

RESEARCH PAPER RP1547

Part of Journal of Research of the National Bureau of Standards, Volume 31,
July 1943

RING STRUCTURES AND MUTAROTATIONS OF THE MODIFICATIONS OF *D*-GALACTURONIC ACID

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ABSTRACT

A study of the two crystalline modifications of galacturonic acid has been made with the object of determining their ring structure. The results show that they are a pair of alpha-beta pyranoses analogous to the alpha and beta galactopyranoses. On oxidation with bromine water, the two modifications yield optically active lactones of mucic acid.

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1. COMPARISON OF THE MUTAROTATIONS OF α - AND β -*D*-GALACTURONIC ACID WITH THOSE OF α - AND β -*D*-GALACTOPYRANOSE

Galacturonic acid, the chief constituent of all pectin material, is one of the most abundant and important sugar derivatives. It is a substituted aldose having the *D*-galactose configuration, and as such it is capable of existing in various modifications. In fact, two crystalline modifications are known, one of which has been assumed to be an open chain modification and the other a pyranose [1].¹ Inasmuch as an open chain modification of a free sugar is unique in the field of carbohydrate chemistry, and since it has been found that substances having the galactose configuration give rise to complex mutarotation reactions indicating the presence of both pyranose and furanose modifications in the equilibrium mixture [2, 3], it seemed desirable to investigate the modifications of galacturonic acid and to study the changes which occur when they are dissolved in water.

One of the crystalline forms of galacturonic acid, a monohydrate originally designated "alpha", is reported to give an initial specific rotation of $+98^\circ$ and an equilibrium value of $+50.9^\circ$; the other, an

¹ Figures in brackets indicate the literature references at the end of this paper.

anhydrous form commonly designated "beta", is reported to give an initial specific rotation of $+27^\circ$ and an equilibrium value of $+55.3^\circ$. Calculated on the anhydrous basis, the same equilibrium value is approached by either the alpha or the beta modification, and either form can be obtained from the equilibrium solution by appropriate treatment. An aldehydohydrate structure was assigned to the alpha modification by Ehrlich and Schubert [1] on the basis that the molecule of water is very tenaciously held, and that the compound develops color quickly with Schiff's fuchsine-aldehyde reagent, whereas the beta modification develops color slowly. Since the positive aldehyde test requires only a very small amount of the open-chain modification, and this might be formed from the cyclic modification after dissolution in water, the evidence for the assignment of the open-chain structure is not sufficient, and, in fact, some investigators have tacitly assumed an alpha pyranose structure [4]. The anhydrous modification has been considered to be a beta pyranose, largely because it is less dextro-rotatory than the monohydrate, and because most sugars crystallize as pyranose modifications.

In publications from this laboratory it has been emphasized that substances having like configurations for the atoms comprising the pyranose ring have similar properties [2, 3, 5]. It therefore seemed of interest to compare the mutarotation curves of the modifications of galacturonic acid with those of α - and β -*D*-galactopyranose. The two modifications of galacturonic acid were prepared and the mutarotation measurements reported in table 1 were made.

For comparison, curves representing the mutarotations of the two modifications of galacturonic acid, and of galactose are given in figures 1 and 2. An examination of the figures reveals that the curves for the two modifications of galacturonic acid are analogous to the curves for the two modifications of galactose. Thus, the mutarotations of the alpha modifications are characterized by an initial rapid change, whereas the mutarotations of the beta modifications are characterized by an initial retardation. Inasmuch as an initial rapid change is characteristic of the α -galactopyranose structure, and an initial retardation is characteristic of the β -galactopyranose structure, the comparisons support the classification of the two modifications of galacturonic acid as an alpha-beta pyranose pair.

