactose leads to the formation of succinic acid, formic acid, and a crystalline lactone, which has been identified[139] as α-*D*-glucosaccharinolactone. Approximately 20% of this lactone is formed from lactose on treatment with $Ca(OH)_2$. Apart from this, *D*-galactose[140,141], formaldehyde[142], and other saccharinic acids were detected in the reaction products. The presence of a small amount of β-*D*-glucoisosaccharinic acid has also been demonstrated[11,54,129,143-146]. α-*D*-Galactometasaccharinic acid was first detected as a product of prolonged treatment of lactose with lime water at room temperature[147]. It was later shown that it can be obtained by treating *D*-galactose[26] or melibiose[99] with solutions of sodium and calcium hydroxides. Crystalline lactulose (4-O-β-*D*-galactopyranosyl-*D*-fructose) was isolated from the products obtained on treating lactose with alkali[138]. At the very beginning of the process lactose (XXXIII) is slowly converted into the corresponding lactulose (XXXIV). Lactulose is then converted at a higher rate, via postulated intermediates, (XXXV) → (XXXVII), into a mixture of α- and β-*D*-glucoisosaccharinic acids (IX) and *D*-galactose (XXXVI), which is converted in its turn into α- and β-*D*-galactometasaccharinic acids (XXXVII).[144]

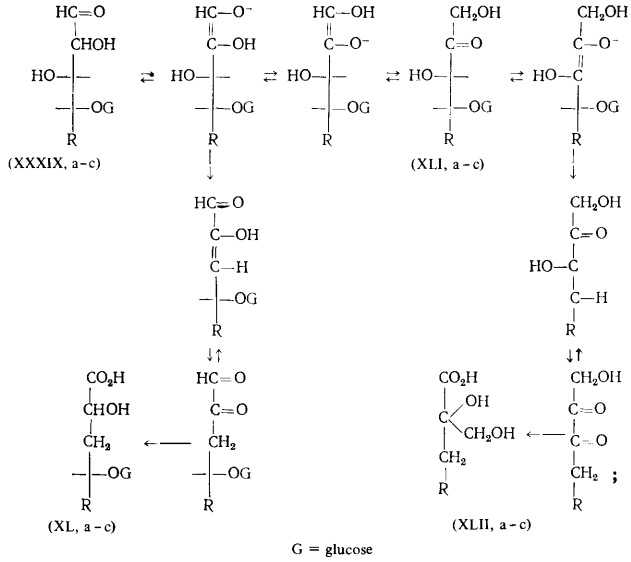
(*b*) *Maltose and Maltulose.* When maltose[54,144] or maltulose[144] are treated with $Ca(OH)_2$ at 25 °C a mixture of α- and β-*D*-glucoisosaccharinic acids is formed. Alkaline degradation of maltose should proceed via maltulose, like the degradation of lactose. However, maltulose decomposes so fast in an alkaline medium, compared with lactulose, that its detection is virtually impossible.

(*c*) *Cello-, manno-, and xylo-oligosaccharides.* It has been established[148] that α-*D*-glucoisosaccharinic acid is the main product of the degradation of cellobiose by $Ca(OH)_2$. Apart from isosaccharinic acid, cellobiulose, *D*-glucose, and *D*-fructose are formed. In NaOH solution other acid products are detected together with isosaccharinic acid. It has been shown[149] that, under the influence of 1 *M* NaOH, cellobiose gives rise to the epimeric 4-O-β-*D*-glucopyranosyl-*D*-mannose (glucosylmannose), cellobiulose, *D*-glucose, *D*-fructose, and *D*-mannose. When cellobiose was treated with 0.04 *N* $Ba(OH)_2$ at 25° and 50 °C, a considerable amount of *D*-glucosaccharinic acid and *D*-glucose was detected[150,151], apart from small amounts of glyceric, 3,4-dihydroxybutyric, and *D*-arabinonic acid. In the presence of oxygen the oxidation reaction involving the formation of aidonic acids predominates[150,152,153]. Cellobiulose[148] reacts with $Ca(OH)_2$ to form cellobiose, *D*-fructose, *D*-glucose, and α-*D*-glucoisosaccharinic acid. Alkaline degradation of cellotetraose[148] and partly hydrolysed cellulose[132] leads to the formation of the same *D*-glucoisosaccharinic acid.

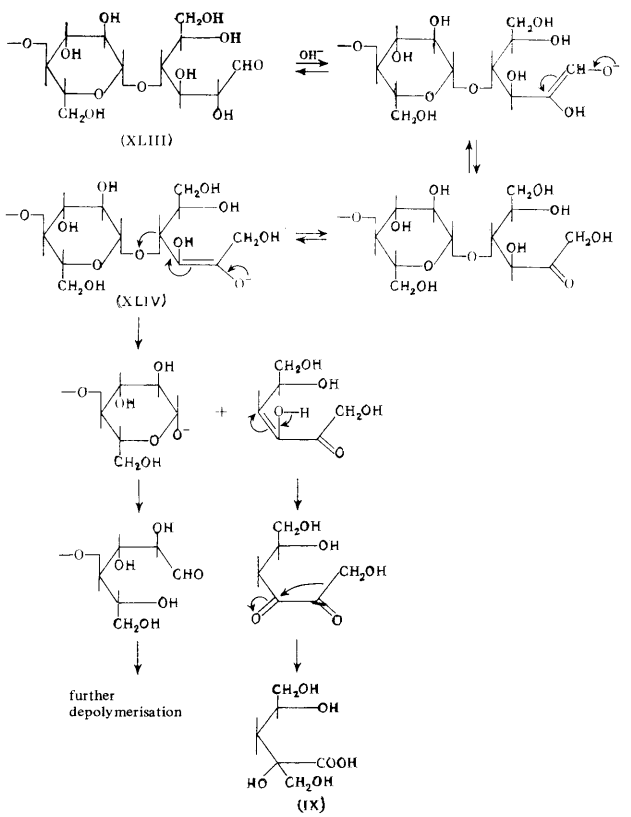
Xylobiose (4-O-β-*D*-xylopyranosyl-*D*-xylose)[154,155] (XXXIXc) undergoes an analogous degradation under the influence of alkali, probably via xylobiulose (4-O-β-*D*-xylopyranosyl-*D*-xylose) (XLIc) and intermediates with formation of 2-*C*-(hydroxy methyl)-2,4-dihydroxybutyric acid (XLIIc). Compound (XLIIc) is formed similarly from xylotriose[156]. By investigating the kinetics of the degradation of the xylotetraose molecule from the reducing end, it has been established[157] that the overall rate of degradation is largely determined by the rate of conversion of the anion derived from the reducing end of the xylose unit into a xylulose unit. In the second stage of the degradation reaction, which determines the overall rate, the terminal group of xylulose rearranges with dissociation of the glycosidic linkage. This reaction stage is slower for cellotetraose than for xylotetraose and the rate is

independent of the number of xylose units in the oligomer. On treatment with bases, isosaccharinic acids (XLII, a-c) and O-glycosylsaccharinic acids (XL,a-c) respectively are formed from cellobiose (XXXIXa), 4-O-β-*D*-mannopyranosyl-*D*-mannose (XXXIXb), and 4-O-β-*D*-xylopyranosyl-*D*-xylose (XXXIXc). O-Glycosylsaccharinic acids hydrolyse to form metasaccharinic acids[158] (Scheme 3):

