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GULOHEPTONIC ACIDS AND α-*d*-α-GULOHEPTOSE [1]

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ABSTRACT

The barium and lead salts of the guloheptonic acids have been made and used for the preparation of the corresponding free acids. The gamma lactone of *d*-α-guloheptonic acid was prepared and reduced with sodium amalgam to give *d*-α-guloheptose, which crystallized in the alpha modification. This new sugar is structurally related to α-*l*-talose and exhibits similar properties. Its mutarotation is complex, consisting in a fast change followed or accompanied by a smaller slow change. The proportions of the constituents involved in the rapid reaction vary with temperature so that a change in temperature results in a rapid mutarotation. The temperature coefficient for the rapid mutarotation corresponds with those for the rapid reactions which cause the deviations in the mutarotations of galactose, arabinose, talose, ribose, and *d*-β-glucoheptose, while the temperature coefficient for the slow change agrees with those for the mutarotations of glucose, mannose, gulose, and other reactions which consist in the interconversion of the alpha and beta pyranoses. The parallelism between the properties of talose and *d*-α-guloheptose is evidence that the configurations of the first five carbon atoms determine in large measure the composition of equilibrium solutions of these sugars.

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I. MUTAROTATION AND PROPERTIES OF α-*d*-α-GULOHEPTOSE

In the course of an investigation [1, 2, 3] [2] of the alpha and beta sugars, a large number of the heptoses have been examined [4] in order to bring out the similarity of structurally related sugars. It has been emphasized that each pentose, ketose, heptose, or other sugar can be considered as structurally related to one of the fundamental types represented by the eight hexoses, glucose, mannose, galactose, talose, gulose, idose, allose, and altrose. Glucose, mannose, and galactose have been investigated extensively, but very

[1] Read at the meeting of the American Chemical Society, Rochester, N. Y., September 1937.

[2] The numbers in brackets here and elsewhere in the text correspond to the numbered literature references at the end of this paper.

little is known about substances containing the talose, gulose, idose, allose, and altrose structures.

Recently [5] the reactions and properties of *α-d*-talose (I) and *β-d*-talose (II) have been studied in the Bureau's laboratory and found to correspond in large measure with those of *l*-ribose (III). It is of further interest to extend the study to the structurally related heptoses. The heptoses structurally related to *α-d*-talose are *α-d-β*-mannoheptose (IV) and *α-l-α*-guloheptose (V). These substances are obtained by means of the cyanhydrin synthesis from *d*-mannose and *l*-gulose, respectively. Crystalline *d-β*-mannoheptose was prepared by Ettel [6], while crystalline *l-α*-guloheptose is not known at present. The author has prepared crystalline *α-d-α*-guloheptose (VI), which is enantiomorphic with *α-l-α*-guloheptose and hence has like properties, except as to the sign of the rotation and as to reactions involving asymmetric substances.

The new sugar crystallizes in slender needle-like prisms which melt at 127° C and give $[\alpha]_D^{20}=-45.7$. When dissolved in water the sugar exhibits the complex mutarotation given in table 1. This mutarotation can be represented by the following equations:

$$[\alpha]_D^{20.1}=-5.2\times10^{-.0179t}-23.6\times10^{-.0897t}-16.9 \quad (1)$$

$$[\alpha]_D^{0.3}=-5.9\times10^{-.00307t}-16.3\times10^{-.0187t}-20.2 \quad (2)$$

in which t is the time measured in minutes after the sugar is dissolved in water. The complex mutarotation shows that the equilibrium is established between certain modifications more rapidly than between the others, and that the solution contains at least three modifications of the sugar in dynamic equilibrium. Inspection of the data and equations representing the mutarotation at 20° C reveals that the rapid reaction, m_2, is responsible for a change of 23.6°, whereas the slow reaction, m_1, is responsible for a change of 5.2°. In other words, the rapid reaction predominates. This is in marked contrast to the mutarotation of glucose, which consists almost exclusively in the slow reaction. On the other hand, the mutarotation of levulose appears to consist almost exclusively in the rapid reaction,[3] and that of talose like that of *α-d-α*-guloheptose consists in the two reactions, with the fast reaction predominating.