II. BROMINE OXIDATION OF THE MODIFICATIONS OF GALACTURONIC ACID

In previous investigations a method was developed for studying the modifications of the sugars present in aqueous solution by means of bromine oxidation in conjunction with mutarotation measurements [6]. Since the several modifications of the same sugar react with bromine at widely different rates, and usually the oxidation reactions are rapid in comparison with the mutarotation reactions, the proportions of the various modifications can be calculated from the reaction rates. Moreover, a study of the reaction products reveals additional information. Pyranoses on oxidation yield delta lactones, whereas furanoses yield gamma lactones. Thus the pyranose modifications of galacturonic acid should give the delta lactone of mucic acid by the reaction of equation I, the furanose modification should give the

TABLE 1.— α -*D*-Galacturonic acid hydrate

4 g per 100 ml at 20° C, read in a 2-dm tube. $^{\circ}S = 10.66 \times 10^{-0.148t} + 2.44 \times 10^{-.16t} + 12.34$. $[\alpha]_D^{20} = 44.83 \times 10^{-0.148t} + 10.26 \times 10^{-.16t} + 51.90$. $[\alpha]_D^{20} = +107.0$ (initial), $+51.9$ (equilibrium).					
Time	Observed reading	k_1+k_2	m_1	Deviation	m_2
Minutes	$^{\circ}S$				
0				(2.44)	
1.3	+24.05			1.51	
1.7	+23.66	0.0368		1.26	0.20
2.4	+23.22	.0290		1.06	.14
3.6	+22.46	.0257		0.69	.15
4.2	+23.13	.0268		.55	.15
4.9	+21.77	.0261		.41	.16
7.1	+20.88	.0236		.17	.16
8.8	+20.30	.0224		.06	.19
17.4	+18.23	.0185			
21.7	+17.43	.0177	0.0148		
25.9	+16.72	.0174	.0151		
30.2	+16.14	.0169	.0149		
60.0	+13.74	.0157	.0146		
∞	+12.34				
Average			0.0148		0.16

β -*D*-GALACTURONIC ACID

4 g per 100 ml at 20° C, read in a 2-dm tube. $^{\circ}S = -7.23 \times 10^{-0.148t} + 1.41 \times 10^{-.13t} + 12.88$. $[\alpha]_D^{20} = -31.84 \times 10^{-0.148t} + 6.21 \times 10^{-.13t} + 56.72$. $[\alpha]_D^{20} = +31.1$ (initial), $+56.7$ (equilibrium).					
Time	Observed reading	k_1+k_2	m_1	Deviation	m_2
Minutes	$^{\circ}S$				
0				(1.41)	
1.9	+6.90			0.80	
2.6	+6.94	0.0041		.68	0.10
3.6	+6.98	.0034		.60	.12
4.8	+7.08	.0046		.34	.13
6.3	+7.22	.0054		.17	.15
7.8	+7.44	.0070		.10	.15
12.7	+8.19	.0098			
19.3	+9.13	.0116	0.0147		
23.5	+9.61	.0121	.0145		
27.1	+10.00	.0126	.0147		
30.5	+10.34	.0130	.0150		
34.9	+10.68	.0132	.0148		
55.1	+11.80	.0140	.0150		
∞	+12.88				
Average			0.0148		0.13

• The method for calculating the equation and the constants is described in detail on page 156 of [6].

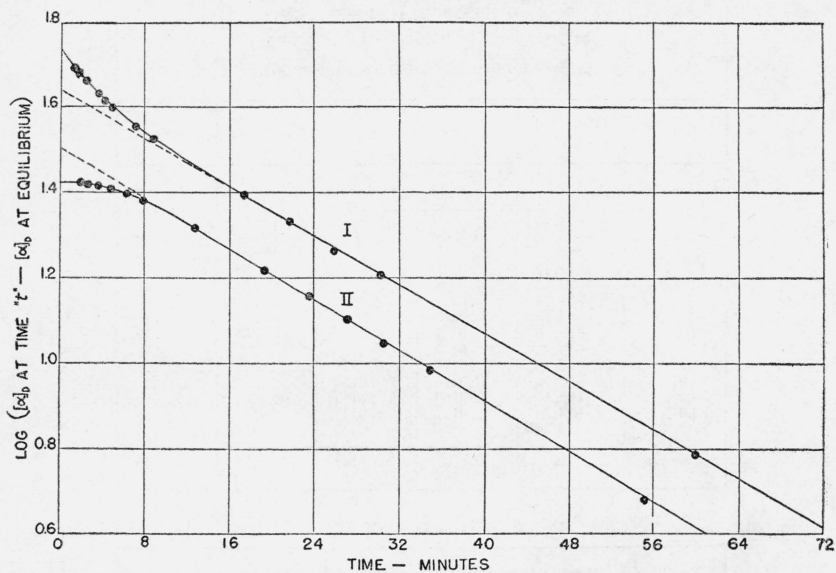


FIGURE 1.—Mutarotations of α - and β -D-galacturonic acid in water at 20°C.
I, α -D-galacturonic acid; II, β -D-galacturonic acid.