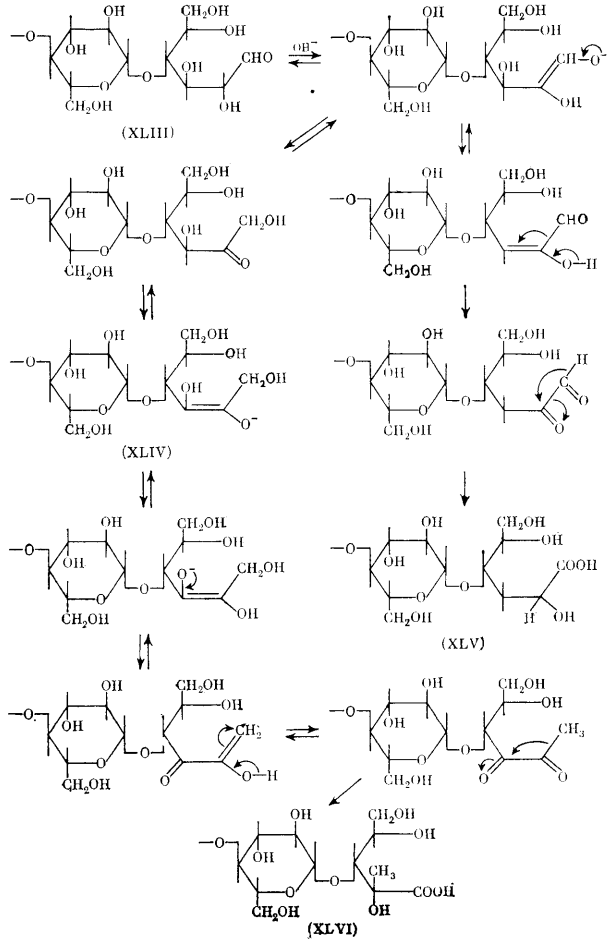
Scheme 3



(*d*) *Cellulose.* Isosaccharinic acid (IX) is the main product of the degradation of cellulose (XLIII) by alkalies[102,159-161] (the "peeling" process).



Alkaline degradation of cellulose and other polysaccharides usually does not go to completion. The termination of the "peeling" process is due to the conversion of the reducing monosaccharide terminal units into non-reducing saccharinic acids[159,162]. Machell and coworkers[163,164] subjected alkali-stabilised hydrocellulose to acid hydrolysis and isolated *D*-glucometasaccharinic acids, whose formation on treatment with alkali may be a consequence of the β-elimination of the hydroxygroup at the $C_{(3)}$ atom in terminal *D*-glucose and subsequent rearrangement of the resulting enol. *D*-Gluco-metasaccharinic acids have also been isolated from the hydrolysate of sulphate cellulose from pine, demonstrating the occurrence of the stabilisation reaction during sulphate digestion[165]. Small amounts of α-*D*-glucosaccharinic acid have also been detected[163]. However, the formation of the usual stable saccharinic end units (XLV) is difficult, since the intermediate enol (XLIV), produced in the course of the formation of the metasaccharinic terminal units, (XLIII) → (XLVI), can readily undergo transformations via the alternative mechanism (XLIII) → (IX):



Hydrocellulose derived from cotton cellulose subjected to alkaline treatment at 170 °C included α- and β-*D*-glucometa-saccharinic and 2-*C*-methylglyceric acids and a smaller amount of α-*D*-glucosaccharinic acid[166]. 2-*C*-Methylglyceric acid has also been detected in the products of the hydrolysis of unbleached eucalyptus and pine celluloses[167].

The stabilisation reaction ("inhibition" process) is usually slower than the degradation reaction ("peeling" process) from the reducing end owing to the influence of the 4-O-sub-stituent. It has been shown[168] that the activation energy

for the degradation of cellulose under the influence of a 5% NaOH solution is 24 kcal mol^{-1}, while the activation energy for the stabilisation reaction is 34 kcal mol^{-1}, the rate of stabilisation increasing with increase of temperature. Above 150 °C glucosidic linkages are hydrolysed with formation of new reducing end groups, which promote further degradation via the "peeling" mechanism[169]. It has been shown[170] that the rate of hydrolysis of the glucosidic linkages in cotton cellulose is directly proportional to the concentration of hydroxide ions and the activation energy is 35.9 kcal $mole^{-1}$. Hydrocellulose undergoes degradation faster and the sensitivity of the pre-hydrolysed wood celluloses to alkali increases during alkaline digestion[171]. With decrease of the degree of polymerisation, the rate of degradation of hydrocellulose increases[162,172].

Much attention has been devoted in recent years to the problem of the formation of saccharinic acids from wood polysaccharides during sulphate digestion. As was to be expected, the main products (50%) of the sulphate digestion of pine cellulose are *D*-glucoisosaccharinic acids[104]. Lactic acid (20%) and insignificant amounts of glycolic, 2-hydroxybutyric, 3-hydroxypropionic, 2,5-dihydroxyvaleric, *D*-xyloisosaccharinic, and 3-deoxypentonic acids were also detected. *D*-Xyloisosaccharinic and *D*-glucoisosaccharinic acids predominate in the sulphate digestion of birchwood[104].

The main products of the conversion of hydrocellulose[175], cotton cellulose[177], and cellobiose[150,186] under the influence of alkalies in the absence of oxygen are isosaccharinic acids, while treatment with atmospheric oxygen in an alkaline medium leads to the oxidation of the terminal aldehyde group to aldonic (mainly arabinonic, mannonic, and erythronic) acids. The oxidative stabilisation of cellulose, glucomannan, and xylan takes place with the intermediate formation of glucosone (*D-arabino*-hexosulose) and xylosone (*D-threo*-pentosulose) structures and their conversion into aldonic acid residues[85,181,182,187].

Alkaline degradation of cellulose is of enormous theoretical and practical importance. In the first place it must be taken into account in the isolation of cellulose from plant materials (alkaline digestion, refining) and chemical processing of cellulose (manufacture of viscose fibre, ethers, xanthates, and certain partly substituted cellulose derivatives for technical purposes, mercerisation of textile materials) in an alkaline medium. Since the degradation of cellulose from the reducing end, which occurs inevitably to some extent under these conditions, leads to a considerable loss of cellulose in the form of low-molecular-weight substances (for example, in the manufacture of cellulose its yield reaches only 20–45% depending on the manufacturing method used), the reduction of losses of this kind to a minimum is an important task for the paper and textile industries. A decrease of these losses can be achieved, in principle, in different ways: by modifying the reducing end groups of cellulose with formation of structural end units resistant to the action of alkalies (by glucosidation and reduction or oxidation of hemiacetal groups) or by decreasing the degree of degradation of cellulose from the reducing end as a result of the acceleration of the stabilisation reaction[136].

The resistance of polysaccharides to the action of alkalies can be increased by the catalytic hydrogenation[188] and reduction with sodium tetrahydroborate[131,159,162,180,188–197] of the terminal aldehyde groups to primary alcoholic groups, by the oxidation of the reducing groups to aldonic acids with chlorite (sodium chlorite or chlorous acid)[198–201], polysulphide (usually sodium polysulphide)[165,176,188,201–207], bisulphite (sodium bisulphite or a mixture of sodium bisulphite and sulphite)[208], and a copper ammine solution[209], by glycosidation (treatment of the polysaccharide with an alcoholic solution of hydrogen chloride[210] or methylation with the aid of dimethyl sulphate and alkali and subsequent treatment with metnyl iodide and silver oxide[131]), by thermal dehydration in an inert medium at 175–220 °C (this probably leads to the formation of an intramolecular anhydride incorporating a glycosidic hydroxyl)[211], and by the conversion of the reducing end groups into mercapto-groups under the influence of hydrogen sulphide in the presence of aqueous sodium carbonate[212].

At the same time there are indications that the degradation of cellulose[158,172] and model compounds[213] can be limited by accelerating the stabilisation reaction with the aid of alkaline earth metal ions (Ca^{2+}, Sr^{2+}, Ba^{2+}). Magnesium[175,187,214–217] and lanthanum[184,218] compounds proved to be the most effective. The role of inhibitors has not been established accurately. It has not yet been fully demonstrated that bivalent cations stabilise the intermediate enol as a result of complex formation[121,219,220] or influence the benzilic rearrangement[102]. Iron, cobalt, copper, and manganese salts have an appreciable catalytic effect on the rate of degradation[35,184,217], while the introduction of lignin, xylan, and glucose intensifies the catalysis by heavy metals[217]. The influence of a multiplicity of reagents has been investigated in order to increase the resistance of polysaccharides to the action of alkalies[221–223].