[3] The temperature coefficients, effect of catalysts, and other evidence indicate that the normal mutarotation of levulose is like the *rapid* initial mutarotation reaction found for many aldoses and differs from the normal *α-β* pyranose mutarotation. The mutarotations of levulose and related substances are being studied in the Bureau's laboratory from this viewpoint.

TABLE 1.—*Mutarotation of α-d-α-guloheptose in water* [1]

0.9957 g in 25 ml at 20.1°C in a 4-dm tube

$°S = -2.38\times10^{-.0179t} - 10.87\times10^{-.0897t} - 7.77$

$[\alpha]_D^{20.1} = -5.2\times10^{-.0179t} - 23.6\times10^{-.0897t} - 16.9$

Initial rotation, $[\alpha]_D^{20.1} = -45.7$

Equilibrium rotation, $[\alpha]_D^{20.1} = -16.9$

Time	Observed reading	$m_1\times10^3$	Deviation	$m_2\times10^3$
Minutes	°S			
2.01	−17.15		7.18	
2.83	−15.90		6.01	94.1
3.68	−14.88		5.06	91.0
5.02	−13.67		3.96	85.8
6.91	−12.27		2.71	86.3
8.89	−11.17		1.75	89.1
11.36	−10.37		1.11	86.7
14.28	−9.59		.50	94.3
17.50	−9.20		.27	92.0
20.22	−8.99		.18	87.9
25.42	−8.62		(.01)	
30.44	−8.45			
35.82	−8.31	18.6		
45.30	−8.14	17.8		
61.13	−7.97	17.3		
∞	−7.77			
Average		17.9		89.7

1.0022 g in 25 ml at 0.3° C in a 4-dm tube

$°S = -2.71\times10^{-.00307t} - 7.56\times10^{-.0187t} - 9.36$

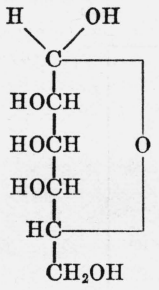
$[\alpha]_D^{0.3} = -5.9\times10^{-.00307t} - 16.3\times10^{-.0187t} - 20.2$

Initial rotation, $[\alpha]_D^{0.3} = -42.4$

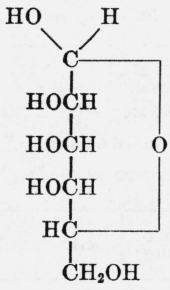
Equilibrium rotation, $[\alpha]_D^{0.3} = -20.2$

3.27	−18.58		6.57	
4.76	−18.14		6.16	18.8
6.99	−17.56		5.65	17.6
9.91	−16.90		5.01	17.7
12.57	−16.33		4.49	17.8
15.55	−15.73		3.94	18.1
21.82	−14.68		2.99	18.4
25.05	−14.25		2.62	18.3
29.81	−13.72		2.16	18.2
35.08	−13.12		1.64	18.9
40.07	−12.73		1.34	18.8
49.93	−12.07		.80	19.6
60.48	−11.61		.48	19.9
70.05	−11.29		.28	20.5
90.37	−10.85		(.06)	
133.02	−10.42			
158.24	−10.24	3.20		
181.04	−10.10	3.25		
241.48	−9.84	3.17		
294.61	−9.73	2.83		
341.70	−9.62	2.92		
∞	−9.36			
Average		3.07		18.7

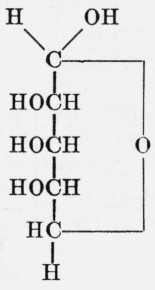
[1] The equations and values for the mutarotation constants, m_1 and m_2, were determined by the method described by Isbell and Pigman (J. Research NBS 18, 156 (1937) RP969). The values given in the column headed "deviation" represent the differences between the observed rotations and those calculated for like times by extrapolation of the mutarotation data for the latter part of the reaction, using the constant, m_1 and beginning the extrapolation after the rapid reaction is complete.