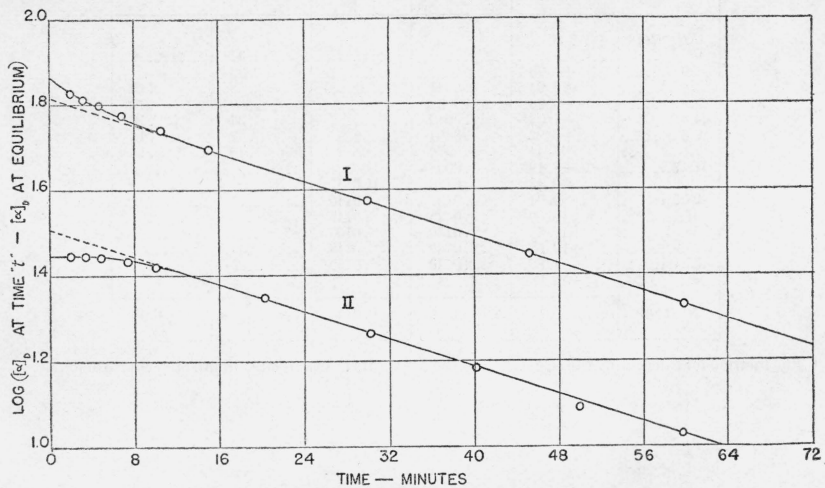
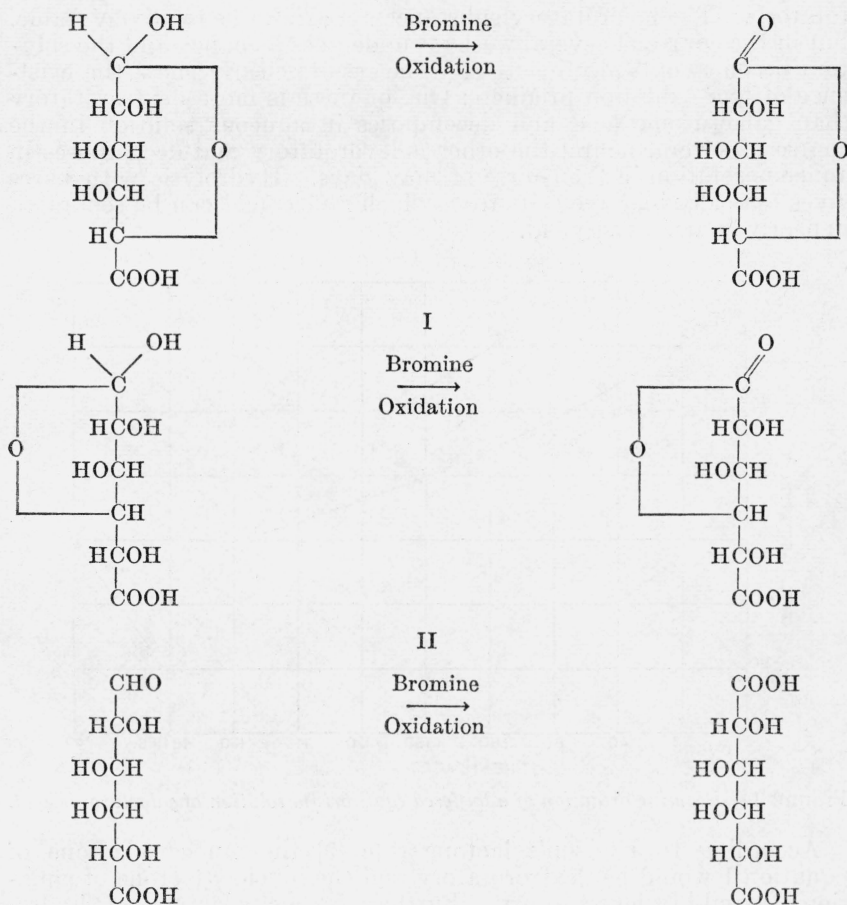


FIGURE 2.—Mutarotations of α - and β -D-galactose in water at 20°C (curves constructed from data given in [2]).
I, α -D-galactose; II, β -D-galactose.

gamma lactone by the reaction of equation II and the open chain modification should give mucic acid by the reaction of equation III.



