remains colorless on the addition of alcoholic potash, whereas the slightest trace of tetramethylquercetin if present produces a bright yellow color. It is very sensitive to light.

Anal. Subs., 5.000, 4.930 mg.: CO_2, 11.810, 11.670; H_2O, 2.51, 2.46 mg. Subs., 2.846, 2.079 mg.: AgI, 8.985, 6.560 mg. Calcd. for $C_{20}H_{20}O_7$: C, 64.52; H, 5.38; CH_3O, 41.67. Found: C, 64.44, 64.59; H, 5.62, 5.58; CH_3O, 41.71, 41.68.

Summary

A method is described for the preparation of pentamethylquercetin, in which quercetin is converted in dioxane solution with the aid of diazomethane into 3,7,3′,4′-tetramethylquercetin, from which pentamethylquercetin is obtained through the agency of dimethyl sulfate and solid potassium hydroxide.

BRISTOL, ENGLAND

[CONTRIBUTION FROM THE CHEMICAL LABORATORY OF THE COLLEGE OF LIBERAL ARTS, NORTHWESTERN UNIVERSITY]

THE REACTIVITY OF THE METHYLATED SUGARS. V. THE ACTION OF DILUTE ALKALI ON TRIMETHYL-*l*-ARABINOSE[1]

BY HARRY T. NEHER WITH W. LEE LEWIS

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In 1895 Lobry de Bruyn and van Ekenstein[2] published their first papers on the interconversion of sugars by alkali, changes since studied by a number of investigators. In an extensive study of the action of alkali and alkaline oxidizing agents on the sugars, Nef[3] found that he could best explain the complicated system of products which he found, by assuming the existence of a sugar enol, such as was first proposed by Fischer[4] and used by Wohl and Neuberg[5] in explanation of some of their work on glyceric aldehyde. Recent work by W. L. Evans[6] on the behavior of a number of reducing sugars in relatively strong alkali, both in the presence of oxidizing agents and in their absence, has strongly supported the enol theory.

In previous papers[7] in this series, the blocking effect of methyl groups upon enolization has been demonstrated. In the present paper these conceptions have been extended to trimethyl-*l*-arabinose.

[1] Abstracted from a dissertation submitted by Harry T. Neher to the Graduate School of Northwestern University, in partial fulfilment of the requirements for the degree of Doctor of Philosophy.

[2] Lobry de Bruyn and van Ekenstein, *Rec. trav. chim.*, **14**, 156, 203, 213 (1895).

[3] Nef, *Ann.*, **357**, 214 (1907); **376**, 1 (1910); **403**, 204 (1914).

[4] Fischer, *Ber.*, **28**, 1149 (1895).

[5] Wohl and Neuberg, *ibid.*, **33**, 3099 (1900).

[6] Evans, *Chem. Rev.*, **6**, 281 (1929).

[7] (a) Gustus with Lewis, THIS JOURNAL, **49**, 1512 (1927); (b) Wolfrom with Lewis, *ibid.*, **50**, 837 (1928); (c) Greene with Lewis, *ibid.*, **50**, 2813 (1928); (d) Gross with Lewis, *ibid.*, **53**, 2772 (1931).

For comparison *l*-arabinose was first treated with saturated lime water at 35°. Under these conditions it would be expected from previous work that there would be found in the reaction mixture *l*-arabinose, *l*-ribose and *l*-keto-arabinose, together with small amounts of saccharinic acid. Evidence of such interconversion has been previously observed. Nef[8] was able to isolate ribonic acid from the oxidation products obtained by the action of alkaline copper sulfate on *l*-arabinose. Van Ekenstein and Blanksma[9] succeeded in separating the aldoses formed in alkaline solution, by oxidation to the corresponding acids and forming the calcium arabonate and the phenylhydrazide of ribonic acid. The ketose was not isolated. Evidence for an intermediate enolic form has been presented by Evans and Conaway[10] in a recent study of the action of potassium hydroxide on *l*-arabinose.

In the present study a molar solution of *l*-arabinose in clear lime water saturated at 35° and held at this temperature to constant rotation, fell from $[\alpha]_D^{35}$ 100° to $[\alpha]_D^{35}$ 62.6° in 195 hours. The solution was now neutral to litmus but acid to phenolphthalein and showed no further change in this respect after standing for two months. The aldose content by iodine titration fell from 99.7 to 84.9%, thus showing no intermediate high iodine absorbing compound, but indicating rather the formation of ketose.

The trimethyl-*l*-arabinose used in this work was prepared in crystalline form for the first time in two steps from *l*-arabinose. Methylation[11] of the free sugar with methyl sulfate and sodium hydroxide gave trimethyl-α-methyl-*l*-arabinoside.[12] This compound, purified by recrystallization from low boiling petroleum ether, was carefully hydrolyzed with dilute acid and trimethyl-*l*-arabinose was finally obtained in crystalline form. The product melted at 81–82° and gave the constant rotation in water of $[\alpha]_D^{25}$ 158.0°. Purdie and Rose[13] gave $[\alpha]_D^{20}$ 127.2° for this compound, which, however, they obtained only as a sirup. The rotation values of the crystals in chloroform solution varied considerably depending upon the conditions under which the crystals were formed. This indicated a mixture of the α- and β-forms, the former predominating since all of these mixtures mutarotated upward to a constant value of $[\alpha]_D^{25}$ 158.0. The lowest value observed in chloroform was $[\alpha]_D^{20}$ 16.4°, obtained from large, well-formed

[8] Nef, *Ann.*, **357**, 214 (1910).