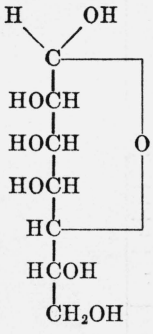
(I) α-*d*-Talose



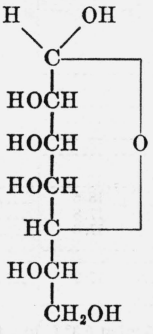
(II) β-*d*-Talose



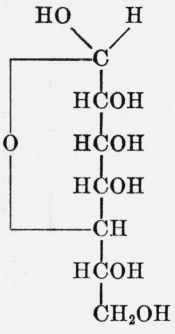
(III) α-*l*-Ribose



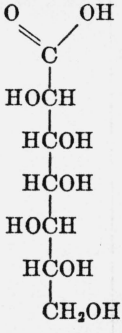
(IV) α-*d*-β-Mannoheptose



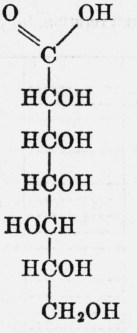
(V) α-*l*-α-Guloheptose



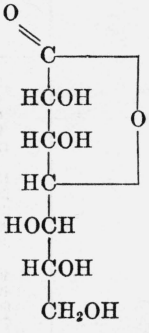
(VI) α-*d*-α-Guloheptose



(VII) *d*-β-Guloheptonic acid



(VIII) *d*-α-Guloheptonic acid



(IX) *d*-α-Guloheptonic-γ-lactone

The rapid mutarotation reaction for α-*d*-α-guloheptose is similar to the rapid mutarotation reactions of galactose [7, 8], arabinose [9], ribose [10], β-glucoheptose [11], talose [12], and levulose. As previously pointed out, whenever the temperature of a solution of galactose, arabinose, or talose is changed a mutarotation occurs. The changes in optical rotation suggest that the equilibrium proportions of the constituents responsible for the rapid reactions vary with temperature, whereas the equilibrium proportions of the constituents responsible for the slow reactions do not vary with temperature. The results given in table 2 show a similar thermal-mutarotation for

d-α-guloheptose. After the solution of d-α-guloheptose is cooled the optical rotation increases in the levo direction at a rate comparable to that of the rapid reaction (m_2). This change comprises the larger part of the mutarotation and shows that the change in temperature causes a disturbance in the equilibrium proportions of the labile constituents. This initial change appears to be followed by a readjustment of the proportions of the normal alpha and beta isomers. This causes a very small decrease in the optical rotation which occurs at a rate comparable to that of m_1. The large alteration in the equilibrium proportions of the constituents concerned in the rapid reaction shows that this reaction involves a large energy change, whereas the small alteration in the equilibrium proportions of the constituents involved in the slow reaction shows that in this case the heat of reaction is small.

TABLE 2.—*Mutarotation of a 5.5-percent aqueous solution of d-α-guloheptose after cooling from 30° to 0.4° C*

$°S = -0.4\times10^{-.002924t} + 3.6\times10^{-.01344t} - 12.8.$

Time	Saccharimeter reading	$m_1\times10^3$	Deviation	$m_2\times10^3$
Minutes	°S		°S	
5.88	−10.20	----------	3.01	----------
8.45	−10.41	----------	2.79	12.8
11.03	−10.62	----------	2.57	13.3
14.05	−10.88	----------	2.31	14.1
17.28	−11.07	----------	2.11	13.5
20.73	−11.27	----------	1.90	13.5
24.81	−11.50	----------	1.66	13.7
30.20	−11.73	----------	1.42	13.4
37.21	−11.98	----------	1.15	13.3
45.41	−12.22	----------	0.90	13.3
60.92	−12.52	----------	.59	12.9
75.26	−12.70	----------	.36	13.3
156.41	−12.90	----------	(.06)	----------
240.00	−12.90	----------	----------	----------
310.00	−12.87	2.92	----------	----------
----------	−12.82	----------	----------	----------
Average	----------	2.92	----------	13.4

The effects of temperature on the rates of reaction (m_1 and m_2) clearly demonstrate that the fast and slow reactions are fundamentally different. Previous measurements [4] have revealed that the temperature coefficients for the slow reactions are in every case less than those for the corresponding fast reactions. Thus, application of the Arrhenius equation to the measurements on mannose, galactose, talose, arabinose, and ribose gave for Q an average value of 16,900 from m_1, and 13,200 from m_2. Application of the same equation to the data for α-d-α-guloheptose gives corresponding values of 14,180 and 12,610. These are equal to temperature coefficients of 2.2 and 2.0 for m_1 and m_2, respectively.