III

Mucic acid is a *meso* compound, and hence on lactone formation gives rise to a racemic mixture because there is equal probability that either end of the molecule may be involved in ring formation. However, the delta and gamma lactones of mucic acid, obtained by oxidation of the pyranose and furanose modifications of galacturonic acid, should be optically active since a *meso* configuration is not present during lactone formation. The formation of optically active lactones has now been observed experimentally. The production of these unique substances is striking evidence that the ring modifications of galacturonic acid are oxidized with bromine directly to the lactones of mucic acid without the intermediate formation either of the open-chain modification of galacturonic acid, or of free mucic acid.

The formation of these optically active lactones is shown by the changes in optical rotation (fig. 3) which occur during and after the oxidation of an equilibrium solution of galacturonic acid. When

bromine is added to the solution the optical rotation increases; the initial increase in dextrorotation is followed by a fairly rapid change in the opposite direction with the result that the solution becomes levorotatory. The levorotatory substance appears to be relatively stable, but in the course of several weeks it undergoes a change and the solution becomes optically inactive. The results clearly show the existence of two oxidation products: One of these is more dextrorotatory than galacturonic acid and decomposes in aqueous solution in the course of several hours; the other is levorotatory and decomposes in aqueous solution in the course of many days. Hydrolysis with bases gives optically inactive salts from which mucic acid can be separated in nearly quantitative yield.

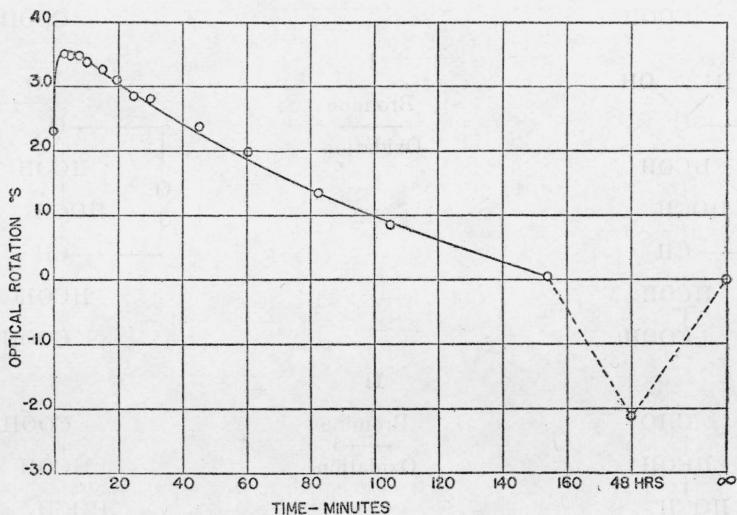


FIGURE 3.—Bromine oxidation of a buffered equilibrium solution of galacturonic acid.

According to Hudson's lactone rule [7] the mucic δ -lactone of equation I would be dextrorotatory and the mucic γ -lactone of equation II would be levorotatory. Furthermore, delta lactones are hydrolyzed by water at room temperature in the course of several hours, whereas gamma lactones are hydrolyzed much more slowly [8]. It is therefore apparent that the dextrorotatory product obtained experimentally is the unknown optically active delta lactone of mucic acid, whereas the levorotatory product is the unknown optically active gamma lactone. The oxidation of an equilibrium solution of galacturonic acid therefore follows equations I and II, and the solution contains both pyranose and furanose modifications. The existence of the furanose modifications in the equilibrium solution is not surprising because we have already demonstrated that the mutarotation involves a fast reaction analogous to the pyranose-furanose interconversion that is characteristic of substances having the galactose structure.