[9] Van Ekenstein and Blanksma, *Chem. Weekblad.*, **10**, 213, 664 (1913).

[10] Evans and Conaway, THIS JOURNAL, **52**, 3680 (1930).

[11] Hirst and Robertson, *J. Chem. Soc.*, **127**, 358 (1925).

[12] In this paper the names of the α- and β-*l*-arabinosides are chosen according to Hudson's rule. It should be noticed that this makes the names of our compounds the reverse of those found in the literature on methylated *l*-arabinose. In other words, the compound called trimethyl-α-methyl-*l*-arabinoside will be that compound referred to by the English workers as trimethyl-β-methyl-*l*-arabinoside.

[13] Purdie and Rose, *J. Chem. Soc.*, **89**, 1204 (1906).

crystals out of a saturated ether solution. It is believed that this was a nearly pure α-form.

On treating trimethyl-*l*-arabinose with lime water at 35°, optical equilibrium was attained in 164 hours with $[\alpha]_D^{35}$ 98.0°. The percentage of apparent aldose by iodine titration gradually rose from 100 to 150–155%. In this respect trimethylarabinose acts like previous methylated sugars studied. The high iodine absorbing value is believed to be due to the presence of a relatively stable intermediate methylated ene-diol. Treatment of the enolized solution with acid brought the iodine value back to 100% aldose but with more difficulty than was the case with the methylated hexoses. Investigation showed the presence of furfural reaching the equivalent of 20% of the sugar present after eight hours' treatment with acid. Thus in the case of the methylated pentoses,[7d] the de-enolizing action of acids, observed in the case of the methylated hexoses,[7b,c] seems to be accompanied by a secondary formation of furfural from one of the compounds present. An equilibrated solution of trimethylarabinose, which was neutral or slightly alkaline, gave no test for furfural. Vacuum distillation of this solution in an atmosphere of nitrogen gave 0.30 mole of methanol (per mole of sugar). This alcoholic distillate contained a trace of furfural (amounting to a decomposition of 0.07% of the sugar). Addition of acid to this sugar solution caused the apparent aldose value to drop to near 100%. The amount of furfural now present was equivalent to a decomposition of 16.7% of the sugar originally present. From the de-enolized and neutralized solution there was obtained 0.54 mole of methanol. Thus the total amount of methanol obtained (0.84 mole) would account for a minimum value of 0.28 mole or 28% of the sugar originally present, assuming that each sugar molecule so decomposing loses three methoxyls. The sirup obtained from the solution gave an aldose value of 99.3%, $[\alpha]_D^{26}$ 138°, and amounted to 64.6% of the original sugar. Thus the methanol and sugar sirup accounted for a calculated 92.6% of the original sugar.

When this sirup was allowed to crystallize, 48.3% of it was recovered as pure crystalline trimethylarabinose. In another case, where the crystallization was carefully carried out over a period of several weeks, the pure crystalline trimethylarabinose obtained amounted to 79% of the sirup. After removal of the crystalline sugar, the remainder of the sirup was oxidized to the aldonic acid and isolated as the brucine salt. This was fractionally crystallized from acetone. Three of the four fractions, amounting to 90% of the total salt, were identified as the brucine salt of trimethylarabonic acid. The fourth fraction did not appear to be homogeneous, and its methoxy content was much too low for a brucine salt of a trimethylpentonic acid.

It will be seen from the above that the sirup isolated from the de-enolized solution was very largely, if not almost entirely, trimethylarabinose. This

selective action of the acid, apparently through the enol, is especially interesting in view of the observations of Gross.[7d] He found that the sirup, obtained in a similar manner from an equilibrated solution of trimethylxylose, consisted almost entirely of trimethyllyxose. In this case the epimer of the sugar originally present was spared in the formation of the furfural.

It should be noted that the amount of methanol obtained after the solution was de-enolized was almost twice that obtained before the acid was added (0.30 to 0.54 mole). While the first fraction is slightly more than one-half the second, it should be remembered that this first fraction would include any slight amount of methanol which would be liberated during the formation of the small amount of saccharinic acids present.

The total amount of methanol obtained corresponded to a decomposition of more sugar than could be accounted for by the amount of furfural found in the solution. It was shown, however, in a separate experiment that quite appreciable amounts of furfural are destroyed by acid concentrations such as were used in the de-enolization.

An interesting observation in regard to the ease of furfural formation under these conditions was made while removing the calcium from an equilibrated solution. The quantitative removal of the calcium with oxalic acid liberated the small amount of saccharinic acids which had been present as calcium salt. After such an acid solution (its acidity was 0.022 normal by alkaline titration) was allowed to stand for twenty-four hours, it was found that the percentage of apparent aldose had dropped considerably and that quite an appreciable amount of furfural was present. This production of furfural by the very mild acid conditions present here is especially interesting when it is recalled that, in general, furfural is formed from the pentoses only by the action of fairly concentrated acids.