(*e*) *Amylose.* Amylose is an alkali-sensitive component of starch. In dilute alkaline solutions in the absence of oxygen amylose is poorly cleaved and degradation of potato amylose (degree of polymerisation 415) ceases after the elimination of 230 glucose units from each chain[224]. On treatment of amylose with oxygen-free 1 *N* and 0.5 *N* NaOH at 100 °C, stepwise depolymerisation takes place vigorously. The degradation proceeds with formation of *D*-glucoisosaccharinic, formic, and lactic acids, while the stabilisation reaction leads to the formation of alkali-resistant amylose with a *D*-glucometasaccharinic end-group[225,226].

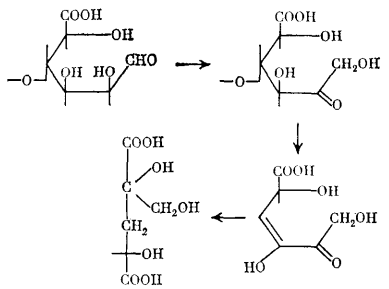
In contrast to amylose, the second fraction of starch (amylopectin) is relatively resistant to the action of alkalies and undergoes only insignificant degradation on treatment with 1 *N* NaOH in the absence of oxygen at room temperature[227], which is apparently due to its highly branched structure. A kinetic study of the degradation of amylose has been made[228]. At 100 °C an increase of the concentration of alkali to 0.1 *N* entails an increase of the rate of degradation. Higher concentrations of alkali do not affect the rate of degradation, while the rate of the stabilisation reaction increases on raising the concentration of alkali to 1.5 *N*. The activation energies for the degradation and stabilisation reactions in 1.25 *N* NaOH are 21.1 and 19.3 kcal mol^{-1} respectively[228].

(*f*) *Xylan.* The xylan from corn cobs is fairly resistant to the action of 1 *N* NaOH at 100 °C [156]§, while its oxidative alkaline degradation leads to large amounts of 3-deoxy-2-*C*-hydroxymethyltetronic acid (xyloisosaccharinic acids)[178]. However, when arabinoxylan from rye flour is treated with an oxygen-free dilute aqueous solution of sodium hydroxide, 3-deoxy-2-*C*-hydroxymethyltetronic and other acids are formed at room temperature[131]. Alkaline degradation of birch xylan in the absence and presence of oxygen leads to the formation of approximately equal amounts of xyloisosaccharinic

§ It has been shown[178] that the molecule of the xylan from corn cobs contains *L*-arabinoduranose residues as well as glucuronic acid and its 4-O-methyl derivative and that the latter add to the main chain via (1 → 2)-linkages. The branching of the $C_{(2)}$ atom in the main chain, joined by (1 → 4)-linkages, should arrest the degradation process.

acid[183]. It has been shown[131] that the inhibition of the degradation is caused by the conversion of the reducing end groups into non-reducing xylometasaccharinic units. After preliminary reduction with tetrahydroborate[131,188], xylans become resistant to the action of alkali and the formation of acids or a decrease of the molecular weight is not observed.

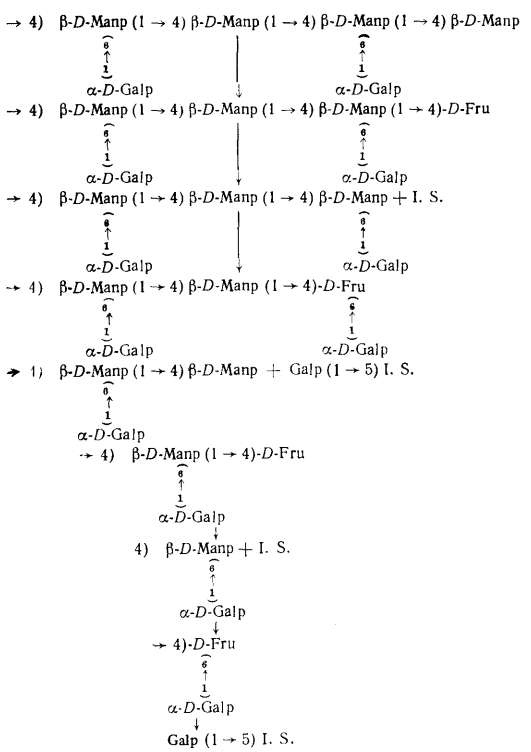
(*g*) *Alginic acid.* The main products of the degradation of alginic acid (heteroglucuronoglycan consisting of *D*-mannuronic and *D*-guluronic acid residues) salts and esters under the influence of alkalies are 3-deoxy-2-*C*-hydroxymethyl-*D*-*erythro*(*threo*)-pentaric acids (dibasic isosaccharinic acids with six carbon atoms) (XLVII) [229]:



3-Deoxy-2-*C*-hydroxymethylpentaric acids (with the *threo*-isomer predominating) are formed also when 4-O-methyl-*D*-glucuronic acid is treated with alkali[230]. The ready isomerisation of 4-O-methyl-*D*-glucuronic acid to the corresponding hexulose in an alkaline medium[231] supports the proposed mechanism.

(*h*) *Guaran.* The alkaline degradation of guaran [a polysaccharide with a main chain consisting of β-(1 → 4)-*D*-mannopyranose residues, to the alternate members of which α-*D*-galactopyranose residues are added via the $C_{(6)}$ atoms] leads to the formation of *D*-glucoisosaccharinic[54,145] and 5-O-α-*D*-galactopyranosyl-*D*-glucoisosaccharinic acids[145]. It has been suggested that the degradation reaction proceeds via the β-alkoxycarbonyl mechanism. The initially reducing terminal mannose residue is converted under the influence of alkali into a fructose residue, which is eliminated in the form of the enol of a dicarbonyl compound; under the reaction conditions, the enol immediately undergoes a subsequent rearrangement to isosaccharinic acid. The formation of *D*-glucoisosaccharinic acid and 5-O-α-*D*-galacto-pyranosyl-*D*-glucoisosaccharinic acid is determined by the structure of guaran. The detection of *D*-galactose and equal amounts of *D*-glucoisosaccharinic and 5-O-α-*D*-galactopyranosyl-*D*-glucoisosaccharinic acids in the reaction products is consistent with the proposed mechanism (see Scheme 4).

Scheme 4



2. Glycans with (1 → 3)-Linkages

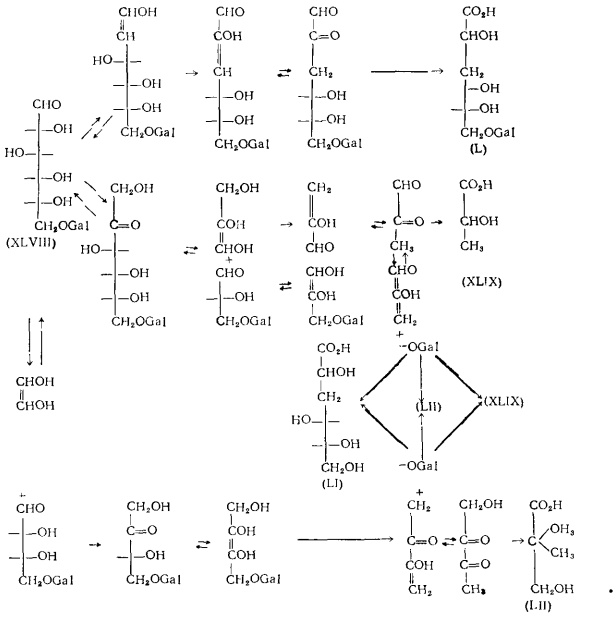
Laminaribiose (3-O-β-*D*-glucopyranosyl-*D*-glucose)[232], turanose (3-O-α-*D*-glucopyranosyl-*D*-fructose)[232], and laminarin[148,233] are degraded by alkalies with the formation of *D*-glucometasaccharinic acids. When 48% of the initial laminarin has been degraded, the process ceases and then restarts after partial hydrolysis of the residue. The termination of the degradation process may be due to a structural feature of the chain. In fact, it has been shown recently[234] that laminarin contains chains with terminal non-reducing mannitol units. The decomposition of laricinan and pachyman[233] takes place in exactly the same way under these conditions with formation of metasaccharinic acids. It may be that the presence of branches is also the cause of the incomplete degradation of these polysaccharides. The results of kinetic studies on the alkaline degradation of (1 → 3)-glucans have been published[233].