Measurements made after oxidation of freshly prepared solutions of the alpha and the beta modifications of galacturonic acid likewise show the production of both delta and gamma lactones of mucic acid, a fact which indicates that the oxidation of the freshly dissolved

crystalline isomer is complicated by a relatively fast pyranose-furanose interconversion. Although a strictly quantitative method for determining the delta and gamma lactones of mucic acid is not available, the approximate amounts can be estimated from the changes in optical rotation which take place when the lactones are hydrolyzed. Our measurements have shown that the delta lactone is hydrolyzed completely by treatment of the solution with barium carbonate at room temperature for five minutes, and that under such conditions the gamma lactone is only slightly affected. Hence the amount of delta lactone can be estimated from the optical rotations observed before and after a short treatment of the oxidation mixture with barium carbonate. By prolonged treatment with barium carbonate the

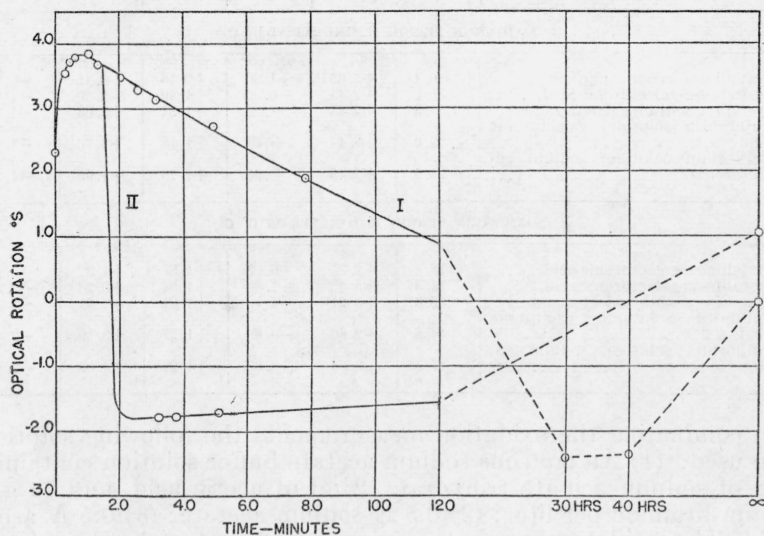


FIGURE 4.—Bromine oxidation of freshly dissolved β -D-galacturonic acid.

I, Changes in optical rotation of a buffered solution containing β -D-galacturonic acid and bromine; II, changes in optical rotation of a sample which was oxidized for 15 minutes. The bromine was then removed, and the delta lactone hydrolyzed by short treatment with BaCO_3 .

gamma lactone is also hydrolyzed. Hence this lactone can be estimated from the difference in the optical rotations measured after short, and after prolonged treatment with barium carbonate. Furthermore, since the final product, barium mucate, is optically inactive, the optical rotation of the solution obtained after hydrolysis of the lactones is proportional to the amount of unoxidized galacturonic acid. The changes in optical rotation which occur during and after the oxidation of a freshly prepared solution of β -galacturonic acid are given in figure 4 together with the changes which occur when the oxidation is interrupted and the product treated with barium carbonate. Additional results obtained by the oxidation of freshly prepared solutions of α - and β -galacturonic acid, and sodium galacturonate, and of equilibrium solutions of these substances are reported in table 2. ||

TABLE 2.—*Bromine oxidation of D-galacturonic acid in solutions buffered with acetic acid and sodium acetate*

Material oxidized	Percent- age of sample oxidized	Optical rotation			Differences in opti- cal rotations	
		Before treat- ment with BaCO ₃	After short treat- ment with BaCO ₃	After long treat- ment with BaCO ₃	Before and after short treat- ment with BaCO ₃ (δ -lac- tone)	Before and after long treat- ment with BaCO ₃ (γ -lac- tone)
1	2	3	4	5	6	7
OXIDATION PERIOD 5 MINUTES AT 0° C						
Crystalline α -galacturonic acid.....	6.1	+2.35	+1.90	+2.16	+0.45	-0.26
Crystalline β -galacturonic acid.....	35.2	+2.41	-0.09	+1.49	+2.50	-1.58
Crystalline sodium galacturonate.....	34.3	+2.43	- 20	+1.51	+2.63	-1.71
Equilibrium solution, galacturonic acid.....	22.6	+2.41	+ .65	+1.78	+1.76	-1.13
Equilibrium solution, sodium ga- lacturonate.....	24.9	+2.49	+ .53	+1.73	+1.96	-1.20
OXIDATION PERIOD 15 MINUTES AT 0° C						
Crystalline α -galacturonic acid.....	18.8	+2.25	+0.93	+1.88	+1.32	-0.95
Crystalline β -galacturonic acid.....	54.8	+3.43	-1.80	+1.04	+5.23	-2.84
Crystalline sodium galacturonate.....	56.3	+3.21	-1.70	+1.01	+4.91	-2.71
Equilibrium solution, galacturonic acid.....	44.8	+2.80	-0.89	+1.27	+3.69	-2.16
Equilibrium solution, sodium ga- lacturonate.....	47.4	+3.04	- .98	+1.21	+4.02	-2.19