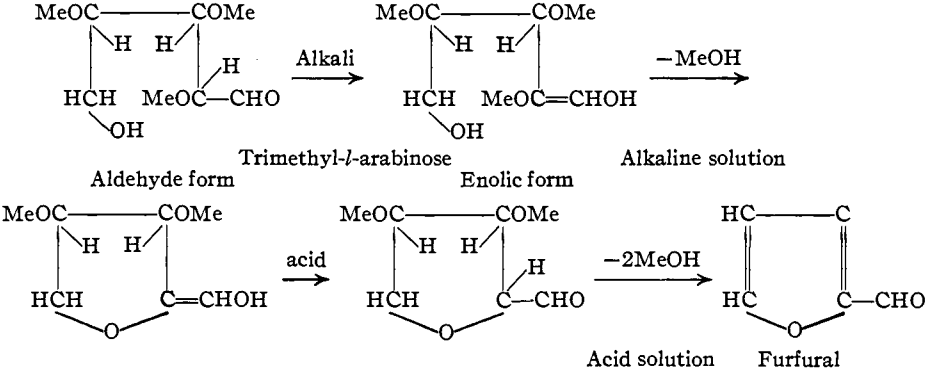
The surprising ease with which furfural was formed under the conditions of our experiments made it desirable to learn, if possible, its source. It seemed obvious from our work that the acid was the inciting factor, since furfural was not formed, except in traces in one instance, until acid was present.

It is believed that the immediate source of furfural is the high iodine absorbing form of the methylated sugar produced by the action of the alkali and believed to be the enol. This view is supported by the following considerations. *l*-Arabinose itself shows no abnormally high iodine absorbing compound when equilibrated with alkali and yields no furfural with acid of the strength used here. Trimethyl-*l*-arabinose could not be the direct source of furfural under the conditions as was proved in independent experiments; concentrations of acid as high as six normal failed to produce any furfural after eight hours. Twelve normal acid produced furfural only in small amounts. The sirup from a de-enolized solution of

trimethylarabinose gave no furfural when treated with acid under the usual de-enolizing conditions. However, when a sample of this sirup was equilibrated in lime water, the aldose value rose, just as with pure trimethylarabinose, and the resulting solution gave, upon addition of acid, amounts of furfural corresponding to those obtained from an equilibrated solution of pure trimethylarabinose.

Finally, it was demonstrated that furfural production bore a direct relation to the amount of apparent enol in the series of test solutions prepared by varying the time, temperature, and alkalinity.

These facts support the following reactions in explanation of the production of furfural from equilibrated trimethyl-*l*-arabinose solution on treatment with small amounts of acid.



Experimental

Preparation of *l*-Arabinose.—The *l*-arabinose[14] was prepared by the hydrolysis of mesquite gum with sulfuric acid according to the directions of Anderson and Sands.[15] It was found that if, in filtering the crude sugar, it was first washed with glacial acetic acid (200 cc. to each 100 g. of the sugar), dried by suction and finally washed with methyl alcohol, the resulting product was pure white in color, gave $[\alpha]_D^{20}$ 102° in water (c = 4.96),[16] and an aldose content of 99.5%. This product was used for methylation without further purification.

The Preparation of Crystalline Trimethyl-*l*-arabinose.—The crude trimethyl-α-methyl-arabinoside was prepared according to the directions of Hirst and Robertson.[17] The light yellow sirup obtained by this method was fractionally distilled. From 150 g. of *l*-arabinose, 110–130 g. of a colorless sirup boiling at 120–126° (12 mm.) was obtained. This sirup set to a soft mass of crystals as soon as it was cooled to 0°. The crystals were filtered from the adhering liquid and washed with a little cold petroleum ether (b. p., 60–90°). The combined filtrate gave an additional 7 g. of crystals when

[14] Acknowledgments are here made to Dr. Ernest Anderson for a portion of the *l*-arabinose used in this study.

[15] Anderson and Sands, "Organic Syntheses," John Wiley and Sons, New York, 1928, Vol. VIII, p. 18.

[16] The concentration is expressed as grams of sugar per 100 cc. of solution.

[17] Hirst and Robertson, *J. Chem. Soc.*, **127**, 360 (1925).

cooled to 0° for several hours. The total solid was recrystallized from light petroleum ether by dissolving it in three times its weight of solvent at about 40° and then cooling to 0°. In this manner, 77 g. of material gave 70 g. of pure trimethyl-α-methylarabinoside, crystallizing in long needles, m. p. 46–46.5°, $[\alpha]_D^{20}$ 46.1° in water (c = 9.9266; yield, 34%.