3. Glycans with (1 → 6)-Linkages

When melibiose (6-O-α-*D*-galactopyranosyl-*D*-glucose) (XLVIII) is treated with calcium hydroxide, the products are[99] *D,L*-lactic acid (XLIX), *D*-galactose, 6-O-α-*D*-galactopyranosyl-*D*-glucometasaccharinic acid (L) and the corresponding isosaccharinic acid. Treatment of melibiose with barium hydroxide[235] led to the formation, apart from the above compounds, of considerable amounts of 3-deoxy-*D*-xylohexonic and 3-deoxy-*D*-lyxohexonic acids (α- and β-*D*-galactometasaccharinic acids) (LI) and 2-*C*-methylglyceric acid (LII). 6-O-α-*D*-Galactopyranosyl-*D*-glucosaccharinic acids are formed via the Isbell mechanism and the glycosidic linkage remains unaffected; the rupture of the glycosidic linkage in melibiose is accompanied by the formation of compounds (XLIX), (LI), and (LII). The cleavage of the $C_{(3)}$–$C_{(4)}$ linkage in the

reducing *D*-glucose unit of the disaccharide leads to the formation of a triose, which rearranges to *D,L*-lactic acid after the elimination of *D*-galactose. The rupture of the $C_{(2)}-C_{(3)}$ bond should lead to the formation of a 4-O-substituted tetrose, which can be cleaved with formation of 2-*C*-methylglyceric acid (LII). The *D*-galactose eliminated in this process can undergo subsequent rearrangement with formation of *D*-galactometasaccharinic acids (LI) (Scheme 5).

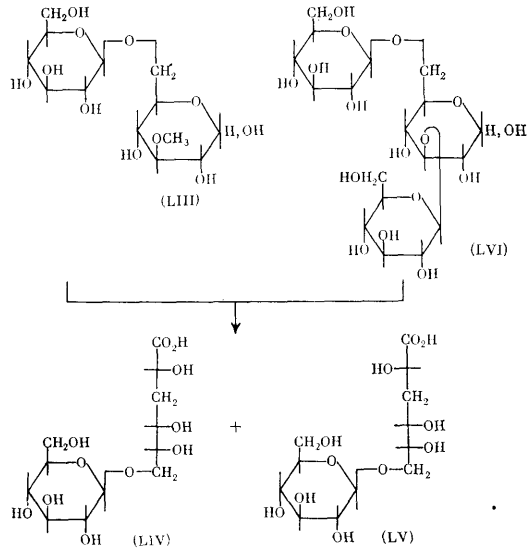
Scheme 5



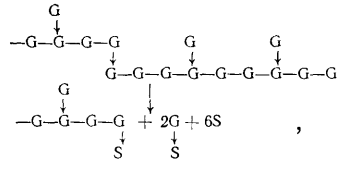
According to this scheme, compound (LII) and pyruvic acid (precursor of lactic acid), labelled at $C_{(4)}$ and $C_{(3)}$ respectively , should be formed from *D*-glucose-6-*t*. In fact, the radioactivities of *D*-glucose-6-*t* (LII) and pyruvic acid were almost identical (to within 5%)[235].

2-*C*-Methylglyceric acid is a product of the successive chain degradation of isomaltose oligosaccharides (isomaltose, isomaltotriose, and isomaltotetraose) under the influence of $Ba(OH)_2$. Apart from 2-*C*-methylglyceric acid, considerable amounts of stabilisation products, in particular 6-O-substituted 3-deoxy-*D*-hexonic acids, are formed[235].

As shown above, substitution at $C_{(6)}$ tends to increase the rates of degradation of 3-O- and 4-O-substituted sugars with retention of the 6-O-substituent. When 6-O-β-*D*-glucopyranosyl-3-O-glucose (LIII) is acted upon by lime water at room temperature, O-glycosylmetasaccharinic acids are formed; 6-O-β-*D*-glucopyranosyl-α-*D*-glucometasaccharinic acid (3-deoxy-6-O-β-*D*-glucopyranosyl-*D-ribo*-hexonic acid) (LIV) and 6-O-β-*D*-glucopyranosyl-β-*D*-glucometasaccharinic acid (3-deoxy-6-β-*D*-glucopyranosyl-*D-arabino*-hexonic acid) (LV) [125]. The acids were characterised by reduction to substituted 3-deoxyhexoses. The same 6-O-glucosylmetasaccharinic acids are formed[236] on treatment of the trisaccharide 3-O-β-6-β-di-*D*-glucopyranosyl-*D*-glucose (LVI) with 0.05 *N* $Ba(OH)_2$:



Compounds (LIII) and (LVI) are models of the (1 → 3)-linked β-*D*-glucan from *Sclerotium rolfsii* containing β-*D*-glucopyranosyl substituents at each third glucose residue of the main (1 → 6)-linked chain[237]. The degradation of this polysaccharide by NaOH in the absence of oxygen at 56 °C leads to compounds (LIV) and (LV)[125]:



where G = β-*D*-glucopyranose, S = *D*-glucometasaccharinic acid residue, a line indicates a (1 → 3)-linkage, and an arrow indicates a (1 → 6)-linkage.

It has been shown[238] that dextran is cleaved on treatment by 1 *N* NaOH at 60 °C with formation of a stable acid dextran containing 1 unit of *D*-glucometasaccharinic acid for each dextran chain. Hydrolysis of the acid dextran leads to α- and β-*D*-glucometasaccharinic acids.

Alkaline degradation of oxidised celluloses and the influence of the supermolecular structure of cellulose on its alkaline degradation are discussed in a review[137].

VI. THE PROPERTIES AND APPLICATIONS OF SACCHARINIC ACIDS

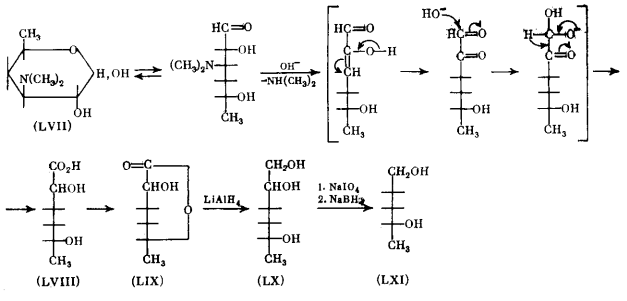
1. The Formation of Saccharinic Acids as an Analytical Method for the Investigation of the Structures of Polysaccharides and Certain Carbohydrate Derivatives

The study of the influence of alkalies on model, partly substituted, monosaccharides, oligosaccharides, and polysaccharides with known structures has shown that in broad outline it is possible to predict which reaction products should be formed when the main polysaccharide chains are acted upon by alkali. Thus polysaccharides with (1 → 2)-linkages are resistant to dilute alkali at 25 °C. Polysaccharides with (1 → 3)-linkages are cleaved by alkali in the absence of oxygen with formation of metasaccharinates and those with (1 → 4)-linkages

are cleaved with formation of isosaccharinates. Polysaccharides with (1 → 5)-linkages are stable, while those with (1 → 6)-linkages exhibit a relative resistance to dilute alkali at 25 °C; they give rise to 6-O-glycosylmetasaccharinate, 2-*C*-methylglycerate, and lactate at a higher temperature and an increased concentration of alkali. Polysaccharides with (2 → 1)-linkages, containing ketose units (for example, inulin), are cleaved by dilute alkali with formation of the usual saccharinates.

In the presence of chain branching the alkaline degradation and the nature of the substances formed can frequently yield information concerning the types of bonds in the initial monosaccharide. Thus the branch at the $C_{(6)}$ atom will be split off and, depending on the type of bonds in the main chain, the product will have stable iso- or meta-saccharinate end groups. The branches at $C_{(4)}$ in main chains joined by (1 → 5)- or (1 → 6)-linkages are not cleaved owing to the resistance of the main chains to the action of alkali. When the branches at $C_{(4)}$ in chains joined by (1 → 3)-linkages as well as branches at $C_{(3)}$ are split off, a stable metasaccharinate terminal unit is formed from the residue in the main chain to which the branch had been attached. This unit will be located at the branch ($C_{(4)}$) in the former case and in the main chain in the latter ($C_{(3)}$). The main chain does not undergo further degradation, but the eliminated branches decompose via a pathway which depends on the type of bonds in the branch. The branches at the $C_{(2)}$ atom in the main chain joined by (1 → 3)-linkages should be split off and should terminate in a 2,3-unsaturated monosaccharide unit, resistant to alkali, formed from the monosaccharide residue of the main chain to which the branch was attached. The branches at the $C_{(2)}$ atom in the main chain, joined by (1 → 4)-linkages, should arrest the degradation process. Thus the use of the saccharinic rearrangement as an analytical method in combination with other procedures makes it possible to obtain extremely valuable information about the structure of polysaccharides.