In conducting the oxidation measurements the following solutions were used: (1) An aqueous sodium acetate buffer solution containing 60 g of sodium acetate trihydrate, 2 ml of acetic acid, and 74 g of sodium bromide per liter; (2) 0.5 N sodium acetate; (3) 0.5 N acetic acid. The oxidation reagent consisted of 25 ml of buffer solution (1), 1 ml of bromide, and 5 ml of either (2) or (3), depending on whether the free acid or the sodium salt was to be studied. The buffered bromine solution was cooled to 0° C and 0.0025 mole of the galacturonic acid, or salt, in 20 ml of ice water was added. Time was measured from the moment the solutions were mixed. In the experiments on the freshly dissolved acid, or salt, the material was mixed with the ice water immediately before the addition to the oxidation reagent; in the measurements on the equilibrium solutions the material was added to 20 ml of water and allowed to stand 18 hours before addition to the oxidation reagent. The reaction mixture in a glass-stoppered flask was immersed in ice and water, and shaken for a period of either 5 or 15 minutes, after which interval the reaction was stopped by shaking the solution for a few minutes with 10 ml of linseed oil dissolved in 20 ml of benzene. The mixture was allowed to separate, and the aqueous layer was withdrawn with a pipette and filtered.

A portion of the filtrate was transferred to a polariscope tube and the optical rotation was read at various times. The rotation at a definite time (20 minutes) was obtained by plotting these readings against time and is recorded in column 3 of table 2.

A second portion of the filtrate was mixed for 5 minutes at 20° C with an excess of barium carbonate. The unreacted barium carbonate was separated by filtration and the optical rotation of the filtrate was read as soon as possible. The values so obtained are recorded in column 4 of table 2. The change in optical rotation produced by short treatment with barium carbonate and recorded in column 6 is a measure of the amount of delta lactone.

A third portion of the filtrate was hydrolyzed by reaction with barium carbonate over a period of 10 days. The optical rotation after this treatment, recorded in column 5 of table 2, represents the amount of unoxidized galacturonic acid² and the difference in the optical rotations of columns 4 and 5, recorded in column 7, is a measure of the amount of gamma lactone.

The results of these studies show that both delta and gamma lactones are formed in the course of the oxidation of either the alpha or the beta modification of galacturonic acid, and of sodium galacturonate. In each case the delta lactone predominates in the oxidation product, but the exact amount cannot be ascertained from the optical rotations until the rotations of the unknown optically active delta and gamma lactones of mucic acid have been determined. The presence of substantial quantities of both delta and gamma lactones in the oxidation products indicates the occurrence of rapid pyranose-furanose interconversion reactions. These rapid reactions complicate the evaluation of the separate velocity constants for the oxidation reactions. Nevertheless, the amounts of oxidation of the two modifications of galacturonic acid under strictly comparable conditions clearly reveal that the beta isomer is oxidized much more rapidly than the alpha isomer. Prior work conducted in this laboratory has shown that beta pyranoses are oxidized by bromine more rapidly than alpha pyranoses. Hence the relative rates of oxidation for the alpha and beta modifications of galacturonic acid support their classification as alpha and beta pyranoses.

The oxidation of freshly dissolved sodium galacturonate follows essentially the same course as that of freshly dissolved β -galacturonic acid. It may be concluded therefore that the sodium salt contains the beta pyranose modification of galacturonic acid.