Since nearly all of the free crystalline sugars contain the pyranose ring, it is probable that the new sugar is also a pyranose. If this be true, the oxygen of the ring lies to the left, and since the sugar is the more levorotatory number of the α-β pair, according to the author's nomenclature this should be designated α-d-α-guloheptose. The

[4] Page 165 of reference [3].

changes in optical rotation which have been found for *d*-α-guloheptose resemble in all respects the changes previously reported for α-*d*-talose. The marked parallelism illustrates in striking manner the advantages gained by basing the classification of the alpha and beta sugars on configurations of the pyranose ring, rather than on the configuration of the terminal asymmetric carbon.

II. THE GULOHEPTONIC ACIDS AND THEIR SALTS

In order to prepare the new sugar, it was necessary to study the separation of the epimeric acids obtained from *d*-gulose by the cyanhydrin synthesis. Previously, La Forge [14] applied the cyanhydrin synthesis to *d*-gulose and prepared the barium salts of the two guloheptonic acids. One of these acids he separated in the pure crystalline state; the other he obtained merely in an impure amorphous condition. The acid derived from the crystaline barium salt gave a levorotatory phenylhydrazide. This levorotation indicates that the hydroxyl on the second carbon lies to the left [15], and since the configurations of the remaining carbons are the same as those of *d*-gulose, the acid has the structure indicated by formula VII. As this was the first guloheptonic acid to be isolated, in accordance with the nomenclature of Fischer it was designated α-guloheptonic acid; and the second acid, which was not obtained pure, was called β-guloheptonic acid. Subsequently, in order to systematize the nomenclature,[5] the author suggested that the names be changed, so that the acids and their derivatives would be called alpha or beta according to whether the second carbon is of the same or different configuration from that of the terminal asymmetric carbon. In this paper the revised nomenclature is used, as illustrated by the names and formulas given on page 642.

The author has succeeded in preparing both of the guloheptonic acids in the crystalline state, as well as the crystalline lead and barium salts. Lead *d*-α-guloheptonate is more levorotatory than barium *d*-α-guloheptonate. The direction of these rotations is evidence [16] that the hydroxyl of the alpha carbon lies to the right, as illustrated in formula VIII. This acid also forms a crystalline phenylhydrazide which is dextrorotatory. The dextrorotation of this derivative substantiates the allocation of the hydroxyl of the alpha carbon to the right. When the crystalline acid is dissolved in water it undergoes lactone formation which gives rise to the mutarotation given in table 3.

TABLE 3.—*d*-α-*Guloheptonic acid*

4.100 g per 100 ml at 20° C in a 2-dm tube $[\alpha]^{20}=°S\times 4.222$					
Time	Observed rotation	$[\alpha]_D^{20}$	Time	Observed rotation	$[\alpha]_D^{20}$
Hours	°S		*Hours*	°S	
0.04	−2.99	−12.6	7.2	−2.62	−11.1
.25	−2.99	−12.6	25.2	−1.85	−7.8
.50	−2.96	−12.5	50.7	−0.73	−3.1
1.0	−2.95	−12.5	96.5	+.35	+1.5
2.0	−2.92	−12.3	120.0	+.89	+3.8
2.9	−2.92	−12.3	144.5	+1.08	+4.6
4.2	−2.81	−11.9	168.5	+1.34	+5.7

[5] Page 529 of reference [4].

By dehydrating an aqueous solution of *d*-α-guloheptonic acid at 100° C the gamma lactone is formed. This substance is useful for the final purification of the acid and for the preparation of α-*d*-α guloheptose. The lactone is slowly hydrolyzed by water with regeneration of the free acid in small quantity and establishing an equilibrium state. This gives rise to the mutarotation given in table 4.