Seventy-five grams of pure, recrystallized trimethyl-α-methylarabinoside was dissolved in enough 4% hydrochloric acid to make a total volume of 1500 cc. The solution was warmed to 85° and kept at this temperature for two hours. The rotation of the solution rose from $[\alpha]_D^{25}$ 2.30° to $[\alpha]_D^{25}$ 7.35°. After hydrolysis was complete (indicated by no further change in rotation), the solution was perfectly colorless, gave no test for furfural, and reduced hot Fehling's solution at once. The cooled solution was partially neutralized with about 45 g. of sodium carbonate, and then completely neutralized with an excess of barium carbonate. The excess carbonate was removed by filtration and the filtrate concentrated under reduced pressure at 40–50°. The salt–liquid residue was then extracted with 100-, 75-, 75- and 50-cc. portions of chloroform, the extract dried over calcium chloride, and the chloroform removed under reduced pressure. The residue was an almost colorless, viscous sirup, weighing 68 g. If pure, recrystallized trimethyl-α-methyl-arabinoside was used in the hydrolysis, this sirup could be directly crystallized to a perfectly white solid, without first distilling it. If, on the other hand, the trimethyl-α-methyl-arabinoside still contained some of the liquid fraction, the sirup obtained at this point was dark colored, and it was not possible to obtain entirely white crystals without first distilling the sirup. In this case the yield was always lower. Therefore, if the hydrolyzed solution was colored instead of colorless, it was an indication that the arabinoside had been contaminated with some of the liquid fraction.

The above sirup was crystallized by dissolving in 200 cc. of dry, warm ether and then placing the solution in the ice box. After several days, 56 g. of pure white, fine crystals were filtered off; $[\alpha]_D^{25}$ 157.8°, constant after twenty-four hours in water (c = 4.473). The yield was 80%. The rotation in chloroform (U. S. P.) varied between $[\alpha]_D^{25}$ 40° and $[\alpha]_D^{25}$ 66°, depending on the speed with which crystallization was brought about. This undoubtedly indicated a mixture of the α- and β-forms coexisting in varying amounts.

Thirty grams of this material was recrystallized from 50 cc. of dry ether; yield, 26.5 g. of crystals dried in vacuum over sulfuric acid. The aldose content, as determined by iodine oxidation, was 99.8% after a one-hour oxidation period and 100% after both one and one-half and one and three-quarters hours.

Anal. Subs., 0.1798, 0.1973: AgI, 0.6640, 0.7257. Calcd. for $C_5H_7O_2(OCH_3)_3$: OCH_3, 48.44. Found: OCH_3, 48.75, 48.57.

The specific rotation in water (c = 4.906) was $[\alpha]_D^{25}$ 152.0° after five minutes, $[\alpha]_D^{25}$ 154.9° after ten minutes; after adding one drop of ammonium hydroxide, $[\alpha]_D^{25}$ 157.8°. No further change was observed in one hour. The rotation in chloroform (U. S. P.) (c = 5.013) was $[\alpha]_D^{25}$ 66.6°; m. p. 81–82°.

Quite large crystals of trimethylarabinose were obtained by dissolving 15 g. of the sugar in 350 cc. of dry ether and allowing the solution to evaporate at 0° over a period of about a week. Their rotation in water (c = 5.005) was $[\alpha]_D^{25}$ 133.4° in ten minutes, 148.1° in twenty minutes, 157.4° in forty-five minutes, 157.8° in three hours, and 158.0° in three days. Their rotation in chloroform (c = 4.996) was $[\alpha]_D^{20}$ 16.4°.

Because of the ease of removing sulfate ions with barium, sulfuric acid would seem to be indicated in the hydrolysis of the arabinoside. A solution of 10 g. of the recrystallized arabinoside in 200 cc. of 5% sulfuric acid was heated under reflux at 80° until the rotation was constant (three hours). The rotation changed from $[\alpha]_D^{25}$ 2.50° to $[\alpha]_D^{25}$ 6.20°. A chloroform extraction of the cooled solution gave 1.5 g. of crystalline

trimethyl-α-methyl-arabinoside. After removal of the sulfate ions with barium, the solution was worked up in the usual manner. The sirup so obtained reduced hot Fehling's solution, but did not crystallize, even after seeding with crystalline trimethyl-arabinose and allowing to stand for several months. Apparently sulfuric acid is not a suitable acid for the hydrolysis of the arabinoside. This is in agreement with the observations of Carruthers and Hirst,[18] who found that the hydrolysis of trimethyl-methylxyloside with sulfuric acid caused decomposition of the sugar with loss of methoxyls.

Behavior of the Sugars in Alkali.—The conditions recommended by Wolfrom and Lewis[7b] were used for the interconversion of both *l*-arabinose and trimethyl-*l*-arabinose.

(a) Interconversion of *l*-Arabinose.—A molar solution (200 cc.) of *l*-arabinose in clear lime water saturated at 35° was allowed to stand at this temperature until the rotation had attained a constant value. The initial alkalinity of the lime water alone, as shown by titration with $N/10$ hydrochloric acid using phenolphthalein as an indicator, was 0.040 normal; the alkalinity of the sugar solution was 0.036 normal. At the conclusion of the interconversion the solution was just neutral to litmus, but acid to phenolphthalein. After standing for two months the solution had developed no free acidity. The polarimetric changes are given in the table below and plotted in Fig. 1.