The saccharinic acid method is particularly useful for the establishment of the structures of mono-O-substituted reducing sugars. This method has been used successfully[239] to determine the absolute configuration in the 5-position of desosamine—an important carbohydrate component of the macrolide antibiotics erythromycin, methymycin, narbomycin, oleandomycin, and picromycin. Alkaline degradation of desosamine (3,4,6-trideoxy-3-dimethylaminohexose) (LVII) led to *erythro* + *threo*-2,5-dihydroxyhexonic acid (LVIII). The δ-lactone of this acid (LIX) gave rise to the hexanetriol (LX) after reduction with lithium tetrahydroaluminate. Oxidation of the hexanetriol with sodium periodate followed by reduction with sodium tetrahydroborate led to pentane-1,4-diol (LXI) whose molecule retains only one asymmetric centre, corresponding to the fifth carbon atom of desosamine. Since the absolute configuration of the pentanediol (LXI) corresponds to that of *D*-glyceraldehyde, it follows that desosamine belongs to the *D*-series.

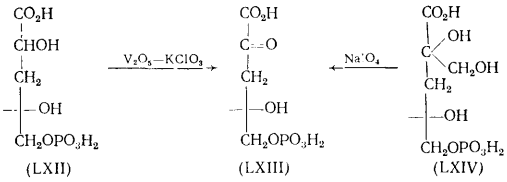


2. Syntheses of Deoxysugars via Saccharinic Acids

Saccharinic acids are particularly useful for the synthesis of deoxysugars and branched sugar derivatives. When γ-lactones of α- and β-*D*-glucometasaccharinic acids are reduced. 3-deoxy-*D*-*ribo*-hexose and 3-deoxy-*D*-*arabino*-hexose are formed respectively[32]. The reduction of the γ-lactones of α- and β-*D*-glucoisosaccharinic acids leads to 3-deoxy-2-*C*-hydroxymethyl-*D*-*erythro*-aldopentose and 3-deoxy-2-*C*-hydroxymethyl-*D*-*threo*-aldopentose respectively. It has been shown[56] that the reduction of both γ-lactones with sodium tetrahydroborate proceeds more effectively than with sodium amalgam. The reduction of the lactone of α-*D*-glucoisosaccharinic acid had been investigated previously[240]. 2-*C*-Methyl-*D*-ribose has been obtained by the reduction of the lactone of α-*D*-glucosaccharinic acid with sodium amalgam[56]¶.

2-Deoxy-*D*-xylose has been obtained by the Ruff cleavage from *D*-galactometasaccharinic acids[241]. Numerous studies[242,244] have been devoted to the conversion of *D*-glucometasaccharinic acid salts into 2-deoxy-*D*-*erythro*-pentose (2-deoxy-*D*-ribose) by the same method. Synthesis via metasaccharinic acids has also been used to obtain 2-deoxy-*D*-*erythro*-tetroses and 2-deoxy-*D*-*threo*-tetroses from *D*-arabinose and *D*-xylose respectively[245].

3-Deoxy-2-oxo-*D*-*threo*-hexonic acid has been obtained from α-*D*-galactometasaccharinic acid[246]. Selective oxidation of a mixture of the 5-phosphates of 3-deoxy-*D*-*erythro*-pentonic and 3-deoxy-*D*-*threo*-pentonic acids (LXII) at the $C_{(2)}$ atom with potassium chlorate and vanadium pentoxide yielded the 5-phosphates of 3-deoxy-2-oxo-*D*-glyceropentonic acid (LXIII). The latter has been obtained also by the periodate oxidation of a mixture of the 5-phosphates of 3-deoxy-2-*C*-hydroxymethyl-*D*-*erythro*- and -*D*-*threo*-pentonic acids (LXIV)[247]:



The 6-phosphates of 3-deoxy-2-oxo-*D*-*erythro*- and *D*-*threo*-hexonic acids have been obtained from the 6-phosphates of *D*-glucometasaccharinic and *D*-galactometasaccharinic acids respectively[248]. The formation of a cyclic enol by oxidising the 6-phosphates of *D*-glucometasaccharinic acid with potassium chlorate in the presence of vanadium pentoxide has been studied[249]. The γ-lactone of α-*D*-glucosaccharinic acid has been used as the initial compound in the synthesis of nucleosides containing branched sugars[250-252].

Certain properties of saccharinic acids have been described in a review[26]. It was shown subsequently[56,145] that α- and β-*D*-glucoisosaccharinic acids are resistant to alkaline solutions up to 125 °C and are not interconverted under these conditions. α-*D*-Glucosaccharinic acid is also not isomerised on treatment with alkali or on heating[56], while the lactones of α- and β-*D*-glucometasaccharinic acids are interconverted via epimerisation[49,120,166,253]. A similar transformation has been observed by Nef[11] for the lactones of *D*-galactometasaccharinic acids. Acids which do not contain hydrogen atoms at $C_{(2)}$ do not undergo this transformation.

¶ The corresponding polyrols can also be obtained by the reduction of saccharinic acids with tetrahydroborate[56].

The γ-lactones of saccharinic acids are more stable in aqueous solutions than the lactones of aldonic acids and remain unchanged for several days. Like normal aliphatic esters and lactones, the lactones of deoxy- and 2-*C*-methylaldonic acids are extremely resistant to non-catalysed hydrolysis[254].