TABLE 4.—*d-α-Guloheptonic γ-lactone*

4.042 g per 100 ml at 20° C in a 4-dm tube		
Time	Observed rotation	$[\alpha]^{20}_D$
Hours	°S	
0.05	+11.91	25.5
5.6	+11.71	25.1
24	+11.56	24.8
72	+10.90	23.3
744	+8.30	17.8
105 days	+7.80	16.7

The salts of *d*-β-guloheptonic acid resemble those of *d*-α-guloheptonic acid and can be separated only by laborious fractional crystallization. Barium *d*-β-guloheptonate gives $[\alpha]^{20}_D = +1.5$, and lead *d*-β-guloheptonate gives $[\alpha]^{20}_D = +16.7$. The high dextrorotation of the lead salt in comparison with the rotation of the barium salt and the *l*-configuration of the alpha carbon are in harmony with the rule [16] correlating the optical rotations of the lead and alkaline earth salts with their configurations. The lead salt on treatment with sulphuric acid gives the free acid, which crystallizes readily. In aqueous solution the acid undergoes lactone formation, giving rise to the complex mutarotation reported in table 5. The character of the mutarotation shows that the delta lactone is formed more rapidly than the gamma lactone. Judging from the changes in optical rotation, the delta lactone is levorotatory in accordance with Hudson's lactone rule.

TABLE 5.—*d-β-Guloheptonic acid*

3.976 g per 100 ml at 20° C in a 4-dm tube $[\alpha]^{20}_D = °S \times 2.1768$					
Time	Observed rotation	$[\alpha]^{20}_D$	Time	Observed rotation	$[\alpha]^{20}_D$
Hours	°S		*Hours*	°S	
0.07	+5.88	+12.8	3.2	+4.81	+10.5
.2	+5.75	+12.5	5.0	+4.95	+10.8
.3	+5.61	+12.2	6.7	+5.16	+11.2
.5	+5.43	+11.8	23.5	+7.44	+16.2
1.0	+5.12	+11.1	47.9	+9.83	+21.4
2.0	+4.77	+10.4	72	+11.72	+25.5
2.5	+4.76	+10.4	222	+19.44	+42.3

III. EXPERIMENTAL DETAILS

1. SEPARATION OF THE ACIDS OBTAINED FROM THE CYANHYDRIN SYNTHESIS

The nitriles of *d*-α- and *d*-β-guloheptonic acids were formed by treating 500 g of gulose-calcium chloride [17] in a 10-percent aqueous solution with an equivalent quantity of sodium cyanide [18]. Hydrolysis of the product with an excess of lime gave a precipitate of basic calcium salts which was collected on a filter and washed. The basic salts were decomposed by carbonation to give a solution containing the normal calcium salts. This solution was mixed with sufficient sulphuric acid to combine with the calcium, and after the addition of one-half volume of isopropyl alcohol, the solution was filtered and the insoluble calcium sulphate was discarded. Rapid evaporation of the aqueous alcoholic solution under diminished pressure yielded 100 g of crystalline acid, which was separated by filtration. The crystalline product contained *d*-α-guloheptonic acid mixed with a small quantity of *d*-β-guloheptonic acid. In the absence of nuclei of crystalline *d*-β-guloheptonic acid, nearly pure *d*-α-guloheptonic acid is obtained at this point.

The crystalline acid thus obtained was used for the preparation of *d*-α-guloheptonic γ-lactone, as described in a separate paragraph. The amount of soluble acids and lactones in the mother liquor was ascertained by titration of a small sample with standard alkali, and then the equivalent quantity of lead oxide was added to convert the acids to normal lead salts. After the lead oxide had dissolved, the mixture was seeded with lead *d*-β-guloheptonate. After standing for several hours an abundant crystallization occurred. The crystalline salts were separated and found to be a mixture of lead *d*-β-guloheptonate and lead *d*-α-guloheptonate. By fractional recrystallization from hot water about 110 g of pure lead *d*-β-guloheptonate and 50 g of lead *d*-α-guloheptonate were obtained. The separation of the two salts, which may be followed by the optical rotations, requires numerous crystallizations. Both salts are relatively difficultly soluble in water and crystallize readily. Lead *d*-α-guloheptonate gives an optical rotation of -6.6, while lead *d*-β-guloheptonate gives $+16.7$.