TABLE I

POLARIMETRIC CHANGE OF *l*-ARABINOSE IN LIME WATER

Time in hours	1	19	27	43	97	119	144	164	195
$[\alpha]_D^{35°}$	100	89.3	85.6	79.6	69.5	67.0	65.0	63.5	62.6

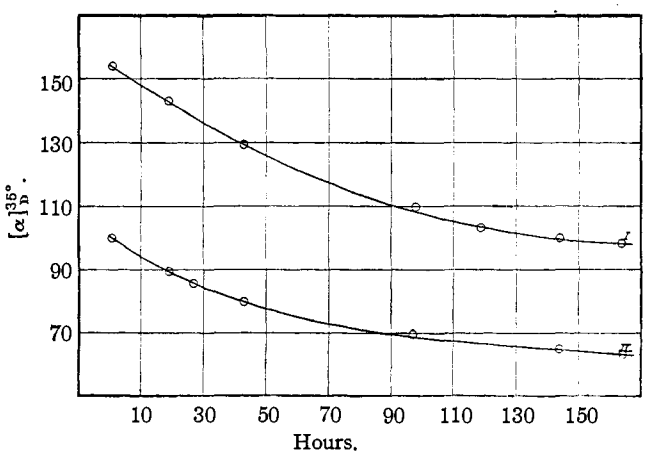


Fig. 1.—Polarimetric change of *l*-arabinose and trimethyl-*l*-arabinose in lime water: I, trimethyl-*l*-arabinose; II, *l*-arabinose.

The aldose content was determined at frequent intervals by means of iodine oxidation according to the method of Cajori as applied by Wolfrom and Lewis to the methylated sugars. It was found in independent tests that the *l*-arabinose was completely oxidized by iodine after thirty minutes. The results of the determinations on the equilibrated *l*-arabinose solution are shown in Table II and plotted in Fig. 2.

(b) Interconversion of Trimethyl-*l*-Arabinose.—A molar solution of trimethyl-arabinose in lime water was allowed to stand at 35° until apparent equilibrium was es-

[18] Carruthers and Hirst, *J. Chem. Soc.*, 121, 2307 (1922).

TABLE II

CHANGE IN ALDOSE CONTENT OF *l*-ARABINOSE IN LIME WATER

Time in hours	2	20	48	97	146	195
Aldose, %	99.7	93.2	88.3	85.4	85.3	84.9

tablished. The solution gradually colored and was quite brown at the conclusion of the reaction. The initial alkalinity of the sugar solution was 0.040 normal; the final alkalinity, as shown by titration with 0.1 *N* hydrochloric acid, was 0.008 normal. The

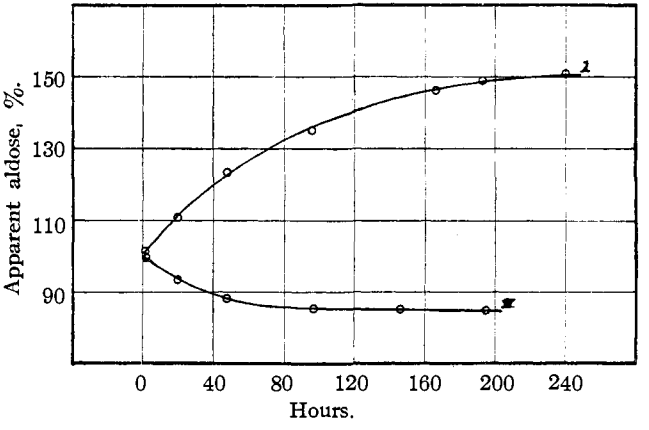


Fig. 2.—Change in apparent aldose content of the sugars in lime water: I, trimethyl-*l*-arabinose; II, *l*-arabinose.

change in rotation is given in Table III and plotted in Fig. 1. The iodine oxidation values were calculated as percentage of aldose. They are shown in Table IV and plotted in Fig. 2. The time of oxidation was one and one-quarter hours.

TABLE III

POLARIMETRIC CHANGE OF TRIMETHYL-*l*-ARABINOSE IN LIME WATER

Time in hours	$[\alpha]_D^{25}$
1	153.7
19	142.7
27	137.5
43	128.9
98	110.0
119	103
144	100
164	98

TABLE IV

CHANGE IN APPARENT ALDOSE CONTENT OF TRIMETHYL-*l*-ARABINOSE IN LIME WATER

Time in hours	Apparent aldose, %
1.5	101.5
20	110.8
48	123.4
96	135.0
164	146.2
193	149.0
240	151.0

(c) Action of Acid on the Equilibrated Solution.—A preliminary study of the action of acid on the equilibrated solution of trimethylarabinose was made by taking 5 cc. of the solution, diluting it to 100 cc., then adding enough concentrated hydrochloric acid to make the desired acid concentration. The change in aldose content was followed by means of the iodine oxidation. The results are given in Table V.

TABLE V

DECREASE IN PERCENTAGE OF APPARENT ALDOSE IN *N* HCl AT 35°

Time in hours	0	1.5	3	18
Percentage aldose	151	128	128	121

DECREASE IN PERCENTAGE OF APPARENT ALDOSE IN 2 *N* HCl AT 35°

Time in hours	0	0.5	2	4	24	45	95
Percentage aldose	151	125	120	114	109	107	99

With 3 *N* hydrochloric acid at 35° the percentage of apparent aldose dropped to 113 after four hours. When a sample of the undiluted solution was treated with 2 *N* hydrochloric acid, the apparent aldose dropped to 117% in four hours.

Aniline acetate showed the presence of furfural in every sample treated with acid, the amount of furfural increasing with increase in time of the acid treatment. No furfural was found in the equilibrated solution before the acid was added.