REFERENCES

1. N.K.Kochetkov, A.F.Bochkov, B.A.Dmitriev, A.I.Usov, O.S.Chizhov, and V.N.Shibaev, "Khimiya Uglevodov" (The Chemistry of Carbohydrates), Izd.Khimiya, Moscow, 1967, p.97.
2. W.Pigman and E.F.L.J.Anet, in "The Carbohydrates", Acad.Press, New York, 1972, Vol.1A, Chapter 4.
3. L.Hough and A.C.Richardson, in "Rodd's Chemistry of Carbon Compounds", Amsterdam–London–New York, 1967, Vol.1, Part F, p.251.
4. T.Enkvist, Finska Kemists.Medd., **71**, 105 (1962).
5. E.Shaw, J.H.Tatum, and R.E.Berry, J.Agric Food Chem., **16**, 979 (1968).
6. H.Kato, M.Mizushima, T.Kurata, and M.Fujimaki, Agric Biol.Chem., **37**, 2677 (1973).
7. R.Koetz and H.Neukom, Carbohydr.Res., **42**, 365 (1975).
8. I.Forsskahl, T.Popoff, and O.Theaner, Carbohydr. Res., **48**, 13 (1976).
9. V.F.Kazimirova and S.N.Danilov, Zhur.Obshch. Khim., **33**, 1424 (1963).
10. R.A.Gakhokidze, Zhur.Obshch.Khim., **46**, 1620 (1976).
11. J.U.Nef, Annalen, **376**, 1 (1960).
12. F.Shafizadeh and Y.Z.Iai, Carbohydr.Res., **7** 263 (1975).
13. A.Herzfeld, Annalen, **220**, 214 (1883).
14. J.E.Mackenzie and J.P.Quin, J.Chem.Soc., 951 (1929).
15. E.G.V.Percival, J.Chem.Soc., 1160 (1934).
16. N.Roy and A.K.Mitra, Carbohydr.Res., **24**, 175 (1972).
17. N.Roy and A.K.Mitra, Carbohydr.Res., **24**, 180 (1972).
18. S.P.Moulik and A.K.Mitra, Carbohydr.Res., **28**, 371 (1973).
19. S.P.Moulik and D.P.Kahn, Carbohydr.Res., **41**, 93 (1975).
20. J.E.Hodge, Adv.Carbohydr.Chem., **10**, 169 (1955).
21. J.M.Sugihara, Adv.Carbohydr.Chem., **8**, 1 (1953).
22. R.S.Tipson, Adv.Carbohydr.Chem., **8**, 107 (1953).
23. H.S.Isbell, H.L.Frush, R.Schaffer, C.W.R.Wade, and R.A.Peterson, Nat.Bur.Stand.Tech.Note, **274**, 36 (1965).
24. W.L.Evans, Chem.Rev., **6**, 281 (1929).
25. W.L.Evans, Chem.Rev., **31**, 537 (1942).
26. J.C.Sowden, Adv.Carbohydr.Chem., **12**, 35 (1957).
27. J.Staněk, M.Černy, et al. "The Monosaccharides". Acad.Press, New York, 1963.
28. E.Peligot, Compt.rend., **7**, 106 (1838).
29. G.J.Mulder, J.prakt.Chem., **21**, 203 (1840).
30. J.D.Crum, Adv.Carbohydrate Chem., **13**, 169 (1958).
31. A.M.Gakhokidze, Zhur.Obshch.Khim., **11**, 109 (1941).
32. H.B.Wood, Jr., and H.G.Fletcher, Jr., J.Org. Chem., **26**, 1969 (1961).
33. A.Ishizu, K.Yoshida, and N.Yamazaki, Carbohydr. Res., **23**, 23 (1972).
34. O.Samuelson and L.Thede, Acta Chem.Scand., **22**, 1913 (1966).
35. R.Malinen and E.Sjöström, Paperi ja Puu, **54**, 451 (1972).
36. M. von Glehn and P.-E.Warner, Chem.Comm., 291 (1967).
37. R.Norrestam, P.-E.Werner, and M.von Glehn, Acta Chem.Scand., **22**, 1395 (1968).
38. P.-E.Werner, R.Norrestam, and C.Rönnquist, Acta Cryst., **B25**, 714 (1969).
39. D.L.Hughes, J.Trotter, and J.Howard, J.Chem. Soc., B,983 (1970).
40. J.C.Sowden and D.S.Strobach, J.Amer.Chem.Soc., **82**, 3707 (1960).
41. A.B.Foster, T.D.Inch, J.Lehman, and J.M.Weber, J.Chem.Soc., 948 (1964).
42. G.Petersson, Carbohydr.Res., **43**, 1 (1975).
43. L.Löwendahl and O.Samuelson, Acta Chem.Scand., **B30**, 691 (1976).
44. L.Löwendahl, G.Petersson, and O.Samuelson, Cellul. Chem.Technol., **10**, 471 (1976).
45. S.Ylner, Acta Chem.Scand., **10**, 1251 (1956).
46. R.H.Cordingly, TAPPI, **42**, 654 (1959).
47. D.L.Ingles, Chem.Ind.(London), 1312 (1961).
48. U.Schmidt, Holzforschung, **55**, 79 (1961).
49. B.Lindberg and O.Theander, Svensk Papperstidn., **65**, 509 (1962).
50. B,Lindberg, J.Tanaka, and O.Theander, Acta. Chem.Scand., **18**, 1164 (1964).
51. H.-L.Hardell and O.Theander, Acta Chem.Scand., **25**, 877 (1971).
52. S.V.Soldatenkov and T.A.Mazurova, Biokhimiya, **21**, 6 (1956).
53. S.V.Soldatenkov, "Biokhimiya Organicheskikh Kislot Rastenii" (Biochemistry of Organic Acids in Plants), Izd.Leningrad.Univ., 1971, p.50.
54. A.A.J.Feast, B.Lindberg, and O.Theander, Acta Chem.Scand., **19**, 1127 (1965).
55. D.Monzie-Guillemet and P.Monzie, Tech.Rech.Papet., **4**, 74 (1966).
56. A.Ishizu, B.Lindberg, and O.Theander, Carbohydr. Res., **5**, 329 (1967).
57. A.Ishizu, B.Lindberg, and O.Theander, Acta Chem. Scand., **21**, 424 (1967).
58. B.Alfredson and O.Samuelson, Svensk Papperstidn., **71**, 679 (1968).
59. J.J.M.Rowe and K.B.Gibney et al., J.Amer.Chem. Soc., **90**, 1924 (1968).
60. V.Alfredson and O.Samuelson, Svensk Papperstidn.. **72**, 361 (1969).
61. M.S.Feather and J.F.Harris, Carbohydr.Res., **15**, 304 (1970).
62. W.Droge, V.Lehmann, O.Luderitz, and O.Westphal, Europ.J.Biochem., **14**, 175 (1970).
63. G.Petersson, Carbohydr.Res., **33**, 47 (1974).
64. G.Petersson, Tetrahedron, **26**, 3413 (1970).
65. G.Petersson, Org.Mass.Spectrom., **6**, 577 (1972).
66. G.O.Aspinall and Sze Chan Tam, Carbohydr. Res., **38**, 71 (1974).
67. R.F.Burns and P.J.Somers, Carbohydr.Res., **31**, 289 (1973).
68. S.A.Barker, A.R.Law, P.J.Somers, and M.Stacey, Carbohydr.Res., **3**, 435 (1967).