2. *d*-β-GULOHEPTONIC ACID

Equivalent quantities of lead *d*-β-guloheptonate and 1 *N* sulphuric acid were mixed and then diluted with an equal volume of isopropyl alcohol. After separating the lead sulphate by filtration, the solution of *d*-β-guloheptonic acid was evaporated rapidly under diminished pressure to a thin sirup from which the crystalline acid separated in good yield. The acid crystallizes in diamond-shaped plates which frequently form in laminated clusters. The crystals melt at 135° C, and in a 4-percent aqueous solution give $[\alpha]_D^{20}=+12.8$. The new acid is soluble in water and much less soluble in alcohol and in acetic acid. After drying at 40° C in vacuo over calcium chloride the new acid corresponds to the following analysis: Calculated for $C_7H_{14}O_8$: C, 37.17; H, 6.24. Found: C, 37.23; H, 6.02. It tastes sour, reacts definitely acid, and requires one equivalent of alkali for neutralization.

Lead d-β-guloheptonate was first obtained from the crude acid resulting from the cyanhydrin synthesis. But for analysis the pure

salt was prepared from *d*-β-guloheptonic acid and an equivalent quantity of lead oxide. The salt crystallizes in concentric clusters of rhombic-shaped plates which are difficultly soluble in cold water, fairly soluble in hot water; at 20° C about 1 g dissolves in 100 ml. In a 2-percent aqueous solution, the new substance gives $[\alpha]_D^{20} = +16.7$. After drying in vacuo at 40° C over calcium chloride it corresponds to the following analysis: Calculated for Pb $(C_7H_{13}O_8)_2$: C, 25.57; H, 3.98; Pb, 31.51. Found: C, 25.67; H, 3.96; Pb, 31.6.

Barium d-β-guloheptonate, first prepared by La Forge [15], was obtained by neutralization of the acid with barium carbonate. The salt crystallizes in rhombic-shaped plates frequently truncated, thereby forming elongated hexagons. In a 3-percent aqueous solution the product gives $[\alpha]_D^{20} = +1.5$. After drying at 40° C in vacuo over calcium chloride it corresponds to the following analysis: Calculated for $Ba(C_7H_{13}O_8)_2$: C, 28.61; H, 4.46; Ba, 23.37. Found: C, 28.29; H, 4.34; Ba, 23.25.

3. *d*-α-GULOHEPTONIC ACID

The crude crystalline acid, obtained from the cyanhydrin synthesis, was purified by converting it into the crystalline γ-lactone, which was recrystallized and then converted into lead *d*-α-guloheptonate. This salt was mixed with an equivalent quantity of dilute aqueous sulphuric acid and after the addition of one-half volume of isopropyl alcohol the solution was filtered. The filtrate was concentrated under reduced pressure to a thin sirup which was then mixed with an equal volume of isopropyl alcohol. Crystalline *d*-α-guloheptonic acid separated in long slender triangular prisms which melt at 128° C. The crude product was recrystallized by dissolving 10 g in 15 ml of water, adding 25 ml of acetic acid, and cooling to 0° C. After standing for several hours about 5 g of *d*-α-guloheptonic acid was separated. In a 4-percent aqueous solution the new acid gives $[\alpha]_D^{20} = -12.6$. After drying at 40° C in vacuo it corresponds to the following analysis: Calculated for $C_7H_{14}O_8$: C, 37.17; H, 6.24. Found: C, 36.35; H, 6.07. The product is sour, reacts acid, and requires one equivalent of alkali for neutralization. The analysis indicates that the product was slightly impure, but as only a small quantity of the material was at hand it was not purified further.