After removal of calcium ions with oxalic acid, the acidity of the solution, as determined by titration with 0.1 *N* sodium hydroxide using phenolphthalein as an indicator, was 0.022 normal. If it be assumed that this acidity was due to the saccharinic acids formed during the alkaline treatment, it is equivalent to 2.2% of the original sugar. Twenty-four hours after removal of the calcium with oxalic acid, an iodine oxidation showed that the apparent aldose content had dropped from the original value of 151 to 132%. The solution gave a distinct test for furfural.

Quantitative Study.—A molar solution (437.7 g.) of trimethylarabinose in lime water was kept in a stoppered flask immersed in a water-bath at 35° until apparent equilibrium had been attained. One hour after preparation of the solution, $[\alpha]_D^{35}$ 153°, the last reading which could be taken before too much color had developed (forty hours), was $[\alpha]_D^{35}$ 124°. After 160 hours the apparent aldose content had increased to 157.5% (see Table XI). The alkalinity of the lime water, as determined by titration with *N*/10 acid, was 0.038 normal; the sugar solution was 0.032 normal. At the conclusion of the equilibration the solution was neutral or very faintly alkaline to litmus. This limited the amount of possible saccharinic acids to a maximum of 3.2% of the sugar.

(a) Removal of Methanol before De-enolization.—The equilibrated solution now weighed 428.4 g. and contained 79.4 g. of sugar. To it was added 50 cc. of water and 25 cc. of lime water in order to maintain a faint alkalinity. This solution was then distilled in an atmosphere of nitrogen, under a pressure of 25 mm., from a water-bath kept at 35°. The distillate, amounting to 160 g., was collected in a series of two flasks kept immersed in an ice–salt mixture. The residue in the flask contained no furfural. The distillate contained 0.028 g. of furfural; this corresponded to a decomposition of 0.056 g. of sugar or 0.07% of that originally present. The furfural in the distillate was destroyed by distilling in the presence of sodium hydroxide. Three such distillations through a fractionating column reduced the final methanol fraction to 51 g. The methanol was identified by its boiling point, and through its conversion into formaldehyde by oxidation with a copper spiral. Both the refractive index (n_D^{20} 1.3347) and density (d^{15} 0.9857) of the solution indicated that it contained 7.8% methanol by weight. This represents 4.0 g. or 0.125 mole of methanol from 0.413 mole (79.4 g.) of trimethylarabinose. Thus one mole of trimethylarabinose gave 0.30 mole of methanol.

The sugar solution, which was still faintly alkaline, was diluted to its original volume. Its apparent aldose content, as determined by iodine oxidation, was now 158%.

(b) De-enolization of the Solution.—To the diluted sugar solution (830 cc.) was added 160 cc. of concentrated hydrochloric acid. After one and a half hours at 35°. samples were removed and analyzed for furfural and aldose content. The amount of furfural found corresponded to a decomposition of 16.7% of the sugar. The apparent

aldose content was 101%. However, because of the presence of the furfural during this determination, the aldose value has little significance. Immediately after the removal of the samples the solution was partially neutralized with 100 g. of sodium carbonate and completely so with barium carbonate, the excess being removed by filtration. The solution was neutral to litmus and was dark brown in color.

(c) **Removal of Methanol after De-enolization.**—The methanol was removed at 35° and 25 mm. in the presence of nitrogen, as described before. The final methanol fraction (after removal of the furfural) amounted to 133 g. Its refractive index (n_D^{20} 1.3341) indicated 5.2% methanol by weight; the density (d^{15} 0.9896) corresponded to 5.4% methanol, the average value being 5.3%. This represents 7.05 g. or 0.22 mole of methanol, and corresponds to 0.54 mole of methanol for each mole of sugar.

(d) **Isolation of the Sirup.**—The sugar solution was concentrated in a vacuum to one-half its original volume. The salt which separated was filtered and washed with a little chloroform. The filtrate was extracted with 50 cc. of chloroform. This procedure of concentration and extraction was repeated until the aqueous residue was reduced to 15 cc. and was almost black in color. The combined chloroform extracts were dried over calcium chloride and the solvent then removed at 40° and 30 mm. The residual sirup was light yellow in color and weighed 51.2 g. (calcd. 79.2 g.), or 64.6%; $[\alpha]_D^{26}$ 138° (c = 2.014) in water; aldose, 99.3%.

The sirup was dissolved in 50 cc. of dry ether, seeded with trimethylarabinose and allowed to stand for several days at 0°. In this manner there was obtained 31.2 g. (48.3% of the sirup) as crystalline trimethylarabinose, $[\alpha]_D^{25}$ 157° (c = 2.830) in water. The sirup remaining after the removal of the crystalline sugar had an aldose content of 99.3%; $[\alpha]_D^{25}$ 125° (c = 2.60) in water.

(e) **Oxidation of the Residual Sirup.**—Fifteen grams of this sirup was oxidized with bromine according to the directions of Hudson and Isbell.[19] The acid solution so obtained was converted into the brucine salt without first isolating the sugar acid. The weight of the brucine salt was 32 g. (calcd. 45.5 g.). This was dissolved in 200 cc. of hot acetone and fractionally crystallized: Fraction I, 6.0 g., $[\alpha]_D^{25}$ −19.7° (c = 3.060) in water; Fraction II, 21.0 g., $[\alpha]_D^{25}$ −20.0° (c = 2.124); Fraction III, 1.8 g., $[\alpha]_D^{25}$ −20.7° (c = 2.160); Fraction IV, 2.0 g. Fraction IV was obtained by evaporating the filtrate from the third fraction to dryness in vacuum. It was a fluffy brown solid, which partially dissolved in water to give a brown solution, incapable of optical reading.