69. A.M.Y.Ko and P.J.Somers, Carbohydr.Res., **33**, 281 (1974).
70. R.F.Burns and P.J.Somers, Carbohydr.Res., **31**, 301 (1973).
71. K.Larsson, L.Olsson, and O.Samuelson, Carbonhydr. Res., **38**, 1 (1974).
72. S.A.Barker, J.M.Edwards, P.J.Somers, and A.Repas, Carbohydr.Res., **6**, 341 (1968).
73. J.U.Nef, Annalen, **357**, 214 (1907).
74. W.L.Evans, R.H.Edgar, and G.P.Hoff, J.Amer. Chem.Soc., **48**, 2665 (1926).
75. M.P.Benoy and W.L.Evans, J.Amer.Chem.Soc., **48**, 2675 (1926).
76. H.Ohle, Ergeb.Physiol., **33**, 694 (1931).
77. H.Kiliani and S.Kleemann, Ber., **17**, 1302 (1884).
78. A.Windaus, Chem.Z., **29**, 564 (1904).
79. H.S.Isbell, J.Res.Nat.Bur.Stand., **32**, 45 (1944).
80. O.Theander, Adv.Carbohydr.Chem., **17**, 223 (1962).
81. E.F.L.J.Anet, Carbohydr.Chem., **19**, 181 (1964).
82. J.C.Sowden, M.G.Blair, and D.J.Kuenne, J.Amer. Chem.Soc., **79**, 6450 (1957).
83. J.C.Sowden and D.J.Kuenne, J.Amer.Chem.Soc., **75**, 2788 (1953).
84. H.P.Humphries and O.Theander, Acta Chem.Scand., **25**, 883 (1971).
85. B.Lindberg and O.Theander, Acta Chem.Scand., **22**, 1782 (1968).
86. J.Kenner and G.N.Richards, J.Chem.Soc., 1784 (1954).
87. R.U.Lemieux, in "Molecular Rearrangements", Part 2, (Edited by P.de Mayo), Intersci.Publ. New York, 1964, p.744.
88. G.Machell and G.N.Richards, J.Chem.Soc., 1938 (1960).
89. R.M.Rowell and J.Green, Carbohydr.Res., **15**, 197 (1970).
90. J.C.Sowden and E.K.Pohlen, J.Amer.Chem.Soc., **80**, 242 (1958).
91. W.M.Corbett and A.M.Liddle, J.Chem.Soc., 531 (1961).
92. M.S.Feather and J.F.Harris, Adv.Carbohydr.Chem., **28**, 161 (1973).
93. J.C.Sowden and R.Schaffer, J.Amer.Chem.Soc., **74**, 499 (1952).
94. J.C.Speck Jr., Adv.Carbohydr.Chem., **13**, 63 (1958).
95. H.A.Hampton, W.N.Haworth, and E.L.Hirst, J.Chem.Soc., 1739 (1929).
96. S.V.Bleshchinskii and S.F.Lozitskaya, Trudy Khim. Inst.Kirgiz.Fil.Akad.Nauk SSSR, **4**, 73 (1951).
97. M.Gibbs, J.Amer.Chem.Soc., **72**, 3964 (1950).
98. J.Kenner and G.N.Richards, J.Chem.Soc., 2916 (1956).
99. W.M.Corbett and J.N.Kenner, J.Chem.Soc., 3281 (1954).
100. R.F.Burns and P.J.Somers, Carbohydr.Res., **31**, 191 (1973).
101. G.Machell and G.N.Richards, J.Chem.Soc., 1932 (1960).
102. G.Machell and G.N.Richards, J.Chem.Soc., 1924 (1960).
103. J.W.Green, J.Amer.Chem.Soc., **78**, 1894 (1956).
104. R.Malinen and E.Sjöström, Paperi Puu, **57**, 728 (1975).
105. E.Fischer, Ber., **26**, 2400 (1893).
106. E.Fischer and L.Beensch, Ber., **27**, 2478 (1894).
107. E.Fischer and B.Helferich, Annalen, **383**, 68 (1911).
108. B.Indberg, Svensk Papperstidn., **59**, 531 (1956).
109. C.S.Hudson, J.Amer.Chem.Soc., **38**, 1566 (1916).
110. C.E.Ballou, Adv.Carbohydr.Chem., **9**, 59 (1954).
111. J.B.Lee, J.Org.Chem., **28**, 2473 (1963).
112. C.Degani and M.Halmann, J.Amer.Chem.Soc., **90**, 1313 (1968).
113. R.L.Whistler and W.M.Corbett, J.Amer.Chem.Soc., **77**, 3822 (1955).
114. R.L.Whistler and W.M.Corbett, J.Amer.Chem.Soc., **77**, 6328 (1955).
115. J.Kenner and G.N.Richards, J.Chem.Soc., 2921 (1956).
116. J.K.Hamilton, Pure Appl.Chem., **5**, 197 (1962).
117. R.Aurell, N.Hartler, and G.Persson, Acta Chem. Scand., **17**, 545 (1963).
118. B.Lindberg and O.Theander, Acta Chem.Scand., **20**, 206 (1966).
119. R.J.Ferrier, W.G.Overend, and A.E.Ryan, J. Chem.Soc., 1488 (1962).
120. J.Kenner and G.N.Richards, J.Chem.Soc., 278 (1954).
121. J.Kenner and G.N.Richards, J.Chem.Soc., 3019 (1957).
122. W.M.Corbett and J.Kenner, J.Chem.Soc., 927 (1957).
123. W.M.Corbett, G.N.Richards, and R.L.Whistler, J.Chem.Soc., 11 (1957).
124. D.M.Brown, F.Hayes, and A.R.Todd, Ber., **90**, 936 (1957).
125. G.O.Aspinall et.al. Canad.J.Chem., **53**, 2171 (1975).
126. S.Lewak aand L.Szabo, J.Chem.Soc., 3975 (1963).
127. W.Jachymczyk, L.Menager, and L.Szabo, Tetrahedron, **21**, 2049 (1965).
128. W.M.Corbett, J.Kenner, and G.N.Richards, J. Chem.Soc., 1709 (1955).
129. J.Kenner and G.N.Richards, J.Chem.Soc., 1810 (1955).
130. M.Sten and T.Mustola, Cellul.Chem.Technol., **7**, 359 (1973).
131. G.O.Aspinall, C.T.Greenwood, and R.J.Sturgeon, J.Chem.Soc., 3667 (1961).
132. R.L.Whistler, J.N.BeMiller, Adv.Carbohydr.Chem., **13**, 289 (1958).
133. J.Honeyman (Editor), "Recent Advances in the Chemistry of Cellulose and Starch, Intersci.Publ. New York, 1959.
134. N.S.Mayat and O.P.Golova, Uspekhi Khim., **28**, 1114 (1959).
135. A.Meller, Holzforschung, **14**, 78, 129 (1960).
136. G.N.Richards, in "Cellulose and Cellulose Derivatives", Wiley Intersci., New York, 1971, p.1007.
137. O.P.Golova and N.I.Nosova, Uspekhi Khim., **42**, 743 (1973)[Russ.Chem.Rev., No.4 (1973)].
138. J.R.Clamp, L.Hough, et al., Adv.Carbohydr. Chem., **16**, 159 (1961).
139. H.Kiliani, Ber., **42**, 3903 (1909).
140. J.U.Nef, Annalen, **357**, 301 (1907).
141. T.M.Lowry and G.L.Wilson, Trans.Faraday Soc., **24**, 683 (1928).
142. G.Klein, Biochem.Z., **169**, 132 (1926).
143. W.M.Corbett and J.Kenner, J.Chem.Soc., 2245 (1953).
144. W.M.Corbett and J.Kenner, J.Chem.Soc., 1789 (1954).
145. R.L.Whistler and J.N.BeMiller, J.Org.Chem., **26**, 2886 (1961).
146. R.J.Whistler and D.G.Medcalf, J.Org.Chem., **27**, 3560 (1962).
147. H.Kiliani, Ber., **16**, 2625 (1883).
148. W.M.Corbett and J.Kenner, J.Chem.Soc., 1431 (1955).