d-α-Guloheptonic γ-lactone was prepared by evaporating and heating an aqueous solution of *d*-α-guloheptonic acid in the presence of a few drops of hydrochloric acid The resulting thick sirup was dissolved in ethyl alcohol and allowed to stand. In the course of 2 days a new substance crystallized in irregular clusters of triangular-shaped plates (possibly truncated rectangular prisms). This substance was separated, recrystallized from ethyl alcohol, and dried at 40° C in vacuo, The product thus obtained is slightly sweet, reacts neutral, but is readily saponified by dilute alkali. It melts at 145° C and in a 4-percent aqueous solution it gives $[\alpha]_D^{20} = +25.5$ and the mutarotation given in table 4. The new substance which is *d*-α-guloheptonic γ-lactone corresponds to the folowing analysis: Calculated for $C_7H_{12}O_7$: C, 40.39; H, 5.81. Found: C, 40.56; H, 5.81.

d-α-Guloheptonic phenylhydrazide was prepared by mixing 1 g of α-guloheptonic acid with 1 ml of phenylhydrazine dissolved in 10 ml of 80-percent (by volume) aqueous ethyl alcohol. After standing for

several hours, crystalline *d*-α-guloheptonic phenylhydrazide separated in slender needle-like prisms which grew into elongated plates. The crystals, which melt with decomposition at 156° C, are difficultly soluble in 95-percent ethyl alcohol but readily soluble in 80-percent aqueous alcohol. After recrystallization from alcohol and drying at 40° C in vacuo the substance in water solution gives $[\alpha]_D^{20}=+29.3$ (0.4962 g in 25 ml read +6.72° S in a 4-dm tube) and corresponds to the following analysis: Calculated for $C_{13}H_{20}O_7N_2$: C, 49.36; H, 6.37. Found: C, 49.37; H, 6.32.

Barium d-α-guloheptonate was prepared in aqueous solution from equivalent quantities of *d*-α-guloheptonic acid and barium hydroxide. The salt crystallizes in rhombic-shaped plates which resemble those of barium *d*-β-guloheptonate. The product obtained after recrystallization from hot water and drying at 40° C in vacuo over calcium chloride gives $[\alpha]_D^{20}=-1.4$ in a 4-percent aqueous solution and corresponds to the following analysis: Calculated for $Ba(C_7H_{13}O_8)_2$: C, 28.61; H, 4.46; Ba, 23.37. Found: C, 28.78; H, 4.50; Ba, 23.37.

Lead d-α-Guloheptonate, $Pb(C_7H_{13}O_8)_2$, was prepared by mixing in an aqueous solution equivalent quantities of *d*-α-guloheptonic acid and lead oxide. The salt crystallizes from hot water in rhombic-shaped plates, which are relatively difficultly soluble in cold water; at 20° C, 0.824 g dissolved in 100 ml of water. The salt also crystallizes in needles which contain 1 molecule of water of crystallization. The anhydrous salt after drying at 40° C in vacuo gives $[\alpha]_D^{20}=-6.6$ in a 1-percent aqueous solution and corresponds to the following analysis: Calculated for $Pb(C_7H_{13}O_8)_2$: C, 25.57; H, 3.98; Pb, 31.51. Found: C, 25.55 H, 4.09; Pb, 31.3.

4. PREPARATION OF α-*d*-α-GULOHEPTOSE

Forty-five grams of *d*-α-guloheptonic γ-lactone, dissolved in 450 ml of water and 150 ml of ethyl alcohol, was reduced with 1,200 g of 3.25-percent sodium amalgam. The reduction was conducted at 0° C, while the solution was stirred and maintained at about pH 3.0 by adding 10-percent aqueous sulphuric acid. After the reaction was complete the resulting crystalline sodium sulphate and mercury were separated. The solution was then evaporated to a thin sirup, which was diluted with three volumes of methyl alcohol. This caused the crystallization of considerable sodium sulphate which was discarded. The solution was then evaporated to a sirup (50 ml) which was extracted with five volumes of ethyl alcohol. After standing several days, about 26 g of crystalline α-*d*-α-guloheptose separated. The crude sugar (25 g) was dissolved in water and the solution was clarified with decolorizing carbon and then concentrated under diminished pressure to a heavy sirup of about 85 Brix. This sirup was mixed with 50 ml of acetic acid and seeded with crystalline α-*d*-α-guloheptose. A satisfactory crystallization occurred during the course of several hours. The crystalline sugar was collected upon a filter and washed, first with acetic acid and finally with ethyl alcohol. This product was then recrystallized in like manner, with the exception that ethyl alcohol was substituted for the acetic acid. The resulting sugar was dried at 40° C in vacuo and used for the analysis and the mutarotation measurements reported in table 1. The sugar crystallizes in