Anal. (Zeisel) Subs., 0.1638: AgI, 0.2488. Calcd. for anhyd. brucine: OCH_3, 15.7; calcd. for brucine salt of trimethylpentonic acid, 25.8. Found: 20.1.

The first three fractions were again fractionally crystallized from acetone: Fraction I, 21.5 g., $[\alpha]_D^{25}$ −21.0° (c = 2.30) in water; Fraction II, 4.9 g. $[\alpha]_D^{25}$ −21.0° (c = 2.24); Fraction III, 1.0 g., $[\alpha]_D^{25}$ −20.8° (c = 2.45). The brucine salt obtained from the oxidation of pure trimethylarabinose gave $[\alpha]_D^{25}$ −21.4° (c = 4.904) in water.

Furfural Production.—The method of analysis used was essentially the one described by Leach,[20] based on a colorimetric comparison of the red color developed with aniline hydrochloride. The amount of furfural found was calculated as the equivalent of trimethylarabinose decomposed.

(a) **Extent of Furfural Production with Time.**—An equilibrated solution of trimethylarabinose of an apparent aldose content of 153% was made 2 *N* in acid with hydrochloric acid. Samples were removed from time to time and analyzed for furfural, which is expressed as equivalent of sugar decomposed. The results are given in Table VI.

[19] Hudson and Isbell, THIS JOURNAL, **51**, 2225 (1929).

[20] Leach, "Food Inspection and Analysis," 3d ed., John Wiley and Sons, New York, **1914**, p. 746.

TABLE VI

EXTENT OF FURFURAL PRODUCTION WITH TIME

Time in hours	1	3	5	8	12	18	24	30	42
Furfural, %	6.5	14.1	16.5	20.8	20.8	20.2	16.7	16.0	13.6

(b) **Action of Acid on Pure Trimethylarabinose.**—The samples to be tested were prepared by dissolving 0.1 g. of trimethylarabinose in 2 cc. of water and then adding 0.2 cc. of concentrated hydrochloric acid. The solutions were allowed to stand at 35°. After one, five, eight and fifteen hours they were tested for furfural. In no case was furfural found to be present. In studying the action of concentrated acid on trimethylarabinose, a 0.1-g. sample of the sugar was dissolved in 2 cc. of 12 *N* hydrochloric acid. After standing for eight hours at 35°, it was diluted to 100 cc. and a 10-cc. sample removed and analyzed for furfural. It was found that the 0.1 g. of sugar gave 0.00025 g. of furfural. This corresponds to 0.0005 g. or 0.5% of the trimethylarabinose present. A 0.1-g. sample of the sugar dissolved in 6 *N* hydrochloric acid gave no test for furfural after eight hours.

(c) **Action of Acid on *l*-Arabinose.**—A 0.1-g. sample of pure *l*-arabinose was dissolved in 2 cc. of water. To this was added 0.2 cc. of 12 *N* hydrochloric acid and the solution allowed to stand at 35°. No furfural was present at the end of eight and fifteen hours. An equilibrated solution of *l*-arabinose, when treated exactly as indicated above, gave no test for furfural after eight and fifteen hours.

(d) **Action of Acid on Furfural.**—Two-cc. samples of solution containing varying amounts of furfural were made acid with 0.2 cc. of hydrochloric acid, and allowed to stand for eight hours at 35°. The amount of furfural was determined by diluting the samples to 100 cc. and taking 10 cc. for analysis. A second series was prepared in which each sample, in addition to the above, also contained 0.1 g. of trimethylarabinose. It is interesting to note the retarding action of the sugar on the decomposition of the furfural.

TABLE VII

ACTION OF ACID ON FURFURAL

Sample no.	1	2	3	4	5
Furfural added, g.	0.002	0.004	0.006	0.008	0.010
Furfural found, g.	.002	.0034	.0048	.0063	.0077
Furfural found, %	100	85	80	78	77

TABLE VIII

ACTION OF ACID ON FURFURAL IN PRESENCE OF TRIMETHYLARABINOSE

Sample no.	1	2	3	4	5
Furfural added, g.	0.002	0.004	0.006	0.008	0.010
Furfural found, g.	.002	.004	.0059	.0076	.0091
Furfural found, %	100	100	98	95	91

(e) **Iodine Oxidation of Furfural.**—The procedure used was exactly the same as with the sugars. The time of oxidation was one hour.