The oxidation of the freshly dissolved alpha or beta modification of galacturonic acid presumably takes place in two ways: The first course is by direct oxidation of the substance used; the second is by conversion to other modifications through the mutarotation reaction, and the subsequent oxidation of these. The predominance of one or the other of the two courses depends on the experimental conditions. When the conditions are such that the mutarotation reaction is rapid in comparison with the bromine oxidation, the apparent rates of oxidation for all modifications approach the rate characteristic of the equilibrium solution. In the present investigation, bromine oxidations of galacturonic acid were conducted with a barium carbonate buffer, as well as with the acetate buffer for which results are reported in table 2. It was found, however, that when barium carbonate was used as buffer, equilibrium of the modifications of galacturonic acid

² The optical rotation of galacturonic acid or of sodium galacturonate in the sodium acetate-acetic acid medium used above is +2.3° at the concentration employed, and is not changed appreciably by treatment with barium carbonate.

was established so quickly that the apparent rates of oxidation for both modifications and for the equilibrium solution were alike. Furthermore, the sensitivity of the delta lactone of mucic acid to hydrolysis by barium carbonate interfered in the analytical method. These results are in contrast to those obtained with the simple sugars for which barium carbonate was found to be a satisfactory buffer. [9]. The sensitivity of the pyranose modifications of galacturonic acid to basic catalysts seems analogous to the sensitivity of the corresponding delta lactone of mucic acid to hydrolysis by barium carbonate.

The fact that the mutarotation reactions of galacturonic acid are rapid in solutions buffered with barium carbonate and carbon dioxide was shown by the following experiment.

One gram of α -D-galacturonic acid was dissolved in 25 ml of water saturated with carbon dioxide, and the solution was shaken for 3 minutes at 20° C with 2 g of barium carbonate. The mixture was filtered, and the optical rotation of the filtrate was read from time to time. The rotation first observed 7 minutes after dissolution of the acid, remained constant over a period of several hours. This experiment shows that treatment of α -galacturonic acid with barium carbonate at 20° C results in an equilibrium mixture within a period of 7 minutes. The rapid establishment of equilibrium explains why, in the presence of barium carbonate, the various modifications of galacturonic acid are oxidized at about the same rate and yield essentially the same oxidation products.

III. PREPARATION OF α -D-GALACTURONIC ACID MONOHYDRATE

Crude galacturonic acid prepared from citrus pectic acid by the method of Mottern and Cole [10] was extracted with methyl alcohol as described by Pigman [11]. After removal of the methyl alcohol by concentration under reduced pressure, a crystalline masecuite was obtained, which was diluted with glacial acetic acid to the point of saturation. After standing for about 1 day, the crystals were separated and washed with aqueous acetic acid. The crystalline galacturonic acid monohydrate thus obtained was recrystallized by dissolving it in an equal weight of hot water, treating with a small quantity of a decolorizing carbon, filtering and adding acetic acid to the point of saturation. The crystals which formed in the course of several hours were separated and recrystallized slowly, with constant motion, from a concentrated aqueous solution. The crystals obtained after several days were collected on a filter and washed with aqueous acetic acid. After drying over sodium hydroxide to constant weight, the alpha galacturonic acid monohydrate gave an initial rotation $[\alpha]_D^{20} = +107.0$ (H₂O, C=4), an equilibrium rotation $[\alpha]_D^{20} = +51.9$, and the mutarotation represented by curve I of figure 1. The initial optical rotation of the hydrate is higher than that previously reported (+97.9); the equilibrium rotation of +51.9 is in fair agreement with that reported by Pigman (+51.5), but it is considerably higher than the rotation reported by Ehrlich and Schubert (+50.9). The specific rotations expressed on the anhydrous basis are +116.9 → +56.7.

IV. PREPARATION OF β -D-GALACTURONIC ACID

The beta modification of galacturonic acid used in the present investigation was originally prepared from the alpha isomer by crys-

tallization from absolute alcohol essentially as described by Ehrlich and Schubert [1]. However, we found that it could be obtained more simply by crystallization from hot glacial acetic acid, in the following manner:

Ten grams of pure finely powdered α -D-galacturonic acid monohydrate is added to 80 ml of glacial acetic acid and the mixture is heated to boiling with stirring. Before the boiling point of the acetic acid is reached the galacturonic acid goes into solution and shortly thereafter the crystalline beta modification separates. The mixture is then cooled to approximately 50° C and the crystals are separated and washed with glacial acetic acid. The product thus obtained is largely the beta modification but additional treatment with hot glacial acetic acid is necessary in order to obtain pure β -D-galacturonic acid. After five successive 15-minute digestions with boiling acetic acid, the material, dried over sodium hydroxide, gave an initial rotation $[\alpha]_D^{20} = +31.1$ ($H_2O, C=4$), an equilibrium rotation $[\alpha]_D^{20} = +56.7$ and the mutarotation represented by curve II of figure 1.