long slender prisms which melt at 127° C. In a 4-percent aqueous solution the new sugar gives an initial specific rotation of −45.7; at equilibrium, $[\alpha]_D^{20} = -16.9$. The sugar is anhydrous, as shown by the following analysis: Calculated for $C_7H_{14}O_7$: C, 40.00; H, 6.71. Found: C, 39.93; H, 6.70.

IV. SUMMARY

By treating *d*-gulose $CaCl_2.H_2O$ with sodium cyanide followed by lime, basic calcium salts of the epimeric guloheptonic acids were precipitated. Decomposition of the mixture with aqueous sulphuric acid and concentration of the resulting solution gave *d*-α-guloheptonic acid ($C_7H_{14}O_8$), which melts at 128° C and gives $[\alpha]_D^{20} = -12.6$; *d*-α-*guloheptonic* γ-*lactone* ($C_7H_{12}O_7$) melts at 145° C and gives $[\alpha]_D^{20} = +25.5$; *d*-α-*guloheptonic phenylhydrazide* ($C_7H_{13}O_7N_2H_2C_6H_5$) melts at 156° C and gives $[\alpha]_D^{20} = +29.3$; *lead d*-α-*guloheptonate*, $Pb(C_7H_{13}O_8)_2$ gives $[\alpha]_D^{20} = -6.6$; and *barium d*-α-*guloheptonate*, $Ba(C_7H_{13}O_8)_2$, gives $[\alpha]_D^{20} = -1.4$. The mother liquor from *d*-α-guloheptonic acid yielded *d*-β-*guloheptonic acid*, $C_7H_{14}O_8$, which melts at 135° C and gives $[\alpha]_D^{20} = +12.8$; *lead d*-β-*guloheptonate*, $Pb(C_7H_{13}O_8)_2$, gives $[\alpha]_D^{20} = +16.7$; and *barium d*-β-*guloheptonate*, $Ba(C_7H_{13}O_8)_2$ gives $[\alpha]_D^{20} = +1.5$. The lead and barium salts are useful for the purification and separation of the two acids. Reduction of *d*-α-guloheptonic γ-lactone with sodium amalgam gives *d*-α-guloheptose, which was separated in the crystalline alpha form.

α-*d*-α-Guloheptose ($C_7H_{14}O_7$) melts at 127° C and in water solution gives $[\alpha]_D^{20} = -45.7$ initially, and exhibits mutarotation until at equilibrium $[\alpha]_D^{20} = -16.9$. Mutarotation measurements were conducted at two temperatures: at 20.1° C $[\alpha]_D = -5.2 \times 10^{-.0179t} - 23.6 \times 10^{-.0897t} - 16.9$; at 0.3° C $[\alpha]_D = -5.9 \times 10^{-.00307t} - 16.3 \times 10^{-.0187t} - 20.2$. The mutarotations show a fast change accompanied by a smaller slow change. Hence the equilibrium solution contains at least three modifications of the sugar in dynamic equilibrium. The proportions of the constituents involved in the rapid reaction vary with temperature so that a change in temperature results in a rapid mutarotation. The temperature coefficient for the rapid mutarotation reaction corresponds with those for the rapid reactions which cause the deviations in the mutarotations of galactose, arabinose, talose, ribose, and *d*-β-glucoheptose. On the other hand, the temperature coefficient for the slow change agrees with those for the slow reactions which cause the normal mutarotations of glucose, mannose, galactose, gulose, and talose. The structure, reactions, and properties of the new sugar resemble those of α-*d*-talose and provide additional evidence that the properties of the sugars are determined in large measure by the configuration of five carbon atoms comprising the pyranose ring.

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