TABLE IX

OXIDATION OF FURFURAL WITH IODINE

Sample no.	1	2	3	4
Furfural added, g.	0.0025	0.0050	0.0075	0.0100
Furfural oxidized, g.	.00056	.00114	.00161	.00217
Furfural oxidized, %	22.2	22.8	21.5	21.7

(f) **Furfural Production from the Sirup Isolated from an Equilibrated Solution of Trimethylarabinose.**—An equilibrated solution (150 g.) of trimethylarabinose (apparent aldose content 153%) was de-enolized with hydrochloric acid and the sugar sirup (18.1 g.) isolated in the manner described previously. The following determinations were made with this sirup: apparent aldose content, 101.6%, $[\alpha]_D^{25}$ 133° (c = 3.991) in water, using white light; n_D^{25} 1.4640. To a solution of 0.1 g. of the sirup in 2 cc. of water was added 0.2 cc. of 12 N hydrochloric acid. The solution was allowed to stand at 35° for fifteen hours. At the end of this time it gave a negative test for furfural. A molar solution of the sirup in saturated lime water (1.92 g. in 10 cc. of solution) was then allowed to stand at 30°. After sixty-four hours an iodine oxidation indicated an apparent aldose content of 114%. Furfural was formed, after the addition of acid, to the extent of 5.7% of the sugar decomposed.

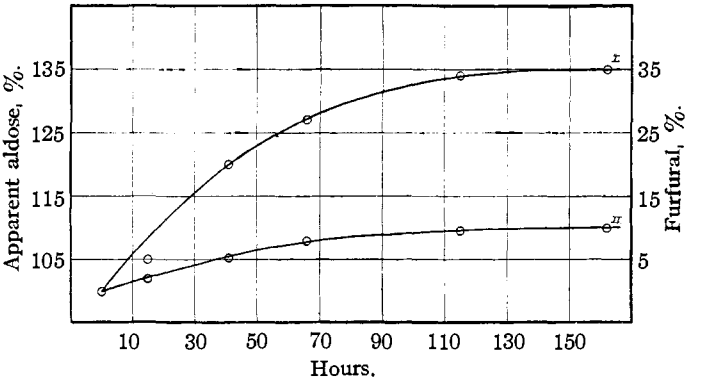


Fig. 3.—Relation between furfural production and increase in apparent aldose content: I, apparent aldose, %—lime water at 30°; II, furfural, %—lime water at 30°.

Ten grams of the sirup was seeded with trimethylarabinose and kept at 0° for several days until crystallization had set in, after which 10 cc. of dry ether was stirred into the mass. After a week 3.3 g. of crystals was removed and the residual sirup again crystallized in the same manner. In this way a total of 7.9 g. or 79% of crystalline trimethylarabinose was obtained in three fractions. The specific rotations in water of the fractions were $[\alpha]_D^{25}$ 157.4° (c = 2.204); $[\alpha]_D^{25}$ 158.0° (c = 2.507); $[\alpha]_D^{25}$ 156.0° (c = 3.070).

(g) **Relation between Furfural Production and Increase in Apparent Aldose Content.**—A molar solution of trimethylarabinose in lime water saturated at 35° was allowed to stand at 30° until the aldose content reached a constant value. Half-cc. samples were removed and added to a solution of 2.0 cc. of water and 0.2 cc. of 12 N hydrochloric acid. These mixtures were kept at 30° for eight hours, after which they were diluted to 100 cc. and 10 cc. removed and analyzed directly for furfural.

A molar solution of trimethylarabinose in saturated lime water was kept at 35° and analyzed for furfural.

A molar solution of trimethylarabinose in dilute sodium hydroxide was allowed to stand at 30°, and analyzed as indicated before. The alkalinity of the sodium hydroxide solution alone was 0.050 normal, and of the sugar solution 0.042 normal. The solution was neutral to litmus after 162 hours.

It is of interest to note that in Tables X, XI and XII the percentage of apparent aldose above 100, is roughly 3.5 times the furfural present.

TABLE X

RELATION BETWEEN FURFURAL PRODUCTION AND INCREASE IN APPARENT ALDOSE CONTENT

Time in hours	Apparent aldose, %	Furfural,[a] %
0	100	0.0
15	105	2.0
41	120	5.3
66	127	8.0
115	134	9.5
162	135	9.9

TABLE XI

RELATION BETWEEN FURFURAL PRODUCTION AND INCREASE IN APPARENT ALDOSE CONTENT

Time in hours	Apparent aldose, %	Furfural, %
0	100	0.0
17	112	4.0
40	128	8.4
118	155	19.2
140	157	20.2
160	157.5	21.0

[a] Calculated as percentage of sugar decomposed.

TABLE XII

RELATION BETWEEN FURFURAL PRODUCTION AND INCREASE IN APPARENT ALDOSE CONTENT

Time in hours	Apparent aldose, %	Furfural, %
0	100	0.0
15	113	3.4
41	125	7.6
66	135	10.1
115	144	12.0
162	145	12.6

Summary

1. Trimethyl-*l*-arabinose has been prepared in crystalline condition, and its constants determined.

2. The behavior of *l*-arabinose and trimethyl-*l*-arabinose in lime water has been shown to be strikingly similar to that observed by Wolfrom and Lewis in the case of *d*-glucose and tetramethyl-*d*-glucose, the trimethyl-arabinose giving evidence of a stable intermediate enol.

3. It has been shown that the action of small amounts of acid on the equilibrated solution of trimethyl-*l*-arabinose causes the formation of furfural.

4. A mechanism has been proposed for the formation of furfural from the enolic form of the sugar thought to be present in the alkaline solution. Evidence has been presented in support of this proposed mechanism.

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