V. COMPARISON OF THE MOLECULAR ROTATIONS OF α - AND β -D-GALACTURONIC ACID WITH THOSE OF α - AND β -D-GALACTOPYRANOSE

Comparisons of the optical rotations of certain acetylated derivatives of galactose and galacturonic acid made by Goebel and Reeves [12] revealed a parallelism, with regular differences which were ascribed to the effect of the substituent groups on the partial rotation of carbon 5. As may be observed from the data given in table 3, the molecular rotations of galacturonic acid, galactose, and their respective glycosides likewise show certain parallelisms. In general, the molecular rotations in the galactose series are more dextro than those in the galacturonic acid series. The differences may be ascribed to the effect of the carboxyl attached to carbon 5 in contrast to the effect of the primary alcoholic group in the sugar.

According to the principle of isorotation [13], the molecular rotation of an alpha pyranose may be considered as $+A+B$, and that of the corresponding beta pyranose as $-A+B$, where A is the optical rotation attributed to the glycosidic carbon, and B is the optical rotation of the remaining asymmetric carbons. The sum of the molecular rotations of the alpha and beta isomers is $2B$ and the difference is $2A$. The value of $2A$ (16,650) for the modifications of galacturonic acid is in accord with the value of $2A$ (17,650) for the alpha and beta modifications of D-galactose. This agreement substantiates the classification of the two modifications of galacturonic acid as an alpha-beta pair of cyclic isomers.

TABLE 3.—Comparison of molecular rotations

	$[M]_D$	$2A$	$2B$
α -D-Galacturonic acid. H_2O	+22,700	16,650	28,750
β -D-Galacturonic acid.....	+6,050		
Methyl α -D-galacturonide. $2H_2O$ [4].....	+31,150	40,100	22,200
Methyl β -D-galacturonide. H_2O [14].....	-8,950		
α -D-Galactose [2].....	+27,150	17,650	36,650
β -D-Galactose [2].....	+9,500		
Methyl α -D-galactopyranoside. H_2O [15].....	+38,050	38,050	38,050
Methyl β -D-galactopyranoside [16].....	0		

VI. SUMMARY

1. A study of the mutarotation reactions of α -*D*-galacturonic acid monohydrate and of β -*D*-galacturonic acid has been made. The mutarotation of α -*D*-galacturonic acid monohydrate follows much the same course as the mutarotation of α -*D*-galactopyranose, and that of β -*D*-galacturonic acid follows much the same course as that of β -*D*-galactopyranose. For α -*D*-galacturonic acid hydrate $[\alpha]_D^{20} = 44.83 \times 10^{-.0148t} + 10.26 \times 10^{-.16t} + 51.90$, corresponding to an initial specific rotation of +107.0, and an equilibrium value of +51.9. For β -*D*-galacturonic acid $[\alpha]_D^{20} = -31.84 \times 10^{-.0148t} + 6.21 \times 10^{-.13t} + 56.72$, corresponding to an initial specific rotation of +31.1, and an equilibrium value of +56.7.

2. In addition to the parallelism in the course of the mutarotation reactions, the molecular rotations and other properties likewise indicate that α -*D*-galacturonic acid monohydrate and β -*D*-galacturonic acid are an alpha-beta pyranose pair analogous to α - and β -*D*-galactopyranose.

3. Both α - and β -*D*-galacturonic acid on oxidation with bromine water in acid solution yield optically active delta and gamma lactones of mucic acid. The formation of optically active lactones is evidence that the ring forms of galacturonic acid are oxidized without the intermediate formation of either the open-chain modification of galacturonic acid, or of free mucic acid, and the formation of both delta and gamma lactones is evidence of a relatively rapid pyranose-furanose interconversion of galacturonic acid.

4. The beta modification of galacturonic acid is oxidized by bromine more rapidly than the alpha isomer.

5. An improved method for converting α -*D*-galacturonic acid monohydrate to β -*D*-galacturonic acid is described.

6. Oxidation measurements show that sodium galacturonate is a salt of β -*D*-galacturonic acid.

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