149. D.J.MacLaurin and J.W.Green, Canad J.Chem., **47**, 3957 (1969).
150. R.M.Rowell, P.J.Somers, S.A.Barker, and M.Stacey, Carbohydr.Res., **11**, 17 (1969).
151. R.M.Rowell, Pulp.Paper Mag.Can., **72**, 74 (1971).
152. O.Samuelson and L.Thede, Acta Chem.Scand., **22**, 1913 (1968).
153. R.Malinen and E.Sjöström, Paperi ja Puu, **54**, 451 (1972).
154. G.O.Aspinall, M.E.Carter, and M.Los, J.Chem. Soc., 4807 (1956).
155. G.O.Aspinall, M.E.Carter, and M.Los, Chem.Ind. (London), 1553 (1955).
156. R.L.Whistler and W.M.Corbett, J.Amer.Chem.Soc., **78**, 1003 (1956).
157. M.H.Johansson and O.Samuelson, Chem.Scripta, **9**, 151 (1976).
158. B.Lindberg, O.Theander, and J.-E.Uddegard, Svensk Papperstidn., **69**, 360 (1966).
159. H.Richtzenhain and B.A.Abrahamsson, Svensk Papperstidn., **57**, 538 (1954).
160. J.W.Green, TAPPI, **39**, 472 (1956).
161. G.N.Richards and H.H.Sephton, J.Chem.Soc., 4492 (1957).
162. H.Richtzenhain, B.O.Lindberg, B.A.Abrahamsson, and K.Holmberg, Svensk Papperstidn., **57**, 363 (1954).
163. G.Machell and G.N.Richards, J.Chem.Soc., 4500 (1957).
164. G.Machell, G.N.Richards, and H.H.Sephton, Chem. Ind.(London), 467 (1957).
165. B.Alfredson, O.Samuelson, and B.Sandstig, Svensk Papperstidn., **66**, 703 (1963).
166. M.H.Johansson and O.Samuelson, Carbohydr.Res., **34**, 33 (1974).
167. P.F.Nelson and O.Samuelson, Svensk Papperstidn., **71**, 325 (1968).
168. D.W.Hass, B.F.Hrutfiord, and K.V.Sarkanen, J. Apl.Polymer Sci., **11**, 587 (1967).
169. A.Meller, Holzforschung, **14**, 81 (1960).
170. Y.-Z.Lai and K.V.Sarkanen, Cellulose Chem. Technol., **1**, 517 (1967).
171. G.Centola, F.Pancirolli, and G.Ceragioli, Chimica e Industria, **87**, 345 (1955).
172. R.L.Colbran and G.F.Davidson, J.Textile Inst., **52**, T140 (1961).
173. R.Malinen and E.Sjöström, Paperi ja Puu, **57**, 101 (1975).
174. D.Monzie-Guillemet, H.Roux, and P.Monzie, Tech. Rech.Papet., **7**, 37 (1966).
175. O.Samuelson and L.Stolpe, TAPPI, **52**, 1709 (1969).
176. L.Jansen and O.Samuelson, Svensk Papperstidn., **72**, 216 (1969).
177. H.Kolmodin and O.Samuelson, Svensk Papperstidn., **73**, 93 (1970).
178. H.Kolmodin and O.Samuelson, Svensk Papperstidn., **74**, 310 (1971).
179. S.M.Aronovic, E.P.Crowell, D.M.Whalen, and B.B.Vurnett, TAPPI, **54**, 1693 (1971).
180. R.Malinen, E.Sjöström, and J.Ylijoki, Paperi ja Puu, **55**, 5 (1972).
181. H.Kolmodin and O.Samuelson, Svensk Papperstidn., **75**, 369 (1972).
182. R.Malinen and E.Sjöström, Paperi ja Puu, **55**, 547 (1973).
183. H.Kolmodin and O.Samuelson, Svensk Papperstidn., **76**, 71 (1973).
184. M.Manouchehri and O.Samuelson, Svensk Papperstidn., **76**, 486 (1973).
185. R.Malinen, Paperi ja Puu, **57**, 193 (1975).
186. R.M.Rowell, Pulp.Paper.Mag.Can., **72**, T236 (1971).
187. O.Samuelson, Papier, **24**, 671 (1970).
188. J.-A.Hansson and N.Hartler, Svensk Papperstidn., **71**, 669 (1968).
189. E.Dryselius, B.Lindberg, and O.Theander, Acta Chem.Scand., **11**, 663 (1957).
190. J.L.Minor, L.E.Kihle, and N.Sanyer, TAPPI, **52**, 2178 (1969).
191. R.M.Rowell and J.Green, TAPPI, **55**, 1326 (1972)
192. A.Meller, TAPPI, **38**, 682 (1955).
193. F.S.Head, J.Text.Ind., **46**, T58 (1965).
194. N.Hartler, Svensk Papperstidn., **65**, 513 (1962).
195. A.Meller, TAPPI, **46**, 317 (1963).
196. A.Meller and E.L.Ritman, TAPPI, **47**, 55 (1964).
197. R.L.Casebier and J.K.Hamilton, TAPPI, **50**, 441 (1967).
198. A.Meller, TAPPI, **38**, 682 (1955).
199. A.Meller, TAPPI, **39**, 722 (1956).
200. W.K.Wilson and A.A.Podgett, TAPPI, **38**, 292 (1955).
201. I.Szabo and O.Teder, Svensk Papperstidn., **72**, 68 (1969).
202. O.Samuelson and N.Hartler, Svensk Kem.Tidskr., **62**, 197 (1950).
203. E.Venemark, Svensk Papperstidn., **67**, 157 (1964).
204. S.A.Rydholm, "Pulping Processes", Interscience, New York, 1965, p.642.
205. P.H.Abenius et al., Svensk Papperstidn., **70**, 612 (1967).
206. A.Teder, Svensk Papperstidn., **71**, 149 (1968).
207. P.Ahlgren, A.Ishizu, I.Szabo, and O.Theander, Svensk Papperstidn., **71**, 355 (1968).
208. A.Meller, Svensk Papperstidn., **65**, 307 (1962).
209. A.Meller, TAPPI, **45**, 481 (1962).
210. R.E.Reeves, W.M.Schwartz, and J.E.Giddens, J.Amer.Chem.Soc., **68**, 1383 (1962).
211. A.Meller, Svensk Papperstidn., **65**, 629 (1962).
212. A.R.Procter and R.H.Wiekenhamp, J.Polymer. Sci., Part C, **28**, 1 (1969).
213. G.Machell and G.N.Richards, TAPPI, **41**, 12 (1958).
214. A.Robert, P.Perolle, A.Viallet, and C.M.Barret, Bull.ATIP, **18**, 151 (1964).
215. O.Samuelson and L.Stolpe, Svensk Papperstidn., **74**, 662 (1969).
216. O.Samuelson and L.Stolpe, Svensk Papperstidn., **74**, 545 (1971).
217. B.Ericsson, B.Lindgren, and O.Theander, Svensk Papperstidn., **74**, 757 (1971).
218. O.Samuelson and L.Stolpe, Svensk Papperstidn., **77**, 16 (1974).
219. J.Defaye and A.Gadelle, Pulp.Paper Mag.Can., **75**, T394 (1974).
220. J.Defaye, H.Driguez, and A.Gadelle, Carbohydr. Res., **38**, C4 (1974).
221. D.W.Clayton and L.M.Marricini, Svensk Papperstidn., **69**, 311 (1966).
222. M.Ya.Zarubin and D.V.Tishchenko, Zhur.Prikl. Khim., **35**, 2724 (1962).
223. G.Chirkin and D.V.Tishchenko, Zhur.Prikl.Khim., **35**, 153 (1962).
224. R.T.Bottle and G.A.Gilbert, Chem.Ind.(London), 1201 (1954).
225. J.Kenner and G.N.Richards, Chem.Ind.(London), 1483 (1954).
226. G.Machell and G.N.Richards, J.Chem.Soc., 1199 (1958).
227. C.J.Stacey, J.F.Foster, and S.N.Erlander, Macromol Chem., **17**, 181 (1956).

228. Y.-Z.Lai and K.V.Sarkanen, J.Polymer Sci., **C28**, 15 (1969).
229. R.L.Whistler and J.N.BeMiller, J.Amer.Chem.Soc., **82**, 457 (1960).
230. L.Löwendahl, G.Peterson, and O.Samuelson, Carbohydr.Res., **43**, 355 (1975).
231. K.Larsson and O.Samuelson, Carbohydr.Res., **31**, 81 (1978).
232. W.M.Corbett and J.Kenner, J.Chem.Soc., 3274 (1954).
233. R.A.Young and K.V.Sarkanen et al., Carbohydr. Res., **21**, 111 (1972).
234. T.E.Nelson and B.A.Lewis, Carbohydr.Res., **33**, 63 (1974).
235. R.F.Burns and P.J.Somers, Carbohydr.Res., **31**, 191 (1973).
236. A.Klemer and K.Homborg, Ber., **96**, 631 (1963).
237. T.E.Nelson, J.Johnson, E.Jantzen, and S.Kirkwood, J.Biol.Chem., **244**, 5972 (1969).
238. T.Bremner, J.S.G.Cox, and G.F.Moss, Carbohydr. Res., **11**, 77 (1969).
239. C.H.Bolton, A.B.Foster, M.Stacey, and J.M.Webber, J.Chem.Soc., 4831 (1961).
240. P.Schorigin and N.N.Makarowa-Semlianskaia, Ber., **66**, 387 (1933).
241. H.Kiliani and P.Loeffler, Ber., **38**, 2667 (1905).
242. G.N.Richards, J.Chem.Soc., 3639 (1954).
243. J.C.Sowden, J.Amer.Chem.Soc., **76**, 3541 (1954).
244. H.W.Diehl and H.G.Fletcher, Arch.Biochem. Biophys., **78**, 386 (1958).
245. H.Venner, Ber., **90**, 121 (1951).
246. I.De Ley and M.Doudoroff, J.Biol.Chem., **227**, 745 (1957).
247. F.Trigalo and L.Szabo, J.Chem.Soc., Perkin Trans.I, 604 (1975).
248. F.Trigalo , W.Jachymczyk, J.C.Young, and L.Szabo, J.Chem.Soc., Perkin Trans.I, 593 (1975).
249. F.Trigalo and L.Szabo, J.Chem.Soc., Perkin Trans.I, 598 (1975).
250. E.Walton, S.R.Jenkins, R.F.Nutt, M.Zimmermann, and F.W.Holley, J.Amer.Chem.Soc., **88**, 4524 (1966).
251. S.R.Jenkins, B.Arison, E.Walton, J.Org.Chem., **33**, 2490 (1968).
252. J.J.Novak, I.Smejkal, and F.Sorm, Tetrahedron Letters, 1627 (1969).
253. B.Alfredson and O.Samuelson, Svensk Papperstidn., **65**, 690 (1962).
254. F.Shafizadeh, Adv.Carbohydr.Chem., **13**, 9 (1958).

Faculty of Chemistry,
Tbilisi State University